

Development of a Wireless Friendly Fire Prevention System Model

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Abstract

While hunting animals is not considered the most ethical of activities, it is in most regions of the world considered sport, and in some locations still a process of food gathering. The focus of this research is on the accidental shooting of hunters by hunters. The hunting accident is an all too common event experienced throughout the world since mankind first hunted for a meal with a ranged weapon.

Now with the use of wireless technology an electronic safeguard system can be designed that will aid in preventing hunting accidents. This thesis will present a method of friendly fire prevention and will attempt to test this concept as a viable solution to the problem.

The concept presented here investigates into the use of location based systems combined with directional data acquisition systems, integrated with a networking ability to pass data between sensor interfacing clones of itself. The principle of the concept is to use both the sensor and networked data acquired to conclude on a possible dangerous shot situation and hence gaining the ability to alert the hunter who's aim is causing the dangerous situation.

This project is composed of the generation of a modelling application that is used to generate dangerous shooting situations between simulated hunters and to test the concept friendly fire prevention method desired. Further more this project contains the development of a physical prototype with contained embedded code written to simulate sections of the desired friendly fire prevention method. This prototype system has the chosen sensors individually tested to show the level and quality of data available to the intelligence of the prototype. This intelligence is in turn tested as a completed example of the concept functioning.

Results from the model will show that even a simple system can provide up to 17% protection coverage from all dangerous shots up to 1000m. Other specific results generated indicated that approximately 25% of hunters mistakenly targeted due to vegetation up to a range of 500m could be saved using this friendly fire prevention method.

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1. Introduction

The problem of friendly fire within hunting is costing the lives of many people across the world. This first chapter on the path to development of a friendly fire prevention system and modelling tool investigates the background on the issue at hand. First the focus is on the definition of the problem, the surrounding issues, and influential factors. This chapter presents the flow and contents of the thesis. Finally research is put forward into current systems as well as alternate research investigating effecting factors sounding the issue of friendly fire within the sport of hunting.

1.1 Research Problem Definition

Hunting has always been part of our existence as human beings. As we have evolved to exist in this world we have developed tools and weapons. It could be said that the first projectile weapon would be something as simple as a thrown spear however proof of bows and arrows have been found dating back thousands of years. It is not an implausible statement to say that as long as humankind has hunted expectedly there would have been hunting accidents. From these origins of a thrown spear and simple bow and arrows, projectile weapons have evolved over the centuries of war and hunting through stages of shotguns, rifles and into all the other branches of what is the modern day gun. It could be stated that along with the development of these new more dangerous guns, more dangerous and unpredictable accidents have been produced, specifically during what is now considered a sport called hunting.

To be specific there are a number of ways in which a hunter can be accidentally shot while hunting. To put aside such incidents as poor gun handling and blatant disregard for firearm regulation, there still exists an all too common problem of shooting at a miss identified target. This simply means a hunter shoots another hunter while thinking he or she is a target animal. Intentionally shooting at a hunter presumed to be an animal when concealed in vegetation is usually one of the most fatal shooting accidents that can occur. This is not an isolated problem with many hunters losing their life every year, many of them young and inexperienced hunters simply being in the wrong place at the wrong time.

Today the human race has advanced in tools and technology so that it is becoming possible to use this technology to prevent or reduce such shooting accidents. The development of smart weapons that can aid with this problem, can now start to be investigated and developed. This technology would specifically aim at preventing shoots at other people. The concept of creating an entire smart weapon is beyond the scope of this thesis however a simple electronic attachment can be simulated and tested that can aid in preventing shooting accidents and hopefully pave the way for future research and development. Such a conceived device would be used to indicate, to a weapon holder, whether his weapon is pointing in an unsafe direction to fire due to another individual being in the line of fire.

1.2 The Problem as it Stands In Hunting

One of biggest risks to hunter's lives today is being shot by a fellow hunter. Sadly enough not only is it usual that the shooter and the shot are from the same hunting party but also that it is usually a young friend or relative. This is both a tragedy for the family but also to the shooter that must live with the knowledge of what has happened. Every year in New Zealand alone one or two more hunters will be fatally shot while out hunting by friends or family. In an article from Investigate Magazine it is said that there has been an average of one hunter killed every nine months from accidental shooting due to miss identification [1].

So what is currently done to attend to this problem you may be asking. It is a fact that the hunters involved in these accidents are in direct violation of the firearms laws when they discharge their weapons. The rules and regulations set out by the New Zealand government are documented in the New Zealand Arms Code [2]. The code is centred on seven basic rules of which Rule 4 clearly states "Identify your target beyond all doubt". As the law views the situation it is obvious that the target is not being properly identified in these accidental situations incidents. This can sometime lead to prosecution of the accidental shooter and sometimes even a criminal charge of man slaughter.

The world organisation in charge of hunting and firearm regulation is called the International Hunter Education Association. This association has statistics available showing the number of fatalities in the busiest hunting areas of the United States of America and part of Canada. The statistics available for 2007 cover a total of 20 states and provinces reporting a total of 239 hunting incident reports [3]. Of these 239 reports, 139 were due to human error in following arms codes leading to the shooting of a fellow hunter. Fortunately out of the entire 239 reports only 19 were fatal which is a low percentage, however they are 19 people that will be missed.

