INVESTIGATION INTO THE DEVELOPMENT OF A PARROT-INSPIRED THERAPEUTIC ROBOT TO IMPROVE LEARNING AND SOCIAL INTERACTION OF CHILDREN WITH AUTISM SPECTRUM DISORDER

A thesis submitted to Auckland University of Technology in fulfilment of the requirements for the degree of Doctor of Philosophy

School of Engineering, Computer & Mathematical Sciences

Auckland University of Technology

Auckland

New Zealand

By

Jaishankar Bharatharaj

April 2018

Abstract

This research reports on the design and development of a parrot-inspired therapeutic robot to improve learning and social interaction abilities of children with autism spectrum disorder. The research also aims to reduce stress levels of participants through robot-assisted therapy.

The increasing deployment of robots in recent decades has inspired new boundaries for human-robot interactions from manufacturing to health industries. Particularly, assistive robotics has found new directions in recent years and been used in numerous applications, including, elderly care, and autism therapy. With inspiration from nature, bio-inspired robots can provide solutions to various problems, which have been applied successfully in real-world situations. Specifically, animal-inspired robots have received notable acceptance in therapeutic settings, such as therapy for the elderly, children with autism spectrum disorder, and patients with dementia.

A number of animal-like robots are developed to provide the benefits of animal-assisted therapy, while overcoming shortfalls, such as biting, allergies, and animal-spread diseases. Autism therapy is one such area for the deployment of animal-inspired robots to improve the lifestyle of children with autism spectrum disorder.

Through an extensive review of the literature and reported benefits, the morphological form for the robot was determined to be parrots for their significant companionship contributed by their living counterparts in various disorders. In this research, a parrot-inspired therapeutic robot is designed to provide therapeutic benefits. The novelty of the research also lies in the fact that there is a complete absence of any robotic study involving the design and development of a parrot-like robot.

The research is set to target improvement in learning and social interaction abilities of children with autism spectrum disorder through engaging a parrot-inspired robot, which represents a common and significant procedure for individuals with limited cognitive capabilities. The research also investigates the psychological and physiological changes in children before and after interacting with the robot.

Several short-term and long-term user studies conducted to validate the effects of robot among children report a positive influence in improvement of learning and social interaction in participants. Salivary and urinary tests indicated reduction in stress levels of children with ASD after interacting with the robot. The research investigating participants' blood pressure, heart rate, and oxygen saturation levels in blood and reported no abnormality in readings during and after interacting with the robot.

'Unchanged' is only the word

which will remain unchanged!

Research can make changes to

the lives of Autism!!!

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Robo Idoso Activo .... RIA

Kinesics And Synchronization in Personal Assistant Robotics .... KASPAR

Artificial Intelligence RObot .... AIBO

Elderly Rehabilitative Interactive Companion .... ERIC

Universal Asynchronous Receiver/Transmitter .... UART

Force Sensing Resistors .... FSR

Polylactic Acid .... PLA

Thermoplastic Polyurethane .... TPU

Adapted Model-Rival Method .... AMRM

Childhood Asperger Syndrome Test .... CAST

Social Network Density .... SND

Standard Deviation .... SD

Confidence Interval CI

Degrees of Freedom .... DF

Significance.. Sig

Javascript Object Notation ....JSON

Sympathoadrenal Medullary .... SAM

Diastolic Blood Pressure.. DYS

Systolic blood pressure ....SYS

Heart rate ....HR

Oxygen saturation levels in blood SPO2

ATTESTATION OF AUTHORSHIP

I confirm that this submission is my own work and to the best of my knowledge, the submission contains no material previously written or published by any other person, nor any material to which a substantial extent has been submitted for the award of any other degree of a university or other institution of higher learning.

Jaishankar Bharatharaj

ACKNOWLEDGMENTS

I, with my wife Hemashree and son Sri Ashwath dedicate this doctoral thesis to our universal mother SRI SUYAMBU ANGALAPARAMESWARI, who is behind all our thoughts and actions.

I am thankful to my mother, Manjula Devi and father, Bharatharaj and all my ancestors who always bless me to succeed and get the best of my life.

I express my sincere gratitude to my primary supervisor Loulin Huang, who believed that I can pursue this research and gave me utmost support throughout the study. I extend my honest gratitude to my co-supervisors, Ahmed Al-Jumaily, Christian Krägeloh, and Mohan Rajesh Elara who were behind each step I have climbed toward success. Their guidance and encouragement helped me during every phase of my research.

Touching the feet of Sri Vanni Vinayagar and all gods in all forms, I accept and acknowledge that their force operated me to think and act during this work.

This is the best place to acknowledge and thank Vanni Ganesh, my brother who is giving me the best of my life without expecting any benefits.

Vijayakumar and Sumathy, my in-laws deserve my heartfelt thanks for their support through this research study.

I am yet to find a word to express how much I owe you. You were behind me during the hardest parts of my life and here I am with the best part of my life to make you happy. Let’s celebrate with our son Sri Ashwath Jaishankar. Thank you, my wife, Hemashree Jaishankar.

I take this opportunity to convey my thanks to Auckland University of Technology for giving me this opportunity and financial support for the course fee. I express my sincere thanks to the Institute of Biomedical Technologies (IBTec) for all financial support toward conducting this research. I also express my sincere thanks to Singapore University of Technology and Design (SUTD) for providing internship during the research.

My deepest appreciation to all parents, teachers, doctors, and student volunteers who contributed during the user studies in India and Singapore.

Finally, my hearty thanks to all children who participated in my research study. Without you, this research would have not been a success. I promise to work for making your life much better through my future research.

Ethics Approval

Approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC) on 11 March 2016. Ethics Approval Number: 15/397.

1. Introduction

1.1. Autism spectrum disorder

The term ‘autism’ was first used by the psychiatrist Eugen Bleuler in 1911 to describe an individual’s withdrawal from social life [1]. After a few decades, Leo Kanner in 1943, published a report on eleven patients and used the term autistic to characterise the traits of children he studied [2]. Since then, several studies have been conducted and various definitions for autism have been constructed. During the 1960s, autism was viewed as a form of childhood schizophrenia [3]-[5]. The studies in 1970s reported that autism stemmed from biological changes in brain development [6]-[8]. In 1980, Diagnostic and Statistical Manual (DSM) III distinguished autism from childhood schizophrenia and added to the manual as “infantile autism” which was then replaced with "Autistic Disorder" in 1987 [9]-[10]. After decades, in 2013, the DSM V mentioned the diagnosis as “Autism Spectrum Disorder” (ASD) with no sub diagnoses, such as Asperger syndrome, Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS), etc. [11]. According to the DSM V manual, people with autism exhibit persistent deficits in social communication and social interaction, and restricted and repetitive behaviour patterns.

Centers for Disease Control and Prevention (CDC) released data on the prevalence of autism in the United States for the year 2010, reporting an estimated 1 in 68 (14.7 per 1000) school-aged children have been diagnosed with ASD. The report also mentioned that ASD is more common among male children than female children: 1 in 42 males versus 1 in 189 females [12]. CDC has further indicated that about 1 percent of the world population has some form of ASD [13]. This leads to the conclusion that there are about 74 million people with ASD around the world at the time of writing this report. In New Zealand, it is estimated that there are about 65,000 people living with ASD, which counts to 1.4% of the total population [14].

The lifetime cost for an individual with ASD in the United States is approximately USD 1.4 million to 2.4 million [15]. Based on this report, the yearly cost to the country is estimated to be USD 236 billion, which is almost 6.16% of the total government's expenditure for the year 2016, reported by the Central Intelligence Agency (CIA) [16].

ASD is generally characterised as a deficiency in social interaction with humans and difficulty in learning, even though, other symptoms may include self-harm, repetitive body movements, diminished eye contact, minimal or no response to heat or cold, unusual attachments to objects [17]. Educating and establishing interaction among children with ASD is very challenging due to the nature of the disorder.

Numerous initiatives have been taken around the world by governments, social groups, and research laboratories to help improve the quality of life of children with ASD and their families. Improving learning abilities and creating social interaction of children with ASD is utmost important to help the 74 million population around the world. Even though causes and a cure is yet to be identified, there are several medicines used among ASD population to treat depression, anxiety, and obsessive behaviours. The next Chapter discuss the medications used among ASD patients in detail.

1.2. Use of medication to treat autism spectrum disorder

As reported by the CDC, there are no medications to cure or treat the core symptoms of ASD [18]. Nevertheless, several medications are used to help people with ASD to function better. Medications are widely used to help reduce depression, anxiety, obsessive behaviour, seizures. They ASD can be broadly classified into six categories; stimulants, antihypertensive, anticonvulsants, antipsychotics, anxiolytics, and antidepressants.

Stimulants are used among the ASD population to help improve attention and reduce hyperactivity. These medicines work by increasing dopamine (neurotransmitter associated with pleasure, movement, and attention) level in the brain [19]. Possible benefits of stimulants include increased attention and decreased distractibility and motor restlessness. Nevertheless, they bring about many side effects, including decreased sleep and appetite, malnutrition, headache, dizziness, and skin rashes. Feelings of hostility and paranoia may be caused through repeated use of stimulants. In addition, excessive dosage of stimulants may cause decreased attention and lower academic performances [20]. Ritalin, Dexedrine, Cylert, Biphetamine, and Dexedrine spansule are several drugs categorised under stimulants.

Another class of drug widely used to treat hypertension and aggression in ASD is antihypertensive [21]. These medicines were earlier used for lowering blood pressure but recently there have been several cases where this class of medicine has helped to reduce aggression in ASD. It is also reported that they are effective in treating compulsive behaviours and tics. On the other hand, antihypertensive drugs result in several negative effects, such as lowered blood pressure, drowsiness, dry mouth, weakness, diarrhoea, headache, and fainting.

Anticonvulsants are also known as mood stabilizers that work by calming hyperactivity in the brain in several ways. These medicines are usually prescribed for patients with severe aggression. Dizziness, drowsiness, fatigue, nausea, tremor, skin rashes, and weight gain are common side effects of anticonvulsants class of medicines [22]. It is recommended to monitor blood levels, bone marrow, and liver function of the patient who uses the medicine. The Food and Drug Administration (FDA) has issued warning on these medicines and indicated that people taking these drugs should be monitored carefully for the signs of suicidal thoughts [23].

To treat severe cases in ASD such as aggression and hyperactivity, antipsychotic drugs are widely used. Drugs in this category adjust the effect of neurotransmitters in the brain to normalise levels. Risperidone, olanzapine, quetiapine, ziprasidone, and aripiprazole are a few of the drugs used in ASD treatment. As with other class of drugs, antipsychotic class drugs do carry negative effects including hyperprolactinemia, weight gain and other metabolic syndrome and related adverse effects, and risk of increased mortality from sudden cardiac death and cerebrovascular accidents [24].

Another type of medication used in ASD is anxiolytics to treat anxiety and aggression that work by targeting key chemical messengers in the brain to help decrease abnormal excitability [25]. Alprazolam, chlordiazepoxide, clonazepam, and lorazepam are included in the anxiolytics class of drugs. Despite helping to reduce anxiety and aggression, these drugs tend to increase the risk of sedation, psychological dependences, drowsiness, poor balance, and behavioural disinhibition [20].

Antidepressants are a group of drugs used to treat depression, inattention, and hyperactivity symptoms in ASD [20]. Even though antidepressants may not cure depression in ASD, it is reported to be effective in reducing the symptom [26]. Antidepressants work by altering the chemicals in the brain (neurotransmitters) that affect the mood and emotions [27]. Like other drugs used in treating symptoms of ASD, antidepressant drugs also carry side effects such as nausea, increased appetite and weight gain, loss of sexual desire and other sexual problems, such as erectile dysfunction and decreased orgasm, fatigue and drowsiness, insomnia, dry mouth, blurred vision, constipation, dizziness, agitation, irritability, anxiety [28].

With the above illustrations, medications have serious side effects in ASD treatment. Further, none of the medications can cure ASD or to treat the core symptoms of ASD. This provided more opportunities for various therapies to be explored. Therapies used in ASD are discussed in detail in the next chapter.

1.3. Therapies for autism spectrum disorder

There have been a number of therapies explored to treat the core symptoms of ASD. The list below illustrates some examples:

- Animal Assisted Therapy
- Applied behaviour analysis therapy
- Auditory integration therapy
- Cognitive behavioural therapy
- Early Start Denver Model (ESDM) therapy
- Floor time therapy
- Massage therapy
- Music (Neurological music) therapy
- Occupational therapy
- Physical therapy
- Picture exchange communication system
- Pivotal responses treatment
- Rapid prompting method
- Relationship development intervention
- Robot assisted therapy
- Sensory integration therapy
- Social skills therapy
- Speech and language therapy
- Treatment and Education of Autistic and Related Communication Handicapped Children (TEACCH)
- Verbal behaviour therapy

The above mentioned therapies have reported benefits through user studies [29]-[67]. Three main categories that demand attention in ASD are psychological, physiological, and social needs. Most of the therapies are designed for improving behaviour and/or communication abilities in ASD and they tend to largely focus on social needs, including learning, and social behaviour.

Nearly all the therapies mentioned above have reported success in some forms while implemented in treating symptoms of ASD. Among those therapies, the Animal Assisted Therapy (AAT) has been studied extensively and has reported numerous benefits in improving psychological, physiological, and social needs of children with ASD. But, this therapy is not accepted by all clinics due to various limitations. Hence, it motivates robot-assisted therapy (RAT) in which a robot is developed which is more effective than AAT, while overcoming the disadvantages of using animals in treating symptoms of ASD. In the literature review in the next chapter, the AAT and various disorders it has been used are discussed in detail among other therapies.

2. Literature review

2.1. Synopsis

In Chapter 1, the detailed information about autism spectrum disorder is presented and the medications and therapies practiced in treating ASD are briefly discussed. It is noted that ASD is one of the disorders among children that needs more attention to prevent and cure. Among various therapies practiced, AAT is widely accepted and many animals have been trained and used to provide therapeutic benefits in ASD treatment.

In this chapter, the application of AAT to treat various disorders are described. The limitations of AAT are discussed later. Next, animal-inspired robots used in RAT for various disorders, particularly, the robots used in treating symptoms of ASD among children is discussed.

Finally, the needs and future potentials of developing a parrot-inspired therapeutic robot to improve learning and social interaction abilities of children with ASD are presented.

2.2. Animal assisted therapy

Animal domestication occurred approximately 15,000 years ago, proving their long history of strong bond with humans [68]. Domesticated pets were used for various purposes including transportation, objects of affection and worship, messenger, and companion. Florence Nightingale discovered the therapeutic potential of animals during the late 1800s when she observed that small pets can help reduce anxiety in humans [69]-[70]. Since then, animal-assisted therapy grew as a potential means of treatment for various disorders including anxiety, bipolar disorder, dementia and ASD. The aim of AAT includes improving patients' physiological, psychological, or social functioning. It is reported that the interaction with animals increases neurochemicals in humans that helps reducing blood pressure and induces relaxation [71]. With such promising benefits, several animals, including dogs, penguins, rats, guinea pigs, horses, birds, cats, and dolphins have been used in therapeutic settings. The earliest use of pet animals in therapeutic settings was in the medieval period where pets provided a part of the therapy to humans [72]. During the 17th century physicians used horses to improve patients' physical and mental health [73]. In 1792, AAT was first recorded at York Retreat in England to help people with mental illness [74]. There have been a number of studies performed during 1900s that indicated the benefits of using animals and birds in therapeutic settings. Since then, researchers across the world have documented the benefits of involving animals in a number of therapeutic settings. A variety of animals, including dogs, cats, equines, goats, dolphins, rabbits, guinea pigs, rats, miniature pigs, llamas, alpacas, donkeys, and birds have been used in AAT. In this review, the influence of animals in psychological disorders, cardiovascular disorders, Alzheimer's disease, dementia, elderly care, and autism therapy are elaborated.

2.2.1. Animal assisted therapy used to treat various disorders

(I) Animals for treating psychological disorders

Animal-assisted therapy (AAT) has long been known to help people with psychological disorders, such as anxiety, depression, and schizophrenia. Numerous works have been published reporting the psychological benefits of AAT [75]-[84]. Maujean, Pepping, and Kendall conducted a systematic review of randomized controlled trials of AAT and their psychological benefits [85]. Out of 66,180 articles identified in the review, eight articles describing seven studies are reported, after applying an exclusion criteria, including duplication, unrelated titles, and those that did not meet inclusion criteria. In this review, the authors reported the benefits of deploying horses, cows, cattle, sheep, dogs, and rabbits in therapeutic setting. The improvements in social motivation, sensory seeking and sensitivity, reduction of sedentary behaviour, inattention and distractibility are reported. The improvement in self-efficacy and coping abilities, and reduction of depression and anxiety were also presented in the review. The authors acknowledged the work of Chu et al. who conducted a study to evaluate the effects of AAT on self-esteem, controls of activities on daily activities, and other psycho-physiological aspects over two months. In this study, Chu et al. compared the AAT with usual treatment of the people who were impatient with schizophrenia [86]. The results showed that a short-term AAT can be beneficial on both emotional well-being and symptoms of schizophrenia. Maujean, Pepping, and Kendall concluded their review on studies on AAT by accepting at least some beneficial psychological effects of using animals in therapeutic settings.

Berget and Braastad reviewed the evidence for the effectiveness of AAT with farm animals for persons with psychiatric disorders, concluding that AAT using farm animals may reduce depression and anxiety, and increase self-efficacy of the people with psychiatric disorders [87]. The authors claimed that many studies involving farm animals in AAT supported their conclusion. The work of Mallon at the Green Chimneys institution with 80 children with behavioural and mental health issues showed that the children participating in the study utilized the farm animals showed the improvements in their symptoms like those got from utilizing the service of a therapist [87].

Bente, Oivind, and Bjarne developed a study that was a randomized controlled trial and follow-up in the context of green care [88]. Green care is a concept where contact with nature is an important part of the process that involves the use of farm animals, gardens, and plants in cooperation with health authorities. The study included 90 participants with schizophrenia, affective disorder, anxiety, and personality disorder. It is reported through this work that there was a significant difference in self-efficacy in the AAT treatment group but not in other groups. It is also reported that there was a significant improvement in cooperation ability among the AAT treatment group. The authors concluded that AAT with farm animals may have a positive influence on self-efficacy and cooperation ability among patients with psychological disorders.

Carolyn et al. reported the effects of an AAT in psychiatric rehabilitation using dogs, rabbits, ferrets, and guinea pigs [89]. The study involved 69 participants with a mean age in years of 41.5 ± 1.7 (SD) with an age range between 20 and 66 years. The study consisted of a rehabilitation group that included AAT compared to a similarly conducted rehabilitation group without using animals. The authors' conclusion was that under AAT, the patients interacted more with other patients than in the other groups. This significant result supports the positive effects of using animals in therapeutic settings to help improve psychiatric conditions. The authors also suggested that the patients receiving AAT socialize more with other patients and demonstrate pleasure during the activity.

Nepps, Charles, and Stephan reported that the AAT can improve ratings of depression, anxiety, pulse, systolic blood pressure, diastolic blood pressure, cortisol levels and pain through the findings from their one-year study among 218 patients hospitalized in the mental health unit of a community hospital which went through an AAT and stress management program [90]. Their results indicated that patients in AAT showed significant improvement on some psychological and physiological measures compared to patients in stress management program.

Sandra and Kathryn examined the effects of AAT in reducing anxiety levels of hospitalized psychiatric patients involving 230 participants using a therapy dog [91]. The study compared AAT with traditional therapeutic recreation method among patients with mood disorder, psychotic disorder, substance use disorder, and other disorders using a mixed-models repeated-measures (method that analyses results from repeated measures design where the outcome is continuous) of anxiety levels. The study found that AAT showed statistically significant reductions in anxiety levels for hospitalized patients with psychotic, mood, and other disorders, while a traditional therapeutic recreation session contributed to the reduction in anxiety only for patients with mood disorders.

In brief, a variety of studies have shown that AAT is beneficial to humans with psychological disorders.

(II) Animals for treating cardiovascular diseases

It can be noted from the literature dating back to the early 20th century that an affiliation between humans and animals has an effect on their cardiovascular systems. In 1929, it was reported that a dog's blood pressure dropped when it was being stroked. Fifty years after this invention, it was identified that the blood pressure of a human stroking a dog dropped as well, encouraging further research on the effects of pet ownership on cardiovascular diseases [92]. Kathie et al.'s study reported the benefits of using animals in therapeutic settings in patients hospitalized with heart failure [93]. The study was a three-group randomized repeated-measures experimental design (A method in which participants are randomly grouped into three groups) among 76 adult participants. During this study, one group received a 12-minute visit from a volunteer with a therapy dog; another group received a 12-minute visit from a volunteer; and the control group received usual care. The patients included in the study had advanced heart failure and were between the ages of 18 and 80 years. Fourteen dogs with ten various breeds were used in the study. Through this study, it was reported that the patients with advanced heart failure had lower cardiopulmonary pressures, neurohormone levels, and anxiety levels after AAT than with patients who were visited by a volunteer and patients given usual care. The authors strongly suggested that AAT can help to reduce anxiety among patients with severe heart failure.

Andrew and William conducted a review of the evidences on the benefits of AAT for patients with cardiovascular diseases [92]. Particularly, the authors mentioned the work of researchers in Australia which showed that the presence of a pet can assist in halting the development of cardiovascular diseases. The study also referred to the work by Friedmann and Thomas who examined the effects of pet ownership on heart rate variability (physiological measure of variation in the time interval between heartbeats) in patients with healed myocardial infarcts. The study hypothesized that pet ownership increased heart rate variability and hence help to decreased cardiovascular mortality.

(III) Animals for treating dementia

The term '*dementia'* is originally derived from the Latin root *de mens,* denoting an observable decline in mental abilities with various characteristics, including gradual decrease in the ability to think and remember, emotional problems, decrease in motivation, and problems with communication [94]. With over 100 types of dementia reported, such as cardiovascular dementia, dementia of the Alzheimer's type, and mixed dementia, it was estimated that about 47.5 million people around the world were diagnosed with dementia in the year 2015 [95]. Persons with dementia (PWD) require utmost care and support even to meet their daily needs such as eating, bathing, taking medication, and socialization due to their inability to live on their own. It is alerting that the PWD population is expected to reach 131.5 million by 2050. Apart from medications, there are a number of therapies that help PWD. AAT is explored extensively in the recent decades for treating PWD. Motomura, Yagi, and Ohyama reported that dog-assisted therapy can influence the mental state of PWD [96]. In their study, eight PWD with the mean age of 84.8 years are examined with mental state tests, such as, the apathy scale, the irritability scale, the depression scale, the activities of daily living, and mini-mental state examination to investigate the effects of using animals on their mental states. It is reported that 63% of the participants mentioned that they started liking dogs after the sessions and they would like to participate in such activities again. The study also indicated significant difference in apathy state before and after interacting with a dog.

The effects of AAT on agitated behaviours and social interactions of PWD were investigated by Nancy in her three-weeks study among 15 participants using a therapeutic dog [97]. During this study, the participants could play with a dog, pet it, feed it, talk to it, and brush it. A therapeutic recreational professional or a student intern collected and recorded the data on each participant using the AAT flow sheet. AAT flow sheet is a tool used to evaluate participants' improvements in social interactions after therapy. This pilot study reported significant reduction in agitated behaviours and an increase in social interaction among PWD.

The influence of AAT in improving social interaction among PWD was tested by Christine et al. during their 12-week study among 21 PWDs in nursing homes and 28 home-dwelling PWDs attending a day-care centre [94]. The study was performed as a part of two cluster randomized controlled trials in which the groups of participants are randomized. During this study, the participants interacted with a dog and its handler for 30 minutes, twice a week and reported that AAT helped create engagement in PWDs among nursing home residents. It is also reported that AAT contributed to a high level of smiles and laughter among the participants during the study.

Christine et al. tested the effects of animal-assisted activity on the balance capability for the home-dwelling PWDs with a total of 80 participants; 42 in the intervention group and 38 in the control group [98]. One of the main objective of the study was to examine if AAT has an effect on factors related to the risk of accidents where people fall. The study was performed as a prospective and cluster-randomized multicentre trial (a multicentre trial is clinical trial which is conducted at more than one clinical centre) with a follow-up study. The results indicated that AAT has shown a positive effect on balance measured by the Berg Balance Scale (a measure used to determine the participant's ability to balance during a series of pre-determined tasks) for participants in the intervention group compared to the control group from pre-test to post-test. Berg Balance Scale is a 14-item scale developed to calculate balance among the elderly in clinical settings. Scoring for the 14 tasks are based on the participants' ability to perform predefined tasks or movements to meet time and distance requirements [98].

Susan and Robert reviewed a number of studies conducted to evaluate the effects of AAT for PWD and concluded that AAT was a promising psychological intervention for PWD [99]. Numerous benefits of AAT among PWD, such as reduction in agitation and aggression, improvement in social behaviour and nutrition were reported in this study. Specifically, the study mentioned the work of McCabe et al. that investigated the effects of introducing a resident dog in a special care unit and reported significant reduction in daytime behavioural disturbance among participants. after AAT.

(IV) Animals for treating Alzheimer's disease

Alzheimer's disease (AD) is a progressive neurodegenerative disorder in which the death of brain cells causes loss of memory and thinking ability. It is further characterized by impairment in a wide spectrum of cognitive abilities in language, judgment, mood, memory, and social behaviours [100]. It is estimated that in 2013, there were about 5.2 million Americans with AD and it is expected to reach 13.8 million by 2050 [101]. As the cure or a method to prevent AD is yet to be identified, numerous efforts are being carried out to improve the quality of life for the individuals with AD. Numerous studies have indicated the usefulness of AAT for patients with AD. Lucia et al. conducted a study to evaluate the efficacy of AAT in patients with AD [102]. The study was based on the formal reality orientation therapy (ROT) protocol that involved 50 participants divided into three groups. ROT therapy is performed by presenting information about time, place, or person to help participants understand their environment. The first group with 16 females and 4 male participants received AAT based on the ROT protocol. The second group with 14 females and 6 male participants received activities based on the ROT protocol. The third group that formed a control group had 7 females and 3 male participants who did not participate in any stimulations. Mini-mental state examination (MMSE) and geriatric depression scale (GDS) were investigated in the study. Both MMSE and GDS are 30 item questionnaires used to measure cognitive impairment and depression in participants respectively. It is reported that AAT structured using the ROT protocol may helped to improve mood and depressive symptoms of the elderly participants.

Enrico et al. performed a repeated measure study on the effects of AAT among patients with AD in a day care centre [103]. The repeated measure study is method in which the experiment is repeated with same participants and conditions to evaluate the reliability of the results. Ten participants (six males and four females) with an average age of 79 years diagnosed with AD were included in the study. The study was conducted as two-weeks pre-intervention, three-weeks control activity with dogs, and three weeks of animal-assisted activities (AAA). The study validated through a statistical analysis the hypothesis that the interaction between humans and dogs influenced the emotional status of elderly patients. The authors reported that AAT significantly reduced anxiety and sadness while increasing positive emotions and motor activity of the patients.

Nancy and Alan examined the effects of observing an aquarium on nutritional intake in the patients with AD [104]. The authors claimed that the nutritional intake and the body weight changed among 68 patients with AD after fish is introduced into AAT for them. In their study, the participants were divided into two groups; treatment and control groups. A fully self-contained automated aquarium with colourful fish were introduced to the treatment group, whereas a scenic ocean picture was introduced to the control group. The study investigated the nutritional intake of participants over a period of two weeks and reported that the participants in the treatment group ate more in the presence of aquariums than the participants in the control group. Increase in nutritional intake has numerous positive effects for the patients with AD including delay in muscle wasting, fewer incidents of falls, prevention of skin infections, decubitus ulcers, and sepsis. As a result, the quality of life of the patients with AD improved.

Barbara et al. studied the effects of introducing resident dogs to the patients diagnosed with AD at an Alzheimer's special care unit [105]. In this study, the records of 22 participants with a mean age of 83.7 years were reviewed. The results were analysed using a two-way repeated measures ANOVA (a measure used to identify how a response is affected by two factors) to evaluate the changes in the scores related to the behaviour problems among the participants. It was found that the presence of a resident dog helped to improve the behaviours of the participants. The authors also acknowledged the work of numerous researchers that proved interactions with animals can have positive effects in a variety of settings, such as home, psychiatric, and nursing facilities.

The effects of companion animals on the persons with dementia of the Alzheimer's type (DAT) was reviewed by Mara and Barbara [106]. They found that the companion animals can provide the patients with a positive feel and comfort. They reported that when a person with DAT becomes bedfast, he can feel warmth, and comfort from an animal sleeping next to him. They also claimed that there are a number of anecdotal reports of resident dogs and cats in nursing homes that are capable of identifying dying residents by lying next to them during the last hours of their life.

(V) Animals for elderly care

The elderly population is rapidly increasing across the globe reporting 900 million people over the age of 60 in the year 2015 [107]. It is expected that by 2050, the number will rise to about 2 billion which would be approximately 21% of the estimated world population. Various countries have taken steps to help this huge population in leading a better life. This includes, social support, elderly care units, healthcare benefits, and subsidized or free transportation. Nevertheless, a variety of diseases (related to bone and joints, visual, hormonal, lungs, kidneys, etc.) and disorders (such as dementia, Parkinson's disease, Alzheimer's, loneliness, mental illness, etc.) affects the quality of life of the elderly. Apart from medications, a variety of therapies are developed and are being followed by the elderly to address those diseases and disorders found among the elderly. The beneficial effects of animals in therapeutic settings among the elderly is well presented in literature through various studies. Marian and William studied the effects of AAT on loneliness in the elderly population in a long-term care facility by involving 45 elderly people [108]. They used the University of California at Los Angeles loneliness scale (UCLA-LS) to measure loneliness among participants. During the study, the participants could hold, stroke, talk to, or play with the dog. Their results showed that AAT can significantly reduce loneliness of residents in long-term care facilities.

Francesca et al. evaluated the effects of using animals for therapeutic needs among the elderly affected with dementia, depression, and psychosis [109]. A total of 21 participants over the mean age of 84.7 years were involved in the study with ten patients in an AAT group and eleven patients in a control group. The study was conducted for a period of over six weeks and was evaluated using MMSE and GDS through statistical analysis. The results showed that under AAT, the depressive symptoms and self-perceived quality of life were improved among the patients.

The influence of pet therapy using a canary on the psychological status and perception of quality of life among institutionalized elderly was investigated by Giovanni et al. [110]. In this study, 144 participants were divided into three groups: Group 1 with 48 participants receiving therapy through trained therapists, Group 2 with 43 participants being given a plant, and Group 3 with 53 participants served as a control group. Group 1 which received AAT exhibited more social interactions than the other two groups.

The authors conclude that animal intervention has influenced improvement as measured by the Brief Symptom Inventory (BSI), an instrument designed to evaluate psychological distress and psychiatric disorders in people, protecting participants from depressive and obsessive symptoms, and anxiety. Marieanna and Rene discussed the benefits of using a dog in AAT for elderly with depression and anxiety [111]. A total of 16 participants, with eight participants in an AAT group and eight participants in the control group contributed to the study over a period of six weeks. The authors used the Beck's Depression Inventory (BDI) and the Beck's Anxiety Inventory (BAI) to validate the study outcomes. BDI is a 21-item self-report inventory used to measure the severity of depression. BDI is also a 21-item self-report inventory which is used to measure the severity of anxiety levels in children and adults. The study reported a significant difference in pre and post BDI mean scores among the AAT group, though no significant difference in the BAI scores was found. It was concluded that AAA can reduce depression levels of residents in long-term care facilities.

Javier et al. conducted a meta-analysis of the effects of AAT on the psychological and functional status of the elderly and the patients with psychiatric disorders [112]. The study analysed methods in assessments, data extraction, statistical analysis, the positive effects of AAT on depression, anxiety, behavioural disturbances, and functional status of participants. Through this study, it is reported that AAT can be effective in reducing psychological and behavioural problems among the elderly.

(VI) Animals for treating autism spectrum disorder

Autism has been used to describe various types of neuropsychological conditions since the early 1900s. Autism was initially thought to be a form of schizophrenia during the 1900s and was given its own category for diagnosis in the diagnostic and statistical manual (DSM) during the 1980s [113]-[114]. DSM is published by the American Psychiatric Association to provide standard criteria for the classification of various mental disorders. Autism spectrum disorder (ASD) is classified as a neurodevelopmental disorder characterised by lack of interest in interacting with peers of same age, minimal or no eye-contact, unusual behaviours and interests, hyperactivity, and self-harming behaviour. ASD is found in all ethnic, race, socioeconomic, and age groups. Centres for disease control and prevention (CDC) estimated that about one percent of the world population (or approximately, 75 million people) has some form of ASD [115]. It is reported that about one in 68 children are autistic in the U.S. In New Zealand, the autism population is roughly 65,000 [116]. The lifetime cost of an individual with ASD in the United States averages from 1.4 million to 2.4 million [117]. The medical experts are still working hard to identify medication that can eradicate autism. Nevertheless, few medicines are prescribed to treat severe symptoms of autism, such as depression, anxiety, and obsessive behaviours. Selective serotonin reuptake (SSRI), antipsychotic, and anticonvulsant medicines are widely used in autism [118], but their side effects are alarming. The U.S. Food and Drug Administration (FDA) has issued warnings that people consuming anticonvulsants medicines should be watched carefully for signs of suicidal thoughts [119]. Side effects of consuming SSRI and antipsychotic medicines includes nausea, sleepiness, weight loss and gain, insomnia, and tremors [120]-[122]. As there is no definitive medical diagnosis or medication to cure these conditions [123], a variety of other methods have been explored.

With such limitations in medications for ASD, alternative methods, including occupational therapy, AAT, speech and language therapy, applied behaviour analysis therapy, massage therapy, music therapy, and robot-assisted therapy have received notable support across the world. With proven benefits of AAT to numerous other disorders as described in the above sections, various studies have explored the benefits of using animals in therapeutic settings involving children with ASD. For instance, Atsushi et al. measured the smiles of a child with ASD using a wearable interface device to report effects of AAT over a period of seven months [124]. The study involved a ten-year old child identified with symptoms of ASD and another normally developed child of the same age. Six dogs were used in the study as therapeutic animals and the participants could interact freely with them during the sessions. The participants' behaviours were video-recorded and coded by the medical examiner using dartfish software (a video software that enable users to analyse online and offline videos) and corresponded with the computer-detected smiles. Through this study, it was identified that both participants exhibited positive social behaviours as children's smiles increased and their negative social behaviours decreased.

Alessandra et al. conducted a critical review on the evidences of the benefits of six studies involving dogs in therapeutic settings for children with ASD [125]. The authors acknowledged that AAT especially improve verbal and non-verbal behaviours of children with ASD.

Ayla and Lee presented a comprehensive literature review on using equines among children with ASD to provide therapeutic benefits [126]. The authors examined 12 studies and reported that eleven studies have shown increased physical and social functioning, communication, sensory sensitivity, sensory motivation and self-regulation, adaptive skills, improved volition, and decreased aberrant behaviour and severity symptoms among children with ASD.

Dolphins are widely known for their intelligence and playful attitude that makes them popular in human culture. Involvement of dolphins in therapeutic settings initially took place in the year 1978 in the U.S. During 1995 to 1996, patients from 22 countries underwent dolphin-assisted therapy at Ocean World in the U.S. [127]. Several studies have indicated the benefits of dolphin-assisted therapy for children with ASD. For example, David et al. presented the effects of short-term dolphin-assisted therapy among 47 participants with various disabilities [127]. The participants received 17 therapy sessions with a minimum duration of 40-minutes interaction with dolphins over a two-week period. The study indicated significant increase in motivation, attention span, gross and life motor skills, and speech and language through dolphin-assisted therapy.

An online survey was conducted by Bradley and Ashley among school teachers in Australia who were working with children diagnosed with ASD to identify their attitudes and experiences towards involving animals in the classrooms [128]. A total of 73 school teachers answered an online questionnaire with a maximum of 58 questions. Most teachers showed a positive attitude towards, and a high interest in the involvement of animal-assisted interventions (AAI) for children. It is important to note that 96.7% of teachers who had not been involved with AAIs expressed interest to adopt AAIs in the future. Some examples of AAT are illustrated in Figure 1.

Figure 1 Animal-assisted therapy illustrations

Sources: http://www.ecofriendlylink.com/blog/animal-assisted-therapy/, http://www.gaebler.com/Starting-an-Animal-Assisted-Therapy-Practice.htm, https://infograph.venngage.com/p/191895/animal-assisted-therapy, http://hakubaldwincenter.org/programs/animal-assisted-therapy-and-activities/, https://www.petfinder.com/animal-shelters-and-rescues/volunteering-with-dogs/animal-assisted-therapy-dogs/, https://therapyanimals2017.wordpress.com/2017/02/16/dolphin-assisted-therapy-isnt-so-therapeutic/.

2.2.2. Limitations of using animal-assisted therapy

In spite of numerous reported benefits, many therapeutic centres, clinics, and hospitals are highly hesitant to accept animals in their therapeutic settings mainly due to the following limitations [129]-[133]:

- ❖ Physical risk to animals and patients
- ❖ Health and safety concerns
- ❖ Animal handler competency
- ❖ Suitability of the type and personality of the animals
- ❖ Counterproductive effects
- ❖ Cultural beliefs
- ❖ Diseases
- ❖ Allergies
- ❖ Ethical issues
- ❖ Animals' health and well-being

No matter how well trained, an animal's behaviour can never be fully predicted. Chandler mentioned that a cat scratching a child, or a dog knocking the patient over indicates the need for risk management which has been ignored [129]. The author also warned the potential of animals to negatively affect the therapeutic process if the patient perceives rejection from the animal, the animal becomes ill or dies, the patient has unreasonable expectations of the animal, or the patient is not respectful of the animal's well-being or safety.

Also, aggravated patients, and mishandled and overscheduled therapies possess a serious concern to the animal safety in AAT. One of the critical concerns with AAT is the possible spread of zoonotic diseases passed between humans and animals [130]. Other possible diseases include ringworm from cats, and salmonella from cats, birds, and horses [131]. The U.S. Department of Agriculture alerts that cross-species infection can occur within a farm or between farms, such as the avian influenza virus between chickens and dogs [132]. It is also emphasized that viruses can be carried from one farm to another when the patients participate in therapy in more than one farm. Cultural beliefs toward animals also limits the application of AAT. For example, some Koreans have expressed hesitance to interact with large dogs as they are usually used as aggressive guard animals in the country [133].

In recent years, there have been an increased research interest in the design and development of robotic pet animals that has the potential to provide the benefits of AAT while avoiding its negative effects. This is also a main motivation of this thesis.

2.3. Animal-inspired therapeutic pet robots

The development and deployment of bio-inspired therapeutic pet robots are undertaken across the world targeting a number of contexts from elderly care to children with special needs [134]. Several studies have indicated the benefits of bio-inspired therapeutic pet robots and their abilities to not only mimic the behaviour of their biological counterparts, but also to retain the essence of benefits provided to humans. Even though several species have been inspired for their morphological or behavioural pattern to develop robotic platforms, this section focuses specifically on the bio-inspired robots used in therapeutic settings based on the popularity and the results reported in academic publications. We divided the section into three subcategories, namely, human-inspired robots, dog-inspired robots, and other bio-inspired robots. We then presented the needs and potentials of developing a parrot-inspired robot targeting improvement in learning and social interaction abilities of children with ASD.

2.3.1. Human-inspired robots

(I) Nao robot

Nao is a human-like robot developed by the French company Aldebaran Robotics with the first public version released in 2008. Initially, this robot was used extensively in soccer playing robots competitions, later being explored in therapeutic settings as well. The latest version (V5, 2014) of this robot with 25 degrees of freedom weighs approximately 4.3 kilograms and about 58cm in height. This programmable robot contains cameras, microphones, range sensors, tactile sensors, and pressure sensors, making the robot a viable platform for studies exploring therapeutic benefits of bio-inspired robots [135]. Nao robot has been studied in various therapeutic settings including elderly care and autism therapy. For instance, David et al. presented the initial observations from their user study to help elderly in geriatric physiotherapy rehabilitation in Spain [136]. In this study, the Nao robot was used to replace one of the usual roles of the physiotherapist, modelling exercising movements for the patients. The authors also compared the effects of real robot and virtual robot in this role of modelling exercising movements. The robot was programmed to perform nine predefined exercises as defined by the physiotherapist, and the participants were monitored on how they responded during real-robot therapy and virtual-robot therapy. It was reported that positive responses from patients during both therapies were observed as they responded well to mimic the exercising movements of the robot. Nevertheless, it is identified that patients responded more to real-robot therapy than to virtual-robot therapy.

Jessica et al. proposed the RIA (Robo Idoso Activo) platform by enhancing the features of Nao to make it an elderly care robot [137]. These features include environmental and patient temperature monitoring, luminosity indication, humidity identification, blood pressure, and glucose monitoring to make the RIA robot suitable for elderly care.

Fancisco et al. presented the development of application as a cognitive stimulation tool for Nao robot in the therapy of patients with dementia [138]. The authors have developed the programming framework to play back music, perform physical movement and speech synthesis, and interact with the human. The study investigated the effects of robot therapy in improving neuropsychiatric symptoms of patience over other traditional therapies. Thirteen dementia patients with a mean age of 83.2 years participated in a one-month long study and contributed in the evaluation of four sessions, namely, language, music therapy, storytelling and physiotherapy. It was found that the neuropsychiatric symptoms of participants showed better than the patients treated with classic therapy methods.