While the view of the law on firearm usage is very ridged a hunters intention to follow these rules may have little effect on his ability to uphold them. It should be clear that most of these hunters involved in these accidents do not intentionally set out to harm

the individuals shot. Physiological and environmental factors are actually the most influential effect on the occurrences of these accidents. In the specific list of factors that effect the hunters ability to perceive what is and is not a target are such things as Buck fever, Dehydration, Poor eyesight, Fatigue and Inexperience. The specific environmental effects are weather such as Fog, Rain, Snow and Light but also location specific factors like vegetation and mountainous terrain.

1.3 Need for a Solution

There are many different ways in which a hunting accident can occur involving a firearm. One of the more notable and more prevalent is recorded as poor gun handling. This covers such results as a poorly carried gun that misfires from dropping and poorly stored firearms in transportation. Other resultant accidents are a result of the shot setup. These are such as a hunter shooting at a target between him and another hunter, a hunter swinging his weapon while following a target, and a person moving into the line of fire. There is one more possible accident which is the fundamental focus of this thesis being the accidental shooting of a hunter due to misidentification. This simply means a hunter will intentionally aim and shoot at what is perceived to be a target animal that later turns out to be a fellow hunter.

Part of the intention of this research is to investigate the technology to generate an accident prevention aid useable by these hunters. In order to conceive of such a device some base requirements of system to be used for this application need to be remembered. Firstly to be used in hunting the technology should try to be as autonomous as possible in that it should not require continual operation by hunters. The concept should also involve technology that lend itself to the task of hunting. An example of such technology consideration can be understood by looking at the hunting task of stalking an animal. In this situation an audible alarm would be a poor choice for indication whereas a concept such as in-scope lights would not attract attention or give away a hunters position.

The conceptual system should be designed with the aim to be completely cloneable and in such is able to interact with any copy of itself worldwide. This would mean that except for an identifying serial number, the unit has the ability of being mass produced without the requirement for infrastructure in hunting areas. If a hunter is to equip himself with this technology then the unit will automatically interact with any hunter who has likewise equipped himself. In this way hunters purchase their own safety however together generate the safety net. Similarly a hunting area can purchase a number of units and would be able to allocate a unit to any hunter entering the hunting area. Cloned design would mean any extra units could be purchased at any time to interact with existing units owned.

It would be nice also as a requirement to not impair the hunters ability to hunt or lessen the hunting experience. Prototype design work in its nature can be bulky and

require awkward electronic configurations to test systems. It is fair to assume that during this research into hunting aid technology the test equipment would be bulky and an annoyance during hunting and for safety reasons will not be tested in such an environment however it can be conceived that final production versions of the concept system could easily clip on a belt and strap to the side of a gun and be out of the way. Any inconvenience caused would be less important than the safety provided.

1.4 Definition of This Research

It can be suggested that a small, non intrusive, durable electrical device can be designed to be attached to a weapon during hunting to reduce the number accidents. Such a device would indicate to its wearer when the weapon is aimed at another such personal electrical device. The device when mounted on a hunter's gun could indicate through his scope the current level of danger of the shot.

Today it can be said that technology is taking over our lives however it is regularly used to save them. Throughout this thesis a concept of a system is put forward suggesting a specific arrangement of technology being hardware and software to generate such a protective device that can be used to reduce the number of shooting accidents within the sport of hunting. Furthermore by simulation, a basic measure of functionality of a concept will be shown. This simulation or model will be generated using the basic operation of the concept system however will allow for editing of the concept system parameters used as initial values.

An Intelligent wireless device can be designed that will reduce the number of shooting accidents in the sport of hunting. A model can be generated from this concept to test different setups of systems and to provide insight into the operation of the concept in more dense networks.

The focus of this investigation is to research the feasibility of a concept system. This is done through a combination of computer modelling and hardware testing of an electronic solution to the problem of friendly fire within the sport of hunting. This research will (a) Design a Model to represent a hunting environment to generate dangerous shooting situations and evaluation protection concepts. (b) Evaluate the operational ability in hunting environments of hardware components such as : Digital location acquisition , Digital Directional Acquisition and Radio Data Transmission. (c) Load the model with field data recorded and test different system's functionality. Finally (d) A hardware prototype will be assembled that utilizes wireless communication processors, short range networking and tested locational and directional data acquisition hardware. This prototype will be tested for simple functionality as a test that a solution of this nature is possible and is able to be implemented with current available technology.

1.5 Principle of Concept as it Appears to Hunters

If instead of considering all possible hunting accidents lets focus only on the miss identification of target accidents and the effecting factors during a hunting expedition. There are a number of contributing situations and conditions that can effect a hunters ability in the field to correctly identify his target. Of these factors, some of the most important include: Buck Fever, Fatigue, Dehydration, Foliage and of course the weather. Foliage and weather are random and unpredictable in that at any given shooting instance the state of the foliage between shooter and target as well as the current fog, rain or snow levels are as found and must be accepted or the shot averted. Buck fever as well as fatigue and dehydration are human factors in that they are characteristic behaviours or conditions regularly experienced by hunters on the hunt. These factors can be influenced by better planning or possibly in the case of buck fever, electronic hunting aids.

Hunting unlike some other sporting activities is carried out in the great outdoor. While long distance travel can be achieved in this environment by off-road vehicles, in order to cover a large section of ground while hunting and not scare away potential targets, a lot of walking is required. Hunting like other outdoor activities usually requires planning and vacation time. This leads to two problem that can occur with inexperience being poor water planning leading to dehydration and a desire to spend long durations hunting, bringing on fatigue. It is a commonly known fact that dehydration and fatigue can both cause impaired perception.

Buck Fever is called so due to its association with hunting deer, is a physiological state that can occur while hunting. It is called a fever because it is in essence an anxiety attack and can have similar symptoms like sweaty hands and forehead. A combination of anticipation and adrenalin overcoming the hunters sense of reason. The condition can make a hunter jumpy or irritated which impairs the hunters perception of what is a target and what is not, which leads to the hunter shooting at movement. Similarly this state can be brought on by the sight of an animal. If a hunter spots an animal and then follows it, the hunter might be more temped to shoot at any movement ahead of him rather than re-sighting the animal. Other mentioned factors like fatigue and dehydration increase the chance of a buck fever perception attack. [4]

The amount of foliage is obviously an effecting factor. If the target is almost completely blocked from view by a tree, then a hunter will be watching for movement. Once a target has moved to an area of lesser foliage and more view, the target can be identified and shot. It is obvious that this is not a clear cut process with the target not always moving into an open view area.

Rain, snow and fog are three weather effects that will at the time of shooting have an effect on target identification. With snow possible built up on the scope of the weapon, rain causing muddy clothing appearing deer-like in colour and of cause view range and

quality are reduced by all 3 effects. It is clear that the chance of an accident increases as these effects increase.

1.6 Thesis Flow and Definition of Argument

This thesis aims to inform the reader of the problem of friendly fire within hunting and to demonstrate how technology today can be used to reduce this horrible occurrence. The problem at hand will be covered in detail before the generation of simulation of a possible solution is analysed in detail. This concept solution is then produced into a simple prototype hardware and various tests are performed and recorded from the technology used. The model used originally as a test for the concept will then be used to test different system setups to give a rough measure of performance.

So far the problem of friendly fire within the sport of hunting has been detailed. A definition of friendly fire has been given and the various types of friendly fire that are recorded in hunting accidents are stated. From this a definition of the research has been outlined. Factors of hunting that can increase the risk of friendly fire specifically human effects and environmental effects have been mentioned. A final introductory section investigates other similar technological advances towards such a system and various large scale needs for the development of a high efficiency version for military applications.

Following the introduction the tools section of the thesis outlines various equipment and hardware used both in prototype generation and the software model creation. Along with each choice of technology used is a short description of various other technological equivalent packages that could have been used.

The modelling section of this thesis outlines the development of the model to its final stage as a test bed for the concept of this project. This model is designed to simulate a close quarter hunting environment in which all the different friendly fire situations occur. By making the model use entered values measures from real systems as start-up or input conditions to the model, different systems can be tested against each other.

Following the modelling section is the detail on the hardware aspect of the research. This includes a steady build up of detail from the block diagram conceptual system to the complex final prototype. Detail is provided on the circuit used, chosen power supply chips, line driver chips and the interaction and interconnectivity between all these hardware aspects. This section also includes detail on the embedded code used and network principles.

The results section not only shows results of the tests performed but also contains details on the choice of tests done and methodology behind the testing. The different tests carried out include the vegetation and foliage radio tests, testing of the digital compass,

testing of the global positioning system receiver, tests run on the model loaded with recorded results and finally proof of concept testing of the prototype unit.

Finally the thesis will finish with conclusions of what has been found, the extent of what can be learnt from these experiments and where progress can be made in the near future. Other possible uses for this system both within the sport of hunting and in other agricultural situations are highlighted.

1.7 Current Systems and Area's of Research Underway

As part of the foundation work to occur before the commencement of this project an investigation into the existence of such a system was performed. As a starting point Cabela International one of the worlds leading hunting suppliers was contacted by email and their response was simply that they are yet to hear of any such device available to aid in the prevention of mistaken identity shootings.

Currently one such friendly fire patent exists which does involve radio communication however it has been designed for military applications and works on a slightly different principle [5]. The patent entitled "Friendly Fire Prevention Systems and Methods" is designed for a larger scale to cover an entire battle theatre where command centres either fixed or mobile are used to do most of the processing. The claims of the patent state that it is based on a group of radio transmitters sending locations of one or more friendly units along with separate groups of vehicular weapon platforms such as tanks and artillery likewise sending weapon targeting information and weapon area damage information to the command centre. These two sets of data are used by the command centres which in turn will give a "safe to fire" or "not safe to fire" command to the weapon platforms by way of the radio communications. This is a two way communication system based on heavier firing units, specifically not infantry fire. An extension of this military location network is the in-vehicle screens updated with troop locations.

This aim of this hunter protection system is fundamentally different in the following ways: This device will only be communicating its location short range while listening for other locations over the radio. One specific aim of this system is to communicate in an ad-hoc communication pattern meaning one radio node can connect to any other clone of itself within radio range. The computer within this device will talk to a direction indicator connected to the gun and indicate to the hunter by way of lights such as red if there is a risk to hit another hunter. In comparison to the military system above this one device aims to be an all in one package that can be easily carried by the hunter however only relies on short range networks as well as public global position receivers. This thesis concept system also requires no additional human interaction other than the hunter turning on or off the system.