Nao robots were also applied in autism therapy and their effects in various aspects such as physiological, psychological, and social interaction benefits to the patients were studied. Adriana et al. presented a series of four single-subject design experiments (a research experiment setup where individual participants' responses are studied in different settings) to investigate if children with ASD showed increased social engagement while interacting with the Nao robot, compared to interacting with a human partner in motor imitation task that involve physical body movements [139]. The study reported that the participants' attention towards the robot intensified when it changed its eye colour or performed physical movement. It also showed that the human-robot interaction was beneficial for the children with ASD having minimal or no eye contact.

Luthffi et al. mentioned the initial response of stereotyped behaviour (repetitive body movements) of the children with ASD during the robot-assisted therapy (RAT) and usual class session [140]. The authors evaluated the stereotyped behaviour of children using Gilliam autism rating scale – 2nd edition (a norm-referenced instrument used in diagnosing autism in individuals aged between 3 and 22 years) and reported that they exhibited less stereotyped behaviour during the RAT compared to children in the usual human-human class sessions. An illustration of Nao robot in autism therapy is presented in Figure 2.

Figure 2 Nao robot in therapeutic setting

Source: https://www.bostonglobe.com/business/2014/06/14/nao-from-aldebaran-robotics-connects-with-autistic-children/l0FpLVqBk4wPsK0q21kxDI/story.html

(II) Zeno robot

Zeno is a child-sized humanoid robot developed by Hanson robotics released in the year 2012 which is more realistic in appearance than other facially expressive robots in terms of expressions. This robot has been explored as a teaching and intervention tool to improve social behaviour of children with ASD. Michelle, Sophia, and Mohammed investigated the abilities of children with autism to identify six emotions, namely: happy, sad, angry, disgust, fearful, and surprise using the Zeno robot and compared them with the normally developed children [141]. The study reported that there was no significant improvement in children with ASD compared to normally developed children for recognizing the basic emotions.

Nahum et al. investigated the effects of using Zeno robots in autism therapy to improve physiological movements such as arm and torso motions in therapeutic settings [142]. It was assumed that enabling robots to make arm and torso movements would encourage children to mimic the motion and enhance their motor skills and improve their social interaction abilities. Figure 3 demonstrates a Zeno robot in a therapeutic setting.

Figure 3 Zeno robot in therapeutic setting

Source: https://blue-ocean-robotics.com/zeno-og-nao-two-humanoid-robots/

The results show that the child who was exposed to the Zeno robot responded positively to the robot and was attracted to it.

(III) KASPAR robot

Kinesics And Synchronization in Personal Assistant Robotics (KASPAR) is a child-sized humanoid robot, developed with minimal expressive features specifically for human-robot interaction studies. It has been used in many human-robot interaction which involved children with ASD. Joshua et al. used KASPAR robot to triadic, a collaborative game involving the robot and two children [143]. Six children with ASD played 23 controlled play sessions each, both with and without the robot. The study showed an improvement in children’s behaviours after they played as pairs with the robot. An autonomously operating robot is also used for improving cooperative skills among the children. Another study was presented by the same authors involved the children with ASD who alternatively played a cooperative, dyadic video game with a human counterpart and playing the same games with a KASPAR robot [144]. It is reported that children with ASD were more entertained, invested, and collaborated with their partners after having session with the KASPAR robot, denoting, interaction with the robot had a positive impact on children’s behaviour. Figure 4 depicts a child interacting with a KASPER robot.

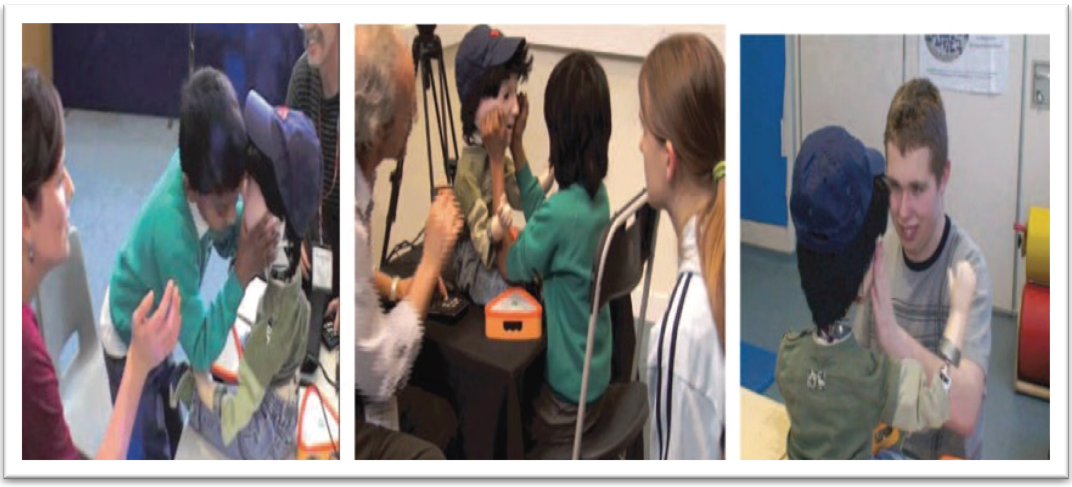


Figure 4 KASPAR robot in therapeutic setting

Source: Dautenhahn, K., Nehaniv, C. L., Walters, M. L., Robins, B., Kose-Bagci, H., Mirza, N. A., & Blow, M. (2009). KASPAR–a minimally expressive humanoid robot for human–robot interaction research. Applied Bionics and Biomechanics, 6(3-4), 369-397.

2.3.2. Dog-inspired therapeutic robots

(I) AIBO robot

Artificial intelligence robot (AIBO) is a dog-like robotic pet designed and developed by Sony at its computer science laboratory. The first consumer model was released in 1999 and has been used in several studies for educational and human-robot interaction research. The company has been releasing new versions every year until 2005. This robot can respond to over 100 voice commands and has been used widely in entertainment, edutainment, and therapeutic settings. For instance, Kanamori et al. reported improvements in utterance, demonstrative language, and satisfaction among the elderly patients after their interaction with the AIBO robot over a period of seven weeks in Japan [145]. Astrid, Daniela, and Manfred described the reactions of children and adults when they encountered AIBO robot for the first time at a shopping mall [146]. The robot was programmed to perform a few predefined actions, and the children's and adults' perception of the robot was investigated through questionnaires. It is reported that 77.9% of children participating in the study believed that the robot can understand them and act accordingly, showing an emotional attachment between the children and the robot. On the other hand, adult participants suggested that this robot could be a substitute for dogs in hospitals, and serve as a companion in elderly care centres.

Gail et al. deployed the AIBO to compare the effects of robotic dog to that of a live Australian Shepherd dog among 72 children aged between 7 and 15 [147]. The study reported that 80% of the participants were within an arm's length from both a live and robotic dog during the sessions. It was also reported that 56%, 70%, and 76% of children affirmed that AIBO had mental states, sociality, and moral standing, respectively.

Toshiyo et al. evaluated the effectiveness of AIBO as an entertainment robot in occupational therapy for patients with dementia and compared the results with a toy dog [148]. Thirteen dementia patients with the mean age of 84 years participated in the study where an AIBO robot and a battery-driven toy dog were used. Increased communication among the participants were observed during the AIBO robot activity. An illustration of AIBO robot interaction with elderly is shown in Figure 5.

Figure 5 AIBO robot in therapeutic setting

Source: https://www.sciencedaily.com/releases/2008/02/080225213636.htm

(II) ERIC robot

Elderly Rehabilitative Interactive Companion (ERIC) is a dog-like therapeutic pet robot developed with the objective to design a low-cost therapeutic robot for elderly care (Figure 6). Various studies have been performed to evaluate the efficacy of this robot in addressing several issues such as interaction, hear rate, and various psychological conditions in the elderly [149]. It was found that facial temperature of participants changed during the interaction with the robot. The ERIC robot was also used in the studies involving the elderly in Singapore and has reported notable acceptance and benefits from the elderly community [149]-[150]. Jaichandar et al. reported the effectiveness of human-robot interactions for the 20 elderly participants using ERIC robot [150]. A significant difference in interactions among participants before and after interacting with the dog-like robot was recorded.

Figure 6 ERIC robot

Source: Elara, M. R. (2012). Comparing Thermography, GSR and Hear rate during stimulated therapeutic pet robot interaction among elderly.

2.3.3. Other bio-inspired robots

(I) PARO robot

PARO is a baby harp seal like therapeutic pet robot designed by the Intelligent System Research Institute, Japan to encourage positive emotions among patients such as happiness and relaxation [151]. Shibata, the inventor of PARO robot claims that the robot's unfamiliar seal-like appearance can influence the acceptance from the users. PARO robot is equipped with tactile, light, audition, temperature, and posture sensors to communicate with people and obtain information from its environment. Through these sensors, the robot can sense being stroked or beaten, recognize the direction of voice among other sensing capabilities. Covered with artificial fur, PARO robot can move its head and legs and can make sounds like a baby harp seal. Several studies have used PARO robot in therapeutic settings and reported numerous benefits, such as reduction in stress and improvement in social interaction. As an illustration, Sean et al. assessed the attitude and emotions of 30 older adults before and after interacting with the PARO robot [151]. The study reported that many participants were positive toward the robot and demonstrated that it can provide notable benefits to people with cognitive or physical impairment. Wada et al. investigated the effects of a PARO robot in a robot-assisted therapy setting among elderly in a day-service centre. Twenty-six participants between the age group of 73 and 93 years were involved in the study three days a week over a period of five weeks. The participants could interact with the robot for 20 to 40 minutes per day. The questionnaire concerning moods and comments of nursing staffs were investigated to confirm significant positive effects in the participants after interacting with the robot. In another study, PARO robot was evaluated in the context of multi-sensory behavioural therapy for elderly patients with dementia [152]. It was found that a PARO robot provides indirect benefits to the participants by increasing their activities in particular modalities of social interaction. The study also reported that the participants' interaction time with the robot increased steadily. Direct interaction with the robot resulted in increasingly attentive behaviour of the participants towards both the robot and other participants. PARO robot has become one of the most preferred therapeutic robot for elderly care. Figure 7 shows an example of PARO robot during user a study.

Figure 7 PARO robot in therapeutic setting

Source: Wada, K., Shibata, T., Saito, T., Sakamoto, K., & Tanie, K. (2005, April). Psychological and social effects of one year robot assisted activity on elderly people at a health service facility for the aged. In Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on (pp. 2785-2790). IEEE.

(II) CuDDler robot

CuDDler robot is a 400mm tall, 200mm wide polar bear like companion robot designed to be an assistive and education tool for children with ASD [153]. CuDDler robot weighs approximately 4kg and has a huggable morphology. It is equipped with a microphone, contact-microphone, as well as tactile and posture sensors for the robot to perceive a human and its environment and to provide appropriate responses. It has three degrees of freedom for its neck, two degrees of freedom for the arms, and one degree of freedom for the eyelids. Contact microphones are used to recognize touch from participants. This robot has been used in therapeutic settings involving children with

ASD, patients with dementia, and in elderly care to provide psychological and physiological benefits.

Wong and Zhong examined the effects of the CuDDler robot in improving learning and social communication skills among children with ASD [153]. Eight children between the ages of four and six years diagnosed with ASD were involved in the study. Ninety percent of the participants responded positively after interaction with the robot. There were significant improvements in turn-taking skills and longer duration of eye-contact engagement among participating children. In another study, Wendy et al. studied the effects of the robot on engagement and emotional states of five elderly adults with dementia [154]. It was found that the robot provided opportunities for the participants to engage in social interaction, encouraging them to play and laugh with each other.

Figure 8 CuDDler robot

Source: Moyle, W., Jones, C., Sung, B., Bramble, M., O'Dwyer, S., Blumenstein, M., & Estivill-Castro, V. (2016). What effect does an animal robot called CuDDler have on the engagement and emotional response of older people with dementia? A pilot feasibility study. International Journal of Social Robotics, 8(1), 145-156.

(III) Probo robot

Probo robot is an imaginary animal-like robot with a trunk, animated ears, eyes, eyebrows, eyelids, mouth, neck, and an interactive belly screen with a huggable appearance. It was designed to act as a social interface and create interaction among participants. The robot has a fully actuated body with 20 degrees of freedom to create facial expressions and make eye-contact. Probo robot has been used widely in studies involving children with disorders, especially for children with ASD.

Cristina et al. used a Probo robot in a study to determine whether the children with ASD enhanced their capabilities in identifying situation-based emotions (sad, happy, and neutral) after interacting with the Probo robot [155]. Their results showed that participating children showed an improved performance in identifying emotions with an overall recognition rate of 84%.

In another study, Ramona et al. investigated the difference in interaction among 30 children with ASD during the interaction with a human and a Probo robot [156]. It was noted that the children had more eye contact with the Probo robot compared to the eye-contact with a human.

Figure 9 Probo robot in therapeutic setting

Source: Saldien, J., Goris, K., Vanderborght, B., Vanderfaeillie, J., & Lefeber, D. (2010). Expressing emotions with the social robot probo. International Journal of Social Robotics, 2(4), 377-389.

This section illustrated the applications and benefits of several therapeutic robots designed through inspiration from animals for various disorders, including ASD. Among various morphologies of animals adopted for the robot design, one very relevant species that was not given much attention is parrots. In the next section, we present the needs and future potentials of a parrot-inspired therapeutic robot for autism therapy.

2.4. Needs and future potential of a parrot-inspired therapeutic pet robot

Several animal-inspired robots have been researched within therapeutic settings where the robots mimic the morphological form, behaviour, and multimodal human-robot interactions. There have been a number of animal-inspired robotic platforms developed and evaluated in the context of therapeutic scenarios. Most of the studies presented successful improvement in physiological, psychological, or social needs of participants. Among several pet animals inspired by roboticists, one very relevant species that has received very little attention is parrot. With approximately 11 million birds living in the U.S., parrots are the fourth most common household animal after dogs, cats, and fish [157]. Parrots are naturally able to emulate human speech and effectively engage in a two-way conversation, a feature rarely found in many of the other animals that provided inspiration to build robotic platforms for being used in therapeutic settings. Parrots can be very rewarding pets to the right owners, due to their intelligence and cognitive abilities, and their desire to interact with people. They can be affectionate with people and demand a lot of attention from their owners. Properly socialized parrots can be friendly, outgoing, and a confident companion. It is identified that parrots are experts in mimicking human voices and other sounds [157]-[158]. These unique features have the potential to be very successful in teaching children with ASD and to improve their social interaction abilities.

Long-time relationships of parrots with humans can be identified through various sources, including ancient Tamil literatures. Parrots were used as a communication medium to transfer messages during the ancient period of India [159]. A parrot is also seen in the hands of main goddess statue of a historical temple built before the 7^{th}

century that proves the existence and relationship of parrots and humans over thousands of years [160].

Grandgeorge and Hausberger examined the effects of parrots in the home environment and identified that the presence of parrots at home can induce well-being in people and help improve social skills among people [161]. Pepperberg, an animal psychologist who has been studying parrots for more than 30 years with more than 100 publications, has reported a number of intelligent behaviours of parrots, such as speaking, and using words in a meaningful manner [162]. An African grey parrot, Alex, from her laboratory had a vocabulary of more than 100 words and could count numbers up to ten [163]. Alex was also able to engage effectively in two-way conversations and differentiate materials such as wood and paper.

Parrots have been used in AAT to help people with psychological or physiological disorders. Earlier, parrots were involved in therapeutic settings for patients with post-traumatic stress disorder, bipolar disorder, and psychotic tendencies [164]-[166]. They have been involved in therapy for war veterans in the U.S. to treat stress disorders [167]. Haw presented a study on deploying parrots as therapeutic animals for psychiatric patients including house-bound, the lonely, and patients with depression [168]. In the author’s another study, parrots were found to be very helpful for middle-aged women suffering from the empty nest syndrome (a feeling of grief and loneliness). Interestingly, the author reported that parrots can provide better companionship to owners than television.

Parrots have been used with elderly care in Japan and numerous benefits to participants, such as improvement in sight, sound, and smell sensitivity among the elderly have been reported [169]. In the U.K., children with ASD reported calming behaviour after interacting with a Caique parrot [170]. An African grey parrot named Sadie helped his owner who had bipolar disorder with psychotic tendencies by repeatedly saying ‘calm down’ when the owner was in a stressful situation [171].

With such promising benefits to humans through parrot-assisted therapy, it still faces the same set of constraints as with any other AAT. One common risky behaviour reported by parrot owners is biting [172]. Having large beaks, parrots can cause severe damage to humans. They can spread diseases such as parrot fever through Chlamydia psittaci bacteria and can be a threat in parrot-assisted therapy [173]. These problems can be eliminated from the design and development of a parrot-inspired therapeutic robot for therapeutic settings. From the engineering point of view, this robot can be complex in terms of design mechanism, actuation framework, motion control, sensor fusion, and hardware-software integration. With such challenges and huge potential for therapeutic applications, through this PhD research, a parrot-inspired robot, KiliRo has been developed and implemented to improve learning and social interaction abilities of children with ASD.

In the next chapter, the formulation of expected features and specifications of KiliRo robot through various user studies conducted among the stakeholders is presented.

3. User Requirement Analysis

3.1. Synopsis

In Chapter 2, the needs and potentials of developing a parrot-inspired therapeutic robot to help children with ASD are presented. Often, the design process involved in the development of therapeutic robots requires extensive user studies to extract user requirements. They are essential to increase user acceptance and make the robot cost effective.

Paediatricians, child psychologists, parents, and teachers of children with ASD were identified as prospective users or stakeholders for the proposed therapeutic robot. Furthermore, they have practical experience dealing with children with ASD and can play vital roles in recommending features and specifications for a therapeutic robot. Hence, they are involved in our study.

The following three methods; brainstorming, interviews, and questionnaires are used to obtain the user requirements for the features and the specifications for our parrot-inspired therapeutic robot. The outcomes of the brainstorming session and the interview were analysed using conversational analysis method and thematic analysis/text mining method respectively. The questionnaire data was analysed using statistical analysis method.

3.2. Brainstorming

Brainstorming is a group activity conducted to identify a solution to a specific problem by collecting a list of ideas spontaneously contributed by the participants. This technique has been widely adopted in product design and development in various sectors [174]-[178]. In this research, the expectations and requirements from the stakeholders are investigated through brainstorming to conclude the features and specifications of the proposed therapeutic robot. This approach eventually helps in developing the robot as expected by the users which will increase the acceptance rate of the robot. Figure 10 illustrates the flow of a typical brainstorming sessions.

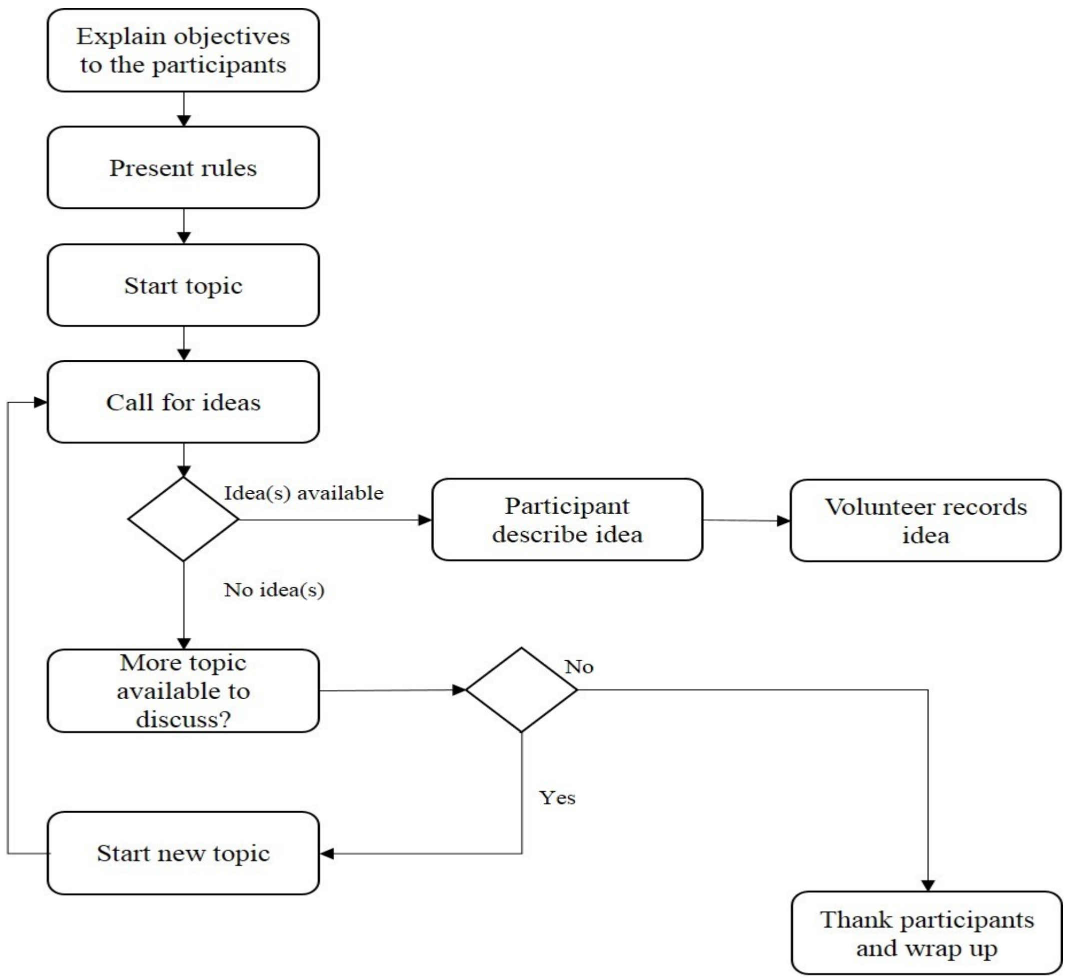


Figure 10 Brainstorming session flowchart

Paediatricians, child psychologists, parents and teachers of children with ASD were contacted through convenience sampling method (a non-probability sampling technique in which the participants are selected based on the convenient accessibility and proximity to the researcher) to participate in our brainstorming sessions. Two hospitals and one special school in India were identified to be the potential places for conducting the brainstorming sessions based on the participants' availability, willingness to participate, and convenience for conducting the sessions. A formal open invitation was sent along with study objectives to seven paediatricians and four child psychologists of two different hospitals in the same city. In the same way, invitations were sent to 22 parents and 14 teachers of a special school in the same city. The potential participants were given one week to respond to the invitation. Participants were chosen to address the problem in medical, psychological, parental, and educational point of views. Out of 47 invitations sent, 25 responded willingness to participate in the brainstorming sessions (five paediatricians, two child psychologists, nine parents, and nine teachers).

Brainstorming sessions with paediatricians and child psychologists were conducted at the hospitals where they were working and the sessions with parents and teachers were conducted at the special school. Three brainstorming sessions were conducted separately with paediatricians, child psychologists, parents and teachers with a minimum duration of 30 minutes. During the first session, the participants were given a brief introduction about the aims of the session. In the first brainstorming session, most common problems faced by the children with ASD were discussed in detail. During the second session, effects of alternative approaches to medication, such as AAT, music therapy, massage therapy, behavioural therapy, and RAT were discussed. In the last session, the most suitable morphology for designing a therapeutic robot was analysed. Two volunteers for each session were recruited to document the discussion points and the data was analysed manually by three researchers and discussed to obtain agreement within the researchers.

Most of the participants mentioned that learning and social interaction are common difficulties faced by children with ASD. Even though other factors, such as minimal or no eye contact and repetitiveness were discussed, learning and social interaction were ranked as the most important issues to be addressed. The paediatricians mentioned that several therapeutic methods have been developed and explored with children with ASD due to no identified medical cure for the disorder and most of their patients (children with ASD) undergo more than one therapy. The child psychologists were positive towards exploring new methods for helping children with ASD so that they can lead a better life. They were concerned about the children's reluctance towards their peers and family members, leaving them separated from their social environment. An intervention tool that can interact with children with them can help them participate in activities with their peers.

Most of the parents and teachers were positive towards new therapeutic methods and technologies for children with ASD. Likewise, teachers were interested to try innovative methods to educate children with ASD. During the third session, several animals were presented in the context of bio-inspired therapeutic robots to help improve learning and social interaction abilities of children with ASD. Out of more than 50 species studied, most participants insisted that parrots are intelligent and can engage in two-way conversations and exhibit cognitive abilities. Another bird discussed in the session is Mynah, a bird of the Sturnidae family that can reproduce various sounds including human speech, but has no ability to engage in two-way communication or exhibit cognitive abilities. With all other animals considered, parrots' distinct ability of engaging in two-way conversations and success in providing therapeutic benefits was more effective to improve learning and social interaction among children with ASD.

Especially, parents and teachers who participated in the sessions were more positive towards designing a parrot-inspired robot for therapeutic needs with mean a value of 88.8% and 77.7%, respectively. Out of five paediatricians who participated, three supported parrot-like morphology, one opposed, and one commented that he could not comment before the robot is built. One psychologist was extremely satisfied with parrot-like morphology considering the abilities of its living counterpart, whereas another psychologist proposed unfamiliar morphology to attract children with ASD, such as a dog with a human head.

Through the brainstorming sessions, it was identified that the core focus of the robot in treating children with ASD was to help improve learning and social interaction abilities. Parrot-inspired morphology was widely accepted by most of the paediatricians, child psychologists, parents, and teachers.

3.3. Interviews

Interviews are one among the most commonly used methods for collecting information from individuals and are used in several research studies [179]-[184]. Primarily, there are three types of interviews: informal (a non-structured interview that takes place in a casual setting with no pre-defined questions from the researcher), semi-formal (a semi-structured interview that incorporates conversational aspects with few pre-defined questions from the researcher), and formal (a structured interview that strictly adhere to the use of an interview protocol to guide the researcher in which only the questions on the interview protocol are asked) interviews used in research studies. In this study, informal and semi-formal interviews were used to obtain the user requirements for the parrot-inspired therapeutic robot. Paediatricians, child psychologists, parents, and teachers of children with ASD were involved in both interviews.

Simulated parrot robot

A simulated parrot robot consisting of one head, two eyes, two legs, two wings and a tail was developed with semi-autonomous behaviours and was presented to the stakeholders towards extracting user requirements for the robot. The simulated parrot robot adopted has two degrees of freedom in each leg, and the head can move left, right, up and down. The tail can move left and right. Two wireless cameras with speaker-microphone pairs were used for real-time video and audio streaming. Figure 11 illustrates the simulated parrot robot used in this study.

Figure 11 Semi-autonomous robot prototype

Procedure

We approached the paediatricians, the child psychologists, parents and teachers of children using a convenience sampling method to partake in an interview to get their opinions and recommendations for the development of the parrot-inspired therapeutic robot. A formal open invitation was sent to 40 potential participants (10 Paediatricians, 10 child psychologists, 10 parents, and 10 teachers) who were given three days to respond to the invitation. Twenty-two stakeholders, (three Paediatricians, two child psychologists, ten parents, and seven teachers) who responded to the invitation were provided with the details of the study objectives and the interview to be conducted.

Members who expressed interest in participating in the study were interviewed using informal and semi-formal interview methods. During this study, we explained the objectives and potentials of designing a parrot-like robot for autism therapy and demonstrated a semi-autonomous parrot robot designed for this interview as presented in Figure 11. The proposed features in the simulated robot, such as talking, face and voice recognition, and response to touch and sound were simulated using a wizard of Oz approach. Wizard of Oz is a type of research experiment in which participants interacts with a system that they believe to be autonomous, but being operated by a human operator. In our study, a human operator controlled the robot's locomotion through a remote control.

The operator remotely activated the behaviours in the robot, based on a live video feed of the situation obtained through a wireless camera. For instance, the remote robot operator identified the person standing in front of the robot through a wireless camera and used a microphone to initiate and maintain communication between the robot and the person. After that, the respondents were asked for their opinion on features and specifications that they would recommend for the end-product based on their experience with children. The informal interviews were conducted in groups for a minimum duration of 30 min and the informal interviews were conducted as a one-to-one session with a minimum duration of 15 min. The interviews were conducted at the participants' convenient times and venues.

Participants

A total of 22 participants (10 parents, 7 teachers, 3 Paediatricians, and 2 child psychologists) participated in the interview (16 females, 6 males). Just over half of the participants were aged between 25-34 years (54.5%), with 36.4% between 35 and 44, and 9.1% between 45-54 years. About 82% of participants had at least a Bachelor's degree and most participants had experience dealing with children with ASD (90.9%) for more than five years.

Over one third of the participants (77.3%) had no prior experience in robot-assisted therapy (RAT), 18.2% heard or read about RAT, and 4.5% had prior experience in RAT. Detailed descriptive information about the participants is illustrated in Table 1.

Table 1 Participants' descriptive information

Factor	Range / category	Mean or %
Age	25-34 years	29.00
	35-44 years	37.00
	45-54 years	50.50
Sex	Male = 6	27.27
	Female = 16	72.73
Education	High school	18.18
	Bachelor's degree	31.82
	Master's degree	22.73
	Doctoral degree	27.27
Exposure to children with ASD	Less than two years	0.00
	2-5 years	9.09
	More than 5 years	90.91
Robot-assisted therapy familiarity	Never heard or read about RAT	72.73
	Read or heard about RAT	22.73
	Used RAT for child / patient / student	4.54

3.3.1. Informal interviews

Informal interviews are performed in a casual setting as a conversational approach with no pre-defined questions from the researcher. Numerous studies have used informal interviews to obtain information about product design, features, and specification requirements from the user before developing the product. This approach is used to interact with paediatricians, child psychologists, parents, and teachers of children with ASD to understand their requirements in a parrot-inspired therapeutic robot. The informal interview sessions were performed as open discussions, where most of the conversations were based on the participants' opinion of robots used for children with ASD and the benefits of applying animal-like morphology to design the robots. The interviews also focused on identifying the participants' opinion on barriers in implementing robot-assisted therapy (RAT) in the home, classroom, clinical, and hospital environments.

A thematic analysis method was used to investigate informal interview responses. Thematic analysis is one of the most common methods used in analysing qualitative research data [185]-[186]. It emphasizes pinpointing, analysing, and recording themes within data. The first phase of analysis requires data familiarization, and therefore we involved reading and re-reading the qualitative responses were read multiple times to familiarize the responses. At the second stage, the data was searched by asking three major questions; 1. What are the motivators for using robots for autism therapy? 2. What are the perceived benefits of parrot-like robots in improving learning and social interaction abilities of children with ASD? 3. What are the perceived barriers of involving robots in autism therapy? Responses from participants were grouped under each of these three categories. They were then discussed among the experts in medical and psychological fields, parents and teachers of children with autism, and within the research team to establish agreement that they were coherent with the themes and representatives of the patterns across different participants' responses.

Most parents of children with ASD who participated in the study acknowledged that they are willing to explore new methods to improve the lifestyle of their children. Especially, they were excited about using robots in educating and playing with their child(ren). Parents had prior knowledge of animals being used in therapeutic scenarios, such as elderly care and autism therapy. But none of the participants, except for one parent, had any experience in the use of robots in autism therapy. Most of the parents accepted that animal-like robots would attract children with ASD. This aligned with the conclusion obtained from the previous studies [187]-[191]. Parrot-like morphology has gained about 90% acceptance. One of the main reasons for the parents' positive response are due to the parrots' natural ability to speak and their intelligence. They strongly supported replicating such behaviours in a robot to create an educational and playful environment for their children. About 70% of parents were positive towards using a parrot-like robot to improve learning and social interaction of children with ASD, while 30% responded that they would know the benefits only after experimenting the robot in real time.

Out of seven teachers who participated in the study, six were positive towards using a KiliRo robot in an educational environment. They agreed that the robot can help encourage children to play with the robot and with other children. Most of the teachers pointed out that talking is very essential in communicating and teaching and the robot should be equipped with such capabilities. However, some worried about losing their job if robots can replace their roles place in teaching children with ASD.

Both child psychologists who participated in the study suggested that new methods should be experimented among children with ASD. They also mentioned that these children are generally good observers, and using robots can encourage them in educational and clinical settings to improve learning and social interactions. Nevertheless, there was a concern that attachment between the robot and the child might be potentially at the expense of attachment with other humans.

Out of three paediatricians who participated in the interview, only one was positive towards using robots in hospital settings. The other two respondents questioned the reliability of such methods and raised concern in ensuring safety of patients, even though they admit some benefits of RAT. Two participants who were not positive towards RAT and mentioned that such methods have been in practice for many decades but are still in an experimental state. They also mentioned that there are many procedures and ethical permissions needed to implement such techniques in a hospital environment, but all three participants were supportive to the advancement of robot deployment in the medical field, such as surgery and hospital automation. All three participants accepted that parrot-like robots can help in improving learning and social interaction among children with ASD and were positive towards using such methods for their patients.

3.3.2. Semi-formal interview

Semi-formal interviews are extensively used in qualitative research to obtain data from users to estimate their satisfaction level towards a product. This method was used to obtain user recommendations on features and specifications for the proposed therapeutic robot. The semi-formal interviews were conducted as a one-to-one session with pre-decided questions from the researcher. The researcher asked five predefined questions to the participants whose responses were used to formulated the user requirements towards future development of a KiliRo robot. It took over 60 days to complete the interviews due to difficulties in reaching participants at their convenient times and places. The questions used in the semi-formal interviews are listed below:

1. What is your opinion of using a parrot-like robot in autism therapy?
2. What are the features you would recommend for a parrot-like robot to help improve learning and social interaction abilities of children with ASD?
3. What features should not be included in the parrot-like robot? Why do you think so?
4. What are the specifications (height, weight, color, material, battery life-time, and cost) you would recommend for a parrot-like robot?
5. Do you have any other comments?

A text-based word analysis method was used to analyse the semi-formal interview responses. It has been used in a number of studies in computer science to extract and categorize text documents, and has also been applied to extract and identify features and specifications in engineering design [192]-[194].

There are many methods to analyse most frequently used and repeated words in word documents. One of the method is online text mining which can be used to investigate the most frequent occurring phrases and frequency of most repeated words found in the responses from the respondents during interviews. One of the limitations in word analysis is that it counts the number of assurances of words in a document but does not take the word meaning into consideration. For example, during the interview, consider a respondent who had mentioned that he/she would not recommend a talking feature in the proposed robot. During the word analysis, talking is added to the word count which may imply it was recommended as a feature in the robot. To overcome this limitation, the questions were formed in such a way that the respondents' opinions on recommended and non-recommended features are obtained through different questions. The decision tree illustrated in Figure 12 illustrates the process followed during the text mining approach.

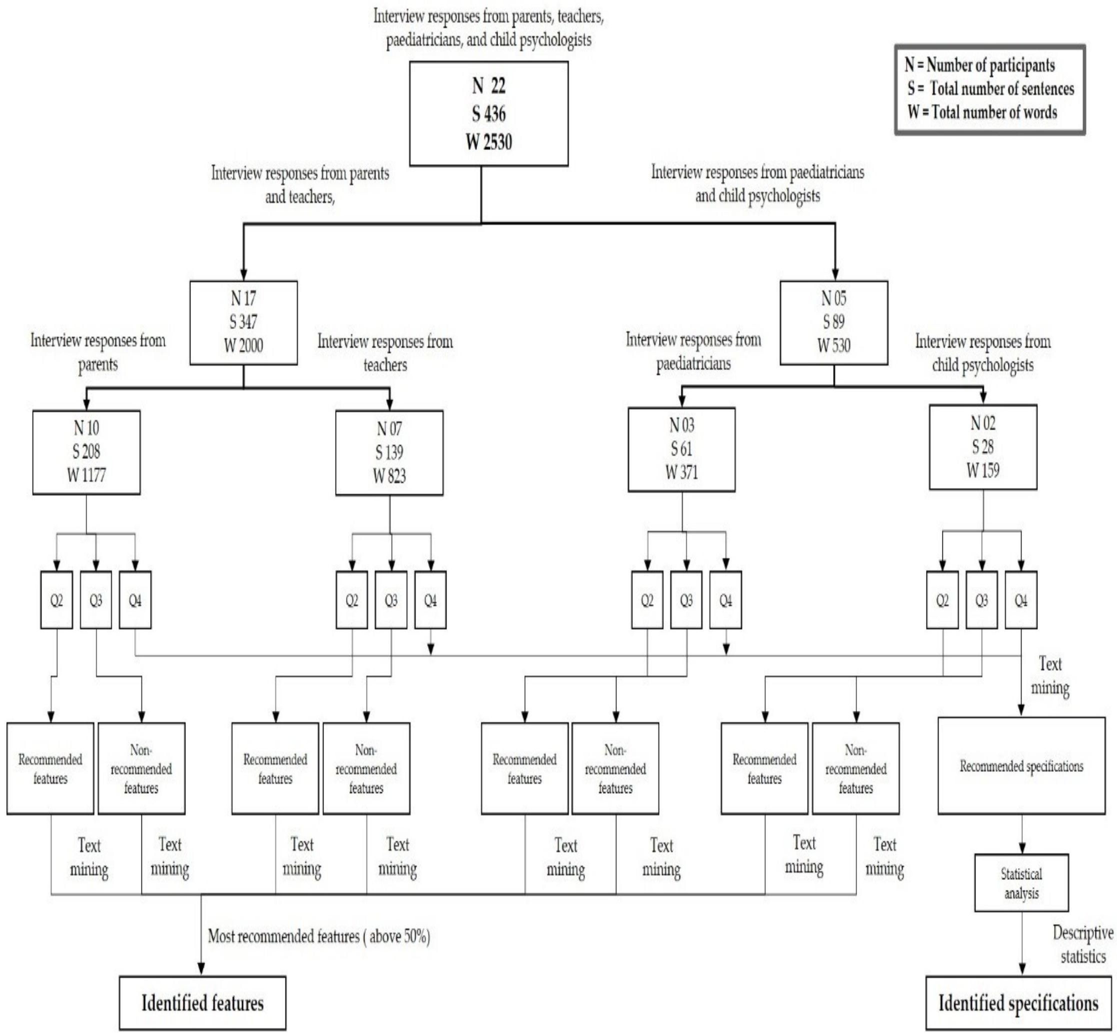


Figure 12 Semi-formal interview decision tree

Similar words were grouped into a single category to refine the recommended features. Table 2 illustrates the categories and similar words that are grouped in the text mining process. These categories were created after the text mining process was carried out based on the most frequent words. After the number of words are identified, the term frequency (TF) is calculated as the ratio between the number of occurrences of the proposed feature

(*pf*) and the total number of words in the processed document (*n*):

$$\mathrm{TF} = \frac{pf}{n} \tag{1}$$

TF is calculated for each category to decide to conclude the features in the next design iteration of the robot. The user requirements were quantified in a range of values which are then analysed using text mining to produce recommended value. The same approach is followed for identifying height, weight, and cost recommendations from the stakeholders.

Table 2 Text analysis categories

Category	Words
Talking / Walking	Talk, talking, speak, speaking / Walk, walking, move, moving
Wings flapping / Head moving	Flap, flapping, swing, swinging / Turn, turning, tilt, tilting
Flying / Singing / dancing	Sing, singing / Dance, dancing
Speech recognition / Touch recognition	Recognize, identify, respond
Virtual monitoring	Wireless, remote, virtual, real-time

A total of 436 sentences with 2,530 words have been recorded during the 22 semi-formal interview sessions. Figure 12 illustrates the decision tree model used for features and specification identification using the text mining approach.

We analysed the responses for the second, third, and fourth questions stated in Section 2.2.2 to retrieve the information on recommended features and specifications. The first and fifth questions were used to identify the general opinions and comments toward the parrot robot. To retrieve user recommendations on features in the proposed robot, we analysed the responses to the second question from the interview sessions.

Answering to non-recommended features for the robot, most of the participants put the safety of the children over possible harm or fear caused to them from some features of the robot. Responses to both the second and the third questions were considered for identifying the features in the robot. Talking, walking, wings flapping, and head moving were the top four recommended features based on the number of occurrences in the analysed data. Considering the non-recommended features, walking, flying, running, and crying were the top four features. As a result, it was concluded that features such as talking, walking, wings flapping, and head moving should be implemented in the robot.

The responses used for extracting the user needs and requirements are listed in Tables 3, 4, and 5.

Table 3 Non-recommended features

Word	**Number of occurrence in the document**	**TF**
Flying	6	0.0170
Walking	4	0.0114
Running	4	0.0114
Crying	4	0.0114

Table 4 Recommended specifications

Factor	**Unit**	**Recommended target**		**Recommended target**	
		Minimum	**SD**	**Maximum**	**SD**
Height	mm	227.3	7.19	350.0	7.24
Weight	kg	1.77	0.87	3.29	1.72
Cost	USD	970.59	601.06	1747.06	11101.20

Table 5 Recommended features

Need rank	User need	Technical requirements	Number of occurrence in the interview document	TF (n=1112)
1	Talking	The robot shall be able to speak	43	0.0390
2	Walking	The robot shall be capable of walking forwards and backwards	25	0.0225
3	Carries camera	The robot shall carry a wireless camera for virtual monitoring	23	0.0207
4	Speech recognizing	The robot shall be capable of speech recognition	20	0.0180
5	Wings flapping	The robot shall be capable of moving wings	15	0.0135
6	Head moving	The robot shall be capable of rotating and tilting head	14	0.0126
6	Touch recognition	The robot shall be capable of recognizing the user's touch	14	0.0126
8	Singing	The robot shall be capable of singing	7	0.0063
9	Flying	The robot shall be capable of flying	5	0.0045
10	Dancing	The robot shall be capable of dancing	4	0.0034

Through the interviews conducted, we precisely identified the requirements from the users towards the parrot-inspired therapeutic robot. Informal interviews revealed the attitudes of stakeholders in their different roles, such as medical staff, psychologist, teacher, and parents. It is interesting to know that most of the users, especially teachers and child psychologists are willing to explore the parrot-inspired robot.