Ironically the intended use of this concept system in detecting a safe firing heading for a gun is very similar to systems used in military training as well as the indoor pastime Laser Tag. The military systems like the laser tag systems are designed to register a digital kill when the gun is pointed at a target and the trigger is pulled. These systems are based on infrared in that line of sight is required. The fundamental difference between these military systems is that the concept system aims only to be short range and autonomous. Objects that block view between hunters but would not block a bullet will not block the communication of locations between individuals of this concept system.

One system the Optical Combat Identification System or O-CIDS has been designed for friendly fire prevention in urban warfare by a company called Cubic [6]. This system promotes the ability to detect a familiar target by way of a laser communicator mounted on the weapon rather than by radio communication. This system does effectively reduce the shooting of friendly units within urban combat situations, however this system immediately seems unsuitable for an application where dense vegetation is the predominant reason for miss identification of a target shooting accidents.

One commercially used laser tag system is the LaZerware™ [7] system. Far too bulky to ever ask a hunter to wear hunting however this is a very popular model sold to indoor laser tag businesses. The idea behind this suit and gun combo kit is to count and store data on shots and hits which are totalled at the end of a "laser tag match". The vests give indication that someone had successfully shot at the vest and a kill shot is noted. These simulated battles are usually carried out indoor where a line of sight between shooter and target is required to take a shot it also ensures visual communication will be possible at the time of shooting. Unfortunately while this system could be adapted and inverted to use optical communication to prevent friendly fire it could only hope to become a downgraded version of Cubic's O-CIDS system at best however it is cost suited for the commercial market.

In June 2004 a paper in New Scientist [8] focused on virtual moving fences as an application of herding livestock stock such as cattle. This is said to be achieved by downloading a fence program wirelessly into each cow or sheep's receiver the sheep can be given some stimulus to encourage it to move to a different location. This stimulus could of course be electric however more humane methods are under development. The benefits stated in this article specifically cover the ability of the wireless system in the field to communicate directly to a PDA or other WI-FI enabled device to allow for remote or virtual stock tracking and control.

Investigating deeper into forestry effects on radio communication lead to an interesting paper entitled "Evaluating the accuracy of GPS positioning in Turkish forests" [9]. The paper used fish eye lense photos of forest canopy cover of test locations along with a coverage rating. The results suggest that signal degradation in heavy forest is

about twice that of a sparse to open wooded area. Positioning can vary up to 7.5-9.9 m on a forest road and as much as 19.9 – 23.8 m in heavy forest.

Another paper entitled "Study of Propagation Loss Prediction In Forest Environment" [10] specifically covers the propagation of radio waves as a results of forest and vegetation. This paper tests a number of frequencies to evaluate environmental effects such as humidity and forest density. After analytically and experimentally testing radio height gain, terrain effect and humidity the following was suggested by the paper: The effect of the terrain can be classified as a usual terrain effect even in forested environments, humidity was said to have a sizeable effect which is suggested is a result of more moisture contained in objects populating the environment rather than simply damper air. The paper concludes by suggesting options for future work such as more intense modelling of propagation loss in forests as well as testing other factors such as rain and heavy winds.

GPS positioning accuracy within a forest is greatly disputed. One such paper that quantifies the results of high accuracy GPS is entitled "Accuracy Analysis of GPS positioning Near Forest Environment" [11]. This paper records long durations of GPS logs of a few receives placed at distances from the edge of a forests tree line. Recorded results within the paper suggest large increases in high accuracy GPS positions with a variance of tens of centimetres. While the GPS unit used in this project is not a high accuracy GPS unit however the error values possible, as a result to forest environments could be an issue. Interestingly enough this paper suggests that the largest effects on GPS signal come not from light vegetation but rather from large branches, tree trunks and terrain detail such as large boulders and rocks.

Directly relating to the tests desired within this thesis is a paper entitled "Digital Compass Accuracy" [12]. With the use of Labview and Matlab this paper states that it attempts to quantify the erroneous effects such as soft and hard iron effects along with any electromagnetic interference and error due to incline. Similar to methods used within this thesis that paper connects a compass to a serial data logging device. Results provided within this paper include both magnetometer outputs compared with compass heading results. While the paper suggests that its purpose is to evaluate effects of mounting compass in fleet management systems the specific test rig used is isolated from as many external effects as possible. The resultant graphed errors show a stable heading with very few erroneous readings. Overall error produced from the experiments within this paper suggest that compass heading without external influence can drift by up to plus or minus ten degrees.

Looking closer into the background behind sensor network positioning one specific paper focuses on GPS free positioning. Entitled "Scalable and Distributed GPS free Positioning for Sensor Networks" [13] this paper is very detailed in the resolving of position of GPS nodes within a network by triangulating their position from other nodes.

This methodology is not absolute in that there is no specific positions assigned to any node other than a known offset or distance between nodes. While amazingly sophisticated and designed for ad hoc networks where no GPS signal or receives are included this system does however require multiple nodes to be in range to establish a position. With dense hunting grounds this methodology could be used however three other hunters would need to be visible to any other hunter at any one time.

The final paper investigated was entitled "Localised Scheme for Three Dimensional Wireless Sensor Networks Using GPS Enabled Mobile Sensor Nodes" [14]. With a self explanatory title this paper focuses on using GPS signals for positioning. Unique to this paper the techniques researched focus on moving nodes with GPS receives. Other nodes within the sensor network through use of position resolution can determine their own position by recording a few positions received from the moving GPS nodes. Similar to this project a simulation was run including initial setup conditions and to test mathematical methods for three dimensional GPS position resolution documented. The specific downfall of this paper despite the advanced localisation technique is that in order to establish position a dense network is required. Furthermore there is a requirement for moving nodes in order to establish infrastructural node positions.