Semi-formal interviews provided the detailed information on the features to be implemented in the robot and the performance of the robot to be expected. Only those features (talking, walking, real-time video, speech recognizing, wings flapping, head moving, and touch recognition) which were ranked top 7 in the user study were to be implemented and the specifications of the robot would be according to the recommendations as illustrated in Table 4.

3.4. Questionnaire

A questionnaire is a research instrument containing a series of questions formulated to gather information from the participants. A closed-format questionnaire was used to understand the participants' attitude towards parrot-like morphology for a therapeutic robot and its possibilities for improving learning and social interaction abilities of children with ASD. This method is followed to quantitatively analyse the stakeholders' attitudes towards the proposed parrot-inspired therapeutic robot. The questionnaire used in this study has eleven questions and used a 5-level 'Likert scale' format (a five or seven-point scaling approach used in research to allow the participants to express how much they agree or disagree to a statement given), ranging from "strongly disagree" to "strongly agree" for all questions except for two questions that followed a multiple-choice format.

The questions used in the questionnaire are illustrated below:

1. Parrot-like morphology might attract children with autism.
2. I recommend the following features in the robot to be developed (options: talking, walking, flying, wing flapping, respond to sound, respond to touch, recognize face, and recognize voice).
3. A parrot-inspired robot could be a companion for children with autism.
4. Parrot-like morphology is suitable for teaching children with autism.
5. My child tried to communicate with the robot during the study.
6. My child observed the learning abilities of the robot during the study.
7. My child accepted the parrot-inspired robot as his/her companion.
8. I recommend parrot-inspired robot for teaching children with autism.
9. My child was happy to interact with the parrot-inspired robot.

10. I recommend the following morphology for robot-assisted therapy (options: parrot, dog, cat, bear, seal, and human).
11. I would use the parrot-inspired robot for teaching my child.

The participants were selected based on the convenient sampling method. Eleven participants; nine parents, one paediatrician, and one child psychologist completed the closed-format questionnaire with no compulsory questions.

Table 6 illustrates the responses from the participants to the nine questions in a 5-point scale. Questions 1 to 11 except 2 and 10 are marked between 1 through 5 (1 is “strongly disagree”, 2 is “disagree”, 3 is “neither disagree or agree”, 4 is “agree” and 5 is “strongly agree”). Cells with no values indicate that the respondents did not provide an answer. The results point to a high degree of acceptance for the parrot-like morphology. Most of the respondents indicated that they would recommend parrot-inspired robot for teaching and improving social interaction of children with ASD. Figures 13 (Parents) and 14 (Paediatrician and child psychologist) illustrates the expected features in the parrot-inspired robot.

Table 6 Responses to questionnaire

Participant	**Q1**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q11**
Parent 1	3	3	4	2	3	3	4	2	4
Parent 2	4	3	5				4		4
Parent 3	4	4	5	4	4	3	4	5	3
Parent 4	5	4	4	4	5	5	5	5	5
Parent 5	4	4	3	4	4	4	4	4	5
Parent 6	4	5	5	5	4	5	5	5	5
Parent 7	4	3	4	3	4		3	3	3
Parent 8	3	4							
Parent 9	4	4	5	4			4		
Pediatrician	4	4	5	4	3	5	4	4	4
Child psychologist	4	4	3	4	4	4	3	3	4
Mean	3.91	3.82	4.30	3.78	3.88	4.14	4.00	3.88	4.11
n	11	11	10	9	8	7	10	8	9

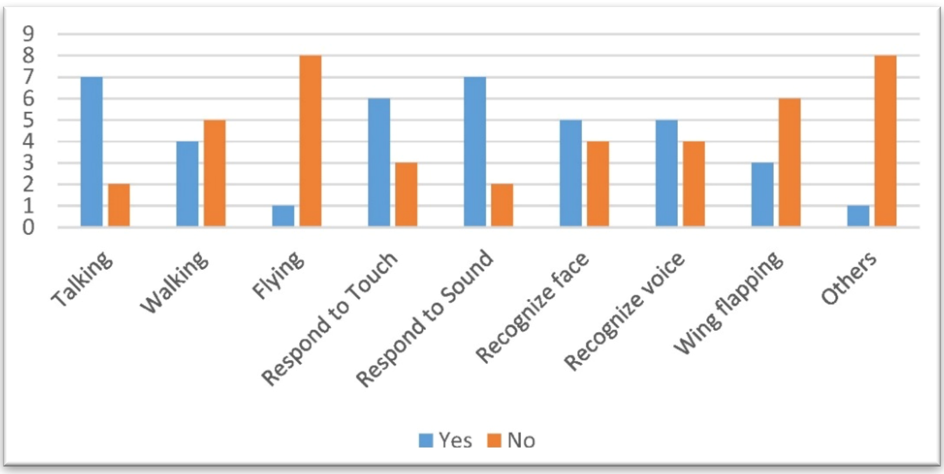


Figure 13 Expected features in the robot (Parents)

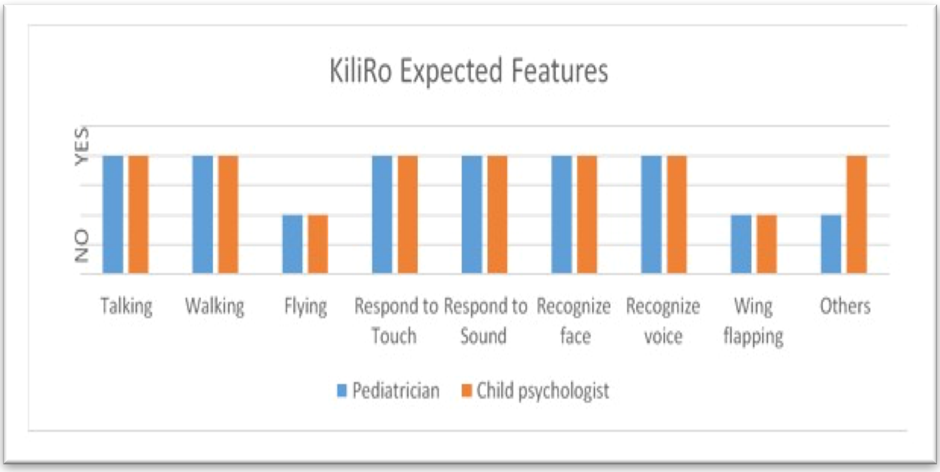


Figure 14 Expected features in the robot (paediatrician and child psychologist)

Through this chapter, the users' recommendations for the features and specifications of the parrot-inspired therapeutic robot aimed to improve learning and social interaction abilities of children with ASD were identified. They will be used in the robot design and development phase presented in Chapter 4.

4. Parrot-Inspired Robot Development

4.1. Synopsis

Following the user requirement analysis described in the previous chapter, the development of the robot is carried out in two phases. During the first phase, the required components to achieve the features and specifications of the robot as recommended by the stakeholders were identified and acquired. During the second phase, the robot development is carried out.

This chapter briefly presents the component identification and acquisition for the parrot robot, followed by its prototype development and validation. An overview of the mechanical, electrical, and software designs of the robot are presented in this chapter, followed by its human – robot interaction model.

4.2. Component Selection

In the process of robot development, several activities, such as creating the morphology, mechanical architecture, deciding the feel of the robot when held, identifying materials and processes, engineering various components to make the robot achieve its tasks, testing, and redesigning the robot to meet requirements. Initially, we concluded the features and specifications of the robot based on the stakeholders' recommendations and considering improvement in learning and social interaction among children with ASD. Most recommended features are considered during this phase and object recognition is included to enable the robot to identify English alphabets and Arabic numerals. Recommended specifications were considered to ensure the robot is developed within the expected range. Apart from the identified recommendations for height, weight, and cost, we also concluded what the material and colour for the robot should be. The concluded features and specifications are illustrated in Table 7.

Table 7 Features and specifications

Features	Specifications (Recommended / Range)
Talking	Height (227.3mm – 350.0mm)
Walking	Weight (1770g – 3290g)
Virtual monitoring	Cost (USD970.59 - 1747.06)
Speech recognition	Material (Plastic, Rubber, Silicon)
Wings flapping	Colour (Green, Red, Grey)
Head moving	
Touch recognition	
Object recognition	

To build the robot, components were identified and acquired to meet the required features and specification. Multiple competitive components were investigated and the decision was made by also considering various other factors, including, standardization of the components, availability and easiness of replacement, safety, and cost. For the consideration of the materials of the components, safety for children, easiness of production and availability of fabrication machine are the key factors. Figure 15 illustrates the framework of components identification based on the user requirements. After components were identified, controller/computer modules for the components were chosen. Three standard modular controllers (one is a small computer, and two are microcontroller based units) were used in the robot for easy integration, configuration, and expansion.

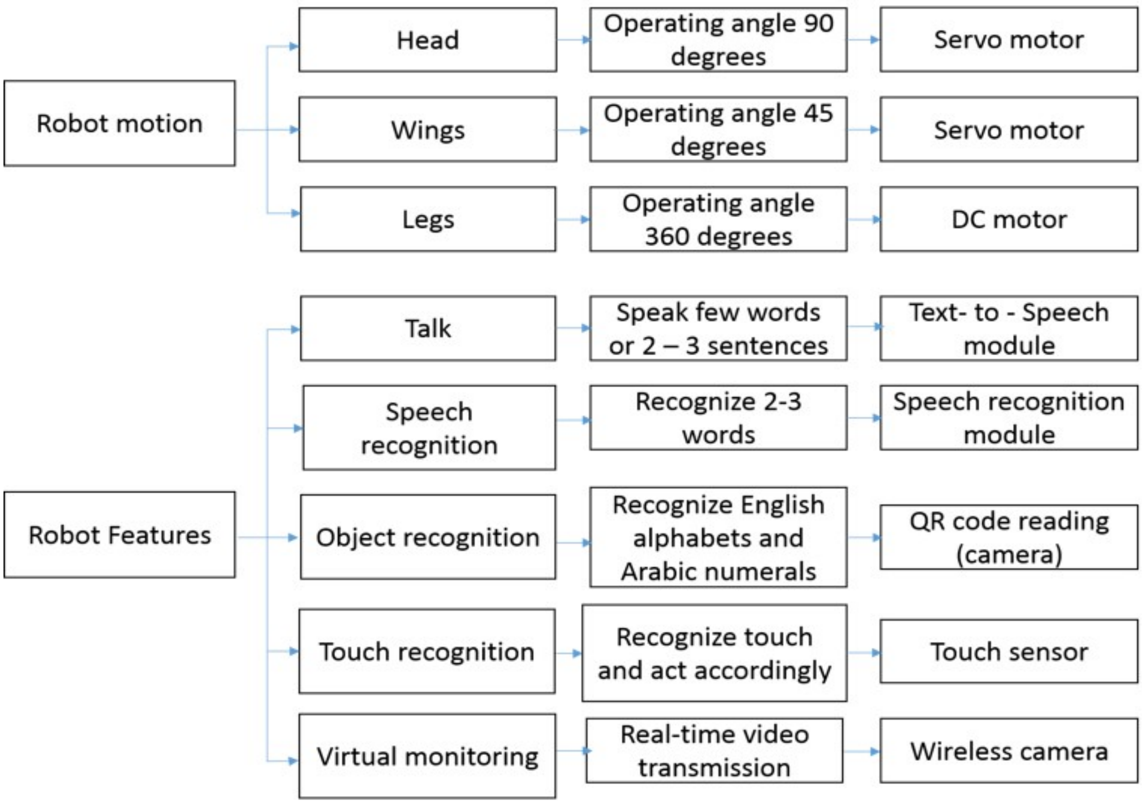


Figure 15 Components identification framework

4.2.1. Robot motion

There are three parts in the robot to be designed with motion capability; 1. Head 2. Wings and 3. Legs. The head and wings are driven by servo motors and the legs by a DC motor. The head turns is 90 degrees in both clockwise and anti-clockwise directions. Two wings open, close, and flap. A movable beak is installed to open and close the mouth of the robot when it is talking. A bipedal mechanism driven by a single 12V DC motor is used for the robot's forward and backward locomotion.

Totally there are five servo motors (one for the head rotation and one for the head tilting, one for the beak open and closed, and two motors for the wings motion) and one DC motor (robot locomotion) in the robot. The servo motors are selected based on the dimension, weight, load capacity, power requirements, and rotation speed. As payloads in the motions of the wings (weighing 40g) and the beak (weighing 20g) are small and they are driven by a small servo motor (manufactured by Tower Pro Pte Ltd with the model number MG90S) as shown in Figure 16 weighing approximately 13.4g with the dimensions of 22.5x12x35.5mm and operating with the speed of 0.1s/60 degree at 4.8V of power. The motor's shaft can rotate about 180 degrees and can be controlled through a standard servo controller. The servo motor controller controls the loop on the system by constantly monitoring the encoder signal and applying a torque to the motor to control it to hold a specific position.

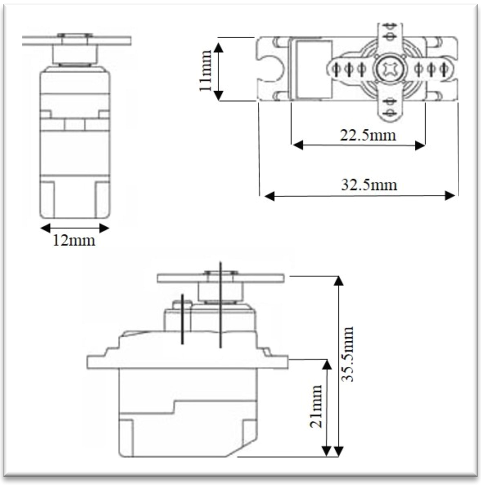


Figure 16 Servo motor specifications

The servo motor used to drive the robot's wings is illustrated in Figure 17. The motor has the dimensions of 55.5x20x44.1mm and weighs about 55g with an operating speed of 0.2 s/60° at 4.8 V of power. It is a high-speed servo motor rotating approximately 180 degrees. The stable and shock proof double ball bearing design of this servo motor satisfies the robot's safety requirements.

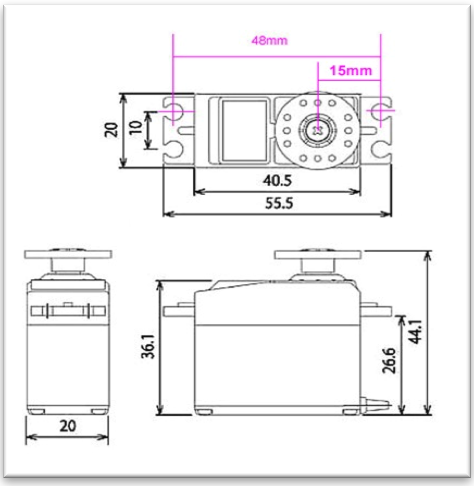


Figure 17 Servo motor (2) specifications

A DC motor is chosen to drive the robot moves forwards and backwards by considering the cost, operating power, motor dimensions and weight, and rotation speed. It can run 120 rotations per minute at 12V power supply. The physical dimensions of the motor are illustrated in Figure 18. The motors used in the robot and their specifications are illustrated in Table 8.

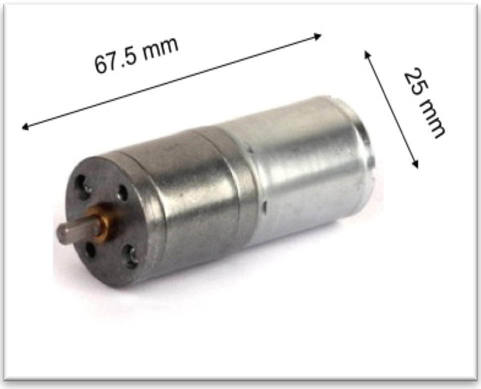


Figure 18 DC motor specifications

Table 8 Motors and their specifications

Item	Servo (1)	Servo (2)	DC motor
Dimensions (mm)	22.5x12x35.5	40.7x19.7x42.9	67.5x25
Weight (g)	13.4	55	100
Stall torque (kg/cm)	1.8	8.5	4.8
Operating voltage (V)	4.8	4.8	4 – 12V
Operating speed (s/60°)	0.1	0.2	120RPM
Connector wire length (mm)	175	300	Extendable
Rotation angle (degree)	180	180	360
Motor type	Limited rotation servo	Coreless Servo Motor	DC Motor

4.2.2. Robot's features

Talking, virtual monitoring, speech recognition, touch recognition, and object recognition are the needed features for the proposed parrot-inspired therapeutic robot. Talking, speech recognition, and touch recognition are essential to create social interaction among participants and the robot. Virtual monitoring is deployed for real-time audio and video transmission. Object recognition enables the robot to recognize alphabets and numbers to help simulate and improve learning abilities of children with ASD.

(I) Talking

We used a text-to-speech conversion unit (Emic-2) manufactured by Grand Idea Studio to enable a speaking feature to be in the robot. The unit is an unconstrained, multi-language voice synthesizer capable of converting digital text into natural sounding speech output using DECtalk text-to-speech synthesizer engine. DECtalk is a speech synthesizer and text-to-speech conversion technique developed by the Grand Idea Studio corporation. DECtalk is a standard unit that can be connected to any asynchronous serial port. There are nine predefined voice styles including male, female, and child-like voices. Speech and voice characteristics, such as speaking rate, pitch, and word emphasis can be altered. The module uses asynchronous 9600bps serial communication protocol to communicate with the host. Emic-2 uses four connections (GNS, 5V, SOUT, SIN) to interface with a microcontroller or a computer. The physical dimensions of this device are 38.1mm x 3.17mm as illustrated in Figure 19. There are four LEDs in the module that provide various state indications. These are illustrated in Table 9.

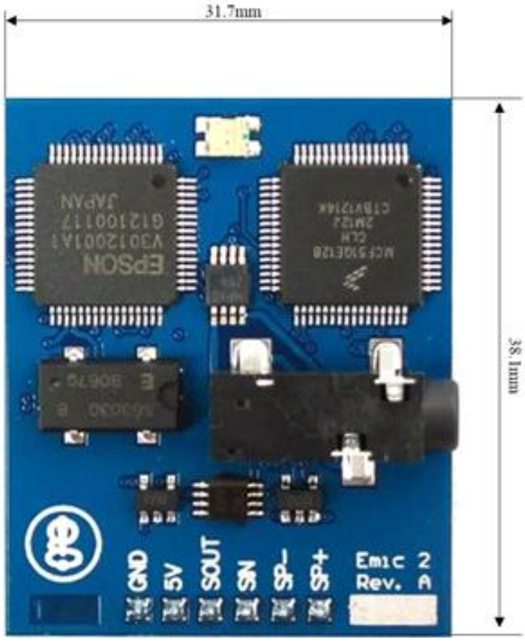


Figure 19 Text-to-speech module physical architecture

Table 9 Text-to-speech LED state indicator

Color	State indication
Green	Idle state (ready to receive command from the host)
Red	Active state (running text-to-speech conversion)
Solid Orange	Initialization state (occurs during power-up)
Blinking Orange	Error state (on-board communication error)

The text-to-speech conversion unit is capable of producing speech in English (the main language of the robot) and Spanish, and can produce a singing voice. Table 10 demonstrates some of the commands and its uses in the Emic-2 text-to-speech conversion unit to select the language, speaking voice, speaking rate, and volume etc. Refer to Appendix A for more details about the text-to-speech conversion unit.

Table 10 Test-to-speech commands and uses

Item	Specifications	Options available	Example code
D(n)	Demonstration message	0: English introduction, 1: Singing, 2: Spanish introduction	: D0 <audio output> :
N(n)	Speaking voice selection	0: Perfect Paul, 1: Huge Harry, 2: Beautiful Betty, 3: Uppity Dennis, 4: Doctor Dennis, 5: Kit the kid, 6: Frail Frank, 7: Rough Rita, 8: Whispering Wendy	: N5 :
V(n)	Volume selection	- 48(softest) to 18 (loudest)	: V-5 :
W(n)	Speaking rate selection	75 (slowest) to 600 (fastest)	: W140 :

(II) Speech recognition

A speech recognition unit, EasyVR Shield 3.0, designed and manufactured by ROBOTEC is used to achieve the speech recognition feature in the robot. This unit has 28 custom speaker-independent (SI) vocabularies and can support nine languages, namely: English, French, German, Italian, Japanese, Korean, Mandarin, and Spanish. Thirty-two user-defined commands can be trained using any of the nine languages. This module provides speaker independent commands in previously mentioned languages. This board has the capacity to record approximately 21 minutes of speech or sounds which can be played back. It can also record and play back live messages for 120 seconds and the audio output from this module directly supports 8Ω speakers. The universal asynchronous receiver/transmitter (UART) is used for serial communication within the module. Figure 20 illustrates the architecture of the speech recognition module.

The unit has two mikroBUS interface connectors and six I/O expansion pins. The audio section contains the main analogue signals, such as microphone signals and amplified DAC outputs.

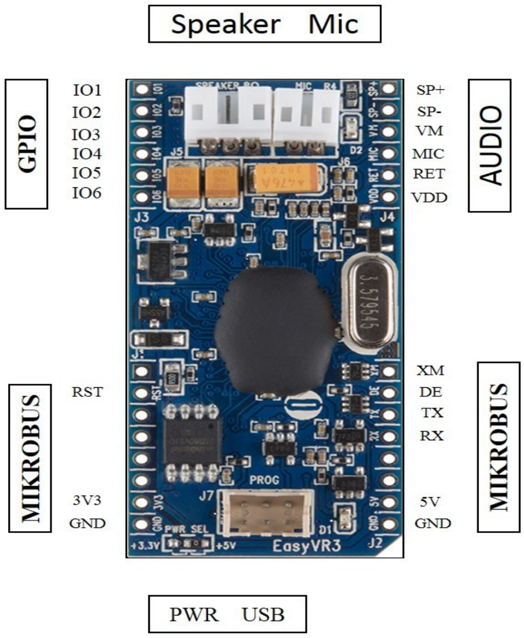


Figure 20 Speech recognition module architecture

The unit is approximately 56.4mm in length, 25.4mm in width, and 9.5mm in height. The module communicates through an asynchronous serial interface (UART) with a baud default rate at 9600 and frames with 8 data bits. The RX pin acts as the receiver data line and the TX pin acts as the output data line. Figure 21 illustrates an example of a data frame denoting the character ‘A’ with a decimal value of 65.

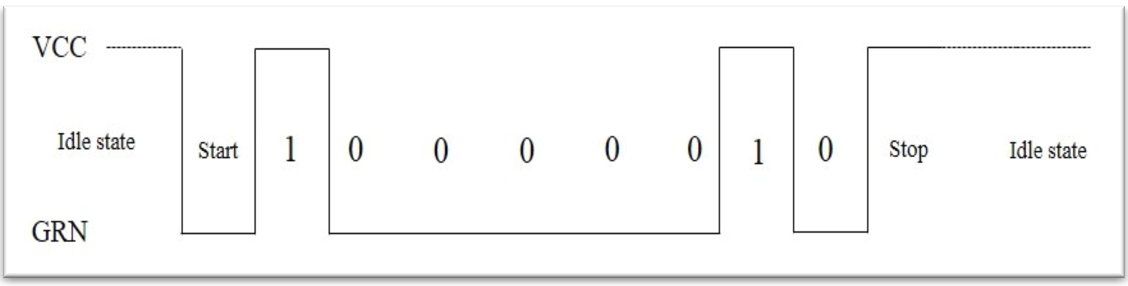


Figure 21 Serial data frame representing ‘A’

The microphone used in receiving audio input is an omnidirectional electret condenser microphone with -38dB of sensitivity and operating voltage of 3V. The microphone can receive audio inputs from 60cm to 300cm. all I/O pins in the unit are initially inputs with weak internal pull-up after powering ON which can be configured to have a strong or no pull-up. The pins should be configured to act as output pins before using it as output pins. The software commander allows the communication between the computer and the speech recognition unit through the USB adapter. Table 11 illustrates the specifications and features of the speech recognition unit. Refer to Appendix B for more details about the EasyVR Shield 3.0 unit.

Table 11 Speech recognition module specifications

Item	**Specifications**
Length (mm)	56.4
Width (mm)	25.4
Height (mm)	9.5
Weight (g)	30
Operating voltage (V)	3.3 – 5
Pre-recorded messages (min)	21
Live recording and playback (min)	2
Audio output (Ω)	8
Audio frequency	100 Hz – 20kHz
Communication protocol	Standard UART

(III) Touch recognition

Force sensing resistors (FSR) are used on the robot's body and head to achieve touch recognition. A FSR can be defined as two-wire devices with a resistance that depends on the force applied. The FSR used in the robot is a member of the single zone force sensing resistor family that are polymer thick film devices manufactured by Interlink Electronics. These sensors exhibit decrease in resistance with increase in force applied to the sensor surface. The force to voltage can be identified using:

$$\mathrm{V} = \frac{\mathrm{R(M)V+}}{(\mathrm{R(M)}+R(FSR))} \tag{4.1}$$

where,

V is the output voltage; V+ is the voltage used; R(M) is the measuring resistor;

Using (4.1), we can identify the voltage produced through the force applied on the sensor's force sensitive area. The sensor has two substrates separated by a space adhesive with approximately 0.03mm to 0.15mm thickness. The two substrates are formed on flexible polymer sheets or a film material. One substrate is coated with FSR carbon-based ink that shorts the two traces together when both substrates are pressed together. This sensor has an active area of 39.6mm x 39.6mm with a thickness of about 0.46mm with an outer dimension of 43.69mm x 43.69mm. Refer to Appendix C for more details about the sensor.

(IV) Robot control

One small computer (Raspberry pi-3, developed by the Raspberry Pi Foundation) and two microcontroller-based units (Arduino MEGA, developed by Arduino) are used to control various activities of the robot. The small computer is based on 1.2 GHz 64-bit quad-code ARM cortex- A53 central processing unit. It has a random-access memory of 1GB and a 32GB micro secure digital card for storage. It communicates with the

Bluetooth short wavelength UHF radio waves and through Wi-Fi 802.11g protocol. It is programmed for recognizing the English alphabet and Arabic numerals using a camera. The credit card sized computer can be fixed easily inside the body of the robot. The physical architecture of the small computer is illustrated in Figure 22.

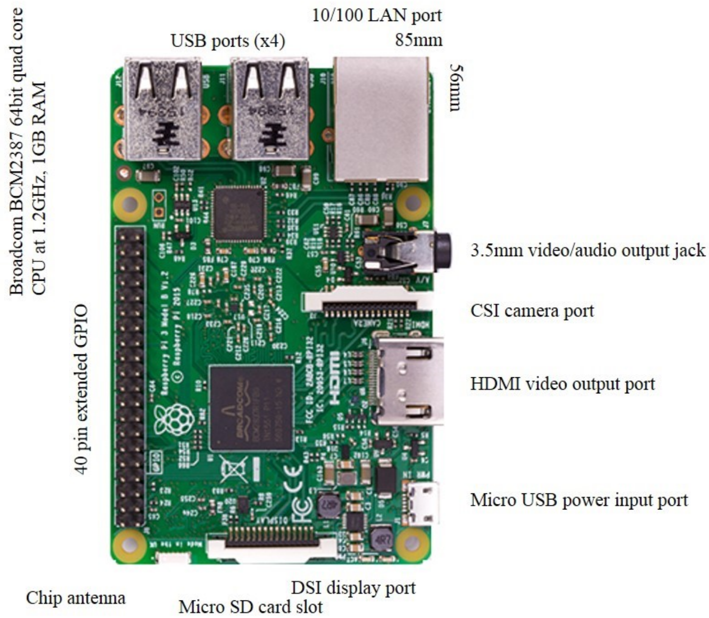


Figure 22 Raspberry pi 3 architecture

Two Atmega328P based microcontrollers were used in the robot to achieve several tasks including motor control and sensor activation. There are 14 digital input/output pins in the controller, out of which six provide PWM output and six analogue input pins. The board has 32KB of flash memory in which 0.5KB is used by the bootloader. The Atmega328P controller can communicate with the computer, another Atmega328P, or with another microcontroller using Bluetooth connectivity. The physical architecture of the controller is illustrated in Figure 23.

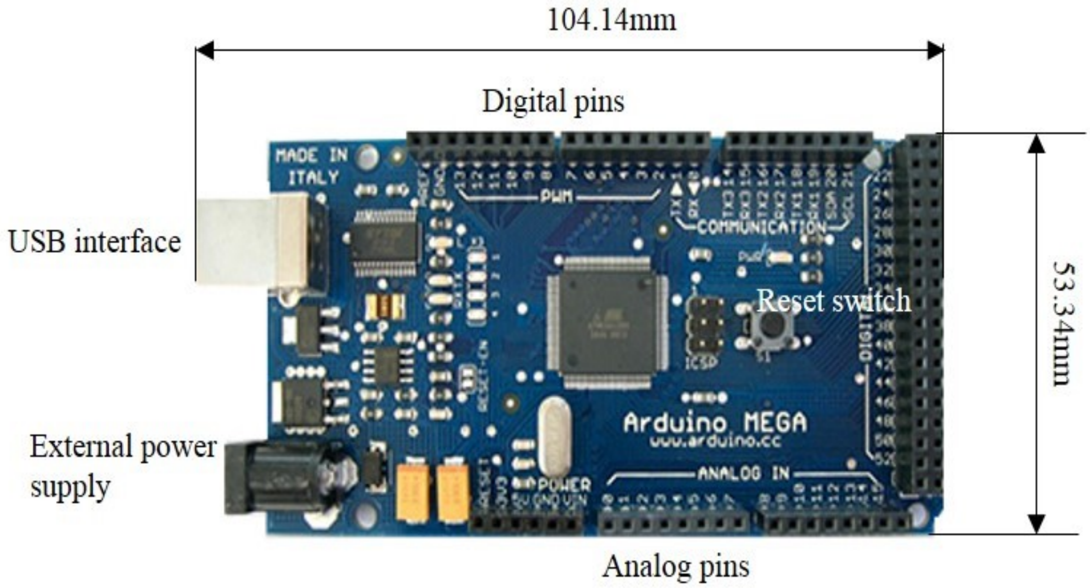


Figure 23 Atmega328 controller physical architecture

4.2.3. Robot power supply

The weight, cost, safety, recharging time, and capacity were considered while selecting the battery for the robot. Lead acid, NiCd (Nickel–cadmium), NiMH (Nickel–metal hydride), and Li-ion (Lithium-ion battery) batteries were considered and Li-ion battery was selected based on the characters such as less toxic, suitability for children, cost, recharging time, and cost. Table 12 presents the specification comparison between the batteries considered. Li-ion batteries are one of the most popular among rechargeable batteries for portable electronics, such as cell phones, and laptops with a high-energy density, tiny memory effect and low self-discharge.

The selected battery has the capacity of 2000mAh and can supply 60 minutes of power to the robot for one full charge.

Table 12 Batteries and their specifications

Specification	Lead Acid	NiCd	NiMH	Li-ion		
				Cobalt	Manganese	Phosphate
Energy Density (Wh/kg)	30-50	45-80	60-120	150-190	100-135	90-120
Fast-Charge Time (hours)	8-16	1	2-4	2-4	1 or less	1 or less
Self-Discharge/month	5%	20%	30%	<10%		
Maintenance Requirement	3-6 Months	30-60 days	60-90 days	Not required		
Toxicity	Very High	Very High	Low	Low		

4.2.4. Robot prototyping

To print the robot parts, a MakerBot Replicator desktop 3D printer was used. Manufactured by MakeBot, the replicator is capable of printing both Polylactic Acid (PLA) and Thermoplastic Polyurethane (TPU) materials, which are used in our robot. PLA material is biodegradable and bioactive thermoplastic aliphatic polyester obtained from renewable resources, such as corn starch. Lactic acid and lactide are mainly used in PLA production. Polymerization of lactide with various metal catalysts is the main method used in producing PLA material. Fused deposition modelling method is used by this printer that can produce layer resolution of 100 microns. It can print parts with dimensions of 285x153x155mm. The parts were created using several drawing tools and converted into STL extension files, which were then uploaded to the MakerBot software for printing.

4.3. Robot development

After the components identification and acquisition is completed, the robot prototype development phase is performed. There were three stages in the robot development phase. Firstly, the prototype is designed to ensure parrot-like morphology and ability to stand stable. Secondly, the prototype is designed considering parrot-like morphology, ability to stand stable and room to contain all components in the body. Finally, the third prototype is designed considering all features and specifications recommended by the stakeholders. Three iterations of the robot developed are presented in Figure 24.

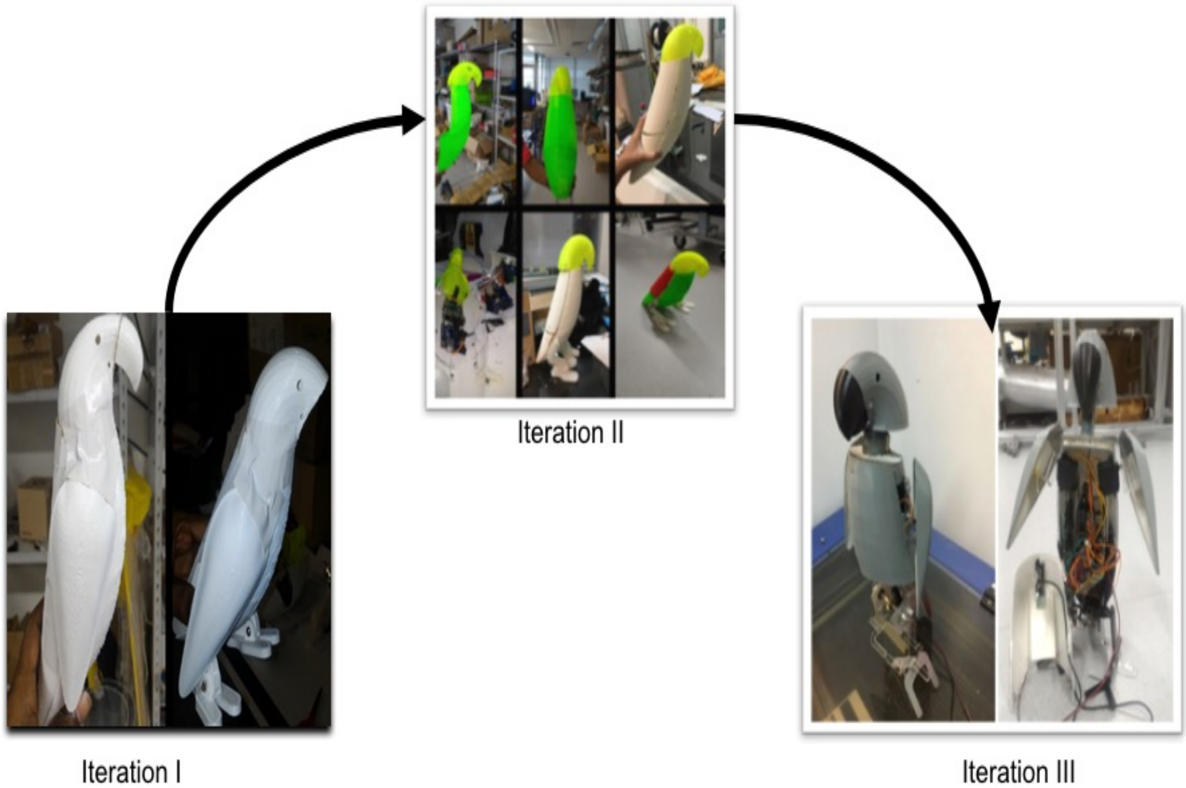


Figure 24 Iterative design of the robot

The third iteration of the robot is developed with features and specification as recommended by the stakeholders as described in Chapter 3. The developed robot is named *KiliRo* as the combination of two words; *Kili* and *Robot*, where, *Kili* is the Tamil word denoting a parrot.

In terms of morphology, the KiliRo robot can be defined as a two-legged robot having the physical appearance of a parrot. As mentioned in Chapter 3, the stakeholders recommended the minimum and maximum height of 227.3 mm and 350 mm for the robot. The recommended weight range was between 1.77 kg and 3.29 kg. These values were considered while designing the robot. The designed robot has a dimension of 240mm x 110mm x 90mm (height x width x depth).

The whole prototype weighs about 2.2 kg which is within the recommended mass for the robot by users (Chapter 3). There are three parts in the developed robot: upper, middle, and lower parts. The upper part of the robot (Head) has one touch sensor, two wireless cameras, three servo motors, a microphone, and a speaker. The middle part of the robot accommodates the controllers, speech synthesis module, text-to- speech module, USB camera, power supply, four touch sensors, two servo motors, one DC motor, and a worm-gear unit. The lower part has two legs with feet.

As recommended by most the stakeholders, the robot is equipped with five touch sensors to enable response to touch. These touch sensors are used to obtain inputs from the participants when being touched or stroked. Two wireless cameras are attached to act as a tool for virtual monitoring, which is one of the recommended features by the teachers and parents. Speech recognition feature is implemented in KiliRo to respond to voice commands. A microphone is used for receiving audio inputs and the speaker is used for producing output. The robot has three controllers; one small computer based on 1.2 GHz 64-bit quad-code ARM cortex-A53 central processing unit, and two ATmega 328P microcontroller based units. The small computer has a random-access memory of

1GB and a 32GB micro secure digital card for storage. A USB camera is attached to this small computer and programmed for reading quick response code.

The microcontrollers manage the speech synthesis, text-to-speech module, touch sensors, servo and DC motors. The controller units are equipped with 14 digital input/output pins, six analogue pins, and 16 MHz quartz crystal. Both controllers have an operating voltage of 5V. The small computer and microcontrollers work independently with individual responsibilities. The speech synthesis module receives audio inputs and converts into computer readable text using the speech-to-text module to execute appropriate actions. The servo motors on the upper part of the robot is used to provide head and beak motions, while the servo motors on the middle part of the robot is used for wings motion. The design architecture of KiliRo robot is illustrated in Figure 25.

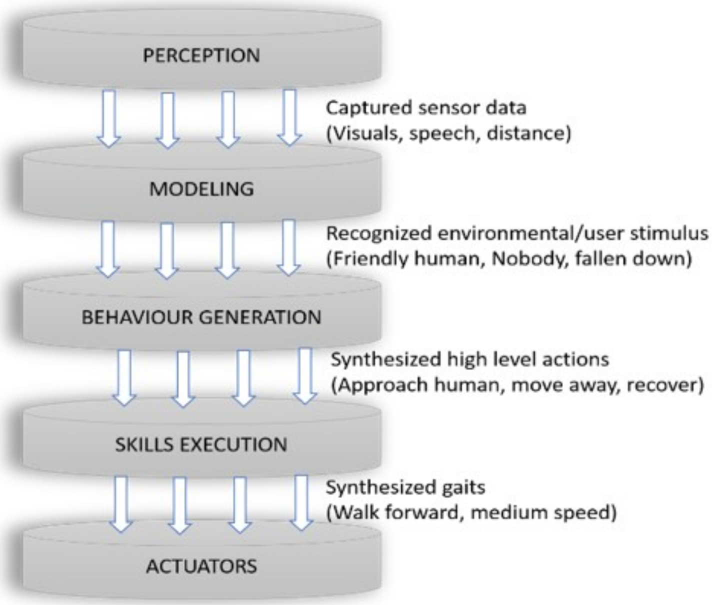


Figure 25 KiliRo – Design architecture

The robot is powered through a two-celled 2000mAh Lithium polymer battery and takes approximately 1.5 hours for charging and has a lifetime of about 45 min. The features and specifications are decided based on the recommendations from the users as obtained in Chapter 3.

As recommended by most stakeholders, the robot is designed with simple motions to attract attention from the children. The robot has a total of seven degrees of freedom (DF); three for the upper body that includes neck and beak, two for the middle body that includes wings, and two for the lower body that includes two legs. The motor positons in KiliRo is illustrated in Figure 26. The Computer Aided Design (CAD) illustration of each part is presented in Figure 27, 28, 29, 30, and 31.

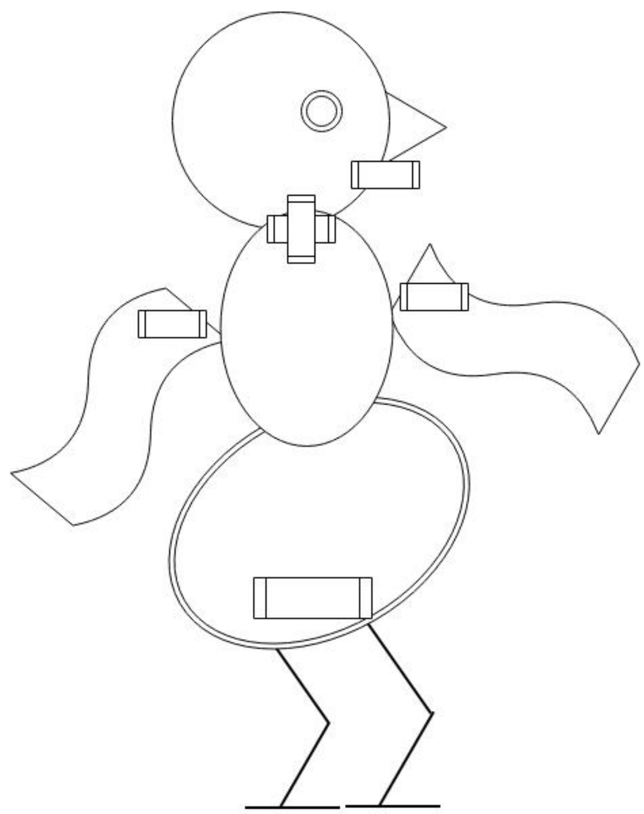


Figure 26 Motors in KiliRo

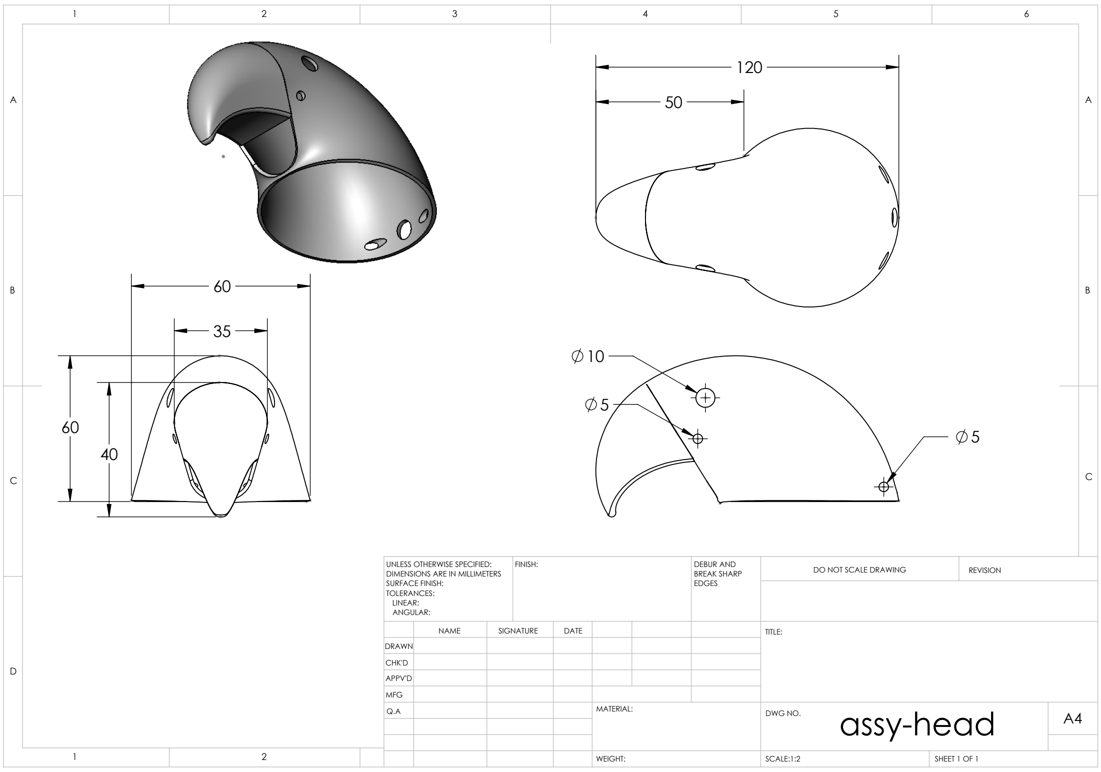


Figure 27 KiliRo-Head schematic illustration

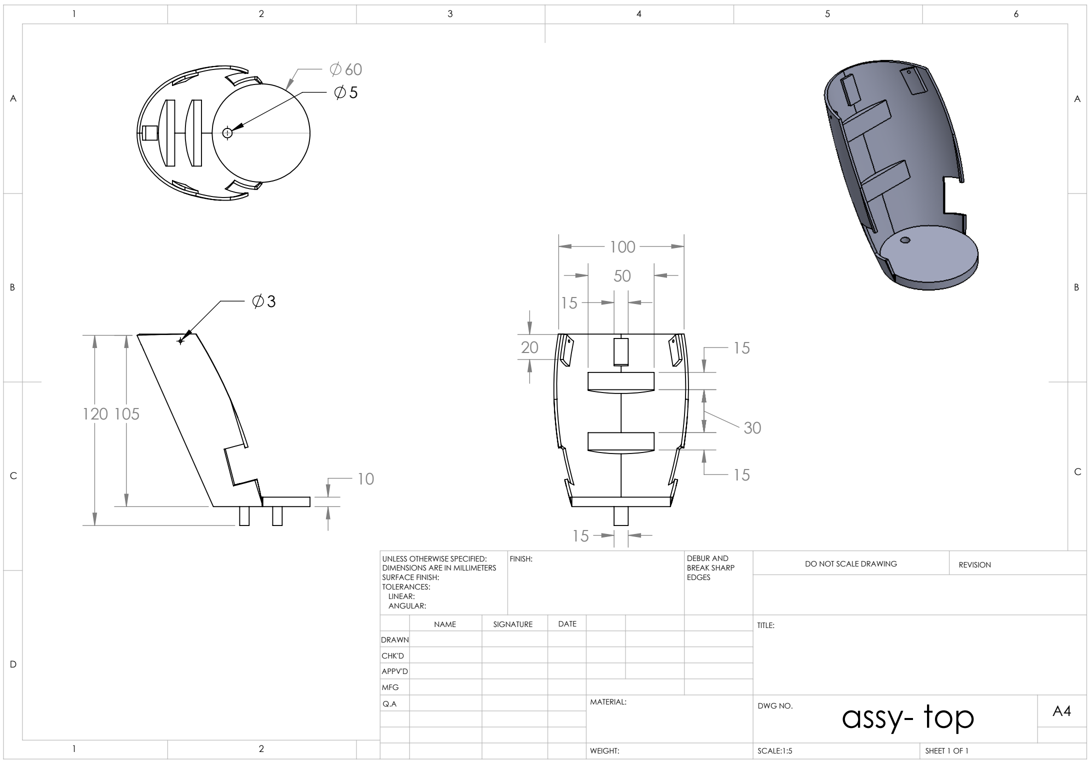


Figure 28 KiliRo-Body part 1 schematic illustration

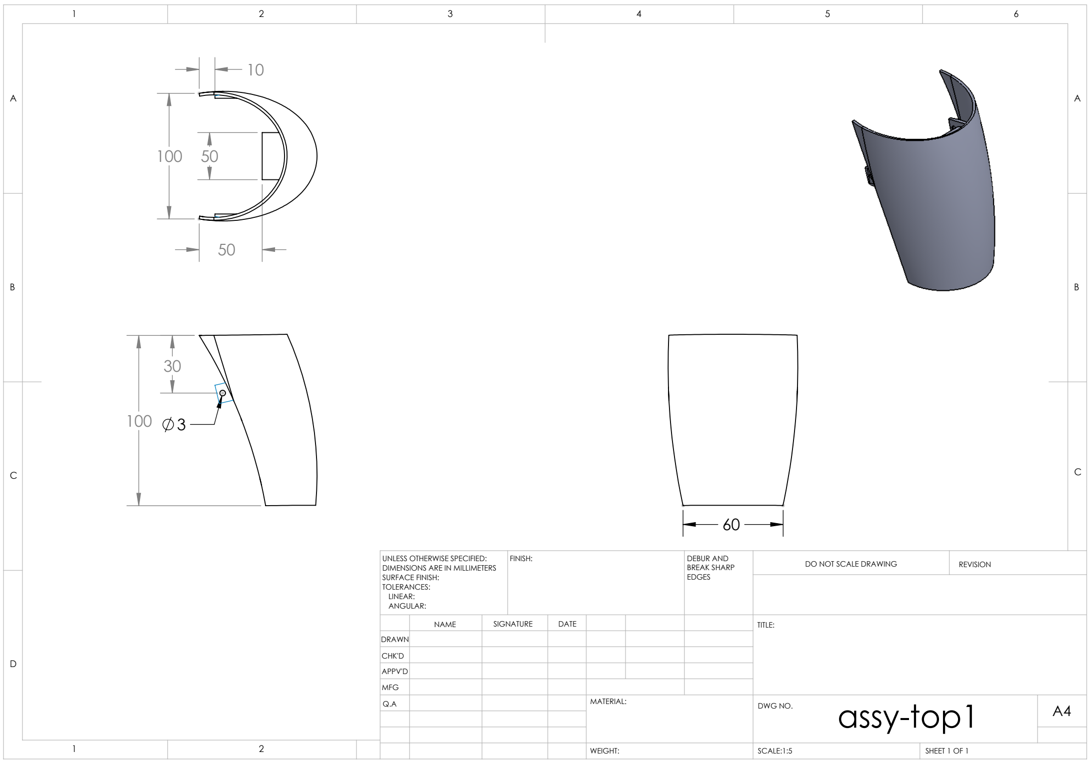


Figure 29 KiliRo-Body part 2 schematic illustration

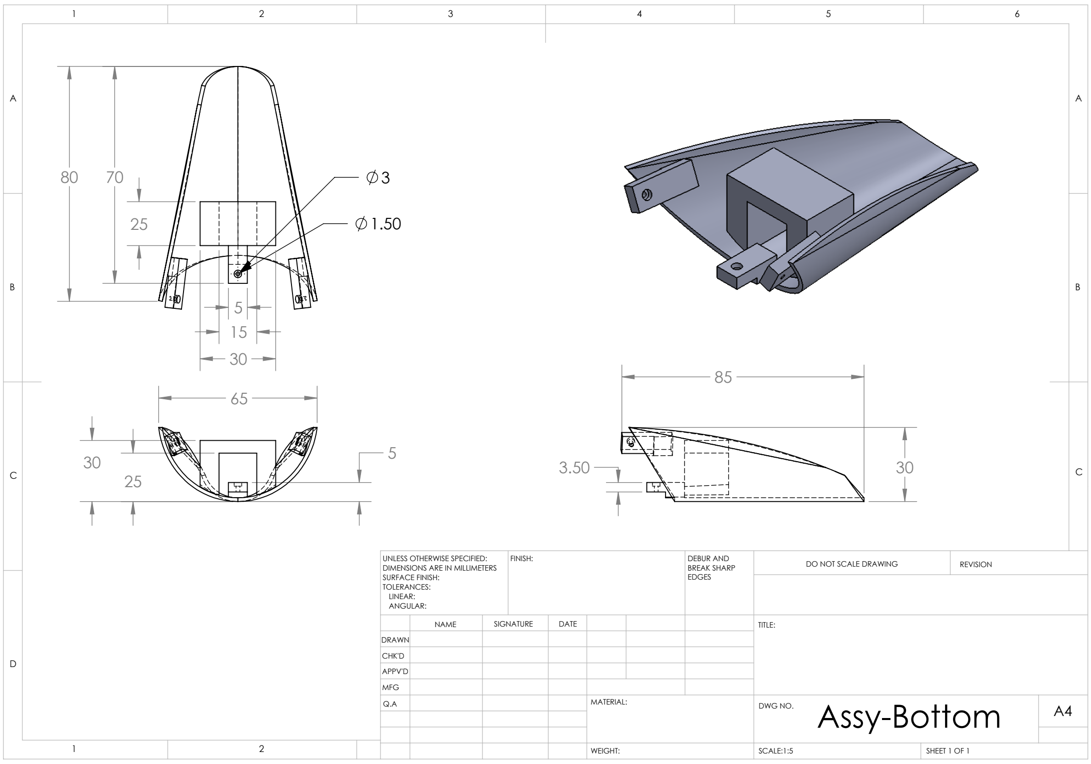


Figure 30 KiliRo-Body part3 schematic illustration

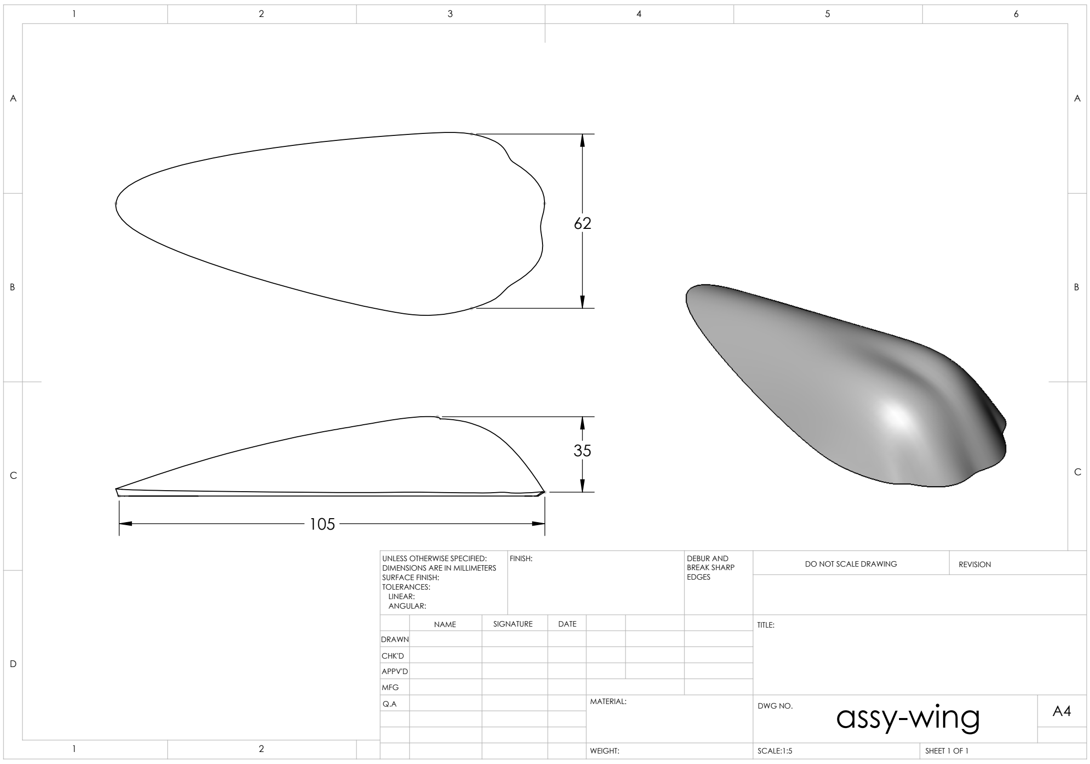


Figure 31 KiliRo-Wings schematic illustration

Figures 32 and 33 illustrates the CAD design and exploded view with hardware attached to the robot.

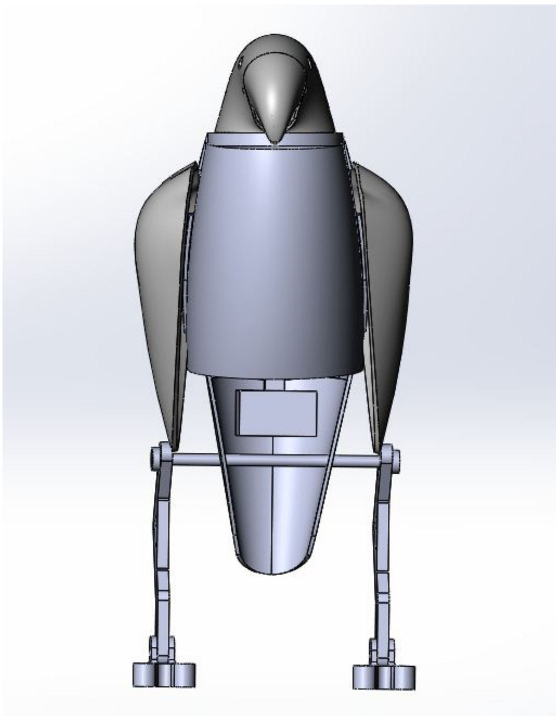
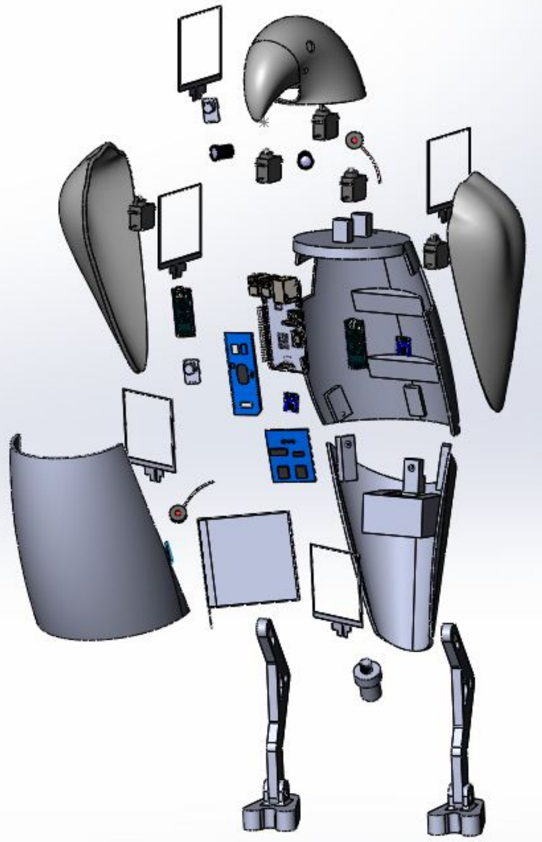


Figure 32 KiliRo – CAD Design



ITEM NO.	PART NUMBER	QTY.
1	Assy Head	1
2	Assy Top(Front)	1
3	Assy Top (Back)	1
4	Assy-Bottom	1
5	Assy-Wing	2
6	Assy Leg	2
7	Servo motor	5
8	Speaker	2
9	Raspberry Pi	1
10	2000mAh Lithium-ion battery	1
11	Wireless Camera	2
12	Mic	1
13	Arduino	2
14	Touch Sensor	5
15	Bluetooth	2
16	Text to Speech module	1
17	Speech recignition module	1
18	DC Motor	1

Figure 33 KiliRo - Exploded View

KiliRo – Walking mechanism

Designing locomotion model is one of the challenging task in legged robots. In the recent years, several efforts of the robotics community have explored methods for effective locomotion modelling for legged robots. Biped mechanism is one of most successful approach used by several legged robots, such as ASIMO and QRIO robots manufactured by Honda and Sony respectively. The robot developed in this doctoral research also uses biped mechanism for walking forward and backward.

It is noted that most of the users recommended the robot to move slowly (Chapter 3) to encourage physical interaction and ensure safety for children during the interaction with the robot. Out of various methods investigated, biped mechanism was chosen to provide locomotion to KiliRo based on locomotion types, speed and stability. A biped mechanism can be defined as an inverted pendulum system with a constrained motion due to the forward and backward impacts of the swing limb with the ground. Robots with biped mechanism are often considered as open kinematic chain during single support phase in which the locomotion is achieved through specific motion in various planes; sagittal, frontal, and transverse planes.

In biped mechanism, the distance between two legs and the foot width play a vital role in achieving robot's stability. Several foot patterns were analysed before concluding to use PIPIT-based design for the robot. During the development, two legs of the robot are separated at 210 mm to provide more stability and ensure equal distribution of body weight to the feet. The legs are connected through an aluminium shaft with a diameter of 3mm to which the worm gear is attached. The aluminium shaft moves up and down inside an elongated hole with a length of 30mm to provide biped motion to the robot. This mechanism ensures the robot feet during the locomotion is not above 3mm in the air. The CAD design of the robot's leg in multiple views and its dimensions is presented in Figure from 34 to 37.

Figure 34 KiliRo leg CAD design – Front view

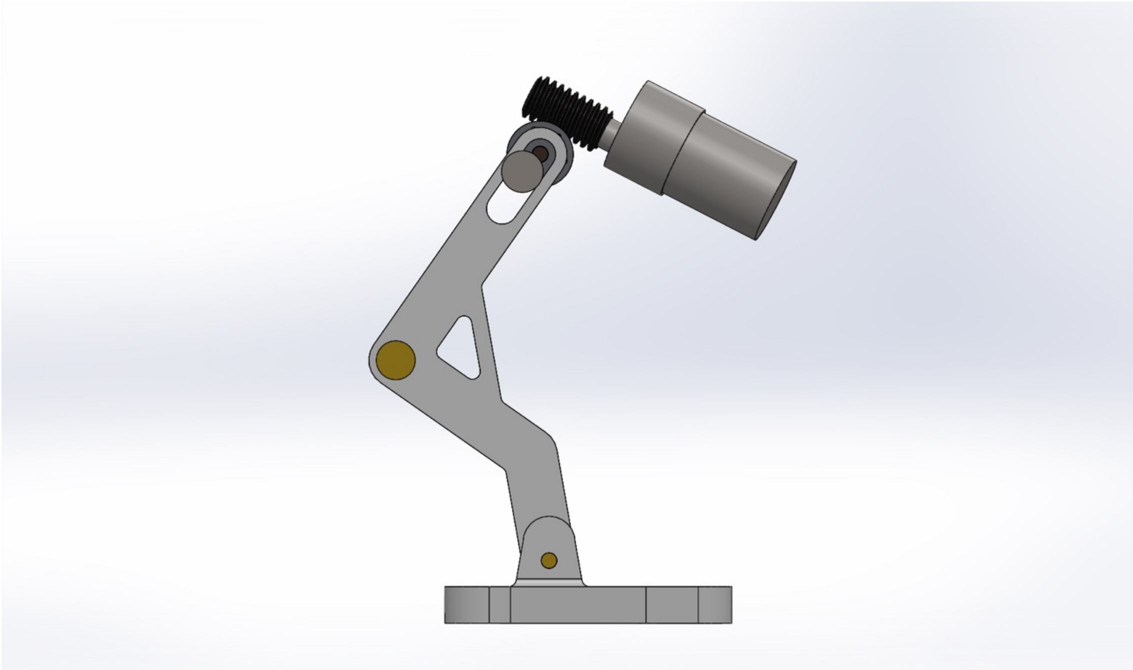


Figure 35 KiliRo leg CAD design – Side view

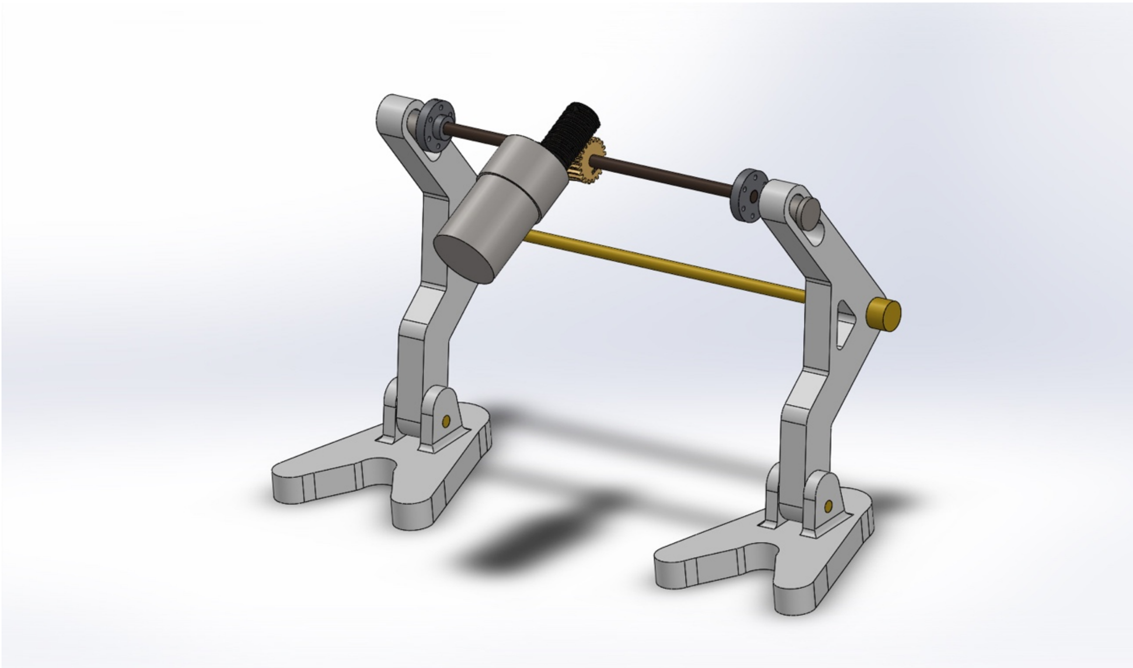


Figure 36 KiliRo leg CAD design – Rear view

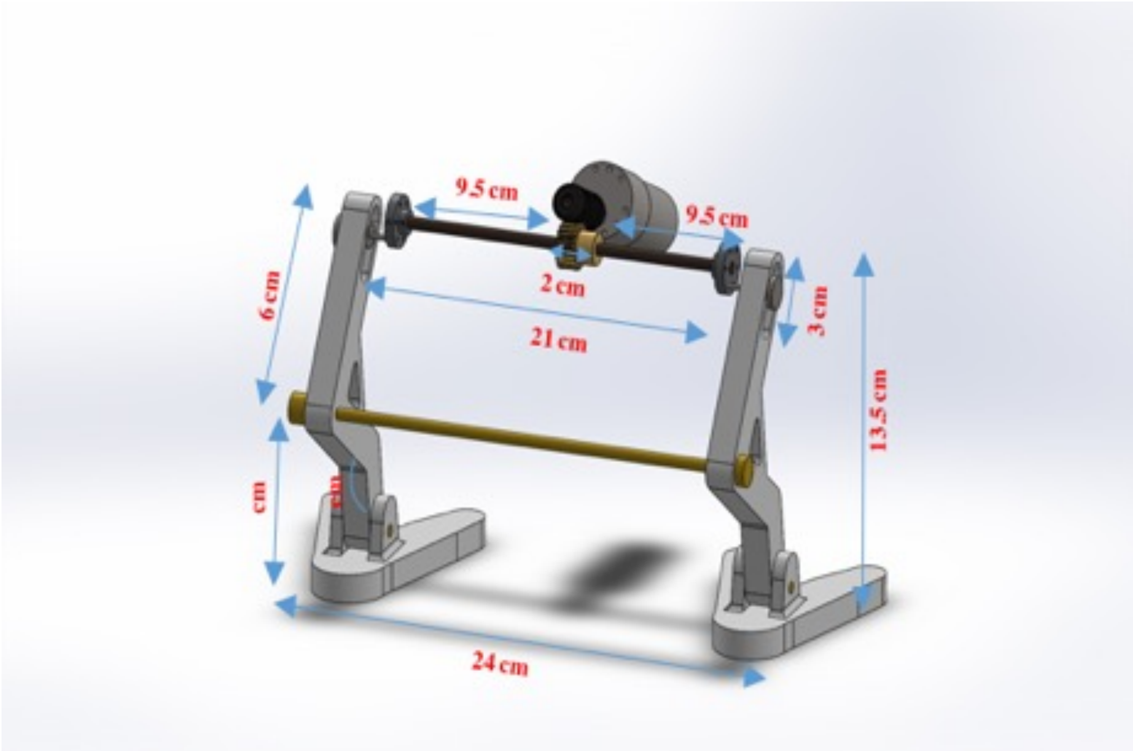


Figure 37 KiliRo leg CAD design – Physical dimensions

As most of the stakeholders recommended slow locomotion for the robot, we used a worm-wheel attached to a gear unit which is operated through a DC motor with 120 RPM. The walking cycle of KiliRo robot is illustrated in Figure 38. The legs can lift to maximum of 3 mm that provides more stability for the robot during locomotion and minimize falling.

As the RPM (12) and WD (.79 inches) are known, the walking speed of the robot can be calculated as,

$$v = \frac{RX\ D\ X\ \pi}{60} \tag{4.3}$$

where, R is the rotation per minute, D is the wheel diameter,

$$v = .5\ inches/sec$$

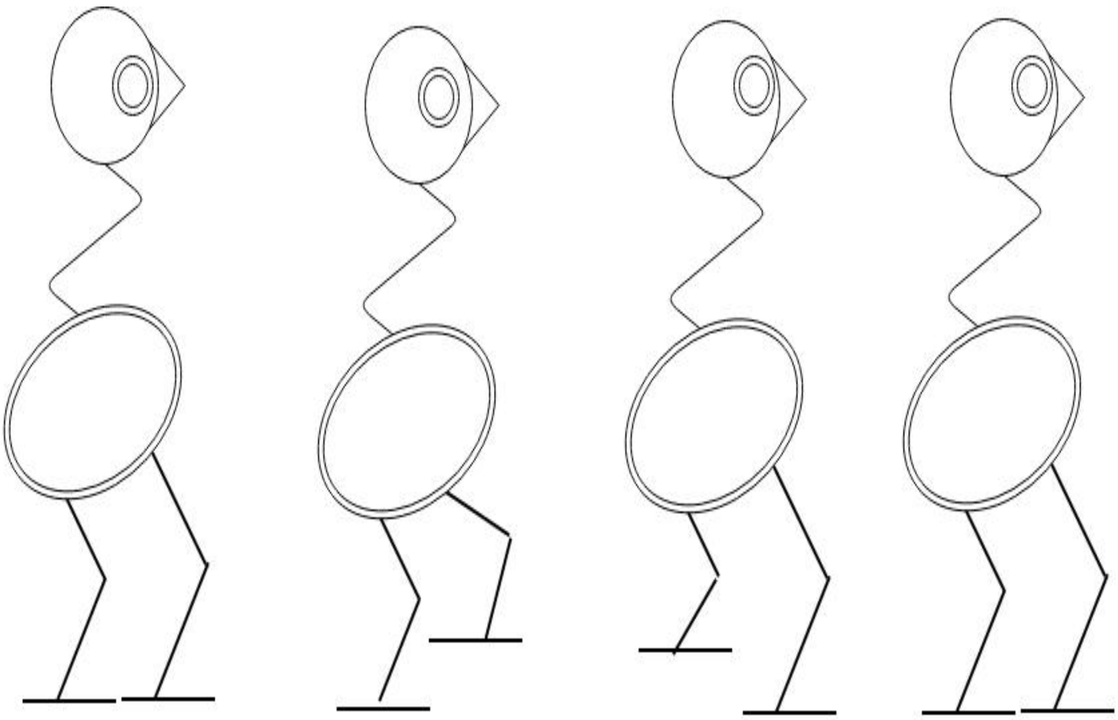


Figure 38 KiliRo - Walking cycle of KiliRo robot locomotion

4.3.1. Electrical design

The electrical schematic diagram of KiliRo robot is presented in Figure 39. The 2000mAh battery supplies power to three control units (one Raspberry pi-3 unit and two Arduino units) used in the robot. Two Wi-Fi cameras and one USB camera are attached to the Raspberry pi-3 small computer. To the first Arduino unit, speech recognition unit and text-to-speech conversion unit are attached. The speech recognition unit is attached to the microcontroller through an adapter. A speaker and a microphone are connected to the speech recognition module.

To the second Arduino unit, five force sensing resistors (FSR), five servo motors, and a DC motor are attached. The DC motor is attached to the controller through a motor driver. The two Arduino microcontrollers communicate with each other using HC-06 Bluetooth unit. HC-05 Bluetooth unit is used to receive commands from the external device, such as cell phone. With all components powered, the battery can provide 60 minutes of power supply to the robot for one full charge.

The user can access the robot through a Bluetooth device, voice, QR code, and wireless communication. Using Bluetooth, the Arduino microcontrollers are accessed and the speech recognition module is accessed via pre-trained words. When a QR code is shown to the USB camera, the recognised alphabet or number is read using the speaker attached.

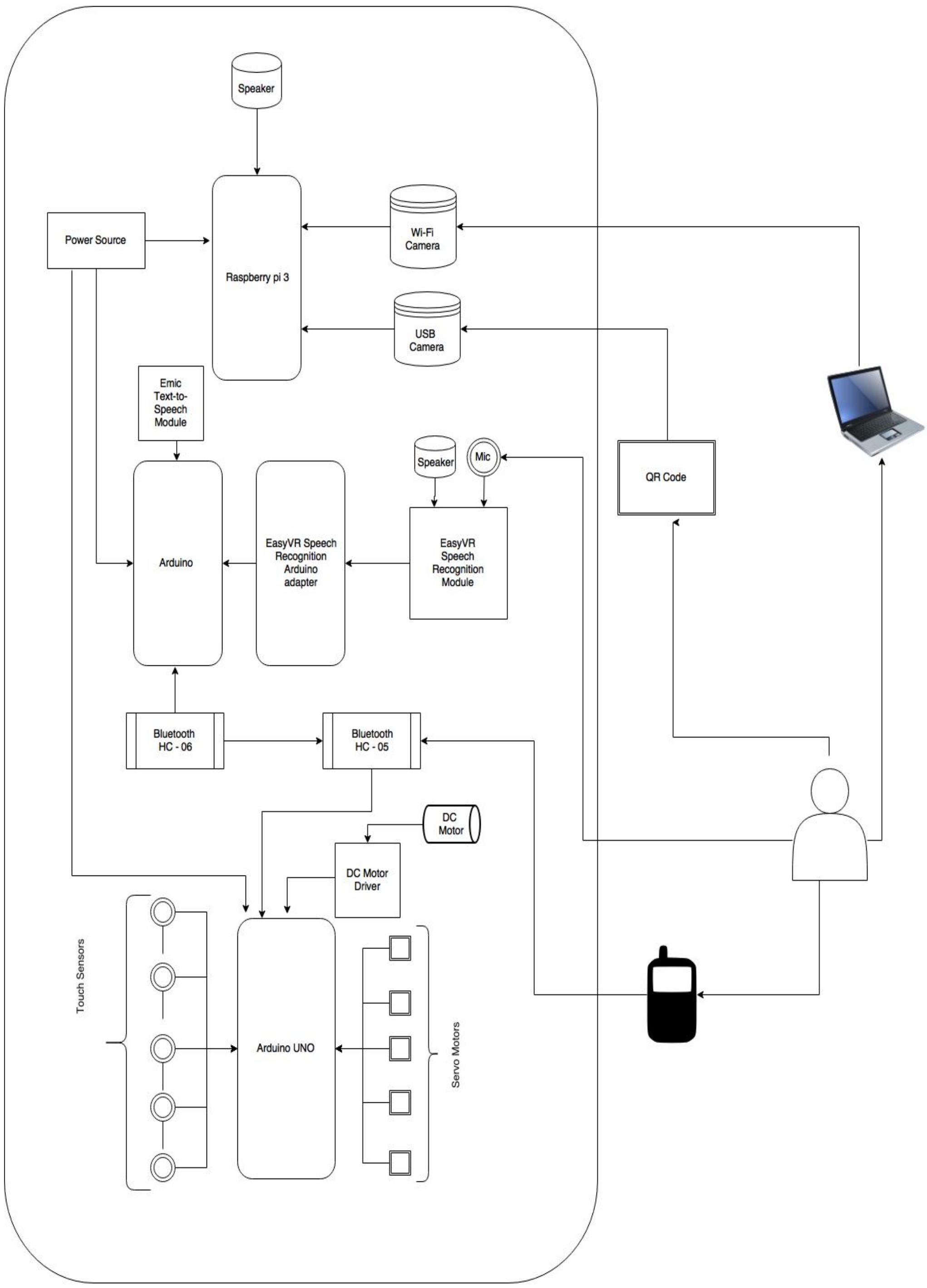


Figure 39 KiliRo – Electrical Schematic

4.3.2. Software design

Text – to – Speech

The text-to-speech unit is a multi-language voice synthesizer that converts a stream of digital text into natural sounding speech. The applications of this systems are manifold including automated information services, computer-based instructions, avatars, and computer-aided systems for the visually impaired. We used this system in our robot to achieve talking in the robot. The unit, Emic-2 attached to the first microcontroller unit in the robot can receive text input at 9600 bps and transform into speech. The text-to-speech unit can read the received text in 9 different voices with option for the user to between English and Spanish.

An instance of the EMIC2 class has been created before using the Emic-2 module which is initialized by calling *begin* (uint8_t rx_pin, uint8_t tx_pin, uint8_t cs_pin) with arguments the RX and TX pins of the serial port. The class provides methods for selecting the voice, the language, and the parser for the robot to use in its speech. It also provides methods for tweaking parameters such as volume and speaking rate that are independent of the choice of parser. A message can be sent to the Emic-2 unit by calling the *speak* method, with argument any type of data (e.g. emic.speak ("I'm KiliRo, the parrot-robot"). The speak method can also read files from the SD card attached to the unit by providing an argument (filename). The architecture of the text-to-speech module is presented in Figure 40.

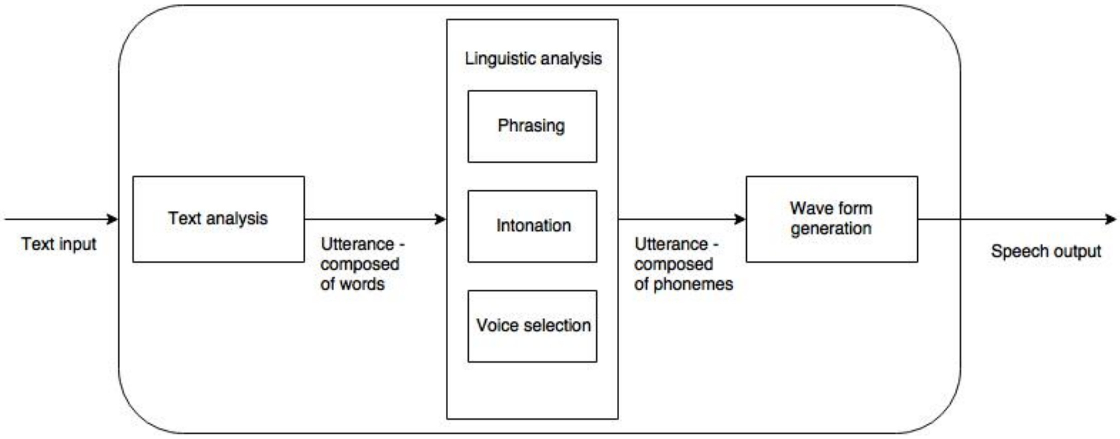


Figure 40 KilIRo – Text-to-speech illustration

A simple command-based interface of this text-to-speech unit makes it easy to integrate into any embedded system, such as Arduino. An example coding for the unit is presented below.

```
#include <SoftwareSerial.h>

#include <SD.h>

#include "EMIC2.h"

SoftwareSerial mySerial(10, 11);

#define RX_PIN 5

#define TX_PIN 6

EMIC2 emic;

int fsrPin = 0;

int fsrReading;

void setup ()

{

  Serial.begin(9600);
```

```
  emic.begin(RX_PIN, TX_PIN);
  emic.setVoice(7);
}
void loop(){
  char i= mySerial.read();
  int fsrReading = analogRead(fsrPin);
  Serial.print("Analog reading = ");
  Serial.print(fsrReading);
  if (fsrReading >= 10)
{
  emic.speak("Hi I am KiliRO, I was developed by Jaishankar Bharatharaj at Auckland University of Technology. I am designed to help improve learning and social interaction abilities of children. I am being developed further to tell stories and act as a life logging system. I will also remind you on taking medications and remind you on your calendar soon.");
  delay (2500);
  emic.speak("Have a Good Day");
  delay(2500);
  emic.setVolume(10);}
 delay (2000);
}
```

Speech recognition

Speech recognition module is used in the robot for speech recognition. The EasyVR module can be attached to hosts with an UART interface such as PIC and Arduino boards. This unit is attached to the Arduino microcontroller used in the robot which is a "slave" module communicating through an asynchronous serial interface. All the I/O pins in the unit are inputs with weak internal pull-up after power on and they must be explicitly configured before using it as output pins. In our system, the EasyVR shield is attached on the top of the Arduino board to which 8Ω speaker and a microphone is connected. The system is trained to recognize "*Talk*" as a command to read the phrase pre-stored in the memory.

The EasyVR unit uses Hidden Markov Model (HMM) to recognize speech commands. The HMM has been used in speech recognition for several decades since it was first used by Jim Baker at Carnegie-Mellon University in the early 1970s. In speech recognition, HMM involves; 1) defining a set of S sound classes for modelling (phonemes or words); sound classes *V ={v 1. v2 • ...• VS}*; 2) collecting the training set of labelled utterances that are in the class; 3) based on each training set, solving the estimation problem to obtain a "*best*" model *A-i* for each class *Vi, i =1. 2. ..., S*; 4) evaluate $P(U|\lambda_i)$, i =1. 2,...S, for the unknown utterance U and identify the speech that produced O as class Vj if

$$P(U|\lambda_j) = \max_{1\le i\le S} P(U|\lambda_i) \qquad (4.4)$$

The HMM model, H uses maximum probabilistic likelihood classification method to choose the most likely class in the observation. For observation sequence $O = O_1, O_2, \dots, O_n$

$$Selected\_Class = arg \max_{Class} [P(H_{Class}|O] \qquad (4.5)$$

The EasyVR module uses the HMM method to recognise the speech commands received. When the module recognises *Talk* voice command, the pre-stored text is read by the Arduino microc7ontroller through the text-to-speech module. Figure 41 illustrates the working model of the speech recognition module in the robot. More details about the EasyVR module and codes can be found in Appendix B.