2. Software Tools and Hardware

This chapter contains details on the tools investigated to perform the work contained within this thesis. Primarily computer applications considered for use as a modelling tool are compared with the final choice presented and supported. Following this, various elements of hardware that could contribute to a prototype are suggested, again with the selected final hardware presented along with reasoning for this option.

2.1 Modelling and Simulation Tools Researched

In order to generate a model of a hunting environment various software packages were investigated. The desire is to find a simulation method that best suits the required application of a hunter simulation as well as having features that make it easy to incorporate a simulated version of the friendly fire prevention solution detailed in this thesis. Some of the main requirements of such a simulation is to ensure that a graphing output was available. Another factor needed when choosing a modelling package are ease of use of the package once the model is setup and the ability of the package to concurrently process both a simulation and simulated hardware.

The radio software simulation package Visual Sense by Ptolemy [15] was able to accurately simulate radio message collisions and interactions and even signal degradation due to objects and environments. The package also had some major drawbacks specifically the addition or generation of more actors or player into a simulated field dynamically while the simulation is in operation. This ability is critical for the ability to re-populate shot animals and hunters. Another downfall is the size of actors and players objects are not scaleable and are pre-drawn and from a pallet. Finally any changes to the simulation parameters must be entered by editing the simulation hunter by hunter rather than at start-up before the simulation runs. Finally to note that in order to enter or generate a simulated version of the suggested prevention system it is required to be coded into the hunter and object.

Another package investigated was Flexisim [16]. While this software package is excellent at simulating objects interaction and focuses very heavily on three dimensional simulations however sadly it has no radio component integrated yet. Due to this a radio

code section would be required to be written into each actor or player in the simulation. Unlike Visual Sense however Flexisim has the ability to generate more object on demand allowing for re-population of the hunting field and there is a dynamic pallet of actors and objects to choose from. One of the benefits of this simulation package is that it is possible to venture into altitude of shots, trajectories of bullets and so on, completely into the third axis. The biggest notable drawback with Flexisim is that it requires the application to be installed to run the simulation. This is not a small application and licences are very costly. Each hunter and animal object is a spawned clone of a hunter or animal primitive. In Flexisim yet again the code for the simulated system would be required to be hard coded. The concept solution suggest in this thesis does not extend itself into three dimensional shots so the use of this visually detailed program for two dimensional simulations would be an overkill.

Given that most of the other modelling packages would require the generation of primitive actors and players and some would require the generation of radio code for the simulation, it makes more sense to customise an application from scratch. For this a rapid application development package Delphi 7 [17] was used to generate an application that could contain a mix of the above simulations. Graphs and file output functions were basic and had been used for many previous projects, also simple drawing functions could be used to generate a visual representation without excess detail. The Delphi package for windows allows for the quick generation of small windows applications using the turbo Pascal language and has the advantage of having complete control over model operation. This was the chosen package for the hunting simulation creation and is detailed further in the next chapter.

2.2 Delphi Modelling Tool

As mentioned in order to maximise flexibility a rapid application development package was used to generate a windows application as a simulation. The chosen software package was Delphi 7.0 and reasons for this option are as follows: Firstly the model is an application meaning it required no additional software over and above windows to work, the application is a single executable file of less than a megabyte. Secondly the application model allows for all parameters to be entered into a setup page created, changing the system being represented in the simulation. Thirdly the application can be run multiple times on a single windows platform allowing for concurrent long duration tests.

The desired outputs from the model such as text files and graphs are not only easily setup and included in the model but can be generated real time. Delphi gives the ability to control finer points of a simulation such as using concurrent processor treads in the form of timers to run the simulation, and to run the simulated friendly fire prevention hardware almost as two different interacting simulations. There is an option to layout

screen within the form of the application as tabbed pages allowing for quick changing between different view pages and maximizing space.

Some of the drawbacks of using Delphi as a modelling tool is the way that the code is implemented. There is no option once the model is generated, to change the code simulating the concept system's operation. This means that the model generated is a model of the systems methodology whereas the parameters entered simply change the system's specifications. These system specifications can be measures from a concept system such as : gun range, vision range, radio range, chance of GPS reception and so on. This is not specific to the process of generating an application in Delphi due to the fact that other modelling programs investigated likewise required the model methodology to be coded into the package. Delphi's output is a compiled application in the form of an executable file and is not changeable once created. Other modelling packages require installation of the complete editing package simply to run the model however this allows for complete manipulation of the model.

It should be mentioned that the two-dimensional graphical components provided within Delphi 7.0 were already very familiar and have allowed for an easy to view two dimensional image of the layout of the hunting field. As mentioned previously with the ability to generate screens or pages to be viewed within the application, it was possible to generate a setup page containing only the required initial values for the concept system to be simulated.

2.3 Global Positional System Options

In order to gain a digital value of location a positioning method and infrastructure is required. Two popular methods of achieving position wirelessly is to use either local radio positioning or alternatively global positioning.

Radio positioning is based on short range repeaters that can calculate range from three known locations simply from timed relayed messages. While this method is used in applications such as cell phone positioning it requires fixed repeaters to be installed with known locations. In cities this is less of a problem however in the middle of the wilderness or even in hunting areas it is not often that three cellular towers are within range. Alternatively a hunting area can be fixed with permanent radio contact points. This can be costly and limits the technology to a specific hunting ground where it has been fitted.

An alternative method is to make use of global infrastructure already installed such as GPS. GPS or global positioning systems use satellites in orbit over the planet to again calculate distance based on time of radio message transmissions. The advantage of such a system is that it can be used freely. By purchasing a GPS interface chip or system it is possible to receive positional messages with no subscription or fees. As a mild downfall this technology can only be used outdoors , perfect for this intended application as a hunting friendly fire prevention aid.

NEMA stands for the Nautical Electrical Manufacturing Association [18]. This association is responsible for the protocols these GPS receivers utilise. A GPS protocol is the method of which the GPS data is formatted and communicated to other devices by a GPS receiver. A small selection of the most commonly used data strings are usually transmitted one after another out of the GPS receiver all following their specific identifying string. The GPS protocol is discussed in more detail in the hardware section of this thesis.

Along with the choice of GPS data format or protocol, GPS receiver hardware must be chosen. For this research project a GPS receiver module will be required that is able to communicate to our radio microprocessor and that supports the GLL data format. For ease of integration mouse type GPS units were investigated. These mouse type units come pre-enclosed and with a connecting cable to the device.

GPS accuracy is rated at a standard ± 5 meters for most non-military receivers. Considering this error if two hunters are standing next to one another, there could obviously be problems in location and indication. As the distance between two hunters increases, the effect of this error decreases rapidly. If two hunters are 50 meters or more apart, a variance in position of 5 meters in any direction could only have around a 20 degree error (or less) in the heading from one hunter to the other (which is a worst case scenario).

2.4 Digital Compass and Magnetometer

In order to achieve a digital heading or direction from a gun a magnetometer or digital compass can be used. These integrated circuit chips can sense very small magnetic fields and generate an appropriate output. Some simple models are 2-axis in that they sense a 2 dimensional magnetic direction while more expensive models have the ability to sense in 3 dimensions allowing for a tilt output along with a heading or direction.

One of the leading producers of these magnetometer IC's is Honeywell. The range of the chips available include both 2-axis, 3-axis, different gauss sensitivities and different output interfaces to name a few features. For the purpose of this research a Honeywell development kit was used. Due to this desire to purchase a development kit for this project two possible options existed, the first being a HRM3200 and the alternative being the more expensive HRM 3300.

The HRM3200 is a 2 axis digital compass while the HRM3300 is a 3 axis kit allowing for a tilt angle to be measured. Since the HRM3300 was excessively expensive and due to the fact that this project does not plan to venture into the altitude component, the chosen kit is the HRM3200 Chip Sensor Development Kit which is a 2-axis digital compass IC with RS-232 serial type output.

For the specific development kit chosen the required input beside power was simple initialisation strings as well as setup strings that are transmitted to the digital compass by way of the RS-232 port. These options allow for such things as setting the output to either direction/ heading or raw sensor data. Another more important example of these configuration strings is the "*"s" string which is used to either start the transmission of the data or to stop it.

The development kit printed circuit board is powered by 9V DC which is provided by way of a 9V battery connected to the serial input. The wiring is such that the 9 Volt is connected to pin 9 of the DB9 serial connector and the 0V or ground is connected to pin 5 of the DB9 as usual. To simplify design all the voltage regulators within the system have been chosen to run from a 9V battery. This is so that the same battery can be connected to pin 9 of both the DB9 serial connectors for external device power provision by way of the serial communication cables.

While it may have been beneficial to use a package that has a wireless communication protocol already included the specifics of this model can be based on a number of protocols such as Zigbee, Bluetooth or Z-Wave. Due to this non specific requirement no specific radio protocol has been included however any further work to be done on this project would be aided by the utilization or integration of a protocol supporting modelling package.

2.5 Wireless System on Chip Technology

A system on a chip (SOC) processor is essentially a processor that has a radio transceiver physically connected to it within the IC. This onboard radio transceiver allows for inter-processor wireless data transfer. The possibilities of this inter-processor communication are endless with devices such as wireless game consol controllers, wireless temperature transmitters and wireless music devices. Within this project the SOC processor will be used to run the operation program code, to communicate with the GPS and Digital Compass as well as talking via wireless communication to other processors.

Wireless communication is usually limited by two properties of the radio communication. The first affecting factor is distance with range of communication being the deciding factor on the coverage area of each processor. The second main affecting factor is data rate. A data rate is the speed at which a set size of data can be passed between one wireless processor and another.

Work undertaken before this project has involved extensive use of the CC2430 microprocessor. This Texas Instrument owned Chipcon produced SOC is able to use the Zigbee protocol however it also has a basic radio communication protocol IEEE 802.15.4 allowing for simple messages to be passed at data rates of up to 250Kilobits per second

or as low as 1.2kbps per second. It is known that higher data rates for this application are going to waste due to the shortness and simplicity of all messages required to be passed.