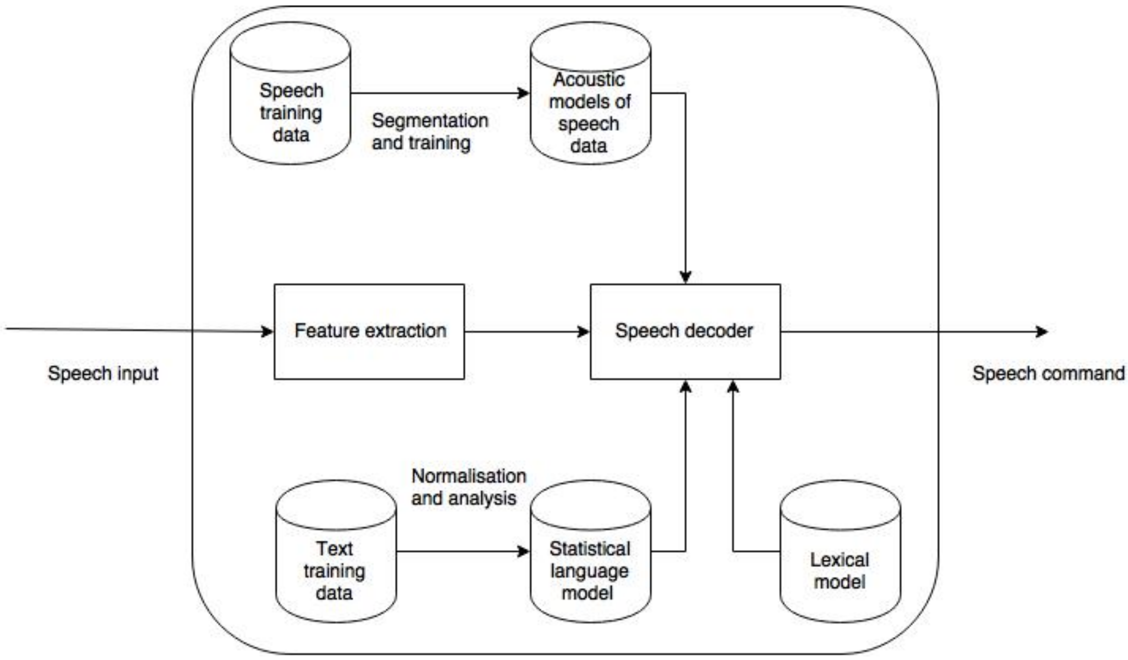


Figure 41 KiliRo - Speech recognition architecture

4.3.3. Human – robot interaction design

Hardware specifications

An android application was developed to control the robot's locomotion, such as head nodding, wings flapping, walking and commanding the robot to talk. The robot communicates with the application through Bluetooth short wavelength UHF radio waves. When the *CONNECT* button is clicked on the application, it sends signal to the HC05 Bluetooth module attached to the ATmega 328P microcontroller unit in the robot. When the connection is established, the robot's locomotion can be controlled through various buttons provided in the application and the user can command the robot to talk by pressing *TALK* button. Figure 42 illustrates the application developed for controlling the robot locomotion.

Figure 42 KiliRo Android application

4.3.4. Follow-up survey

A follow-up survey was conducted to identify if the stakeholders are satisfied with the newly developed KiliRo robot using a Likert Scale closed-format questionnaire. Table 13 illustrates the responses from 18 participants for the 10 questions raised on a 5-point scale. We were unable to contact two parents and one paediatrician who participated during the interview sessions that targeted extraction of user requirements. Questions from 1 to 10 are marked between 1 through 5 (1 is strongly disagree, 2 is disagree, 3 is neither disagree or agree, 4 is agree, and 5 is strongly agree). The majority of respondents indicated that they are satisfied with the developed robot and expectations were met. Especially, most of them acknowledged that they would recommend and use the robot for children with ASD.

Table 13 Responses to the closed-format questionnaire follow-up survey

Sl. No	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
1	4	4	5	4	4	4	5	5	4	4
2	5	4	4	4	4	4	4	5	4	4
3	5	4	4	3	4	4	4	4	4	5
4	4	4	4	3	4	4	4	4	4	4
5	5	4	4	4	4	5	4	5	5	5
6	3	3	4	3	3	4	4	4	4	5
7	4	2	4	3	3	5	5	4	5	5
8	4	3	5	4	4	3	5	4	4	4
9	4	4	4	2	4	3	5	4	4	4
10	4	4	4	3	3	4	4	3	4	3
11	4	4	4	3	5	4	5	4	4	4
12	4	4	4	3	3	4	4	4	4	4
13	5	4	4	4	4	4	5	4	3	4
14	4	3	4	4	3	4	4	4	4	4
15	4	4	4	4	4	4	4	3	2	4
16	4	4	4	4	4	3	5	3	3	4
17	4	4	4	3	3	4	4	4	3	4
18	4	3	4	4	3	4	4	4	4	4
Mean	**4.22**	**3.77**	**4.27**	**3.66**	**3.94**	**4.27**	**4.77**	**4.44**	**4.44**	**4.72**

In this chapter, we elaborated the component identification and acquisition for the KiliRo robot, followed by its prototype development and validation. Detailed explanation on the mechanical, electrical, and software designs of the robot were also presented in this chapter, followed by its human – robot interaction model.

In next chapter, we present the results of short-term and long-term user studies conducted to identify the effects of KiliRo robot in improving learning and social interaction abilities of children with ASD. we also present the results of user studies that investigated the psychological and physiological effects of KiliRo robot among these children.

5. Results

5.1. Synopsis

Chapter 4 briefly presented the component identification and acquisition for the parrot robot, followed by its prototype development and validation through follow-up survey. An overview of the mechanical, electrical, and software designs of the robot were also presented in this chapter with its human – robot interaction model.

The developed robot can be deployed in three sectors in the field of robotics namely, education, entertainment, and therapeutic needs. Literature points to successful design and development robots in each of the above-mentioned fields. Nevertheless, a robot that can be deployed in multiple settings can provide more benefits to the stakeholders. Particularly, such robot in autism therapy can improve learning and social interaction abilities of children more effectively. Figure 43 illustrates the positioning of KiliRo robot in social robotics.

Figure 43 KiliRo positioning in social robotics

The developed robot has been tested through several short-term and long-term user studies involving children with ASD to verify the robot's effectiveness in improving children's learning and social interaction abilities.

Interviews, closed-format questionnaires, and manual observation methods were used to report the improvements in learning abilities of children. The paediatricians, child psychologists, parents and teachers were involved in interviews and answering to questionnaires. Social network density analysis (a process of investigating social structures using networks and graph theory) and comparison study (comparing social interaction interest of children with ASD towards human and KiliRo robot) were used to monitor improvements in social interaction abilities of children. A few responses from the closed-format questionnaire were also analysed to study social interaction improvements in children.

Several other indicators that influence the learning and social interaction abilities including emotion changes, stress level reduction, and physiological changes were also monitored before, during, and after interacting with the robot. Urinary and salivary tests were performed to obtain protein and α-amylase levels, respectively, to report the changes in stress levels of children before and after interacting with the robot. This is a pioneering human–robot interaction study to investigate changes in stress levels using salivary samples. Systolic and diastolic blood pressure, heart rate, and arterial oxygen saturation level in blood were monitored to investigate the physiological changes in children before, during, and after interacting with the robot.

In this Chapter, the results of the user studies performed to evaluate the effects of KiliRo robot in improving learning and social interaction abilities of children are presented.

5.2. Improvements in learning abilities

The effects of using KiliRo robot among children with ASD in improving their learning abilities were investigated using several short-term and long-term user studies. The improvements were tested using informal and semi-formal interviews, closed-format questionnaires, and manual observation methods.

A new teaching technique, Adapted Model-Rival Method (AMRM), has been developed to improve learning and social interaction abilities of children with ASD. AMRM is an adaption of the conventional model-rival method invented by Dietmar Todt, and the label-training procedure developed by Irene Pepperberg, to train parrots [195].

In Todt's method, two people play the role of parrot peers in the wild. In this method, the first person handles a targeted item and trains the second person (the model/rival) by presenting and raising questions about the item (e.g. what colour is this?). The correct responses were rewarded by the trainer, showing referential and functional label indicating 1:1 correspondence between the label and the item. The second person acts as a model for the bird responses and its rival for the trainer's attention. The trainer teaches the rival for correct answer if he/she provides an incorrect response. The bird is included initially in the interactions and rewarded for correct responses. Training is adjusted according to the level of teaching.

Pepperberg has developed the label training procedure by modifying model-rival method to train Alex, the African grey parrot [195]. In her method, one human acts as a trainer for a second human in the presence of the bird. During the session, the trainer presents an object and asks questions about the object (e.g. what material? what shape?) and gives the object itself as a reward for correct responses. Incorrect responses were handled by scolding and removing the object from sight. The second human acts as a model for the bird's responses and as a rival of the bird for the trainer's attention during the training sessions. Unlike the model-rival method, Pepperberg’s technique involves repeating the interactions while repeating the roles of the human model and trainer and occasionally involves the parrot in the session. Using this method, she reported that Alex could engage in effective two-way communication and learnt over 100 words [163].

The AMRM developed in this research from the model-rival method and label training procedure is focused on improving the learning and social interaction abilities of children through an indirect teaching technique using the parrot-inspired robot, KiliRo. In this method, the researcher teaches the robot (as a second person in the model-rival method) in the presence of children with autism. The AMRM assumes that the abilities of KiliRo including speaking, mimicking, recognizing, and learning will stimulate the children to learn what the robot is learning. For example, when the researcher teaches KiliRo, the abilities of the robot would attract participants to get involved and create new paths for them for learning and social interaction. Children with ASD are expected to be curious by the ability of KiliRo and start to compete with the robot to identify the object before it does. Responses from participants will be monitored regularly and the complexity of the questions in the training will be adjusted to increase the competition between the robot and children, resulting in a more dynamic and exiting experience for the children. It is proposed that this method will act as a new teaching method to improve learning abilities of children with ASD in robot inclusive classrooms. An illustration of AMRM is presented in Figure 44.

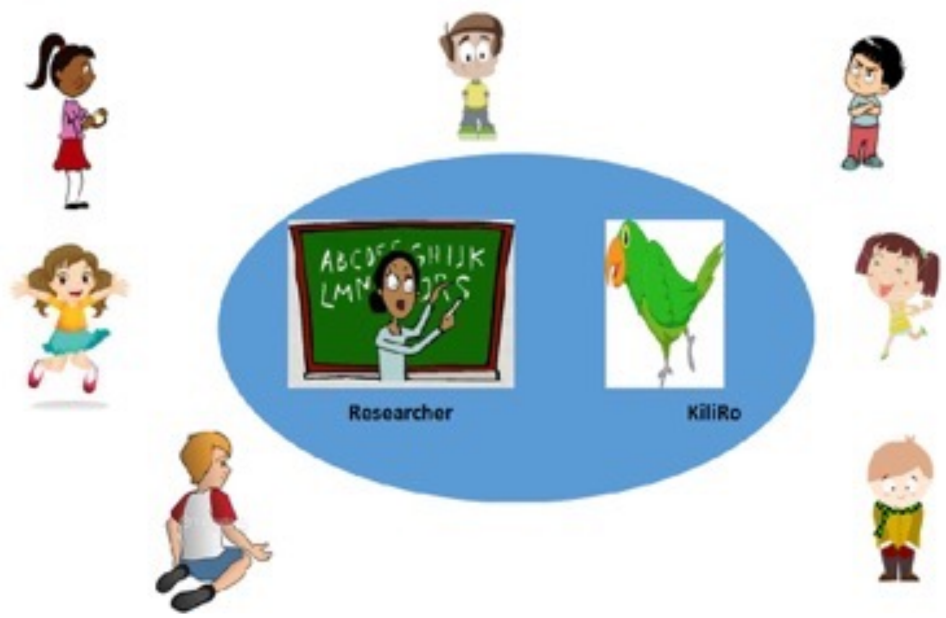


Figure 44 Illustration of AMRM

5.2.1. Interviews

Informal and semi-formal interviews were conducted with paediatricians, child psychologists, teachers, and parents to evaluate the effects of KiliRo in improving leaning abilities of children with ASD. The convenience sampling method (a non-probability sampling technique where subjects are selected based on their convenient accessibility and proximity to the researcher) was used to approach potential participants for this anonymous research interview. A formal open invitation was sent to 100 potential participants (25 paediatricians, 25 child psychologists, 25 teachers, and 25 parents). Fifty-four respondents who accepted the invitation were provided with complete details of the objectives of the study. Interviews were conducted in India and Singapore with 54 participants (8 paediatricians, 7 child psychologists, 20 teachers, and 19 parents) who were working specifically with children with ASD.

Half of the participants were aged between 35-44 years, with 46.2% between 25-34 years and less than 4% between 45-54 years of age. Male and female participants were 48.1% and 51.8% respectively. About 37% of respondents had a doctoral qualification, and 46.3% of participants had at least a Bachelor's degree. Most participants (76%) had experience dealing with children with ASD for more than five years. Only 11% of the participants had prior experience dealing with robot-assisted therapy (RAT). Detailed descriptive information about the participants is illustrated in Table 14.

The informal interviews were conducted with no pre-decided questions and the discussion was around the learning abilities of children with ASD. The interview also addressed the issues raised by the respondents. During the semi-formal interviews, a few pre-decided questions were asked to the respondents to identify the attitudes of respondents towards using KiliRo among children with ASD.

Table 14 Respondents' descriptive information

Factor	**Range / category**	**Mean or %**
Age (years)	25-34	46.2
	35-44	50
	45-54	3.7
Sex	Male	26
	Female	28
Education	High school	16.6
	Bachelor's degree	24.07
	Master's degree	22.2
	Doctoral degree	37
Exposure to children with ASD (years)	2-5	24
	More than 5	75.9
Familiarity with robot-assisted therapy	No exposure	55.5
	Read or heard about	33.3
	Used for child / patient/ student	11

The study consisted of four sessions. During each session, the robot performed various activities in the presence of children with ASD. Respondents were then interviewed to obtain their opinion towards the improvement of children's learning ability during the interaction with the robot.

In the first task, a member of the research team operated the robot to walk forwards and backwards, and move its head up and down. In addition to that, KiliRo spoke a few words and communicated with a member of the research team leading the session. In the second task, the researcher taught letters of the English alphabet to KiliRo. After a few minutes of training, KiliRo's learning ability was checked by being asked to identify a letter presented to it. For the third task, a member of the research team taught the number systems to KiliRo. After a few minutes of training, KiliRo was checked for its ability to learn numbers. This was done by the robot being asked to identify a printed number. The fourth task involved identifying individuals. In this session, a member of the research team showed a real person to KiliRo and taught relationships such as mother or father of a child. For instance, a parent of the participating child was shown to KiliRo and taught that he/she is the child's father/mother. After few minutes of training, KiliRo was checked for its ability to recognize that person.

The respondents were then interviewed for their opinions on the effects of using KiliRo in improving learning abilities of children with ASD. A thematic analysis method was used to process their responses. Thematic analysis is one of the common methods used in analysing qualitative research data [185]-[186]. This method emphasizes on locating, analysing, and recording themes found within data. The first phase of analysis requires data familiarization in which interview responses were read multiple times. During the second stage, the data was searched and grouped by addressing three major questions; 1. What are the motivators for using KiliRo? 2. What are the perceived benefits of using KiliRo? 3. What are the perceived barriers of implementing KiliRo?

Most participants supported using robots to improve learning abilities of children with ASD. It should be noted that out of eight paediatricians, four responded that the robot had helped with improving the learning abilities of children. Three respondents were not sure if the improvement was due to the robot. One participant suggested that the study should be performed for at least one year to confirm the improvement.

The child psychologists who participated in the study were more positive toward the improvement of children's learning abilities after interacting with the robot. Nevertheless, more than half of them pointed out the difficulties of using robots to teach regular subjects, such as maths, and language. Most of them noted that children were attracted when the robot was answering questions asked by the researcher during the second and third tasks. They also indicated that this attraction would encourage children to learn through the AMRM.

Majority of the teachers who participated in the study accepted that the parrot-like morphology attracts children with ASD and it helped to improve their learning interests. They also mentioned the speaking ability of the robot would encourage children to interact with the robot and teacher, thus can help improve their learning abilities. Some teachers were concerned with the difficulties they may face in handling the robot in their classes, as they have never used robots in teaching before.

Most of the parents who participated in the study had no prior exposure to robots. Most of them observed only their children and paid little attention to other children during the study. Among 19 participants, 14 parents acknowledged that their children were more attentive when the robot was learning and answering questions. Three parents mentioned that their children showed no interest in the robot. One mother mentioned that her child's learning ability did not improve after interaction with KiliRo and the remaining parents had no comments.

Overall, most of the responses from paediatricians, child psychologists, teachers, and parents indicated that the robot had positively influenced the learning abilities of children with ASD.

5.2.2. Closed-format questionnaire

A closed-format questionnaire was presented to the same 54 respondents who participated in the interviews. It contains 14 questions and a 5-level 'Likert scale' format ranging from strongly disagree to strongly agree was used for all questions except for two questions that followed a multiple-choice format. The questions were prepared to evaluate the acceptance of the robot and AMRM and to understand the expected features of KiliRo. The questions used in the questionnaire are illustrated below:

1. AMRM could help improve learning abilities of children with autism.
2. AMRM could help improve social interaction abilities of children with autism.
3. Parrot-like morphology might attract children with autism.
4. I recommend the following features in KiliRo (options: talking, walking, flying, wing flapping, respond to sound, respond to touch, recognize face, and recognize voice).
5. KiliRo could be a companion for children with autism.
6. Parrot-like morphology is suitable for teaching children with autism.
7. My child tried to communicate with the robot during the study.
8. My child observed the learning abilities of KiliRo during the study.
9. My child accepted KiliRo as his/her companion.
10. I recommend KiliRo for teaching children with autism.
11. My child was happy to interact with KiliRo.
12. AMRM might help improve cognitive abilities of children with autism.

13. I recommend the following morphology for robot-assisted therapy (options: parrot, dog, cat, bear, seal, and human).
14. I would use KiliRo for teaching my child.

Table 15 illustrates the responses from 54 participants for the 12 questions raised on a 5-point scale. Questions 1 to 14 except 4 and 13 are marked between 1 through 5 (1 is strongly disagree, 2 is disagree, 3 is neither disagree or agree, 4 is agree and 5 is strongly agree). Cells with no values indicate that the respondents did not provide an answer. For the questions 4 and 13, respondents marked multiple answers. The majority of respondents indicated that the proposed AMRM would help improve learning and social interaction abilities of children with autism spectrum disorder. The results also point to a high degree of acceptance for the parrot-like morphology. Most of the respondents indicated that they would recommend KiliRo and the AMRM for teaching children with autism spectrum disorder.

Table 15 Closed-format questionnaire responses

Participant	Q1	Q2	Q3	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q14
Paediatrician 1	4	4	3	4	4	4	4	4	4	4	4	4
Paediatrician 2	3	4	4	4	4				4	4		3
Paediatrician 3	4	4	4	4	4				4	3	4	4
Paediatrician 4	4	4	3	4	4	4	4		3	4	4	4
Paediatrician 5	4	4	4	4	4			3	2	4	4	4
Paediatrician 6	2	3	2	3	3	3	3	4	4	4	3	
Paediatrician 7	4	4	4	4	4			4	3		4	3
Paediatrician 8	2	3	3	3	3	3	3	4	2	3	2	3
Child psychologist 1	4	4	4	4	4	4	4	4	4	4	4	4
Child psychologist 2	3	4	4	4	4	4	4	4	3	4		
Child psychologist 3	4	4		3	3	3	3	3	4	3	4	4
Child psychologist 4	3	3	4	4	4	4	4	4	3	4	3	3
Child psychologist 5	3	3	4	4	4	4	4	4	3	4	3	4
Child psychologist 6	4	4	4	4	4	4	4	4	4	4	4	4

Child psychologist 7	4	4	3	4	3	3	3	4	4	4	4	4
Teacher 1	4	5	4	5	5	4	4	4	4	4	4	5
Teacher 2	4	4	4	5	5	4	4	4		4	4	5
Teacher 3	4	4	4			4		4	4	4	4	4
Teacher 4	4	4	5	4	4	4	4	4	4		4	
Teacher 5	3	4	4	5	4	4		4	3	4	4	5
Teacher 6	4	5	4		4			4		4	4	4
Teacher 7	4	4	3	4	4	3		3	3	4		4
Teacher 8	4		4	4		3		4	4		3	
Teacher 9	2	3	3	3	2	3	4	4	2	3	3	3
Teacher 10	4	4	4	5	4	4	4	5	4	4		4
Teacher 11	5	4	5	5	4			4	4	3	3	3
Teacher 12	3	3	4					4		4		3
Teacher 13	4	4	4	5	4			5		4	4	
Teacher 14	4	4	4	3	4	3	3	4	3	4		4
Teacher 15	4	4	4	3	3	4	4		4	4	4	4
Teacher 16	3	4	4	4		4	4		3			4
Teacher 17	2	4	4	4	2			3	2			3
Teacher 18	5	4	5	5	4					5		4
Teacher 19	4	4	4	4	5	4	4	5	5	5	4	4
Teacher 20	4	4	5	5	4	4	4	5	5	5	4	5
Parent 1	4	4	3	3	4	2	3	3	4	2	4	4
Parent 2	4	4	4	3	5				4			4
Parent 3	4	5	4	4	5	4	4	3	4	5	3	3
Parent 4	5	4	5	4	4	4	5	5	5	5	5	5
Parent 5	4	4	4	4	3	4	4	4	4	4	4	5
Parent 6	4	4	4	5	5	5	4	5	5	5	5	5
Parent 7	4	3	4	3	4	3	4		3	3	3	3
Parent 8	3	3	3	4								
Parent 9	4	4	4	4	5	4						
Parent 10	4	4	5	4	5	4	4	5	5	4	4	4
Parent 11	4	4	4	4	4			4	4	4	4	4
Parent 12			5		5				4	4	4	4
Parent 13	3	3	4	4	4				4	4		4

Parent 14	4	4	5	4	4	4	4	5	4	4	4	5
Parent 15	5	5	5		5	4	4		3	3		4
Parent 16	4	4	4	4	4	4	4	4	4	4	4	4
Parent 17	4	4	4		4			4	4			4
Parent 18		4	4	4	4	4	3	3	3	3		4
Parent 19	5	5	4		4	5		5			3	4
Mean	3.78	3.92	4.02	4.00	4.00	3.78	3.81	4.05	3.67	3.91	3.76	3.96
n	52	52	53	47	49	38	32	41	46	44	38	47

As it can be observed from the above table, most of the participants who responded to the questionnaire had acknowledged that KiliRo can help improve learning and social interaction abilities of children with autism. Particularly, the average response (3.78 and 3.92) for the first and second questions indicated that paediatricians, child psychologists, teachers, and parents of children with ASD agreed that KiliRo could have a positive influence. Moreover, the mean value for the questions, 3, 5, and 6 (4.02, 4.00, and 4.00) showed that the respondents were positive towards using a parrot-like robot. Finally, most of the participants indicated that they would use KiliRo robot for teaching their child. The mean value (3.96) for the last question indicated the acceptance of the KiliRo robot among participants.

The nonparametric equivalent of the analysis of variance, Kruskal-Wallis test (a non-parametric method for comparing two or more independent samples of equal or different sample sizes) was conducted to test whether the scores were significantly different by sample group (paediatrician, child psychologist, teacher, and parent). This test does not make any assumptions about the distribution of scores and is thus the most appropriate test for this sample size. The only significant difference was noted for Questions 3 ($\chi 2$ (3) =8.57, $p<.5$) and 6 ($\chi 2$ (3) =7.89, $p<.5$). A parametric analysis of variance using post-hoc Tukey (a method to confirm where the differences occurred between groups) was then conducted to identify which specific groups differed significantly on Questions 3 and 6. For Question 3, mean scores of the paediatrician sample (Mean (M)=3.38, Standard Deviation (SD)=0.74) did not differ significantly from those of the child psychologists (M=3.83, SD=0.41). The scores of the child psychologists were not significantly different to the scores of any of the other groups. The only significant difference was between the paediatricians and the teachers (M=4.10, SD=0.55) as well as the paediatricians and the parents (M=4.16, SD=0.60). For Question 6, the post-hoc analyses did not reveal any significant differences. The mean scores for both questions by groups are displayed in Figures 45 and 46.

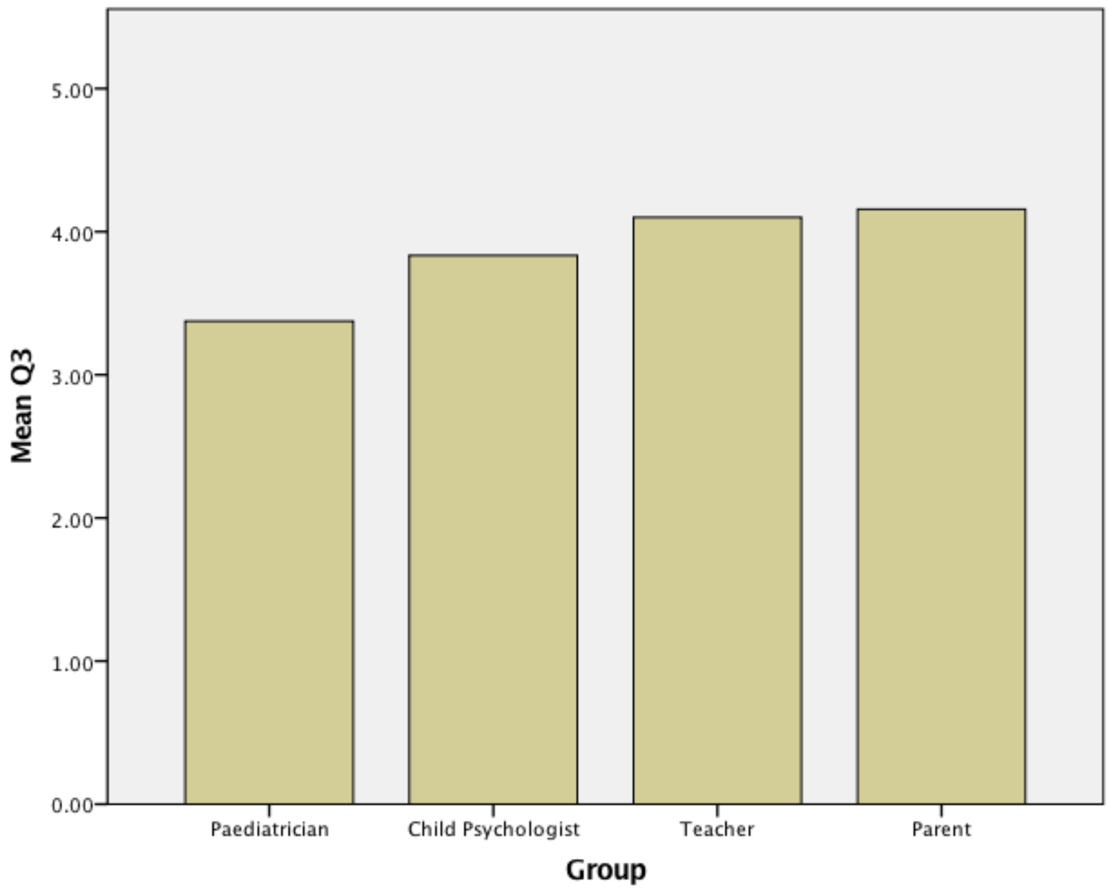


Figure 45 Mean scores of participants for Question 3

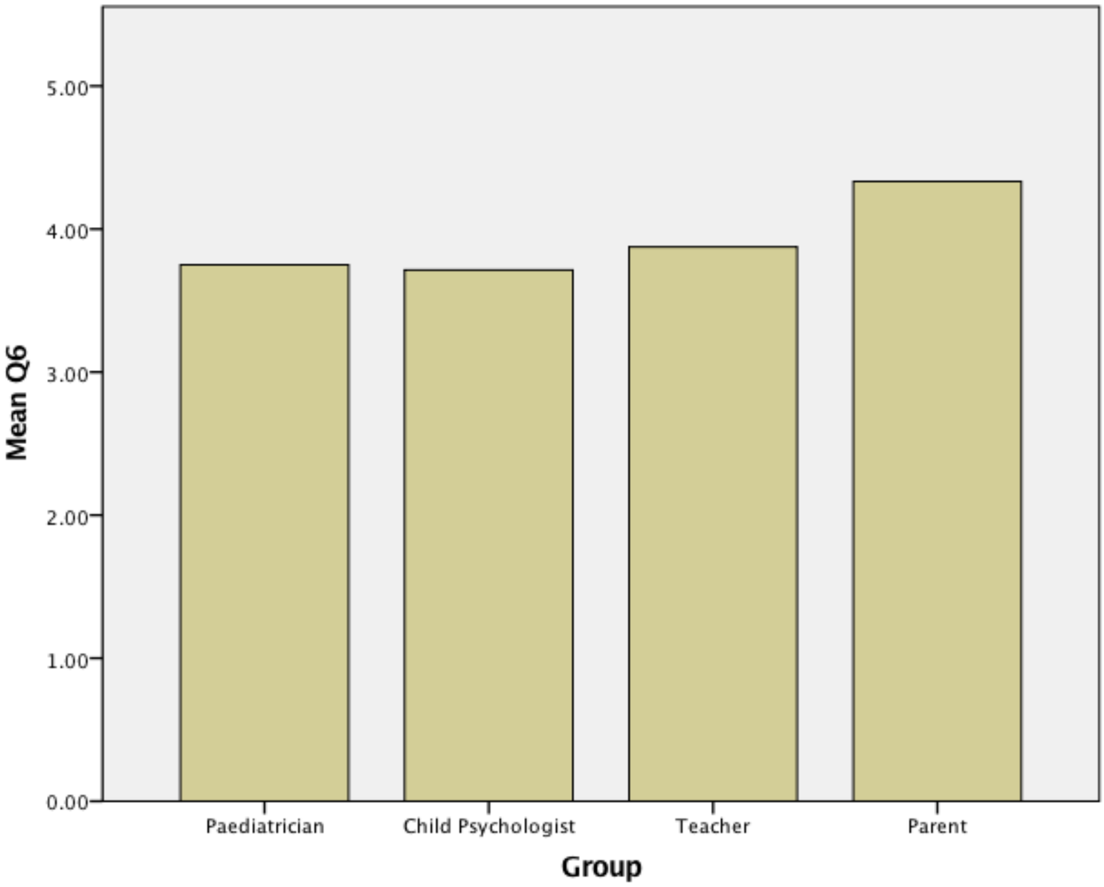


Figure 46 Mean scores of participants for Question 6

5.2.3. Manual observation

Manual observation study was conducted with participants at a special school for children with ASD (6-Dots academy) in India. Twenty-five volunteers have been recruited for assisting the research team in various needs including, monitoring and recording learning improvements, ensuring safety of participants, and taking care of children. Confidentiality agreements have been signed by the volunteers before participating in the study. They were recruited based on interviews conducted at colleges and schools. Two paediatricians and one child psychologist with at least 5-years of experience in practice were involved in the study as advisors. They ran two consultation sessions for the parents of participating children on the first and last day of the study.

A total of 70 invitations to participate in the research study were sent to the parents of children in five pre-identified schools three weeks before the scheduled period for the study and 49 parents accepted to the invitation. A meeting was conducted with interested parents at the proposed study venue seven days prior to the experiments and they were required to complete the Childhood Asperger Syndrome Test (CAST) questionnaire to identify autism behaviours in their children. The CAST consists of 39 yes or no questions [197] in which children scoring 15 and above were classified to have symptoms of autism. According to this rule, out of 49 children, 7 were excluded from the study. Three children were excluded from the study due to severe autism behaviour as judged by the paediatrician and the child psychologist. Inclusion and exclusion criteria were applied among the remaining 39 participants to evaluate improvement in learning abilities of children after interacting with the KiliRo robot. The criteria include, a simple task of identifying alphabets from 'A' to 'G' and Arabic numerals from '1' to '7'. Participants who could identify at least 6 out of 14 items were excluded from the study and the remaining were included in the research study. These criteria were applied to ensure the changes in learning abilities (identifying numbers and alphabets) are due to the interaction with the robot.

Finally, the study was conducted with 25 children with ASD over a period of 14 days. They were 6 to 16 years old (with the average age of 8.6 years and a standard deviation of 2.66) and had no exposure to robots. Consent from parents has been obtained and the parents were informed that they may withdraw from participation at any time. Safety precautions in the study were explained to them in detail.

Children were exposed to the robot for a minimum duration of 30 minutes each day over 14 days. They can interact and carry the robot freely. There were no compulsory attendance requirements for the participants, though the researcher and volunteers were present every day throughout the study adhering to the maximum working hours as instructed by employment rights in New Zealand (40 hours per week) and India (48 hours per week). Two sessions were conducted each day with a minimum of 15 minutes per session. During the sessions, the robot was placed on a table with the dimension of 3x3 square feet. Its ability to recognize the letters of the alphabet and numbers shown to it was demonstrated in front of participating children based on the ARMR setting.

It was expected that the children believe that the robot is answering the questions on alphabets and numbers autonomously as in the case of trained real parrots. One volunteer was allocated to each child to monitor improvements in his/her learning. In the meantime, one volunteer was allocated to each child to ensure the accuracy in monitoring and outcome reporting by the first volunteer. The volunteers were also required to manually enter the data on participants' social interaction such as the number of attempts to identify alphabets and numbers shown to the robot and the results of identifying the alphabets and numbers before the robot did.

The study reported notable improvements in children's learning ability. Out of 25 participants, 19 children showed improvements in the capability of identifying alphabets and numbers after 14 days of interaction with the robot. It was identified that nine children showed more than 100% improvement, identified by the successful identification of alphabets and numbers by children before and after interacting with the robot. Particularly, one child showed 250% of improvement. Table 16 illustrates the study results with details of children's learning improvements.

Table 16 Children's learning improvement

Participant No	Capability to identify items		% of
	Before	After	improvement
1	4	9	125
2	2	7	250
3	4	1	
4	4	10	150
5	4	6	50
6	5	7	40
7	3	7	133
8	2	0	
9	4	10	150
10	5	9	80
11	3	7	133
12	3	4	33
13	3	2	
14	4	7	75
15	3	5	67
16	3	4	33
17	3	1	
18	5	2	
19	3	5	67
20	3	9	200
21	5	7	40
22	2	5	150
23	4	5	25
24	4	2	
25	3	7	133

The responses in Table 17 can be written as an array of values n rows and p columns as below.

Use symbol x_{jk} to indicate the value of the k^{th} variable denoting identification of alphabets and number, observed on the j^{th} child corresponding to Table 17.

		Before	After
Participant 1	:	x_{11}	x_{12}
Participant 2	:	x_{21}	x_{22}
Participant 3	:	x_{31}	x_{32}
.	:	.	.
.	:	.	.
Participant *n*	:	x_{n1}	x_{n2}

The transpose of responses in Table 17 can then be written in the following array X:

$$X = \begin{bmatrix} 4 & 2 & 4 & 4 & 4 & 5 & 3 & 2 & 4 & 5 & 3 & 3 & 3 & 4 & 3 & 3 & 3 & 5 & 3 & 3 & 5 & 3 & 4 & 4 & 3 \\ 9 & 7 & 1 & 10 & 6 & 7 & 7 & 0 & 10 & 9 & 7 & 4 & 2 & 7 & 5 & 4 & 1 & 2 & 5 & 9 & 7 & 5 & 5 & 2 & 7 \end{bmatrix}$$

Where, x_{11},x_{21}, ….. x_{n1} are the numbers of the items which can be identified by the children before interacting with the robot. The arithmetic mean of these values is:

$$\overline{x_1} = \frac{1}{n} \sum_{j=1}^{n} x_{j1} \tag{5.1}$$

In the same way, the mean value of the number of the items which can be identified by the children after interacting with the robot is:

$$\overline{x_2} = \frac{1}{n} \sum_{j=1}^{n} x_{j2} \tag{5.2}$$

Putting those means together, we have:

$$\bar{x} = \begin{bmatrix} \overline{x_1} \\ \overline{x_2} \end{bmatrix} = \begin{bmatrix} 3.52 \\ 5.52 \end{bmatrix} \tag{5.3}$$

It is noted that the average of the children's ability to identify letters and numbers has increased from 3.52 to 5.52 after interacting with the robot.

A measure of spread is provided by the variance which can be calculated using:

$$S_2 = \frac{1}{n} \sum_{j=1}^{n} \left(x_{j2} - \overline{x_2}\right)^2 \tag{5.4}$$

where, n indicates the total number of participants.

Using (5.3) and (5.4), $S_1 = 0.82$ and $S_2 = 8.25$

With the above results, it can be noted that the average ability of children to identify alphabets and numbers have increased from 0.82 (before interaction with the robot) to 8.25 (after interaction with the robot).

A measure of linear association $S_{(1,2)}$between the capability of children to identify items before and after interacting with the robot can be identified using:

$$S_{(1,2)} = \frac{1}{n} \sum_{j=1}^{n} \left(x_{j1} - \overline{x_1}\right)\left(x_{j2} - \overline{x_2}\right) \tag{5.5}$$

Where, x_{j1}, x_{j2} are the number of items identified by each participant before and after interacting with the robot, and $\overline{x_1}, \overline{x_2}$ are the mean values of items identified before and after interacting with the robot.

Using (5.5), $S_{(1,2)} = 0.51$.

The above result of linear association indicates improvements in children's ability to identify items before and after interaction with the KiliRo robot.

Calculating correlation, R between the variables is essential to identify if the results on learning improvement before and after interaction with the robot are significant. Correlation is a statistical technique used to identify how strongly the pairs of variables are related. For this study, correlation coefficient i^{th} (before interaction with the robot) and k^{th} (after interaction with the robot) variable is:

$$R_{1,2} = \frac{S_{1,2}}{\sqrt{S_1}\sqrt{S_2}} \tag{5.6}$$

Using (5.6), $R_{1,2} = 0.20$

The correlation result indicates the results are significant.

A paired-samples t-test (a statistical method that compares the means of two related groups to determine whether there is a statistically significant difference between these means) is used to compare the results of children's ability to identify items which revealed a significant difference before and after interaction with KiliRo robot (t (25) =(-3.52), p<.01). The mean scores are also displayed in Figure 47.

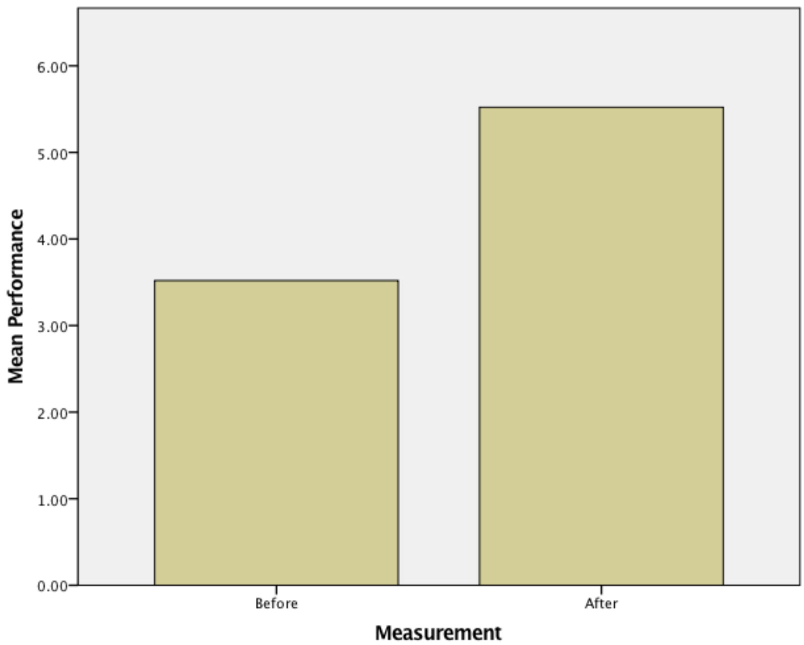


Figure 47 The mean scores of the learning abilities before and after interacting with the robot

5.3. Improvements in social interaction abilities

The effects of the KiliRo robot in improving the social interaction abilities of children with ASD was investigated using two user studies, namely, social network density analysis and comparison study. The closed-format questionnaire results mentioned in section 5.2.2 were also analysed in detail to identify the paediatricians, child psychologists, teachers, and parents' opinion in social interaction improvement among children using the KiliRo robot.

Using social network density analysis (SND) method, the first user study was conducted to evaluate the changes in interaction among children when they interact with the robot. SND is an effective method to identify how two groups of populations interacted with one another. The second user study was conducted in the same way when the children were introduced to a person and a robot and the effects of a person and the robot on the improvements in children's social interaction were compared.

5.3.1. Social network density analysis

In social network density (SND) analysis method, participants are denoted by nodes and successful interaction is indicated by connections among the nodes as illustrated in Figure x. It is reported that the network density can be used to show the improvements in interaction among participants [198]. During this 49-day study, interaction is defined as looking, smiling or laughing, holding hands, touching, initiating verbal or non-verbal communication, hugging, petting, stroking at other participants or the robot, and offering robot to other participants. These behaviours are monitored and recorded by volunteers.