For this wireless communication project a slower communication frequency will be used to hopefully gain communication distance. For ease of use as well as brand confidence this project will again use a Texas Instrument SOC IC. Some system on chip processors were investigated that had USB functionality. This technology had been added to a range of both sub 1-GHz radio processors and the 2.4GHz equivalents. In order to best choose a SOC processor the following factors can be compared:

Processor	Frequency	Range	Data Rate	USB Controller
CC1110	348MHz-928MHz	Good	Slow	No
CC1111	348MHz -928MHz	Good	Slow	Yes
CC2510	2.4GHz - 2.483GHz	Medium	Fast	No
CC2511	2.4GHz - 2.483GHz	Medium	Fast	Yes

Table 2.6: Compared Wireless Processors

In the above table the trade off between range and data rate has been plainly stated however for the purposes of this research the high data rate is not as important as distance of transmission. For this reason the CC1110 seems the best processor for the application.

The CC1110 like all other members of the CC range produced by Texas Instruments has three possible memory sizes available. These are the F32, F64 and F128 versions of a microprocessor and have 32K, 64K and 128K of memory available. The demo kits for the CC chip range are released with the 128K memory processor which should be more than ample for this application. Likewise channelling is available within each of the frequency range by changes to a single radio register allowing for 256 easily assessable channels within a single subnet (visible from a single chip). This again will be more than enough for this application.

2.6 Final Hardware Component Selection

The final list of chosen hardware is as follows:

Device	Product Name	Producer
Radio Microprocessor	CC1110	Texas Instruments
Digital Compass	HRM3200	Honeywell
GPS Receiver	PGM-648	Polstar

Table 2.7: List of Chosen Hardware

The CC1110 Radio Microprocessor has many beneficial features for this application. It can be ordered in a development kit that arrives with multiple boards. These boards are motherboards containing the processors however have different antenna balance circuitry designed for the different frequencies used. This gives the ability to test more than one frequency for this processor. The kits also come with development daughter boards that act as the flash programmers for the motherboards. These development daughter boards called a "SmartRF04EB" could be used as dummy nodes if programmed correctly.

The digital compass as stated has been chosen due to price and the non requirement for an altitude component to the project. The compass also comes in a easy to use development kit with some example software. Compass accuracy on the HRM3200 is amazing with jitter being little more than a point of a degree as shown in the results section of this paper.

The final chosen GPS Receiver compared to alternatives proved to be more accurate, significantly cheaper and able to be supplied by a local supplier. As mentioned the protocol included in these devices is identical however the PGM-648 boasted mild waterproofing. This was beneficial for GPS testing however would prove to become a hassle later as mounting magnets needed to be removed from the GPS units enclosure.

3. System Overview

Contained within this thesis is a concept idea of a system to prevent friendly fire. The modelling of such a system is the final desired outcome however it is important to understand the fundamental logic behind the idea. This chapter will focus on the composition of the concept from first principles, involving the description of how a single system would function and continuing on to the interaction between multiple systems and how they provide friendly fire prevention coverage.

3.1 Principle of Solution

The suggested system is an electronic solution to friendly fire prevention within the sport of hunting. This suggested solution to aid in the prevention of friendly fire will utilize technology including Global Positional System Receivers, Gun Direction Sensors and Intelligent Electronics. The solution will be tested both in physical concept and in modelling in order to demonstrate the effectiveness of the proposed possible electronic friendly fire prevention solution.

To understand the concept of this suggested system it is first important to understand that this system is designed to be carried by each hunter on his person or weapon while hunting. The current desire is that a hunter would mount a system onto his weapon and that this system would not interfere with the weapon any more than mounting an extra scope. The concept has been aimed primarily at larger hunting rifles in concept and particularly rifles that have an attached scope.

Now that it is established that the system is to be carried by every hunter it is also important to note that the system should be both unique and uniform in that it can communicate with any copy of itself (any other hunter's system) and still remain uniquely identifiable in any hunting area by way of a unique ID or serial number programmed during production. This identifier is used later on as an individual device ID over the radio communication network established by these devices.

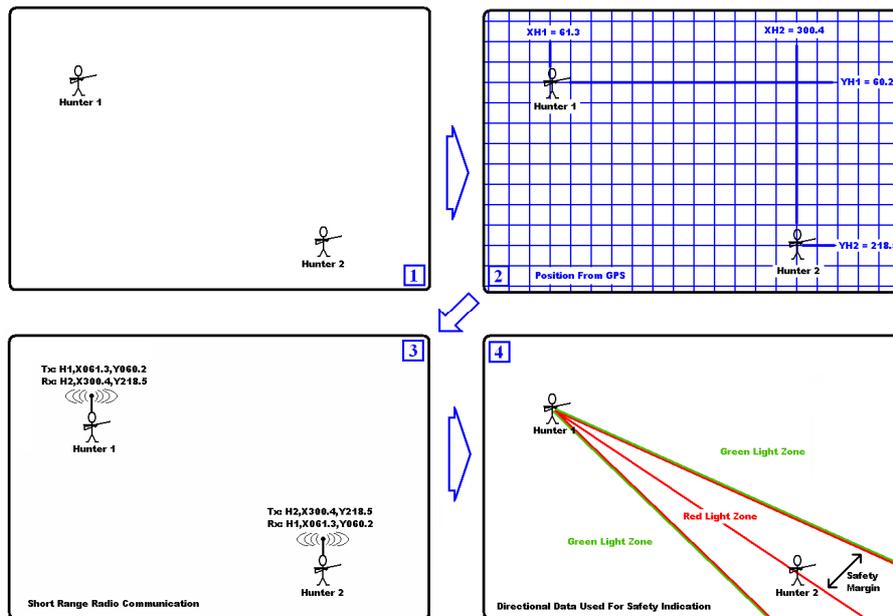


Figure 3.1a: Operation Overview

The specific concept of this system's operation that makes it unique is that it utilizes short range radio communication to interact with other hunters carrying the same hardware. If two hunters are within a hunting area and both have the equipment attached the situation is now set as shown in the top left of figure 3.1a.