By identifying and calculating interaction nodes, SND provide a detailed information about the improvement in interaction among participants after the KiliRo robot is introduced to them. Ten participants (S1 through S10) with a mean age of 10.50 (SD=3.66) were involved in the study. One group consists of Participants S1, S2, S3, and S4, and another group consists of the remaining participants. The participants in each group were from the same school and knew each other prior to this study. Participant S5 from a different school did not know any of the other participants before the study. A manual observation method was used to evaluate the improvements in social interaction of participating children. For this purpose, five volunteers were allocated to monitor and record the improvements in social interaction of children during the sessions with the KiliRo based on the behaviours such as looking, smiling or laughing, holding hands, touching, initiating verbal or non-verbal communication, hugging, petting, stroking at other participants or the robot, and offering robot to other participants. Each volunteer was allocated two participants to ensure the accuracy in monitoring and reporting their observations regarding participants' social interaction.

On the first day of the study, all the ten participants were monitored for 60 minutes and their number attempts to interact with each other were recorded before interaction with the robot. An interaction was recorded if a participant exhibited more than six successful attempts to interact with another participant through any of the defined means of interaction: looking, smiling or laughing, holding hands, touching, initiating verbal or non-verbal communication, hugging, petting, stroking at other participants or the robot, and offering robot to other participants.

At the next step, the robot was introduced to participants and was operated to move, speak and move head and wings. The children were allowed to freely interact with the robot. This repeated for 49 days. At each day, SND was calculated to investigate if the interaction with the robot influenced in improving interaction among children.

In the social network diagram, nodes S1 through S10 represent participants and node KiliRo represents the robot. The connection between the participants or robot denotes an interaction. SND before interaction with the robot is illustrated in Figure 48. As can be seen in the figure, S5 did not interact with any other participant, and there were two groups of participants who interacted with each other.

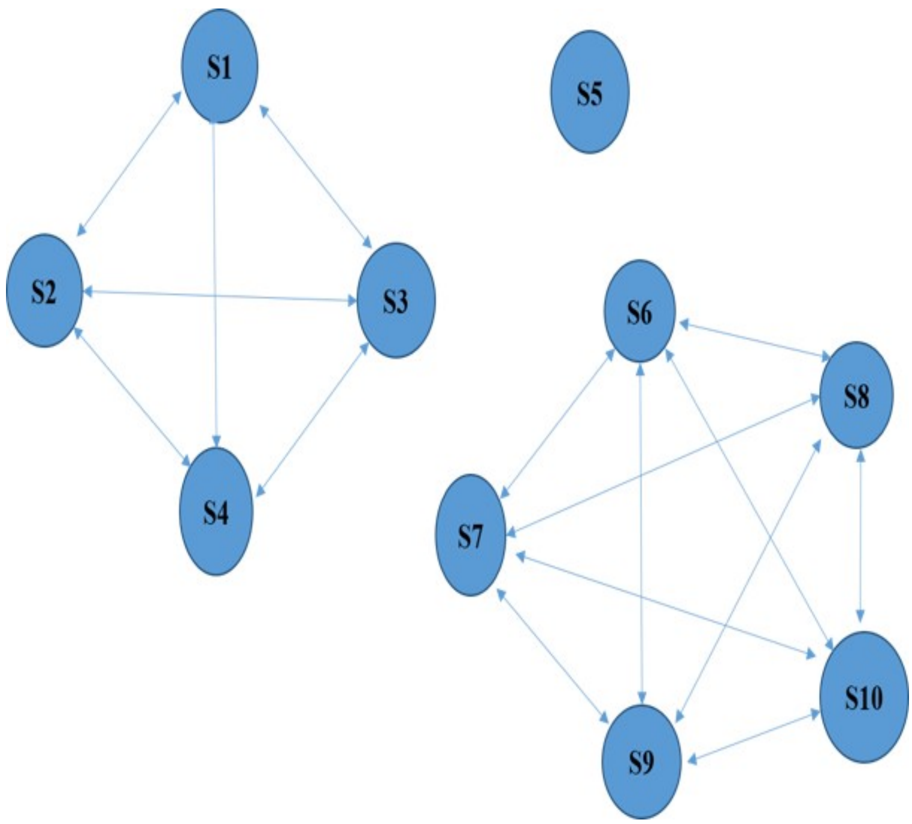


Figure 48 SND before interacting with the robot

The social network analysis diagram calculated after interacting with KiliRo robot is illustrated in Figure 49. As can be seen in the figure, participants interacted both with the KiliRo as well as among other children.

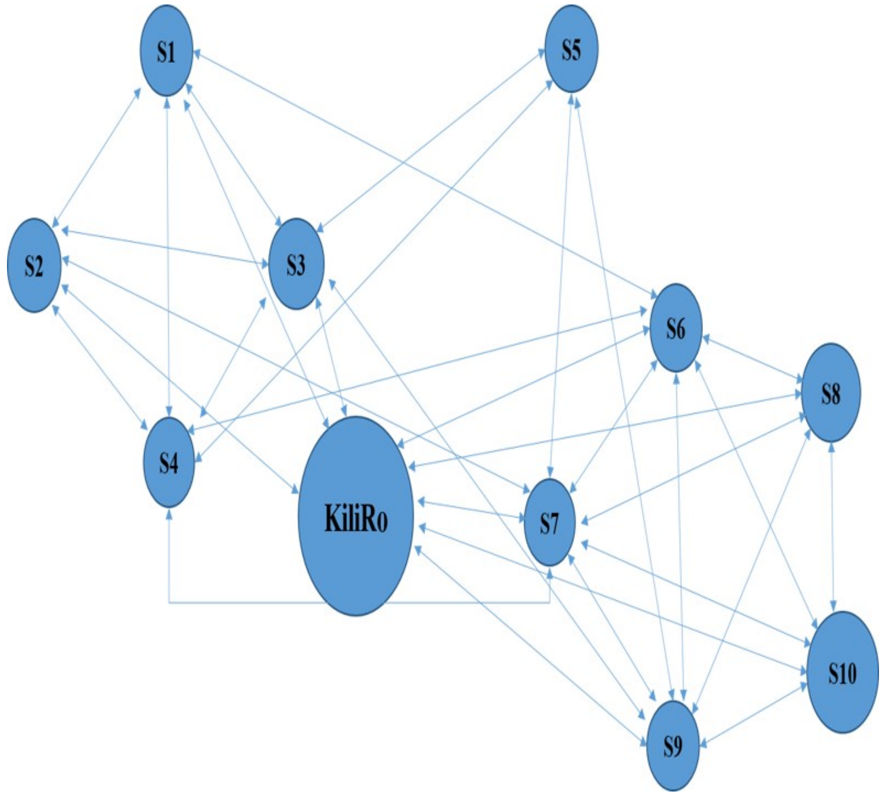


Figure 49 SND after interacting with the robot

Network density calculation:

$$SND = \frac{AC}{\mathrm{PC}} \tag{5.7}$$

Where, PC (potential connection) is the maximum number of connections that potentially exists between all nodes in the network, whereas, AC (actual connections) are the ones that were actually observed between the nodes.

PC is calculated as:

$$PC = \frac{n*(n-1)}{2} \tag{5.8}$$

where, n is the total number of nodes in the network.

From the above equations, SND increases from 0.36 to 0.6 after children interact with the robot. In other words, the social interaction density among children has almost been doubled after interaction with the KiliRo robot.

During this study, the time spent by each participant interacting with the robot is also monitored during every session. It is identified that the majority of children increased interaction time with the robot from week 1 through week 7. The average interaction time spent by each participant is presented in Table 17.

Table 17 Participants' interaction time with the robot

Participant number	**Week**							**Total interaction time (Out of 105 minutes)**	**Average interaction Time (Out of 15 minutes)**
	W1	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**		
1	5	4	6	4	9	8	9	45	6.43
2	4	6	5	6	8	9	8	46	6.57
3	3	4	2	4	7	6	9	35	5.00
4	9	8	5	3	7	9	7	48	6.86
5	8	8	6	9	5	10	7	53	7.57
6	5	6	3	8	10	6	12	50	7.14
7	7	9	9	8	6	10	8	57	8.14
8	3	7	6	7	5	9	10	47	6.71
9	6	8	7	9	8	11	11	60	8.57
10	7	11	12	10	14	13	14	81	11.57

The results shown in table reveal a positive upward trend. A Mann-Kendall nonparametric trend test (used to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time) was conducted to test whether this trend was significant. With a sample size of 10, the critical cut-off value of Tau (used to measure the ordinal association between two measured quantities) was 0.47. The Tau value of the results was 2.02, confirming that the positive trend was significant.

5.3.2. Effects of human and KiliRo

A study involving ten children with ASD was conducted to compare the effects of improvements in their social interaction by introducing a person and KiliRo robot to them. The study that was conducted in two settings with three sessions each. During the first setting, a stranger (man) was introduced to the children. There were three sessions in the study each with a minimum of 15-minutes duration. During the first session, the stranger was simply present in the room and did not performed any activities. In the second session, he read alphabets and numbers to the children and in the third session, the person sung a song to them.

The sessions with a similar setup were conducted where the person was replaced by the KiliRo robot. The robot performs the same behaviours as the person did. The number of interactions (or non-interactions) reflected through each of the following twelve behaviours were monitored and recorded during each session.

1. looking at the person / robot
2. Going close to the person / robot
3. Touching the person / robot
4. Smiling / laughing at the person / robot
5. Hitting the person / robot
6. Having verbal / non-verbal communication with the person / robot
7. Looked at other participants
8. Going close to the other participants
9. Touching other participants
10. Smiling / laughing during the session
11. Hit other participants
12. Having verbal / non-verbal communication with other participants

The study results are presented in Table 18. Successful interaction is recorded when more child exhibited target behaviour for more than six times.

Table 18 Human Vs KiliRo integration study results

Parameter	Presence of Person			Presence of KiliRo robot		
	I	II	III	I	II	III
1	7	5	4	3	3	1
2	8	8	8	6	4	4
3	10	10	10	6	6	4
4	10	8	7	8	6	4
5	10	8	7	6	5	4
6	8	6	9	7	5	1
7	8	9	10	7	7	6
8	10	10	10	9	9	9
9	10	10	10	9	9	9
10	10	9	10	8	8	8
11	10	10	10	9	9	9
12	10	10	10	9	9	9

Mean, standard deviation (SD), and confidence interval (CI) for the session sessions with the person and the robot interaction is presented in Table 19. The interval plot diagram (a plot with confidence intervals) for three sessions where person and robot are presented in Figure 50.

Table 19 Human and Robot interaction results

Factor	Mean	SD	95% CI
Person session I	9.250	1.138	(8.069, 10.431)
Person session II	8.583	1.676	(7.403, 9.764)
Person session III	18.750	1.913	(7.569, 9.931)
Robot session I	7.250	1.815	(6.069, 8.431)
Robot session II	6.667	2.146	(5.486, 7.847)
Robot session III	5.567	3.085	(4.486, 6.847)

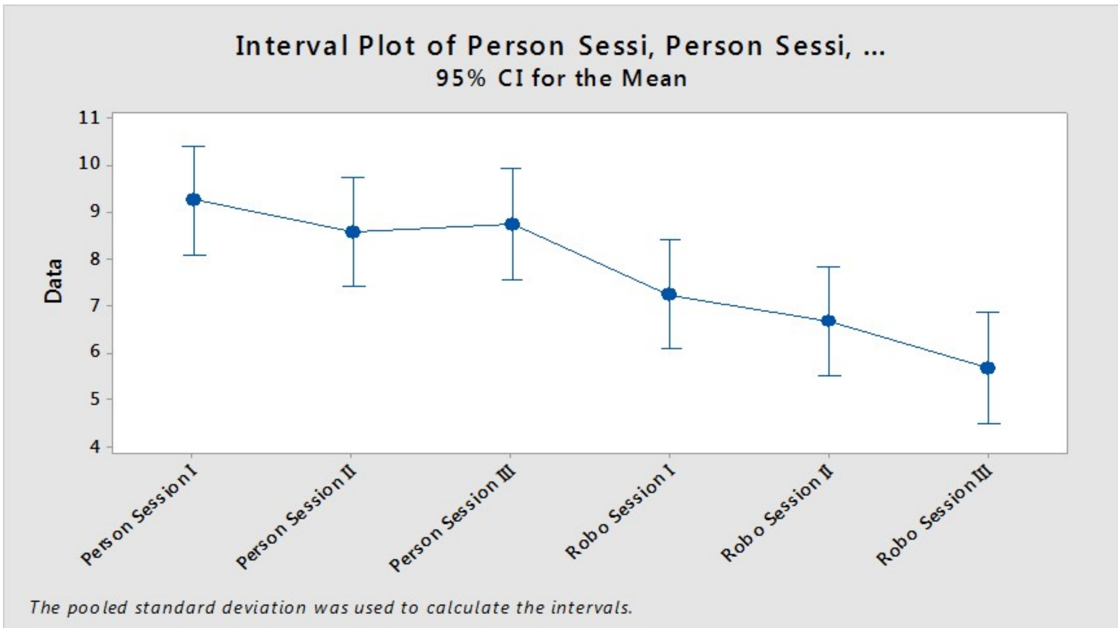


Figure 50 Interval Plot for three sessions with Person and Robot

From descriptive statistics (used to describe the basic features of the data in a study and provide simple summaries about the sample and the measures), it can be noted that the mean value of “No” (denoting no interaction) for the twelve behaviours decreases with successive sessions which is least in the sixth session. It indicates that children with ASD exhibited more interactions when the robot was introduced compared to the sessions with persons. It is also noted that more interactions among children were observed during the last session in which the robot was singing a song.

The results were tested using paired $t - test$ (used to compare two population means where in which observations in one sample can be paired with observations in the other sample) to compare the effects of introducing a new person and a robot among children with ASD. For conducting the statistical analysis, we set two hypotheses as below.

H_0: $\mu d = 0$ (there is no significant difference between the two sessions)

H_1: $\mu d \neq 0$ (there is significant difference between two sessions)

Paired $t - test$ for three session's pair response with person and robot is presented in Table 20 where, t is the test statistics, df is degrees of freedom and Sig is significance level.

Table 20 Paired t-test results

Pair Test	Mean	t	df	Sig (2 tail)
Pair I	2.00	5.42	11	.00
Pair II	1.92	5.70	11	.00
Pair III	3.08	4.79	11	.00

Through $Paired\ t - test$, it is identified that children with ASD had a different effect on their interaction capabilities from that when the KiliRo robot was introduced to them. Area graph (a line chart that graphically illustrates quantitative data) for sessions I, II, and III are illustrated in Figures 51, 52, and 53 respectively, which indicates that the number of "*No*" denoting unsuccessful interaction were highest during the first session with person and least with robot during the third session. Through this user study, it is identified that introducing KiliRo to children with ASD is more effective in their social interaction than introducing a person. In the figure, Index represents the 12 behaviours monitored and the Data represents the unsuccessful interactions.

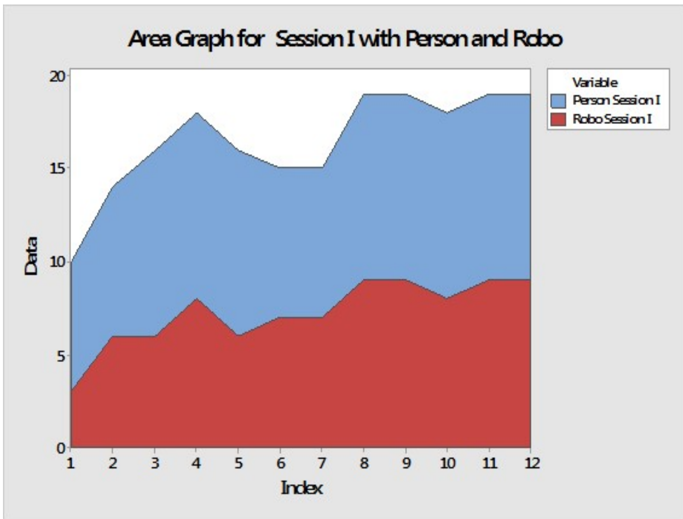


Figure 51 Area graph illustrating Session I

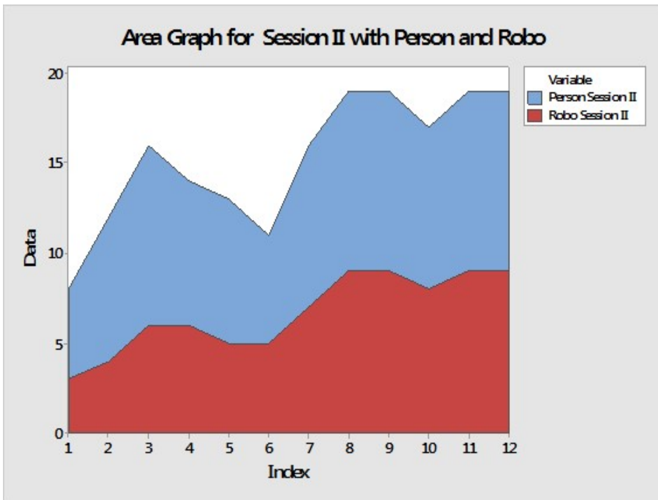


Figure 52 Area graph illustrating Session II

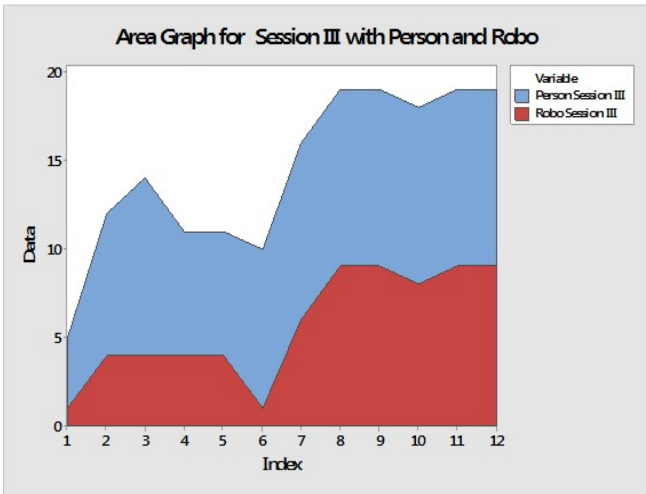


Figure 53 Area graph illustrating Session III

5.3.3. Closed-format questionnaire

The closed-format questionnaire results mentioned in section 5.2.2 were analysed in detail to identify the paediatricians, child psychologists, teachers, and parents' opinion in social interaction improvement among children using the KiliRo robot. Particularly, the responses for questions 2 (AMRM could help improve social interaction abilities of children with autism), 5 (KiliRo could be a companion for children with autism), 7 (My child tried to communicate with the robot during the study), 8 My child observed the learning abilities of KiliRo during the study), 9 (My child accepted KiliRo as his/her companion), and 11 (My child was happy to interact with KiliRo) which were focused on obtaining responses from participants towards social interaction abilities are very relevant.

The responses are grouped into four categories according to the types of respondents: Doctors, Child Psychologists, Teachers, and Parents. The sum of responses to the questions are put in an array of values as shown below.

The symbol x_{jk} is used to indicate the value of the k^{th} variable, (respondents' response in 'Likert scale' format ranging from strongly disagree to strongly agree), observed on the j^{th} item (question number).

Hence, n measurements on p variables can be written as:

		Q2	Q5	Q7	Q8	Q9	Q11
Doctor	:	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}
Child psychologist	:	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}
Teachers	:	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}
Parents	:	x_{41}	x_{42}	x_{43}	x_{44}	x_{45}	x_{46}

where, Q2, Q5, Q7, Q8, Q9, Q11 denotes the question numbers in the closed-format questionnaire.

These results can also be written as an array of values of n rows and p columns as below.

$$X = \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} & x_{16} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} & x_{26} \\ x_{31} & x_{32} & x_{33} & x_{34} & x_{35} & x_{36} \\ x_{41} & x_{42} & x_{43} & x_{44} & x_{45} & x_{46} \end{bmatrix} = \begin{bmatrix} 3.75 & 3.75 & 3.50 & 3.50 & 3.80 & 3.71 \\ 3.71 & 3.86 & 3.71 & 3.71 & 3.86 & 3.86 \\ 4.00 & 4.29 & 3.71 & 3.90 & 4.12 & 4.06 \\ 4.00 & 3.87 & 3.92 & 3.91 & 4.17 & 3.86 \end{bmatrix} \quad (5.8)$$

It can be noted from (5.8) that all the entries correspond to the positive feedback from the respondents about the fact that KiliRo can improve social interaction abilities of children with ASD. The maximum variation in responses between groups is less than 5%. Meaning a good consensus was also achieved among the respondents.

5.4. Changes in emotion

This research focused on monitoring the changes in emotions of children during the interaction with the robot, as emotions play a vital role in encouraging interaction. Emotion recognition is one of the widely-used analysis in therapeutic settings to identify participants' emotions during the study and validate their interaction interests. It has been extensively used in human-robot interaction studies involving children with ASD to validate the system [199]-[201]. Particularly, identifying emotions of children with ASD during the interaction with the robot is an efficient way of validating the impact of the robot on participants in improving their social interaction abilities.

Project Oxford emotion recognition system is used for the recognition of eight types of emotions, namely, anger, contempt, disgust, fear, happiness, neutral, sadness, and surprise of the children. The project Oxford emotion recognition API is a web based system that detects the facial images in each picture and evaluates the above mentioned eight emotional and produce corresponding values [202]. The system uses world-class machine learning techniques to interpret the values of emotion in the given picture. The system also provides the result of JavaScript Object Notation (JSON) with details of detected faces in the given picture and scores.

In this study, a human operator remotely controlled the locomotion of KiliRo in such a way to appear to the participants as being autonomous and able to make decisions by itself. The synthesised behaviours included learning alphabets, numbers and recognizing humans. A wireless camera module was used to provide a vision capability for the robot. A microphone and a speaker were used to enable KiliRo to mimic hearing and speaking behaviour. Infrared remote control was used to control the robot's head, legs, and tail locomotion. The operator remotely activated the behaviours in KiliRo, based on a live video feed of the situation in which the participants interacted with the robot. For instance, the remote robot operator identified the person standing in front of the robot through a wireless camera and used a microphone to initiate and maintain communication between the robot and the person.

In the user study to investigate the emotions of children, local schools for children with autism spectrum disorder were approached using a convenient sampling method. A formal open invitation was sent to 19 parents with information about the study. Parents who expressed willingness to participate in the study were required to complete the CAST questionnaire to identify autism behaviour in their children and same set of exclusion criteria were applied as described in section 5.2.3 to exclude 3 out of 12 children. The study was performed with nine participants aged between 6 and 16 years with the mean age of 9.33 years and standard deviation of 3.39.

The study was divided into 15 sessions, each session lasted for 15 minutes. The whole study was conducted over a period of 5 consecutive days and with 3 sessions each day. The sessions were conducted between 10 am and 12 pm with a 30-minutes break between the sessions. All children participated in all sessions performed. The study was conducted at the same venue with the same participants. In the study, there were four tasks for the robot to perform as described below.

In the first task, a member of the research team remotely operated the robot to walk forwards and backwards, move its tail up and down, and move its head up and down. In addition to that, KiliRo spoke a few words and communicated with a member of the research team leading the session. This task also involved the participating children where the behaviours of the robot were synthesised by the remote operator in response to the observed situations. This task was conducted to validate the acceptance, likeability, and interaction interest of children towards the KiliRo robot and its parrot-inspired morphology.

In the second task, the researcher taught letters of the English alphabet to KiliRo. After a few minutes of training, KiliRo's learning ability was checked by being asked to identify a letter presented to it. A member of the research team then answered the question to simulate the proposed behaviour of KiliRo.

For the third task, a member of the research team taught the number systems to KiliRo. After a few minutes of training, KiliRo was checked for its ability to learn numbers. This was done by being asked to identify a printed number put in front of it.

The fourth task involved identifying individuals. In this session, a member of the research team showed a real person to KiliRo and taught relationships such as mother or father of a child. For instance, a parent of the participating child was shown to KiliRo and taught that he/she is the child's father/mother. After few minutes of training, KiliRo was checked for its ability on how it has learnt by showing the same person and asking who he/she was.

During the five-day study, 580 pictures were taken using five smart phone cameras to investigate eight types of emotions among participants. The Project Oxford emotion recognition API was used to evaluate the pictures to obtain 2360 individual facial emotion values.

Figure 54 illustrates the average values of eight emotions identified through pictures taken during the study. Overall, neutral, happiness, sadness, and surprise are the four emotions exhibited highly by the participants. Anger, contempt, disgust, and fear are found in less than 5% on the scale. Neutral emotion is found to be common in children with autism during the study with the highest value on day 2 (83%) and lowest on day 4 (59.5%). Happiness is found to rank next to neutral emotion. The emotion Happiness of children gradually improved from day 1 through day 5. It was also noted that the emotion sadness drastically declined on the last day of the study. Furthermore, surprise has increased heavily from day 1 to day 5. The above results can influence the interaction interests of children with peers as emotion play a vital role in encouraging interactions.

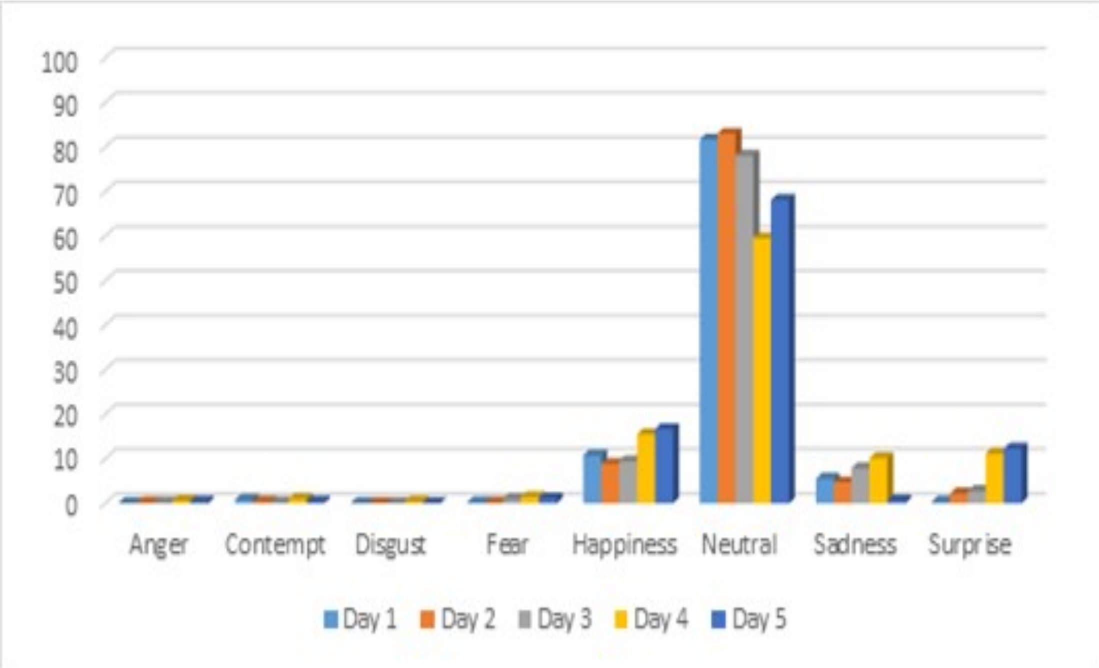


Figure 54 Emotion values of participants

Manual observation by volunteers was also performed during the study to investigate the effects of the robot during this five day study. The observations showed that, initially, the participants were not attracted to the robot and continued doing their own work. When the robot started moving, four out of nine participants immediately responded by looking at the robot. The interest of children increased when the robot started to communicate with the researcher. Notably, one child grabbed the robot and started talking to it. The study on the fifth day was much more interactive compared to the first day. It showed the positive attraction for the children towards the parrot-inspired robot, KiliRo. Figure 55 shows the interaction of participants with the robots during the study.

Figure 55 Participants interacting with the robot (more pictures in Appendix D)

Figure 56 illustrates the values of facial emotions as identified using the emotion API system mapped in the scale of 0 to 1 for one of the pictures taken during the study.

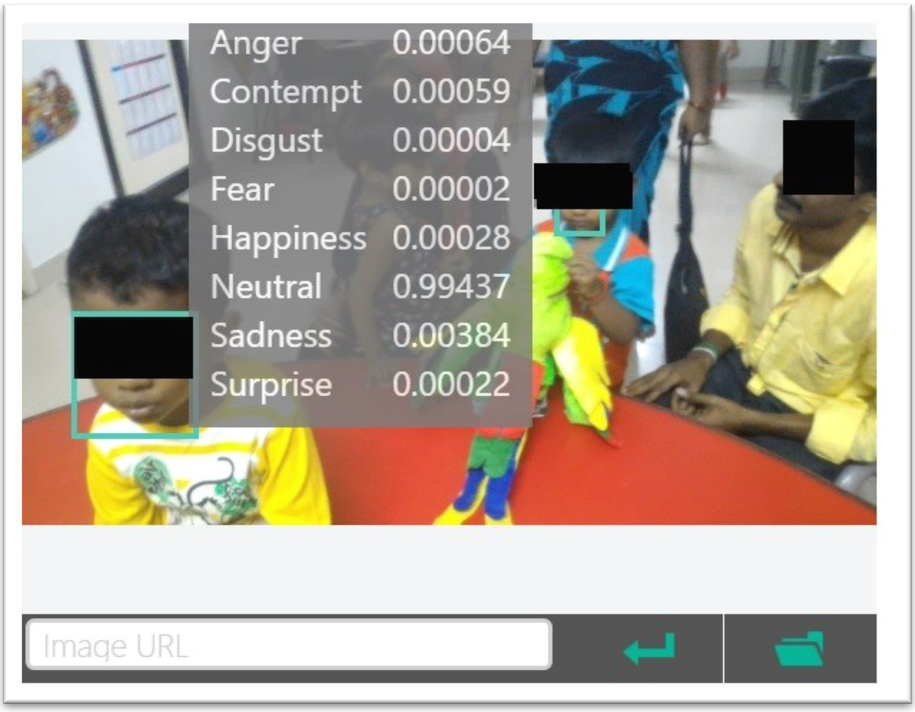


Figure 56 Illustration of emotion values

Even though each emotion has its own features, there are common characteristics between the emotions making them related to one another [203]. To validate the reliability of the Project Oxford emotion recognition system used in this study, we deployed the Spearman's Rho correlation method (a nonparametric measure of statistical dependence between the rankings of two variables to assesses how well the relationship between two variables can be described using a monotonic function) and analysed the correlation between eight emotion variables identified. Spearman's method is an efficient way to show how strongly the variables are related to one another.

For a sample size of n, the n raw scores X_i, Y_i are converted to ranks $r\,X_i$, $r\,Y_i$ and the correlation r_s is calculated using,

$$r_s = \rho_{rg_X, rg_Y} = \frac{COV\,(rg_X, rg_Y)}{\sigma_{rg_X}, \sigma_{rg_Y}}$$

where,

ρ denotes the correlation coefficient applied to the rank variables, $COV\,(rg_X, rg_Y)$ is the covariance of rank variables, and $\sigma_{rg_X}, \sigma_{rg_Y}$ are the standard deviations of the rank variables.

Through this test, it is noted that, all eight emotions were significantly correlated to one another at 0.001 correlation levels. Hence, the method used in this study is highly reliable. Table 21 illustrates the Spearman's correlation results.

Table 21 Spearman's correlation results

	Spearman's rho	Anger	Contempt	Disgust	Fear	Happiness	neutral	sadness	surprise
Anger	Correlation Coefficient	1.000	.461**	.614**	.525**	.107	-.203**	.373**	.266**
	Sig. (2-tailed)	.	.000	.000	.000	.066	.000	.000	.000
	N	296	296	296	296	296	296	296	296
Contempt	Correlation Coefficient	.461**	1.000	.657**	.211**	.197**	-.127*	.215**	.174**
	Sig. (2-tailed)	.000	.	.000	.000	.001	.029	.000	.003
	N	296	296	296	296	296	296	296	296
Disgust	Correlation Coefficient	.614**	.657**	1.000	.536**	.124*	-.400**	.352**	.441**
	Sig. (2-tailed)	.000	.000	.	.000	.033	.000	.000	.000
	N	296	296	296	296	296	296	296	296
Fear	Correlation Coefficient	.525**	.211**	.536**	1.000	-.099	-.306**	.395**	.609**
	Sig. (2-tailed)	.000	.000	.000	.	.090	.000	.000	.000
	N	296	296	296	296	296	296	296	296
Happiness	Correlation Coefficient	.107	.197**	.124*	-.099	1.000	-.497**	-.031	-.147*
	Sig. (2-tailed)	.066	.001	.033	.090	.	.000	.599	.011
	N	296	296	296	296	296	296	296	296
neutral	Correlation Coefficient	-.203**	-.127*	-.400**	-.306**	-.497**	1.000	-.163**	-.234**
	Sig. (2-tailed)	.000	.029	.000	.000	.000	.	.005	.000
	N	296	296	296	296	296	296	296	296
sadness	Correlation Coefficient	.373**	.215**	.352**	.395**	-.031	-.163**	1.000	-.198**
	Sig. (2-tailed)	.000	.000	.000	.000	.599	.005	.	.001
	N	296	296	296	296	296	296	296	296
surprise	Correlation Coefficient	.266**	.174**	.441**	.609**	-.147*	-.234**	-.198**	1.000
	Sig. (2-tailed)	.000	.003	.000	.000	.011	.000	.001	.
	N	296	296	296	296	296	296	296	296

5.5. Changes in stress levels

Literature points to non-invasive methods for assessing human psychological and social behavioural processes as a highly convenient and effective approach in many clinical settings. Particularly, these methods are found to be very useful in research studies involving special needs children. For instance, Wada and Shibata investigated the 17-KS-S and 17-OHCS hormone levels in the elderly using urinary samples to evaluate the stress levels in the elderly while interacting with a seal-like robot [204]. However, there are other hormones in the human body whose proportional relationships to psychological changes are more easily quantified. It is identified that higher protein levels in urinary samples may indicate higher stress levels in subjects [205]. Previous studies have reported that a person's alpha-amylase level generally increases during stressful situations [206]. Sympathoadrenal medullary (SAM) activity is examined in alpha amylase test and increased alpha-amylase levels serve as an indicator of increased stress levels [207]. The SAM is a physiological connection between the sympathetic nervous system and the adrenal medulla. It is crucial in an organism's physiological response to outside stimuli. In this research, the changes in stress levels were monitored to investigate if there are any biological changes in children through interaction with the robot. They were monitored as stress can have direct influence in the learning and social interaction abilities of children with ASD.

In the experiments presented in this chapter, urinary and salivary tests were used to evaluate the stress levels in children with autism before and after interacting with the robot. This is a pioneering human robot interaction study to use urinary and salivary test for validating the effects of robotic engagement on children with ASD.

Urinary sample was used to measure protein levels and salivary sample was used to measure the alpha-amylase levels in the participating children which serves as a stress marker. The first batch of samples were collected by the children's parents and were handed over to the laboratory technicians on the first day of the study, before the KiliRo robot is introduced to the children.

The second batch of samples was collected during the last week of the study to evaluate the changes in stress levels after the children's interaction with KiliRo robot for over 7 weeks. Both the urinary and salivary samples were stored at the study venue between 9 a.m. and 11 a.m. Seven participants with the mean age of 10.0 and standard deviation of 3.51 were involved in the study. The samples were labelled as Subject 1 through Subject 7 to protect the identity of the children.

The children were exposed to the robot for a minimum duration of 60 minutes each day over 49 days. Four sessions were conducted each day with a minimum of 15 minutes per session. During the first session, the robot was placed on a table with the dimension of 3x3 square feet. The participants could have open interaction with the KiliRo robot. The second and third sessions involved activities around learning abilities of the robot. Letters of the alphabet and numbers were shown to the robot, and its ability to recognize them was demonstrated in front of participating children.

Table 22 shows the protein and alpha-amylase levels of participants before and after interacting with the robot. It is observed that the mean protein level of participating children dropped from 40.31 to 17.40 after interacting with the KiliRo robot.

Wilcoxon Signed Ranks Test (a non-parametric statistical hypothesis test used when comparing two related samples, matched samples, or repeated measurements on a single sample to assess whether their population mean ranks differ), was used to identify if the changes in stress levels were statistically significant. This analysis was used to compare related or repeated measurements on the same sample. According to the test, the changes were statistically significant ($z=-2.37$, $p<.05$). The obtained results clearly demonstrated the efficacy and validity of the developed KiliRo robot in lowering the stress level of children with autism through close human robot interactions.

It is also noted that the alpha-amylase levels dropped in the second sample test report, from a mean of 305.71 to 151.29. Even though the alpha-amylase level for Participant 5 increased at the second-time point, the overall reduction in the alpha-amylase levels of the group was statistically significant (related-samples Wilcoxon Signed Ranks Test, $z=-2.20$, $p<.05$).

Table 22 Urinary and salivary test results

Participant number	**Protein (mg/dL) Normal value 0- 20mg/dL**		**Alpha-amylase (U/L) Normal value 59-401U/L**	
	Before	**After**	**Before**	**After**
1	69.7	19.8	564	98
2	22.5	8.4	179	76
3	29.5	18.8	348	132
4	32.5	25.0	218	121
5	19.9	10.4	113	131
6	22.5	13.4	177	81
7	85.2	26.0	541	420

This study proved that interactions with KiliRo robot helped significantly reduce stress levels of children with ASD. The study also provides more opportunity for similar investigations in robot-assisted therapy studies among various stakeholders. The mean results of urinary and salivary tests are presented in Figures 57 and 58 respectively.

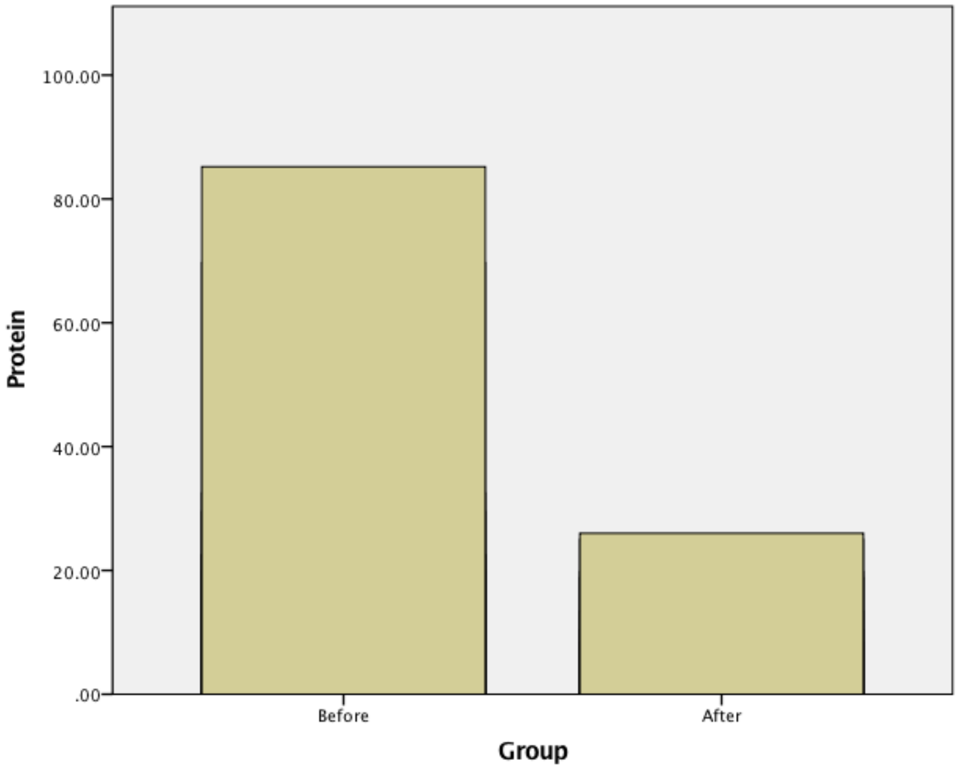


Figure 57 Urinary sample test results

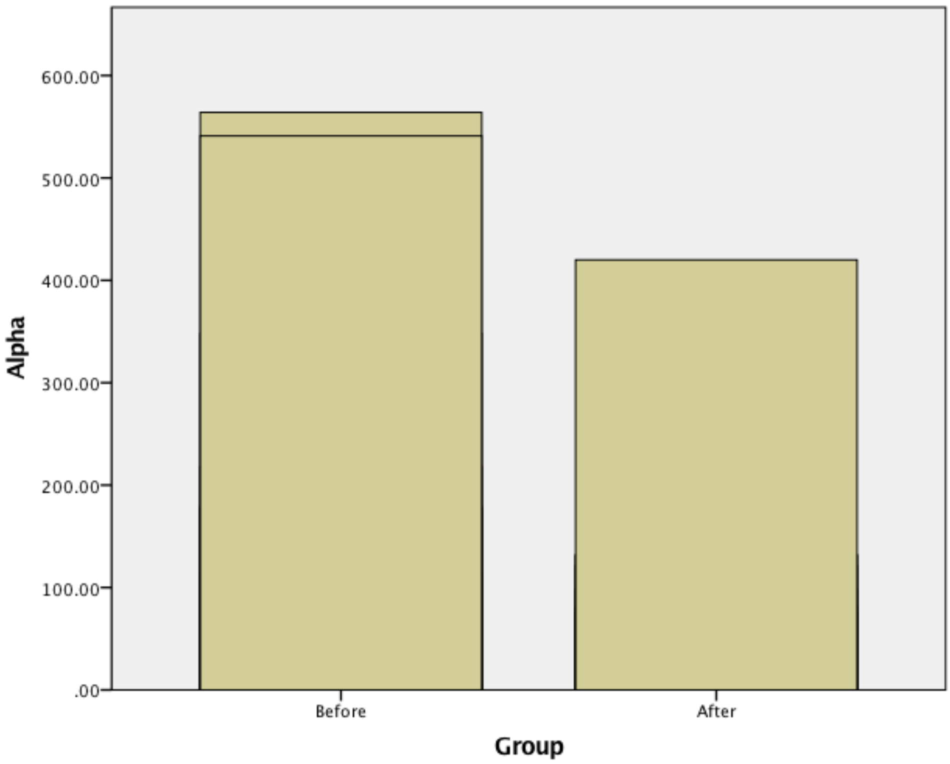


Figure 58 Salivary sample test results

5.6. Changes in blood pressure, heart rate, and oxygen saturation levels

Investigating the diastolic and systolic blood pressure, heart rate, and oxygen saturation levels in blood aids in monitoring the improvements in vital signs in a human body [208]-[209]. These physiological measures can be used to assess the physiological effects of using the KiliRo robot in children with ASD. The participants' oxygen saturation level carried by haemoglobin was also used for the same purpose. In this research, the physiological changes in children were monitored to investigate if there are any changes in children's blood pressure heart rate, and oxygen saturation levels children due to the interaction with the robot to ensure clinical safety for children. It is also important to note that these physiological changes can directly affect the children's learning and social interaction abilities.

This study involved 14 participants with the mean age of 9.71 years and standard deviation of 3.24. The tests were performed seven times during the entire study and the mean value was calculated to report children's physiological changes. Fourteen volunteers were allocated for taking diastolic (DYS) and systolic (SYS) blood pressure, heart rate (HR), and oxygen saturation levels in blood (SPO2) measurements before, during, and after interacting with KiliRo. When the heart beats, it contracts and pushes blood through the arteries to the rest of the body which creates pressure on the arteries, called systolic blood pressure. The diastolic blood pressure indicates the pressure in the arteries when the heart rests between beats. Heart rate is the heartbeat speed measured by the number of contractions of the heart per minute. Oxygen saturation level is an estimate of the amount of oxygen in the blood.

The volunteers were given training by experts for performing and recording the values of these tests. The study was guided by a paediatrician and a child psychologist. The readings were taken using commercially available measuring devices such as OMRON blood pressure monitor.

The average results of SYS, DIA, HR and SPO2 data entered by the volunteers are shown in Table 23. The average results of the complete study were considered for evaluating the changes in SYS, DIA, HR and SPO2 levels due to the interaction with KiliRo robot. Results from the notes taken by the volunteers show that there was no notable change in DIA and SYS blood pressure, heart rate, and oxygen saturation levels in the blood of the participants before, during, and after interaction with the robot, except for a few cases. For instance, in SYS blood pressure readings, one participant recorded more than 120 before interaction, four participants during interaction, and two after interaction. For all measures (SYS, DIA, HR, and SPO2), mean values before, during, and after interactions were virtually unchanged.

Table 23 Physiological analysis results

Participant number	**Systolic blood pressure (mmHg) Normal range < 120 mmHg**			**Diastolic blood pressure (mmHg) Normal range < 80mmHg**			**HR (pbm) Normal range 60-100 bpm**			**SPO2 (%) Normal range 94% - 99%**		
	Before	**During**	**After**	**Before**	**During**	**After**	**Before**	**During**	**After**	**Before**	**During**	**After**
1	99	131	130	57	61	58	99	75	77	99	90	99
2	101	153	118	67	78	70	92	96	87	98	99	97
3	112	107	130	61	61	56	75	77	80	94	97	99
4	99	93	80	61	57	55	80	78	77	95	96	95
5	109	121	113	94	81	87	107	109	103	96	97	97
6	115	133	101	66	63	64	92	71	95	99	97	96
7	109	103	101	72	71	64	101	87	95	99	96	98
8	103	101	95	64	75	70	83	90	89	85	87	95
9	125	105	104	87	72	79	83	85	65	97	96	99

10	102	115	98	69	68	69	92	91	100	94	95	98
11	98	99	98	64	51	58	103	98	102	97	99	99
12	98	84	88	69	68	62	109	89	87	94	96	99
13	95	96	91	60	66	57	83	87	82	99	97	96
14	109	107	102	70	66	64	78	74	73	99	99	97
Mean	102.5	110.6	103.5	68.6	67.0	65.2	91.2	86.2	86.6	96.1	95.8	97.4

The means of SYS, DIA, HR, and SPO2 are illustrated in Figure 59. To investigate the effect of interacting with KiliRo, nonparametric Wilcoxon related-samples tests were conducted comparing the scores before and scores after exposure. The differences were only significant for diastolic blood pressure (z=-2.35, p<.05). Hence, we concluded that the interaction with KiliRo robot did not have notable changes in blood pressure, heart rate and oxygen saturation levels in the blood.

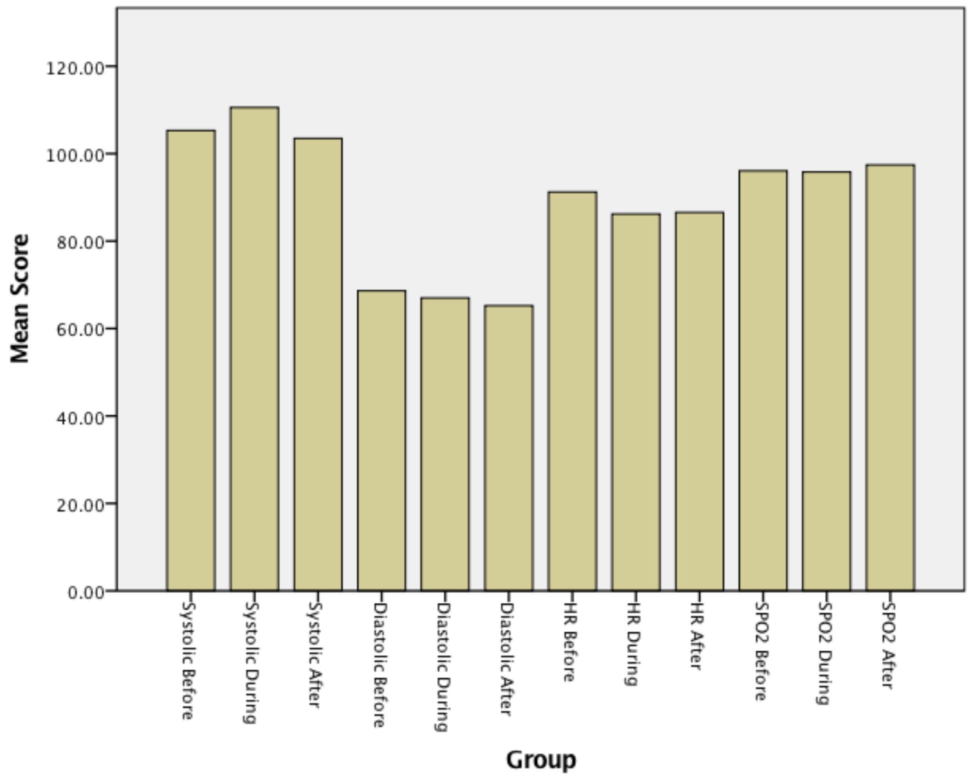


Figure 59 The mean values of SYS, DIA, HR, and SPO2

In this chapter, we presented the results of several user studies conducted to validate the effects of KiliRo robot in improving learning and social interaction abilities of children with ASD. The results indicate improvements in learning and social interaction of children after interacting with KiliRo robot. It is also identified that interaction with KiliRo robot can help reduce the stress levels of participants.

In the next chapter, the summary of the thesis with discussions, conclusions, and future works are presented.

6. Summary

6.1. Discussions

The aim of this research was to design and develop a parrot-inspired therapeutic robot, KiliRo, to improve learning and social interaction abilities of children with ASD. The study also aimed to investigate the changes in stress levels, systolic and diastolic blood pressure, heart rate, and oxygen saturation levels in the blood before and after interacting with KiliRo.

The study has shown that the robot can improve learning and social interaction abilities of the participants. Through urinary and salivary sample investigations, the research also reported a significant reduction in stress levels of children after interacting with KiliRo. The blood pressure, heart rate, and oxygen saturation level reports indicated no abnormality in participants during and after interacting with the robot.

The results of this study concur with previous studies that reported positive influences of bio-inspired therapeutic robots in improving learning and social interaction abilities of children with ASD. The results also align with some previous studies which indicated reduction in stress levels of participants through robot-assisted therapy.

This study has produced four significant outcomes to engineering, product design, and user studies. Firstly, this is the first study, to our knowledge, to design and develop a parrot-like robot for therapeutic settings. Secondly, even though most product design occurs based on the user recommendations, this is a pioneering study to construct features and specifications of a therapeutic robot purely based on the stakeholders' recommendations. Thirdly, only one other study, to our knowledge has examined the stress levels of elderly through urinary tests. But, in this study, the urinary samples of children with ASD were investigated to report changes in stress levels after interacting with the robot. Finally, this study used salivary samples for the first time in robot-assisted therapy involving children with ASD to investigate stress levels.

Even though this doctoral research has reported significant results in improving learning and social interaction abilities and reducing stress levels of children with ASD using KiliRo robot, there are several limitations that need to be considered and further studied. The main limitation is that the sample size of children who participated in the user studies was not large enough to produce reliable findings that permit generalisation of the key findings of the research. Particularly, only seven participants were involved in urinary and salivary sample tests that reported reduction in stress levels. Another important limitation is the duration of user studies conducted. User studies with longer duration are needed to confirm the research findings. It is also worth noting that the study did not have a control group to compare the results, except in one study that monitored social interaction abilities. Future studies are necessary to replicate these results with adequate active control conditions and research designs that control for order effects and the effects of novelty of exposure to robot. Nevertheless, this thesis could be regarded as early exploratory research that highlighted the potential for using a bio-inspired parrot robot for improving the learning and social interaction abilities and reducing stress levels in children with ASD.

This study reinforces the recommendation for the deployment of bio-inspired robots in therapeutic settings. The findings of this research can contribute considerably to the design and development of novel bio-inspired robotic platforms for various therapeutic needs. The results also imply direct practical evidence that learning and social interaction of children with ASD can be improved using therapeutic robots. The findings of this study through urinary and salivary sample tests can encourage more such investigations in robot-assisted therapies.

Furthermore, longer studies with a larger sample size would provide more generalised findings in improving the learning and social interaction abilities of children with ASD. Conducting cross-country validation would be more useful in validating the effects of

KiliRo among participants. Extended development is essential to improve the appearance of the robot. Exploring other materials, such as silicon and artificial fur could be helpful in improving the physical appearance of KiliRo.

6.2. Conclusions

The rapid increase in the ASD population across the globe is demanding more research studies to help improve the quality of life of about 74 million people. With no medication to identify the cause or cure this disorder, several therapies were explored to meet the psychological, physiological, and social interaction needs of people with ASD. Particularly, improving learning and social interaction of children with ASD is essential to improve their quality of life. Several methods were deployed and experimented in recent decades to meet this demand.

The research presented in this thesis has successfully designed and developed a parrot-inspired therapeutic robot to help children with ASD in improving learning and social interaction. The study is based on the idea that the parrot-like morphology and its abilities would attract children to interact with it and encourage them in learning. It is also hypothesised that the interaction with the robot helped to reduce the stress levels of the participants.

Through development of a new teaching technique, AMRM, the study investigated the improvement in learning among children with ASD using KiliRo robot. The improvements in learning were reported through interviews, closed-format questionnaires, and manual observation methods. Out of 54 participants, the majority of paediatricians, child psychologists, parents, and teachers of children with ASD, who responded to the interviews and closed-format questionnaires acknowledged that KiliRo can help improve learning and social interaction abilities of children with ASD. Another user study conducted with 25 children with ASD indicated that the interaction with KiliRo significantly improved the learning abilities of the participants.

The improvements in social interaction among participants were monitored and analysed using SND, and a comparative study. The SND analysis indicated that the interaction among participants almost doubled after introducing the robot. It is also identified that the interaction time of participants with the robot had increased significantly throughout the study. The comparative study reported that introducing KiliRo robot has more effects in children with ASD than introducing a human. Another study conducted to identify emotions of participants reported that children with ASD are not afraid of a parrot-like robot and are happy to interact with it.

Urinary and salivary test reports indicated that the stress levels of changes have significantly dropped after interacting with the robot. Through blood pressure, heart rate, and oxygen saturation level monitoring, the study reported no abnormality in children during and after interacting with the robot.

The implications of these findings provide more opportunities for the development of therapeutic robots and encourage professionals in medical, psychological, and teaching sectors to explore deployment of a robot for various needs. With this, the research provides multi-disciplinary application for therapeutic robots and provides collaborative research opportunities.

Considering the quote *"If they can't learn the way we teach, we teach the way they learn",* it is strongly believed that the contribution of this doctoral research will provide more opportunities for exploring new methods to improve learning and social interaction of children with ASD.

6.3. Future works

The research presented in this thesis designed, developed, and evaluated the parrot-inspired robot, KiliRo, among children with ASD. There are several lines of research opportunities arising from this study which should be pursued.

The extension of work presented in Chapter 3 with a larger sample size could be helpful in generalizing the acceptance of a parrot-like morphology in a therapeutic setting. We also aim to develop an automated word analysis tool which can extract words of interest in a large document representing qualitative data.

There are more possibilities on further research and development in the robot design presented in Chapter 4. We aim to explore soft materials such as silicon and artificial fur to improve the aesthetic appeal of the robot. We are keen to implant camouflaging features in the robot to change its colour according to the children's emotions. Another area of our future work will be developing the robot with the ability to identify the symptoms of ASD in children.

The research will be conducted with a larger sample size to support the findings of this research illustrated in Chapter 5. It is proposed that studies will be conducted for several months in three countries with a minimum sample size of 100 participants to identify the effects of the robot in learning and social interaction abilities.

We have experienced difficulties in collecting biological samples of children to investigate stress levels. Hence, in future studies, we aim to use hair samples to investigate cortisol levels of participants for monitoring changes in stress levels after interacting with the robot.

7. Contribution to thesis

7.1. Journal publications

7.1.1. Published

1. Bharatharaj, J., Huang, L., Mohan, R. E., Al-Jumaily, A., & Krägeloh, C. (2017). Robot-Assisted Therapy for Learning and Social Interaction of Children with Autism Spectrum Disorder. Robotics, 6(1), 4.
2. Bharatharaj, J., Huang, L., Mohan, R. E., Al-Jumaily, A., & Krägeloh, C. (2017). Sociopsychological and physiological effects of a robot-assisted therapy for children with autism. International Journal of Advanced Robotic Systems.

7.1.2. In Press

1. Social engagement of children with autism spectrum disorder in interaction with a parrot-inspired therapeutic robot (Journal – Procedia Computer Science ELSEVIER).

7.1.3. Submitted

1. A Text Mining based User Requirement Analysis in the Development of a Parrot-Inspired Therapeutic Robot (Journal – ASME Journal of Engineering and Science in Medical Diagnostics and Therapy).

7.2. Conference publications

7.2.1. Published

1. Bharatharaj, J., Huang, L., & Al-Jumaily, A. (2015, December). Bio-inspired therapeutic pet robots: Review and future direction. In Information, Communications and Signal Processing (ICICS), 2015 10th International Conference on (pp. 1-5). IEEE.
2. Bharatharaj, J., Huang, L., Al-Jumaily, A. M., Krageloh, C., & Elara, M. R. (2016, November). Experimental evaluation of parrot-inspired robot and adapted model-rival method for teaching children with autism. In Control, Automation, Robotics and Vision (ICARCV), 2016 14th International Conference on (pp. 1-6). IEEE.
3. Bharatharaj, J., Huang, L., Al-Jumaily, A. M., Krageloh, C., & Elara, M. R. (2016, December). Effects of Adapted Model-Rival Method and parrot-inspired robot in improving learning and social interaction among children with autism. In Robotics and Automation for Humanitarian Applications (RAHA), 2016 International Conference on (pp. 1-5). IEEE.
4. Bharatharaj, J., Huang, L., Al-Jumaily, A., Rajesh, M., & Krägeloh, E. C. Investigating the Effects of Robot-Assisted Therapy among Children with Autism Spectrum Disorder using Bio-markers. IOP Conference Series: Materials Science and Engineering.

7.2.2. In press

1. Bharatharaj, J., Huang, L., Mohan, R. E., Al-Jumaily, A., & Krägeloh, C. (2017). Formulation of Features and Specifications of a Parrot-Inspired Robot using Text Mining Approach. The 36th JSST Annual International Conference

on Simulation Technology, October 25-27, 2017 Tokyo Denki University, Tokyo Japan.

7.3. Awards and recognitions

7.3.1. Best paper of the conference award

1. Title: Effects of Adapted Model-Rival Method and parrot-inspired robot in improving learning and social interaction among children with autism.

   Conference: Robotics and Automation for Humanitarian Applications (RAHA) 2016 International Conference.
2. Title: Investigating the Effects of Robot-Assisted Therapy among Children with Autism Spectrum Disorder using Bio-markers.

   Conference: 2017 International Conference on Advanced Technologies in Design, Mechanical and Aeronautical Engineering.

7.3.2. Best oral presentation of the conference award

1. Title: Investigating the Effects of Robot-Assisted Therapy among Children with Autism Spectrum Disorder using Bio-markers.

   Conference: 2017 International Conference on Advanced Technologies in Design, Mechanical and Aeronautical Engineering.

7.3.3. Other recognitions

1. Selected as the 'Finalist' in international robotics competition at 'Robotics and Automation for Humanitarian Applications (RAHA) 2016 International Conference'.
2. Selected as the 'Finalist' for the 'Best Student Presentation Award (IBTec)' at MEDSCI NZ Congress 2017.

References

1. Feinstein, A. (2011). A history of autism: Conversations with the pioneers. John Wiley & Sons.
2. Kanner, L. (1943). Autistic disturbances of affective contact. Nervous child, 2(3), 217-250.
3. Ornitz, E. M., & Ritvo, E. R. (1968). Perceptual inconstancy in early infantile autism: The syndrome of early infant autism and its variants including certain cases of childhood schizophrenia. Archives of general psychiatry, 18(1), 76-98.
4. Rutter, M. (1968). Concepts of autism: A review of research. Journal of Child Psychology and Psychiatry, 9(1), 1-25.
5. Bender, L. (1969). A longitudinal study of schizophrenic children with autism. Psychiatric Services, 20(8), 230-237.
6. Rutter, M. (1972). Childhood schizophrenia reconsidered. Journal of autism and childhood schizophrenia, 2(3), 315-337.
7. Gubbay, S. S., Lobascher, M., & Kingerlee, P. (1970). A neurological appraisal of autistic children: Results of a Western Australian survey. Developmental Medicine & Child Neurology, 12(4), 422-429.
8. Rutter, M. (1978). Diagnosis and definition of childhood autism. Journal of Autism and developmental disorders, 8(2), 139-161.
9. Campbell, M., Petti, T. A., Green, W. H., Cohen, I. L., Genieser, N. B., & David, R. (1980). Some physical parameters of young autistic children. Journal of the American Academy of Child Psychiatry, 19(2), 193-212.
10. Ozonoff, S., South, M., & Miller, J. N. (2000). DSM-IV-defined Asperger syndrome: Cognitive, behavioral and early history differentiation from high-functioning autism. Autism, 4(1), 29-46.
11. American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (DSM-5®). American Psychiatric Pub.

12. Developmental, D. M. N. S. Y., & 2010 Principal Investigators. (2014). Prevalence of autism spectrum disorder among children aged 8 years-autism and developmental disabilities monitoring network, 11 sites, United States, 2010. Morbidity and mortality weekly report. Surveillance summaries (Washington, DC: 2002), 63(2), 1.

13. Bharatharaj, J., Huang, L., & Al-Jumaily, A. (2015, December). Bio-inspired therapeutic pet robots: Review and future direction. In Information, Communications and Signal Processing (ICICS), 2015 10th International Conference on (pp. 1-5). IEEE.

14. Taylor, N. (2016). Associations between sensory issues, mealtime behaviours, and food and nutrient intakes in children with Autism Spectrum Disorder: a thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Human Nutrition and Dietetics at Massey University, Albany, New Zealand (Doctoral dissertation, Massey University).

15. Lifetime Costs of Autism Average $1.4 Million to $2.4 Million. (2014, June 08). Retrieved October 09, 2017, from https://www.autismspeaks.org/science/science-news/lifetime-costs-autism-average-millions

16. CIA. Retrieved October 09, 2017, from https://www.cia.gov/library/publications/the-world-factbook/fields/2056.html

17. American Psychiatric Association. Task Force on DSM-IV. (1991). DSM-IV options book: Work in progress (7/1/91). American Psychiatric Press.

18. Autism Spectrum Disorder (ASD). (2015, February 24). Retrieved October 09, 2017, from https://www.cdc.gov/ncbddd/autism/treatment.html

19. Abuse, N. I. Stimulant ADHD Medications: Methylphenidate and Amphetamines. Retrieved October 09, 2017, from https://www.drugabuse.gov/publications/drugfacts/stimulant-adhd-medications-methylphenidate-amphetamines

20. Lakhan, S. E., & Kirchgessner, A. (2012). Prescription stimulants in individuals with and without attention deficit hyperactivity disorder: misuse, cognitive impact, and adverse effects. Brain and behavior, 2(5), 661-677.

21. Sweeney, D. P., Forness, S. R., & Levitt, J. G. (1998). An overview of medications commonly used to treat behavioral disorders associated with autism, Tourette syndrome, and pervasive developmental disorders. Focus on Autism and Other Developmental Disabilities, 13(3), 144-150.

22. Smith, M. C., & Bleck, T. P. (1991). Convulsive disorders: toxicity of anticonvulsants. Clinical neuropharmacology, 14(2), 97-115.

23. Patorno, E., Bohn, R. L., Wahl, P. M., Avorn, J., Patrick, A. R., Liu, J., & Schneeweiss, S. (2010). Anticonvulsant medications and the risk of suicide, attempted suicide, or violent death. Jama, 303(14), 1401-1409.

24. Muench, J., & Hamer, A. M. (2010). Adverse effects of antipsychotic medications. Am Fam Physician, 81(5), 617-622.

25. Pietrangelo, A. (2016, November 07). About Anxiolytics. Retrieved October 09, 2017, from https://www.healthline.com/health/anxiolytics

26. Daviss, W. B. (2008). A review of co-morbid depression in pediatric ADHD: etiologies, phenomenology, and treatment. Journal of child and adolescent psychopharmacology, 18(6), 565-571.

27. Antidepressant Medication. Retrieved October 09, 2017, from https://www.helpguide.org/articles/depression/antidepressant-medication.htm

28. Cohen, J. S. (1990). Antidepressant drug side effects.

29. Martin, F., & Farnum, J. (2002). Animal-assisted therapy for children with pervasive developmental disorders. Western journal of nursing research, 24(6), 657-670.

30. Fine, A. H. (Ed.). (2010). Handbook on animal-assisted therapy: Theoretical foundations and guidelines for practice. Academic Press.

31. Foxx, R. M. (2008). Applied behavior analysis treatment of autism: The state of the art. Child and adolescent psychiatric clinics of North America, 17(4), 821-834.

32. Hastings, R. P. (2003). Behavioral adjustment of siblings of children with autism engaged in applied behavior analysis early intervention programs: The moderating role of social support. Journal of autism and developmental disorders, 33(2), 141-150.

33. Dawson, G., & Watling, R. (2000). Interventions to facilitate auditory, visual, and motor integration in autism: A review of the evidence. Journal of autism and developmental disorders, 30(5), 415-421.

34. Sinha, Y., Silove, N., Wheeler, D., & Williams, K. (2006). Auditory integration training and other sound therapies for autism spectrum disorders: a systematic review. Archives of disease in childhood, 91(12), 1018-1022.

35. Wood, J. J., Drahota, A., Sze, K., Har, K., Chiu, A., & Langer, D. A. (2009). Cognitive behavioral therapy for anxiety in children with autism spectrum disorders: A randomized, controlled trial. Journal of Child Psychology and Psychiatry, 50(3), 224-234.

36. Sukhodolsky, D. G., Bloch, M. H., Panza, K. E., & Reichow, B. (2013). Cognitive-behavioral therapy for anxiety in children with high-functioning autism: a meta-analysis. Pediatrics, 132(5), e1341-e1350.

37. Davlantis, K. S., Dawson, G., & Rogers, S. J. (2017). Treating Autism Spectrum Disorder with the Early Start Denver Model. Evidence-Based Psychotherapies for Children and Adolescents, 272.

38. Fulton, E., Eapen, V., Črnčec, R., Walter, A., & Rogers, S. (2014). Reducing maladaptive behaviors in preschool-aged children with autism spectrum disorder using the Early Start Denver Model. Frontiers in pediatrics, 2.

39. Hess, E. B. (2015). DIR®/Floortime™: A Developmental/Relational Play Therapy Approach Toward the Treatment of Children With Developmental Delays, Including Autism

Spectrum Disorder (ASD) and Sensory Processing Challenges. Handbook of Play Therapy, 357-379.

40. Mercer, J. (2017). Examining DIR/Floortime™ as a treatment for children with autism 625-635.

41. Lee, M. S., Lee, J. A., Park, T. Y., & Shin, B. C. (2014). Autism spectrum disorders and massage therapy. In Comprehensive guide to autism (pp. 2233-2245). Springer New York.

42. Field, T. (2014). Massage therapy research review. Complementary therapies in clinical practice, 20(4), 224-229.

43. Ichinose, T., Takehara, N., Matsumoto, K., Aoki, T., Yoshizato, T., Okuno, R., & Akazawa, K. (2016). Development of a System Combining a New Musical Instrument and Kinect: Application to Music Therapy for Children with Autism Spectrum Disorders.

44. Perez, T., Barnes, I., Sosa, M., Rodriguez, M., & Tourgeman, I. (2017). B-20the Effect of Music Therapy on the Mirror Neuron System in Children with Autism Spectrum Disorder: A Systematic Literature Review. Archives of Clinical Neuropsychology, 32(6), 667-765.

45. Tomchek, S. D., & Koenig, K. P. (2016). Occupational therapy practice guidelines for individuals with autism spectrum disorder. AOTA Press, The American Occupational Therapy Association, Incorporated.

46. Ashburner, J., Rodger, S., Ziviani, J., & Jones, J. (2014). Occupational therapy services for people with autism spectrum disorders: Current state of play, use of evidence and future learning priorities. Australian occupational therapy journal, 61(2), 110-120.

47. Srinivasan, S. M., Pescatello, L. S., & Bhat, A. N. (2014). Current perspectives on physical activity and exercise recommendations for children and adolescents with autism spectrum disorders. Physical therapy, 94(6), 875-889.

48. Colebourn, J. A., Golub-Victor, A. C., & Paez, A. (2017). Developing Overhand Throwing Skills for a Child With Autism With a Collaborative Approach in School-Based Therapy. Pediatric Physical Therapy, 29(3), 262-269.

49. Hill, D. A., & Flores, M. M. (2014). Comparing the Picture Exchange Communication System and the iPad (TM) for Communication of Students with Autism Spectrum Disorder and Developmental Delay. TechTrends, 58(3), 45.

50. Cooper, L. (2017). Using the Picture Exchange Communication System with families of children with autism. Learning Disability Practice, 20(4), 22-25.

51. Koegel, R. L., & Kern Koegel, L. (2006). Pivotal Response Treatments for Autism: Communication, Social, and Academic Development. Brookes Publishing Company. PO Box 10624, Baltimore, MD 21285.

52. Steiner, A. M., Gengoux, G. W., Klin, A., & Chawarska, K. (2013). Pivotal response treatment for infants at-risk for autism spectrum disorders: A pilot study. Journal of autism and developmental disorders, 43(1), 91-102.

53. Tostanoski, A., Lang, R., Raulston, T., Carnett, A., & Davis, T. (2014). Voices from the past: Comparing the rapid prompting method and facilitated communication. Developmental Neurorehabilitation, 17(4), 219-223.

54. Ochs, E., & Solomon, O. (2010). Autistic sociality. Ethos, 38(1), 69-92.

55. Gutstein, S., & Sheely, R. K. (2002). Relationship development intervention with children, adolescents and adults: Social and emotional development activities for Asperger syndrome, autism, PDD and NLD. Jessica Kingsley Publishers.

56. Gutstein, S. E., Burgess, A. F., & Montfort, K. (2007). Evaluation of the relationship development intervention program. Autism, 11(5), 397-411.

57. Ricks, D. J., & Colton, M. B. (2010, May). Trends and considerations in robot-assisted autism therapy. In Robotics and Automation (ICRA), 2010 IEEE International Conference on (pp. 4354-4359). IEEE.

58. Ferrari, E., Robins, B., & Dautenhahn, K. (2009, September). Therapeutic and educational objectives in robot assisted play for children with autism. In Robot and Human Interactive

Communication, 2009. RO-MAN 2009. The 18th IEEE International Symposium on (pp. 108-114). IEEE.

59. Lang, R., O'Reilly, M., Healy, O., Rispoli, M., Lydon, H., Streusand, W., & Didden, R. (2012). Sensory integration therapy for autism spectrum disorders: A systematic review. Research in Autism Spectrum Disorders, 6(3), 1004-1018.

60. Pfeiffer, B. A., Koenig, K., Kinnealey, M., Sheppard, M., & Henderson, L. (2011). Effectiveness of sensory integration interventions in children with autism spectrum disorders: A pilot study. American Journal of Occupational Therapy, 65(1), 76-85.

61. Rao, P. A., Beidel, D. C., & Murray, M. J. (2008). Social skills interventions for children with Asperger's syndrome or high-functioning autism: A review and recommendations. Journal of autism and developmental disorders, 38(2), 353-361.

62. Bellini, S., Peters, J. K., Benner, L., & Hopf, A. (2007). A meta-analysis of school-based social skills interventions for children with autism spectrum disorders. Remedial and Special Education, 28(3), 153-162.

63. Adams, C., Lockton, E., Freed, J., Gaile, J., Earl, G., McBean, K., & Law, J. (2012). The Social Communication Intervention Project: a randomized controlled trial of the effectiveness of speech and language therapy for school-age children who have pragmatic and social communication problems with or without autism spectrum disorder. International Journal of Language & Communication Disorders, 47(3), 233-244.

64. Koegel, R. L., O'dell, M. C., & Koegel, L. K. (1987). A natural language teaching paradigm for nonverbal autistic children. Journal of autism and developmental disorders, 17(2), 187-200.

65. Schopler, E., & Van Bourgondien, M. E. (1991). Treatment and education of autistic and related communication handicapped children. Autistic adults at Bittersweet Farms, 1, 85.

66. Mesibov, G. B., Shea, V., & Schopler, E. (2005). The TEACCH approach to autism spectrum disorders. Springer Science & Business Media.

67. Sundberg, M. L., & Michael, J. (2001). The benefits of Skinner's analysis of verbal behavior for children with autism. Behavior Modification, 25(5), 698-724.

68. Sutter, N. B., Bustamante, C. D., Chase, K., Gray, M. M., Zhao, K., Zhu, L., & Quignon, P. (2007). A single IGF1 allele is a major determinant of small size in dogs. Science, 316(5821), 112-115.

69. Jorgenson, J. (1997). Therapeutic use of companion animals in health care. Journal of Nursing Scholarship, 29(3), 249-254.

70. All, A. C., Loving, G. L., & Crane, L. L. (1999). Animals, horseback riding, and implications for rehabilitation therapy. Journal of Rehabilitation, 65(3), 49.

71. Beetz, A., Uvnäs-Moberg, K., Julius, H., & Kotrschal, K. (2012). Psychosocial and psychophysiological effects of human-animal interactions: the possible role of oxytocin. Frontiers in psychology, 3.

72. Fine, A. H. (Ed.). (2010). Handbook on animal-assisted therapy: Theoretical foundations and guidelines for practice. Academic Press.

73. All, A. C., Loving, G. L., & Crane, L. L. (1999). Animals, horseback riding, and implications for rehabilitation therapy. Journal of Rehabilitation, 65(3), 49.

74. Perelle, I. B., & Granville, D. A. (1993). Assessment of the effectiveness of a pet facilitated therapy program in a nursing home setting. *Society & Animals*, *1*(1), 91-100.

75. Rice, S. S., Brown, L. T., & Caldwell, H. S. (1973). Animals and psychotherapy: A survey. Journal of community psychology, 1(3), 323-326.

76. Holcomb, R., & Meacham, M. (1989). Effectiveness of an animal-assisted therapy program in an inpatient psychiatric unit. Anthrozoös, 2(4), 259-264.

77. Draper, R. J., Gerber, G. J., & Layng, E. M. (1990). Defining the role of pet animals in psychotherapy. Psychiatric journal of the University of Ottawa: Revue de psychiatrie de l'Universite d'Ottawa, 15(3), 169-172.

78. Davis, J. H. (1988). Animal-facilitated therapy in stress mediation. Holistic Nursing Practice, 2(3), 75-83.

79. Barker, S. B., & Dawson, K. S. (1998). The effects of animal-assisted therapy on anxiety ratings of hospitalized psychiatric patients. Psychiatric services, 49(6), 797-801.

80. Marr, C. A., French, L., Thompson, D., Drum, L., Greening, G., Mormon, J., & Hughes, C. W. (2000). Animal-assisted therapy in psychiatric rehabilitation. Anthrozoös, 13(1), 43-47.

81. Hines, L., & Fredrickson, M. (1998). Perspectives on animal assisted activities and therapy. Companion animals in human health, 23-29.

82. Chandler, C. K. (2017). Animal-assisted therapy in counseling. Taylor & Francis.

83. Menna, L. F., Santaniello, A., Gerardi, F., Di Maggio, A., & Milan, G. (2016). Evaluation of the efficacy of animal-assisted therapy based on the reality orientation therapy protocol in Alzheimer's disease patients: a pilot study. Psychogeriatrics, 16(4), 240-246.

84. Hoagwood, K. E., Acri, M., Morrissey, M., & Peth-Pierce, R. (2017). Animal-assisted therapies for youth with or at risk for mental health problems: A systematic review. Applied Developmental Science, 21(1), 1-13.

85. Maujean, A., Pepping, C. A., & Kendall, E. (2015). A systematic review of randomized controlled trials of animal-assisted therapy on psychosocial outcomes. Anthrozoös, 28(1), 23-36.

86. Chu, C. I., Liu, C. Y., Sun, C. T., & Lin, J. (2009). The effect of animal-assisted activity on inpatients with schizophrenia. Journal of psychosocial nursing and mental health services, 47(12), 42-48.

87. Berget, B., & Braastad, B. O. (2011). Animal-assisted therapy with farm animals for persons with psychiatric disorders. Annali dell'Istituto superiore di sanita, 47(4), 384-390.

88. Berget, B., Ekeberg, Ø. & Braastad, B. O. (2008). Animal-assisted therapy with farm animals for persons with psychiatric disorders: effects on self-efficacy, coping ability and

quality of life, a randomized controlled trial. Clinical practice and epidemiology in mental health, 4(1), 9.

89. Marr, C. A., French, L., Thompson, D., Drum, L., Greening, G., Mormon, J., & Hughes, C. W. (2000). Animal-assisted therapy in psychiatric rehabilitation. Anthrozoös, 13(1), 43-47.

90. Nepps, P., Stewart, C. N., & Bruckno, S. R. (2014). Animal-assisted activity: Effects of a complementary intervention program on psychological and physiological variables. Journal of evidence-based complementary & alternative medicine, 19(3), 211-215.

91. Barker, S. B., & Dawson, K. S. (1998). The effects of animal-assisted therapy on anxiety ratings of hospitalized psychiatric patients. Psychiatric services, 49(6), 797-801.

92. Wolff, A. I., & Frishman, W. H. (2004, December). Animal-assisted therapy in cardiovascular disease. In Seminars in Integrative Medicine (Vol. 2, No. 4, pp. 131-134). WB Saunders.

93. Cole, K. M., Gawlinski, A., Steers, N., & Kotlerman, J. (2007). Animal-assisted therapy in patients hospitalized with heart failure. American Journal of Critical Care, 16(6), 575-585.

94. Gustafson, L. (1996). What is dementia?. Acta Neurologica Scandinavica, 94(s168), 22-24.

95. Olsen, C., Pedersen, I., Bergland, A., Enders-Slegers, M. J., & Ihlebæk, C. (2016). Engagement in elderly persons with dementia attending animal-assisted group activity. Dementia, 1471301216667320.

96. Motomura, N., Yagi, T., & Ohyama, H. (2004). Animal assisted therapy for people with dementia. Psychogeriatrics, 4(2), 40-42.

97. Richeson, N. E. (2003). Effects of animal-assisted therapy on agitated behaviors and social interactions of older adults with dementia. American Journal of Alzheimer's Disease & Other Dementias®, 18(6), 353-358.

98. Olsen, C., Pedersen, I., Bergland, A., Enders-Slegers, M. J., & Ihlebæk, C. (2016). Effect of animal-assisted activity on balance and quality of life in home-dwelling persons with dementia. Geriatric nursing, 37(4), 284-291.

99. Filan, S. L., & Llewellyn-Jones, R. H. (2006). Animal-assisted therapy for dementia: a review of the literature. International Psychogeriatrics, 18(4), 597-611.

100. McCabe, B. W., Baun, M. M., Speich, D., & Agrawal, S. (2002). Resident dog in the Alzheimer's special care unit. Western journal of nursing research, 24(6), 684-696.

101. Alzheimer's Association. (2013). 2013 Alzheimer's disease facts and figures. Alzheimer's & dementia, 9(2), 208-245.

102. Menna, L. F., Santaniello, A., Gerardi, F., Di Maggio, A., & Milan, G. (2016). Evaluation of the efficacy of animal-assisted therapy based on the reality orientation therapy protocol in Alzheimer's disease patients: a pilot study. Psychogeriatrics, 16(4), 240-246.

103. Mossello, E., Ridolfi, A., Mello, A. M., Lorenzini, G., Mugnai, F., Piccini, C., ... & Marchionni, N. (2011). Animal-assisted activity and emotional status of patients with Alzheimer's disease in day care. International psychogeriatrics, 23(6), 899-905.

104. Edwards, N. E., & Beck, A. M. (2002). Animal-assisted therapy and nutrition in Alzheimer's disease. Western journal of nursing research, 24(6), 697-712.

105. McCabe, B. W., Baun, M. M., Speich, D., & Agrawal, S. (2002). Resident dog in the Alzheimer's special care unit. Western journal of nursing research, 24(6), 684-696.

106. Baun, M. M., & McCabe, B. W. (2003). Companion animals and persons with dementia of the Alzheimer's type: Therapeutic possibilities. American Behavioral Scientist, 47(1), 42-51.

107. Ageing and health. (n.d.). Retrieved October 09, 2017, from http://who.int/mediacentre/factsheets/fs404/en/

108. Banks, M. R., & Banks, W. A. (2002). The effects of animal-assisted therapy on loneliness in an elderly population in long-term care facilities. The journals of gerontology series A: biological sciences and medical sciences, 57(7), M428-M432.

109. Moretti, F., De Ronchi, D., Bernabei, V., Marchetti, L., Ferrari, B., Forlani, C., & Atti, A. R. (2011). Pet therapy in elderly patients with mental illness. Psychogeriatrics, 11(2), 125-129.

110. Colombo, G., Buono, M. D., Smania, K., Raviola, R., & De Leo, D. (2006). Pet therapy and institutionalized elderly: A study on 144 cognitively unimpaired subjects. Archives of gerontology and geriatrics, 42(2), 207-216.

111. Le Roux, M. C., & Kemp, R. (2009). Effect of a companion dog on depression and anxiety levels of elderly residents in a long-term care facility. Psychogeriatrics, 9(1), 23-26.

112. Virués-Ortega, J., Pastor-Barriuso, R., Castellote, J. M., Población, A., & de Pedro-Cuesta, J. (2012). Effect of animal-assisted therapy on the psychological and functional status of elderly populations and patients with psychiatric disorders: a meta-analysis. Health Psychology Review, 6(2), 197-221.

113. Deyoe, J. R. (1913). Atypical organization and connectivity of the inferior frontal gyrus in children with autism spectrum disorders: an fcMRI study (Doctoral dissertation, Sciences).

114. American Psychiatric Association. (1980). Diagnostic and statistical manual, 3rd edn (DSM-III). American Psychiatric Association, Washington.

115. Autism Spectrum Disorder (ASD). (2016, July 11). Retrieved October 09, 2017, from https://www.cdc.gov/ncbddd/autism/data.html

116. Taylor, N. (2016). Associations between sensory issues, mealtime behaviours, and food and nutrient intakes in children with Autism Spectrum Disorder: a thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Human Nutrition and Dietetics at Massey University, Albany, New Zealand (Doctoral dissertation, Massey University).

117. Emerson, N. D., Morrell, H. E., & Neece, C. (2016). Predictors of age of diagnosis for children with autism spectrum disorder: The role of a consistent source of medical care, race, and condition severity. Journal of autism and developmental disorders, 46(1), 127-138.

118. Esbensen, A. J., Greenberg, J. S., Seltzer, M. M., & Aman, M. G. (2009). A longitudinal investigation of psychotropic and non-psychotropic medication use among adolescents and

adults with autism spectrum disorders. Journal of autism and developmental disorders, 39(9), 1339-1349.

119. FDA Dictates Suicide Ideation Warning for Antiepileptics Used for Bipolar Disorder. (n.d.). Retrieved October 09, 2017, from http://www.psychiatrictimes.com/articles/fda-dictates-suicide-ideation-warning-antiepileptics-used-bipolar-disorder

120. Grimsley, S. R., & Jann, M. W. (1992). Paroxetine, sertraline, and fluvoxamine: new selective serotonin reuptake inhibitors. Clinical pharmacy, 11(11), 930-957.

121. Posey, D. J., Stigler, K. A., Erickson, C. A., & McDougle, C. J. (2008). Antipsychotics in the treatment of autism. The Journal of clinical investigation, 118(1), 6.

122. Kolevzon, A., Mathewson, K. A., & Hollander, E. (2006). Selective serotonin reuptake inhibitors in autism: a review of efficacy and tolerability. The Journal of clinical psychiatry, 67(3), 407-414.

123. Autism Spectrum Disorder (ASD). (2015, February 24). Retrieved October 09, 2017, from https://www.cdc.gov/ncbddd/autism/treatment.html

124. Funahashi, A., Gruebler, A., Aoki, T., Kadone, H., & Suzuki, K. (2014). Brief report: the smiles of a child with autism spectrum disorder during an animal-assisted activity may facilitate social positive behaviors—quantitative analysis with smile-detecting interface. Journal of autism and developmental disorders, 44(3), 685-693.

125. Berry, A., Borgi, M., Francia, N., Alleva, E., & Cirulli, F. (2013). Use of assistance and therapy dogs for children with autism spectrum disorders: A critical review of the current evidence. The journal of alternative and complementary medicine, 19(2), 73-80.

126. Mapes, A. R., & Rosén, L. A. (2016). Equine-Assisted Therapy for Children with Autism Spectrum Disorder: a Comprehensive Literature Review. Review Journal of Autism and Developmental Disorders, 3(4), 377-386.

127. Nathanson, D. E., de Castro, D., Friend, H., & McMahon, M. (1997). Effectiveness of short-term dolphin-assisted therapy for children with severe disabilities. Anthrozoös, 10(2-3), 90-100.

128. Smith, B. P., & Dale, A. A. (2016). Integrating animals in the classroom: The attitudes and experiences of Australian school teachers toward animal-assisted interventions for children with Autism Spectrum Disorder. Pet Behaviour Science, (1), 13-22.

129. Chandler, C. K. (2017). Animal-assisted therapy in counseling. Taylor & Francis.

130. Waltner-Toews, D. (1993). Zoonotic disease concerns in animal-assisted therapy and animal visitation programs. The Canadian Veterinary Journal, 34(9), 549.

131. Cole, M., & Howard, M. (2013). Animal-assisted therapy: Benefits and challenges. In Biotherapy-History, Principles and Practice (pp. 233-253). Springer Netherlands.

132. Farm Animal Diseases. (n.d.). Retrieved October 09, 2017, from https://www.nal.usda.gov/awic/farm-animal-diseases

133. Chandler, C. K. (2005). Animal assisted therapy in counseling.

134. Bharatharaj, J., Huang, L., & Al-Jumaily, A. (2015, December). Bio-inspired therapeutic pet robots: Review and future direction. In Information, Communications and Signal Processing (ICICS), 2015 10th International Conference on (pp. 1-5). IEEE.

135. Alemi, M., Meghdari, A., Ghanbarzadeh, A., Moghadam, L. J., & Ghanbarzadeh, A. (2014, October). Impact of a social humanoid robot as a therapy assistant in children cancer treatment. In International Conference on Social Robotics (pp. 11-22). Springer, Cham.

136. López Recio, D., Márquez Segura, E., Márquez Segura, L., & Waern, A. (2013, March). The NAO models for the elderly. In Proceedings of the 8th ACM/IEEE international conference on Human-robot interaction (pp. 187-188). IEEE Press.

137. Vital, J. P., Couceiro, M. S., Rodrigues, N. M., Figueiredo, C. M., & Ferreira, N. M. (2013, May). Fostering the NAO platform as an elderly care robot. In Serious Games and

Applications for Health (SeGAH), 2013 IEEE 2nd International Conference on (pp. 1-5). IEEE.

138. Martín, F., Agüero, C. E., Cañas, J. M., Valenti, M., & Martínez-Martín, P. (2013). Robotherapy with dementia patients. International Journal of Advanced Robotic Systems, 10(1), 10.

139. Tapus, A., Peca, A., Aly, A., Pop, C., Jisa, L., Pintea, S., & David, D. O. (2012). Children with autism social engagement in interaction with Nao, an imitative robot: A series of single case experiments. Interaction studies, 13(3), 315-347.

140. Ismail, L. I., Shamsudin, S., Yussof, H., Hanapiah, F. A., & Zahari, N. I. (2012). Robot-based intervention program for autistic children with humanoid robot nao: Initial response in stereotyped behavior. Procedia Engineering, 41, 1441-1447.

141. Salvador, M. J., Silver, S., & Mahoor, M. H. (2015, May). An emotion recognition comparative study of autistic and typically-developing children using the zeno robot. In Robotics and Automation (ICRA), 2015 IEEE International Conference on (pp. 6128-6133). IEEE.

142. Torres, N. A., Clark, N., Ranatunga, I., & Popa, D. (2012, June). Implementation of interactive arm playback behaviors of social robot Zeno for autism spectrum disorder therapy. In Proceedings of the 5th International Conference on PErvasive Technologies Related to Assistive Environments (p. 21). ACM.

143. Wainer, J., Robins, B., Amirabdollahian, F., & Dautenhahn, K. (2014). Using the humanoid robot KASPAR to autonomously play triadic games and facilitate collaborative play among children with autism. IEEE Transactions on Autonomous Mental Development, 6(3), 183-199.

144. Wainer, J., Dautenhahn, K., Robins, B., & Amirabdollahian, F. (2010, December). Collaborating with Kaspar: Using an autonomous humanoid robot to foster cooperative

dyadic play among children with autism. In Humanoid Robots (Humanoids), 2010 10th IEEE-RAS International Conference on (pp. 631-638). IEEE.

145. Kanamori, M., Suzuki, M., & Tanaka, M. (2002). Maintenance and improvement of quality of life among elderly patients using a pet-type robot. Nihon Ronen Igakkai zasshi. Japanese journal of geriatrics, 39(2), 214-218.

146. Weiss, A., Wurhofer, D., & Tscheligi, M. (2009). "I love this dog"—children's emotional attachment to the robotic dog AIBO. International Journal of Social Robotics, 1(3), 243-248.

147. Melson, G. F., Kahn Jr, P. H., Beck, A. M., Friedman, B., Roberts, T., & Garrett, E. (2005, April). Robots as dogs?: children's interactions with the robotic dog AIBO and a live australian shepherd. In CHI'05 extended abstracts on Human factors in computing systems (pp. 1649-1652). ACM.

148. Tamura, T., Yonemitsu, S., Itoh, A., Oikawa, D., Kawakami, A., Higashi, Y., ... & Nakajima, K. (2004). Is an entertainment robot useful in the care of elderly people with severe dementia?. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 59(1), M83-M85.

149. Jaichandar, K. S., Elara, M. R., & García, E. A. M. (2012, July). Investigation of facial infrared thermography during interaction with therapeutic pet robot during cognitive training: A quantitative approach. In Proceedings of the 6th International Conference on Rehabilitation Engineering & Assistive Technology (p. 28). Singapore Therapeutic, Assistive & Rehabilitative Technologies (START) Centre.

150. Sheba, J. K., Mohan, R. E., & García, E. A. M. (2012, July). Easiness of acceptance metric for effective human robot interactions in therapeutic pet robots. In Industrial Electronics and Applications (ICIEA), 2012 7th IEEE Conference on (pp. 150-155). IEEE.

151. McGlynn, S. A., Kemple, S., Mitzner, T. L., King, C. H. A., & Rogers, W. A. (2017). Understanding the potential of PARO for healthy older adults. International Journal of Human-Computer Studies, 100, 33-47.

152. Sabanovic, S., Bennett, C. C., Chang, W. L., & Huber, L. (2013, June). PARO robot affects diverse interaction modalities in group sensory therapy for older adults with dementia. In Rehabilitation Robotics (ICORR), 2013 IEEE International Conference on (pp. 1-6). IEEE.

153. Wong, H. Y. A., & Zhong, Z. W. (2016, October). Assessment of robot training for social cognitive learning. In Control, Automation and Systems (ICCAS), 2016 16th International Conference on (pp. 893-898). IEEE.

154. Moyle, W., Jones, C., Sung, B., Bramble, M., O'Dwyer, S., Blumenstein, M., & Estivill-Castro, V. (2016). What effect does an animal robot called CuDDler have on the engagement and emotional response of older people with dementia? A pilot feasibility study. International Journal of Social Robotics, 8(1), 145-156.

155. Pop, C. A., Simut, R., Pintea, S., Saldien, J., Rusu, A., David, D., ... & Vanderborght, B. (2013). Can the social robot Probo help children with autism to identify situation-based emotions? A series of single case experiments. International Journal of Humanoid Robotics, 10(03), 1350025.

156. Simut, R. E., Vanderfaeillie, J., Peca, A., Van de Perre, G., & Vanderborght, B. (2016). Children with autism spectrum disorders make a fruit salad with Probo, the social robot: an interaction study. Journal of autism and developmental disorders, 46(1), 113-126.

157. Parrot. (2017, October 10). Retrieved October 11, 2017, from https://en.wikipedia.org/wiki/Parrot

158. West, M. J., & King, A. P. (1990). Mozart's starling. American Scientist, 78(2), 106-114.

159. Azhagar KillaiVidu Thoothu – 153-157. (2017, May 10). Retrieved October 09, 2017, from https://oldtamilpoetry.com/2017/05/10/azhagar-killaividu-thoothu-153-157/

160. Meenakshi Temple. (2017, October 08). Retrieved October 09, 2017, from https://en.wikipedia.org/wiki/Meenakshi_Temple

161. Grandgeorge, M., & Hausberger, M. (2011). Human-animal relationships: from daily life to animal-assisted therapies. Annali dell'Istituto superiore di sanità, 47(4), 397-408.

162. Pepperberg, I. M., & Pepperberg, I. M. (2009). The Alex studies: cognitive and communicative abilities of grey parrots. Harvard University Press.

163. Pepperberg, I. (2004). Talking with Alex: logic and speech in parrots; exploring intelligence. Scientific American Mind.

164. Siebert, C. (2016, January 28). What Does a Parrot Know About PTSD? Retrieved October 09, 2017, from https://www.nytimes.com/2016/01/31/magazine/what-does-a-parrot-know-about-ptsd.html

165. Parrots As Animal Assisted Therapy. (2013, October 07). Retrieved October 09, 2017, from http://www.forparrots.com/2013/09/07/parrots-as-animal-assisted-therapy/

166. Quinlan, S. Animal Assisted Therapy.

167. Barco, M. D. (2007, July 15). Parrots Used in PTSD Therapy for War Veterans. Retrieved October 09, 2017, from http://www.npr.org/templates/story/story.php?storyId=11989027

168. Haw, C. (2007). Parrots as therapy for psychiatric patients. The Psychiatrist, 31(4), 154-155.

169. Therapy Birds: "Emotional Support Animal? Or Merely A Pet? (n.d.). Retrieved October 09, 2017, from https://www.petcha.com/therapy-birds-emotional-support-animalor-merely-a-pet/

170. Parrots As Service Animals | Pet Birds by Lafeber Co. (2017, September 05). Retrieved October 09, 2017, from https://lafeber.com/pet-birds/parrots-service-animals/

171. Skloot, R., & SUBURB, O. H. N. I. A. (2008). Creature comforts. New York Times, 31.

172. Wilson, L. (2001). Biting and screaming behavior in parrots. Veterinary Clinics of North America: Exotic Animal Practice, 4(3), 641-650.

173. Vanrompay, D., Harkinezhad, T., Van de Walle, M., Beeckman, D., Van Droogenbroeck, C., Verminnen, K., & Cauwerts, K. (2007). Chlamydophila psittaci transmission from pet birds to humans. Emerging infectious diseases, 13(7), 1108.

174. Sutton, R. I., & Hargadon, A. (1996). Brainstorming groups in context: Effectiveness in a product design firm. Administrative Science Quarterly, 685-718.

175. Srinivasan, V., Lovejoy, W. S., & Beach, D. (1997). Integrated product design for marketability and manufacturing. Journal of Marketing Research, 154-163.

176. Miaskiewicz, T., & Kozar, K. A. (2011). Personas and user-centered design: How can personas benefit product design processes?. Design Studies, 32(5), 417-430.

177. Van Nes, N., & Cramer, J. (2005). Influencing product lifetime through product design. Business Strategy and the Environment, 14(5), 286-299.

178. Kudrowitz, B. M., & Wallace, D. (2013). Assessing the quality of ideas from prolific, early-stage product ideation. Journal of Engineering Design, 24(2), 120-139.

179. Brown, S. L., & Eisenhardt, K. M. (1995). Product development: Past research, present findings, and future directions. Academy of management review, 20(2), 343-378.

180. Briggs, C. L. (1986). Learning how to ask: A sociolinguistic appraisal of the role of the interview in social science research (Vol. 1). Cambridge University Press.

181. Hollway, W., & Jefferson, T. (2000). Doing qualitative research differently: Free association, narrative and the interview method. Sage.

182. Baxter, J., & Eyles, J. (1997). Evaluating qualitative research in social geography: establishing 'rigour'in interview analysis. Transactions of the Institute of British geographers, 22(4), 505-525.

183. Opdenakker, R. (2006, September). Advantages and disadvantages of four interview techniques in qualitative research. In Forum Qualitative Sozialforschung/Forum: Qualitative Social Research (Vol. 7, No. 4).

184. Gardial, S. F., Clemons, D. S., Woodruff, R. B., Schumann, D. W., & Burns, M. J. (1994). Comparing consumers' recall of prepurchase and postpurchase product evaluation experiences. Journal of Consumer Research, 20(4), 548-560.

185. Boyatzis, R. E. (1998). Transforming qualitative information: Thematic analysis and code development. Sage publications.

186. Smith, J., & Firth, J. (2011). Qualitative data analysis: the framework approach. Nurse researcher, 18(2), 52-62.

187. Scassellati, B., Admoni, H., & Matarić, M. (2012). Robots for use in autism research. Annual review of biomedical engineering, 14, 275-294.

188. Diehl, J. J., Schmitt, L. M., Villano, M., & Crowell, C. R. (2012). The clinical use of robots for individuals with autism spectrum disorders: A critical review. Research in autism spectrum disorders, 6(1), 249-262.

189. Leite, I., Martinho, C., & Paiva, A. (2013). Social robots for long-term interaction: a survey. International Journal of Social Robotics, 5(2), 291-308.

190. Colton, M. B., Ricks, D. J., Goodrich, M. A., Dariush, B., Fujimura, K., & Fujiki, M. (2009). Toward therapist-in-the-loop assistive robotics for children with autism and specific language impairment. In AISB new frontiers in human-robot interaction symposium (Vol. 24, p. 25).

191. Cabibihan, J. J., Javed, H., Ang, M., & Aljunied, S. M. (2013). Why robots? A survey on the roles and benefits of social robots in the therapy of children with autism. International journal of social robotics, 5(4), 593-618.

192. Wilson, W. M., Rosenberg, L. H., & Hyatt, L. E. (1997, May). Automated analysis of requirement specifications. In Proceedings of the 19th international conference on Software engineering (pp. 161-171). ACM.

193. Koh, H. C., & Tan, G. (2011). Data mining applications in healthcare. Journal of healthcare information management, 19(2), 65.

194. Yang, M. C., & Ji, H. (2007). A text-based analysis approach to representing the design selection process. In International Conference on Engineering Design, ICED'07.

195. Giret, N., Péron, F., Nagle, L., Kreutzer, M., & Bovet, D. (2009). Spontaneous categorization of vocal imitations in African grey parrots (Psittacus erithacus). Behavioural processes, 82(3), 244-248.

196. Aït-Mokhtar, S., & Sándor, Á. (2010). U.S. Patent Application No. 12/772,655.

197. Gilarska, M., & Kwinta, P. Temperament traits in 4-year-old children born prematurely– may they suggest a threat for mental functioning?

198. Wasserman, S., & Faust, K. (1994). Social network analysis: Methods and applications (Vol. 8). Cambridge university press.

199. Arkin, R. C., Fujita, M., Takagi, T., & Hasegawa, R. (2003). An ethological and emotional basis for human–robot interaction. Robotics and Autonomous Systems, 42(3), 191-201.

200. Kulic, D., & Croft, E. (2005, August). Anxiety detection during human-robot interaction. In Intelligent Robots and Systems, 2005 (IROS 2005). 2005 IEEE/RSJ International Conference on (pp. 616-621). IEEE.

201. Suzuki, K., Camurri, A., Ferrentino, P., & Hashimoto, S. (1998, October). Intelligent agent system for human-robot interaction through artificial emotion. In Systems, Man, and Cybernetics, 1998. 1998 IEEE International Conference on (Vol. 2, pp. 1055-1060). IEEE.

202. Emotion API Preview. Retrieved October 11, 2017, from https://azure.microsoft.com/en-us/services/cognitive-services/emotion/

203. Chen, L. S., Huang, T. S., Miyasato, T., & Nakatsu, R. (1998, April). Multimodal human emotion/expression recognition. In Automatic Face and Gesture Recognition, 1998. Proceedings. Third IEEE International Conference on (pp. 366-371). IEEE.

204. Wada, K., & Shibata, T. (2007). Living with seal robots—its sociopsychological and physiological influences on the elderly at a care house. IEEE Transactions on Robotics, 23(5), 972-980.

205. Phillips, N. (2016, October 03). 24-hour Urine Protein Test. Retrieved October 11, 2017, from https://www.healthline.com/health/24-hour-urine-protein#process3

206. Rohleder, N., Wolf, J. M., Maldonado, E. F., & Kirschbaum, C. (2006). The psychosocial stress-induced increase in salivary alpha-amylase is independent of saliva flow rate. Psychophysiology, 43(6), 645-652.

207. Backes, T. P., Horvath, P. J., & Kazial, K. A. (2015). Salivary alpha amylase and salivary cortisol response to fluid consumption in exercising athletes. Biology of sport, 32(4), 275.

208. Patel, M., & Wang, J. (2010). Applications, challenges, and prospective in emerging body area networking technologies. IEEE Wireless communications, 17(1).

209. Rady, M. Y., Rivers, E. P., & Nowak, R. M. (1996). Resuscitation of the critically III in the ED: responses of blood pressure, heart rate, shock index, central venous oxygen saturation, and lactate. The American journal of emergency medicine, 14(2), 218-225.

Appendices

Appendix A

Emic-2 Text-to-Speech Module is an unconstrained, multi-language voice synthesizer that converts a stream of digital text into natural sounding speech output. Using the universally recognized DECtalk text-to-speech synthesizer engine, Emic 2 provides full speech synthesis capabilities for any embedded system via a simple command-based interface.

Features

High-quality speech synthesis for English and Spanish languages

Nine pre-defined voice styles comprising male, female, and child

Dynamic control of speech and voice characteristics, including pitch, speaking rate, and word emphasis

Industry-standard DECtalk text-to-speech synthesizer engine (5.0.E1)

On-board audio power amplifier and 1/8” (3.5 mm) audio jack

Single row, 6-pin, 0.1” header for easy connection to a host system

Key Specifications

Power requirements: +5 VDC, 30 mA idle, 46-220 mA active (depending on speech parameters and output load)

Communication: asynchronous 9600 bps serial

Operating temperature: -20 to +70 °C (-4 to +158 °F)

Dimensions:1.25”Wx1.5”Lx0.37”H(3.17Wx3.81Lx0.94Hcm)

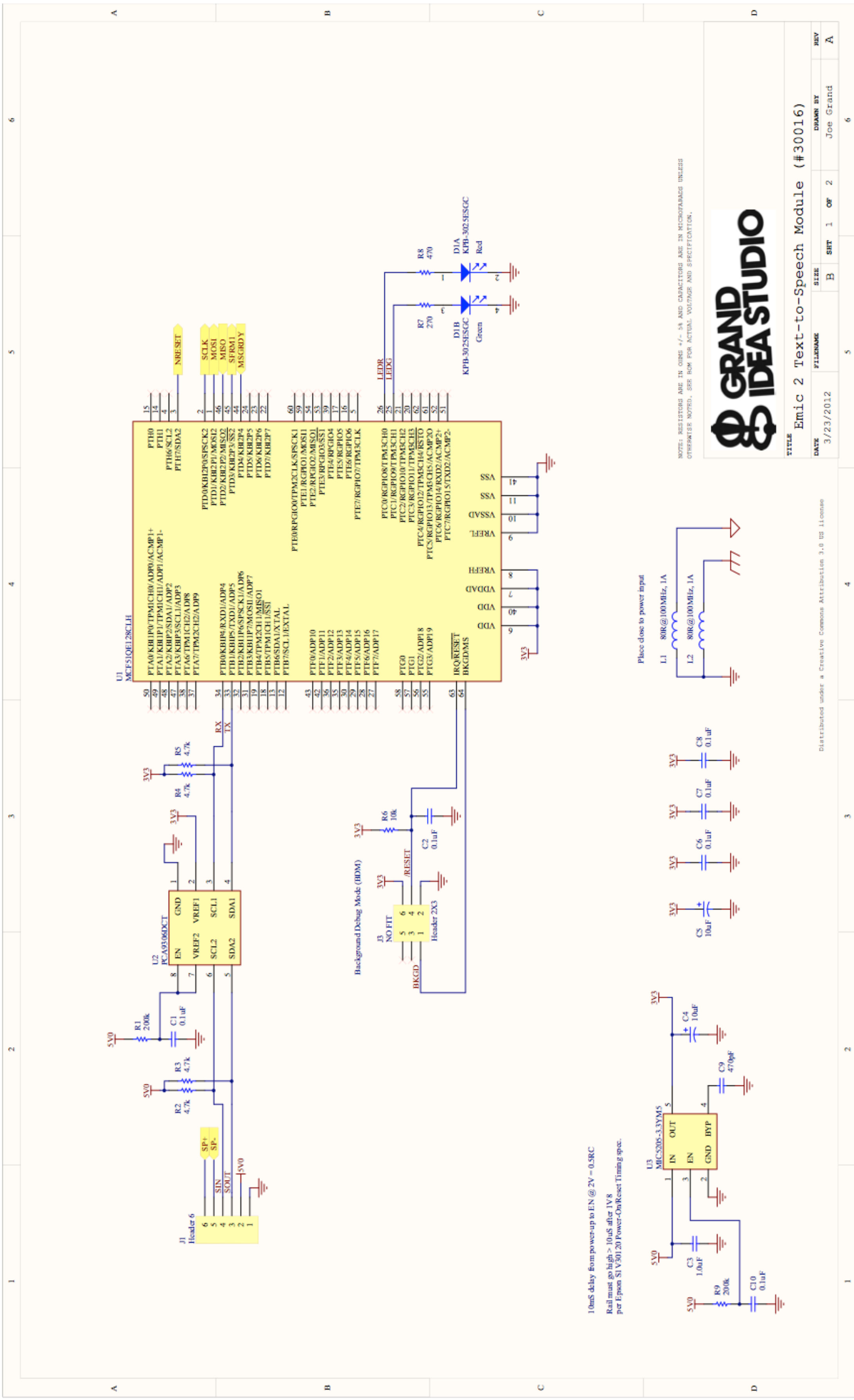


Figure 60 Emic-2 Circuit diagram

Connections

Emic 2 interfaces to a host microcontroller or computer system using only four connections (GND, 5V, SOUT, SIN). Additional connections (SP+, SP-) are available for direct interfacing to an 8Ω speaker. A 1/8" (3.5mm) audio jack provides a single-ended, monaural output for easy connection to headphones, amplified speakers, or other audio equipment.

Pin	Pin Name	Type	Function
1	GND	G	System ground. Connect to power supply's ground (GND) terminal.
2	5V	P	System power, 5 VDC input.
3	SOUT	O	Serial output to host. 5 V TTL-level interface, 9600 bps, 8 data bits, no parity, 1 stop bit, non-inverted.
4	SIN	I	Serial input from host. 3.3 V to 5 V TTL-level interface, 9600 bps, 8 data bits, no parity, 1 stop bit, non-inverted.
5	SP-	O	Differential audio amplifier output, bridge-tied load configuration, negative side. Connect directly to 8 Ω speaker.
6	SP+	O	Differential audio amplifier output, bridge-tied load configuration, positive side. Connect directly to 8 Ω speaker.

Type: I = Input, O = Output, P = Power, G = Ground

Status Indicator

A visual indication of Emic 2's operating state is given with the on-board light-emitting diode (LED):

1. Green: Idle state. Waiting for a valid command to be sent by the host.

2. Red: Active state. For example, during a text-to-speech conversion.

3. Orange (Solid): Initialization state. Occurs on power-up only. Emic 2 takes approximately three seconds to properly initialize on power-up before it is ready to receive commands.

4. Orange (Blinking): Error state. Emic 2 has malfunctioned due to an on-board communication error. If a power cycle of Emic 2 does not remedy the situation, please contact Parallax technical support for further assistance.

If the LED is OFF, Emic 2 may not be receiving power.

Command Set

All commands are ASCII-based printable characters and are not case-sensitive (upper case and lower case will both work). Each command must be terminated with a CR or LF.

Sx Convert text-to-speech: x = message (1023 characters maximum)

Dx Play demonstration message: x = 0 (Speaking), 1 (Singing), 2 (Spanish)

X Stop playback (while message is playing)

Z Pause/un-pause playback (while message is playing)

Nx Selectvoice:x=0to8

Vx Set audio volume (dB): x = -48 to 18

Wx Set speaking rate (words/minute): x = 75 to 600

Lx Select language: x = 0 (US English), 1 (Castilian Spanish), 2 (Latin Spanish) Px Select parser: x = 0 (DECtalk), 1 (Epson)

R Revert to default text-to-speech settings

C Print current text-to-speech settings

I Print version information

H Print list of available commands

Sample code:

```
/*
  Emic 2 Text-to-Speech Module: Basic Demonstration
  Author: Joe Grand [www.grandideastudio.com]
  Contact: support@parallax.com
  Program Description:
  This program provides a simple demonstration of the Emic 2 Text-to-
Speech
  Module. Please refer to the product manual for full details of system
  functionality and capabilities.
// include the SoftwareSerial library so we can use it to talk to the Emic 2
module
#include <SoftwareSerial.h>
#define rxPin 2    // Serial input (connects to Emic 2 SOUT)
#define txPin 3    // Serial output (connects to Emic 2 SIN)
#define ledPin 13  // Most Arduino boards have an on-board LED on this
pin
// set up a new serial port
SoftwareSerial emicSerial =  SoftwareSerial(rxPin, txPin);
void setup()  // Set up code called once on start-up
{
```

```
  // define pin modes
  pinMode(ledPin, OUTPUT);
  pinMode(rxPin, INPUT);
  pinMode(txPin, OUTPUT);
  // set the data rate for the SoftwareSerial port
  emicSerial.begin(9600);
  digitalWrite(ledPin, LOW);  // turn LED off
  /*
    When the Emic 2 powers on, it takes about 3 seconds for it to successfully
    intialize. It then sends a ":" character to indicate it's ready to accept
    commands. If the Emic 2 is already initialized, a CR will also cause it
    to send a ":"
  */
  emicSerial.print('\n');             // Send a CR in case the system is already up
  while (emicSerial.read() != ':');   // When the Emic 2 has initialized and is ready, it will send a single ':' character, so wait here until we receive it
  delay(10);                          // Short delay
  emicSerial.flush();                 // Flush the receive buffer
}
```

```
void loop()  // Main code, to run repeatedly
{
  // Speak some text
  emicSerial.print('S');
  emicSerial.print("Hello. My name is the Emic 2 Text-to-Speech module. I would like to sing you a song.");  // Send the desired string to convert to speech
  emicSerial.print('\n');
//   digitalWrite(ledPin, HIGH);              // Turn on LED while Emic is outputting audio
  while (emicSerial.read() != ':');   // Wait here until the Emic 2 responds with a ":" indicating it's ready to accept the next command
//  digitalWrite(ledPin, LOW);
  delay(500);   // 1/2 second delay
   emicSerial.print('S');
  emicSerial.print("Hello");  // Send the desired string to convert to speech
  emicSerial.print('\n');
//   digitalWrite(ledPin, HIGH);              // Turn on LED while Emic is outputting audio
  while (emicSerial.read() != ':');   // Wait here until the Emic 2 responds with a ":" indicating it's ready to accept the next command
//  digitalWrite(ledPin, LOW);
```

```
  delay(500);    // 1/2 second delay

  // Sing a song

//  emicSerial.print("D1\n");

//    digitalWrite(ledPin,  HIGH);                  // Turn on LED while Emic is
outputting audio

//  while (emicSerial.read() != ':');   // Wait here until the Emic 2 responds
with a ":" indicating it's ready to accept the next command

//  digitalWrite(ledPin, LOW);

//  while(1)      // Demonstration complete!

//  {

//    delay(500);

//    digitalWrite(ledPin, HIGH);

//    delay(500);

//    digitalWrite(ledPin, LOW);

//  }

}
```

Appendix B

EasyVR Shield

The EasyVR Shield 3 is an adapter board for the EasyVR 3 module, designed to simplify its use among the Arduino community.

The EasyVR 3 is a multi-purpose speech recognition module designed to easily add versatile, robust and cost effective speech recognition capabilities to almost any application.

The Shield is compatible with any Arduino board using UNO-R3 Shield headers, running at either 3.3V or 5V levels, by using the IOREF pin to select the EasyVR operating voltage.

EasyVR Shield 3 Features

Compatible with Arduino boards that have the 1.0 Shield interface (UNO R3) including, but not limited to:

Arduino Zero

Arduino Uno

Arduino Mega

Arduino Leonardo o Arduino Due

Supports 5V and 3.3V main boards through the IOREF pin (defaults to 5V if this pin is absent) Supports direct connection to the PC on main boards with a separate USB/Serial chip and a special software-driven "bridge mode" on boards with only native USB interface, for easy access and configuration with the EasyVR Commander

Enables different modes of serial connection and also flash updates to the embedded EasyVR module (through the Mode Jumper)

Supports remapping of serial pins used by the Shield (in SW mode)

Provides a 3.5mm audio output jack suitable for headphones or as a line out.

The EasyVR 3 module can be used with any host with an UART interface powered at 3.3V – 5V, such as PIC and Arduino boards. Some application examples include home automation, such as voice controlled light switches, locks, curtains or kitchen appliances, or adding "hearing" to the most popular robots on the market.

It can be easily plugged into a solder-less breadboard or standard prototyping board, and it is compatible with the mikroBUS™ specifications (see www.mikroe.com/mikrobus). Separate male headers are provided inside the package, along with a microphone cable assembly and speaker wires (loudspeaker not included).

Main Features

Up to 32 user-defined commands, sub-divided in up to 15 Speaker Dependent (SD) groups, 1 SD trigger and 1 Speaker Verification (SV) group of max 5 commands, that can be trained in ANY language [1].

A selection of 26 built-in Speaker Independent (SI) commands for ready-to-run basic controls, in the following languages:

English (US)

Italian

German

French

Spanish

Japanese

With the optional Quick T2SI Lite license, up to 28 custom Speaker Independent (SI) command vocabularies, with up to 12 commands each [2], for a total of 336 possible commands.

Supported languages:

US English

French

German

Italian

Japanese

Mandarin

Spanish

Please note: The Quick T2SI Lite license registration code is sold separately and is available for sale from your distributor or directly from us: please send an email to our sales if you are interested.

SonicNet™ technology for wireless communications between modules or any other sound source (Audio CD, DVD, MP3 Player).

Up to around 21 minutes of pre-recorded sounds or speech [3].

Up to about 120 seconds of live message recording and playback [4].

Real-time Lip-sync capability [5].

DTMF tone generation.

Differential audio output that directly supports 8Ω speakers.

Easy-to-use Graphical User Interface to program Voice Commands and audio.

Standard UART interface (powered at 3.3V – 5V).

Simple and robust documented serial protocol to access and program through the host board.

6 General purpose I/O lines that can be controlled via UART commands.

[1] SD/SV commands are entirely user-defined and they are intended to work only with the voice that trained them. SD only tries to match the trained words, while SV also tries to match the characteritics of the voice and to prevent use by unkown people (voice password).

[2] SI commands are meant to work with any people in the same language group and do not require training. A few pre-defined commands can be directly used, while additional commands can be created with a QuickT2SI™ Lite license (sold separately).

[3] At the maximum compression rate.

[4] Starting with firmware Revision 1.

[5] Starting with firmware Revision 4.

EasyVR Programming

Communication with the EasyVR module uses a standard UART interface compatible with 3.3-5V TTL/CMOS logical levels, according to the powering voltage VCC.

The initial configuration at power on is 9600 baud, 8 bit data, No parity, 1 bit stop. The baud rate can be changed later to operate in the range 9600 - 115200 baud.

The communication protocol only uses printable ASCII characters, which can be divided in two main groups:

Command and status characters, respectively on the TX and RX lines, chosen among lower-case letters.

Command arguments or status details, again on the TX and RX lines, spanning the range of capital letters.

Each command sent on the TX line, with zero or more additional argument bytes, receives an answer on the RX line in the form of a status byte followed by zero or more arguments.

Sample code:

```
#include <Herkulex.h>

#include <Wire.h>

#include <Adafruit_MotorShield.h>

#include "utility/Adafruit_MS_PWMServoDriver.h"

Adafruit_MotorShield AFMS = Adafruit_MotorShield();

Adafruit_DCMotor *myMotor1 = AFMS.getMotor(1);

Adafruit_DCMotor *myMotor2 = AFMS.getMotor(2);

Adafruit_DCMotor *myMotor3 = AFMS.getMotor(3);

void setup() {

  //Herkulex

  delay(2000);  //a delay to have time for serial monitor opening

//  Serial.begin(115200);    // Open serial communications
```

```
//  Serial.println("Begin");
  Herkulex.beginSerial1(115200); //open serial port 1
  Herkulex.reboot(2); //reboot first motor
  Herkulex.reboot(1); //reboot second motor
  delay(500);
  Herkulex.initialize(); //initialize motors
  delay (200);
  Serial.begin(9600); // Serial Communication With LapTop
//  Serial1.begin(9600); // Serila Communication with HC-06
  Serial.println("Adafruit Motorshield v2 - DC Motor test!");
  AFMS.begin();
  myMotor1->setSpeed(150);
  myMotor2->setSpeed(150);
  myMotor3->setSpeed(150);
 }
void loop() {
  if (Serial.available())
  {
    char i = Serial.read();
//    Serial.println(i);
```

```
Serial.print("Bluetooth char received is \t");

Serial.print(i);

Serial.println("");

switch (i)

{

 //DC MOTOR BACKWARD

 case 'F':

  {

   myMotor1->run(BACKWARD);

   myMotor2->run(FORWARD);

   myMotor3->run(BACKWARD);

   break;

  }

 // DC MOTOR OFF

 case 'S':

  {

   myMotor1->run(RELEASE);

   myMotor2->run(RELEASE);

   myMotor3->run(RELEASE);

   break;
```

```
 }
// DC MOTOR FORWARD
case 'M':
 {
  myMotor1->run(FORWARD);
  myMotor2->run(BACKWARD);
  myMotor3->run(FORWARD);
  break;
 }
case 's':
 {
  Serial.println("hello");
  Herkulex.moveSpeedOne(2, -500, 1000, LED_BLUE);
  Herkulex.moveSpeedOne(1,  -500, 1000, LED_BLUE);
  delay(1200);
  break;
 }
 case 'p':
  {
  Serial.println("hello");
```

```
  Herkulex.moveSpeedOne(2, 500, 1000, LED_BLUE);
  Herkulex.moveSpeedOne(1,  500, 1000, LED_BLUE);
  delay(1200);
  break;
 }
// Herkulex 2 upwards
case 'u':
 {
  Serial.println("hello");
  Herkulex.moveSpeedOne(2, 700, 1000, LED_BLUE);
  delay(1200);
  break;
 }
// Herkulex 2 downwards
case 'd':
 {
  Serial.println("hello");
  Herkulex.moveSpeedOne(2, -700, 1000, LED_BLUE);
  //delay(1200);
  break;
```

```
 }
 // Herkulex 1 upwards
case 'l':
 {
   Serial.println("hello");
   Herkulex.moveSpeedOne(1, 700, 1000, LED_BLUE);
   //delay(1200);
   break;
 }
// Herkulex 1 downwards
case'r':
 {
   Serial.println("hello");
   Herkulex.moveSpeedOne(1, -700, 1000, LED_BLUE);
   //delay(1200);
 }
case 'T':
 {
   Serial.println("hello");
   Herkulex.moveSpeedOne(2, 0, 1000, LED_BLUE);
```

```
Herkulex.moveSpeedOne(1,  0, 1000, LED_BLUE);

//delay(1200);

break; }}}}
```

Appendix C

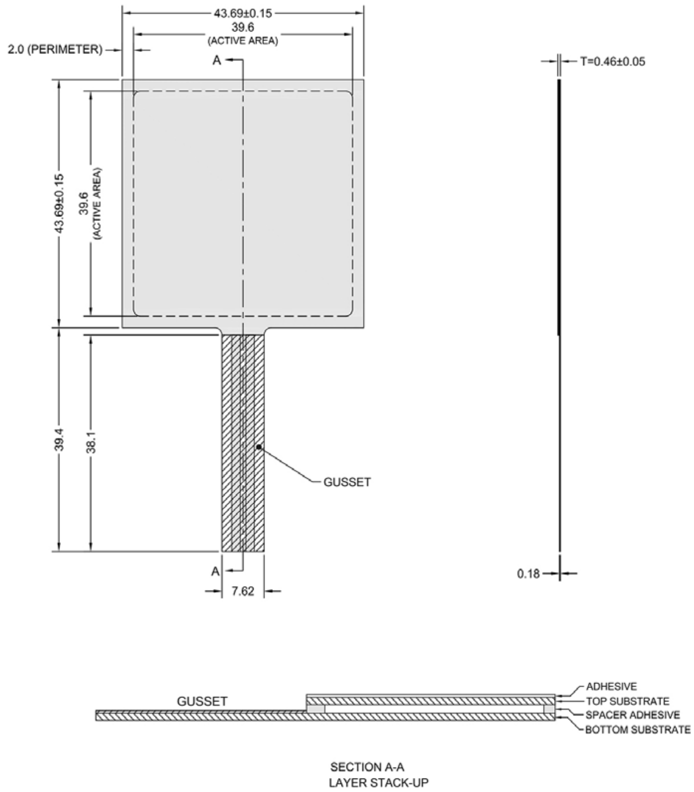
Force Sensing Resistors

Reference: www.interlinkelectronics.com

Description

Interlink Electronics FSR® 400 Series is part of the single zone Force Sensing Resistor® family. Force Sensing Resistors, or FSR's, are robust polymer thick film (PTF) devices that exhibit a decrease in resistance with increase in force applied to the surface of the sensor. This force sensitivity is optimized for use in human machine interface devices including automotive electronics, medical systems, industrial controls and robotics.

Actuation Force	~0.2N min
Force Sensitivity Range*	~0.2N – 20N
Force Resolution	Continuous (analog)
Force Repeatability Single Part	+/- 2%
Force Repeatability Part to Part	+/- 6% (Single Batch)
Non-Actuated Resistance	>10 Mohms
Hysteresis	+10% Average (RF+ - RF-)/RF+
Device Rise Time	< 3 Microseconds
Operating Temperature Performance	
Cold: 40oC after 1 hour	-5% average resistance change -15%
Hot: +85oC after 1 hour	average resistance change +10% average
Hot Humid: +85oC 95RH after 1 hour	resistance change



Exploded View

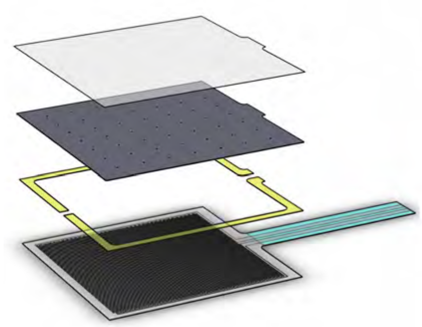


Figure 61 Touch sensor – Exploded View

Appendix D

User study pictures

Figure 62 User study picture

Figure 63 User study picture

Figure 64 User study picture

Figure 65 User study picture

Figure 66 User study picture

Figure 67 User study picture

Figure 68 User study picture

Figure 69 User study picture

Figure 70 User study picture

Figure 71 User study picture

Figure 72 User study picture

Figure 73 User study picture

Figure 74 User study picture