Conceptually each of the hunter's hardware will be able to acquire their own position by way of global positioning satellites talking to a connected receiver shown in the top right of figure 3.1a. From this point the hunters hardware can communicate its own location to other hunters by way of a short range radio communication module connected to the microprocessor. This communication ends with all hardware being aware of their own location as well as knowing of other hunters location within range. This is shown in the bottom left of figure 3.1a where the radio data is detailed. A list is formed consisting of all known data and the next part of the process can proceed.

The final step of the system before it restarts the entire process is to obtain a direction value or reading of the current heading or aim of the hunters weapon. With this direction heading and the list of known other hunters location a calculated safe or unsafe zone can be found with the inclusion of a safety margin clearly visible in the bottom right of figure 3.1a. From this point either a green "clear to shoot light" will be illuminated or alternatively a red "other hunters being in line of fire" light.

The device held by each hunter can indicate back to the hunter the current safe or unsafe condition of the direction his or her gun is currently pointing. This can be an audible warning however with consideration to a hunter who is trying to sneak up on an animal, small indication lights would be the best option. The following diagram has the concept pictorially laid out with each hunters hardware labelled.

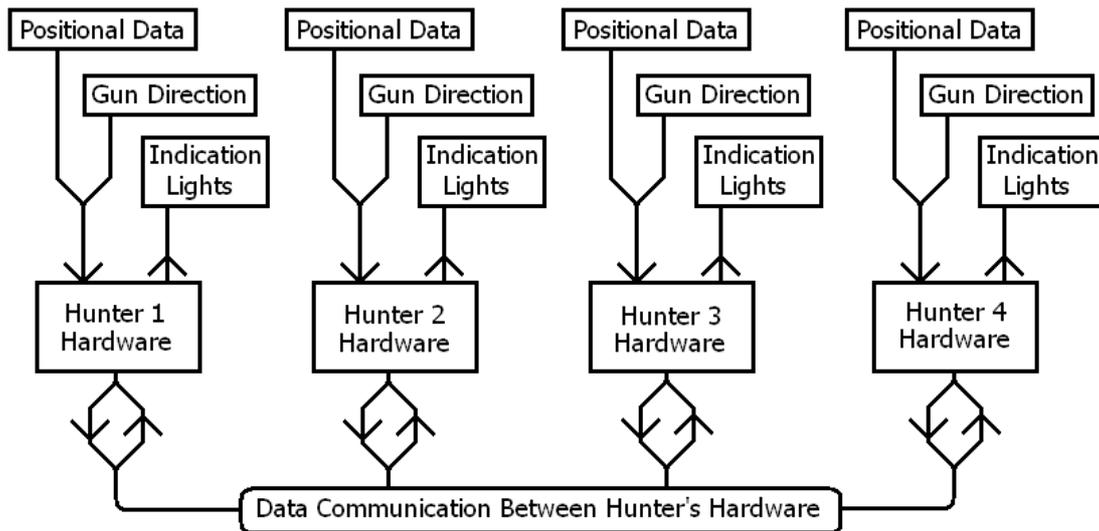


Figure 3.1b: Concept System & Conceived Interactivity

The easiest and most globally available way to obtain a position reference to your current location on the planet is GPS. Global Positioning Satellites circle the world thanks to a few governments and international corporations and, provided that you are outside and have a receiver that can see at least a few of these satellites, you have your position value. While the receiver hardware was originally very expensive now cheaper versions can be purchased almost anywhere. Whatever the receiver used, the operation for their GPS hardware is the same, simply apply power, wait a while and outcomes a string of letters by serial communication protocol produced by NEMA with position data contained. NEMA is the standard for GPS data and contains many formats suited for the different applications of GPS.

Conceptually getting the direction of the gun is a simple process for a human. Take out a compass, place it on top of the gun, read off a direction. Unfortunately to do this digitally with electronics requires a few complex and expensive microchips. These chips called magnetometers can sense the direction of the earth magnetic field in more than one direction. Available in 2 or 3 axes these chips can be used to sense rotation in any direction able to show angle of tilt and twist. For the purposes of this application the chips chosen are 2 axes and are being used only to obtain a directional heading for the gun in only one direction.

The interconnectivity of the hunters is vital. By each hunter's hardware transmitting its own location and receiving the location of other hunters within range a hunter's hardware can build up a list of other hunters and positions. Using this data, an angle or heading to each other hardware can be calculated. A check can be performed and if the gun directional data indicates that the gun is pointed within a safety margin of one of these headings to another hunter then the shot can be called "Unsafe" and the hunter made aware.

Unfortunately this system's operation will in no way be 100 percent effective. In fact there are a number of different possible outcomes for each shot. As each shot is processed it has the possibility of being safe or unsafe in terms of reality governed by the laws of physics and the universe, but also has a chance of being safe or unsafe as it appears to the system. In diagram 3.1c each possible shot outcome is documented. The left to right transition represents Real Shot Safety whereas the vertical transition represents the systems determination of the shot. The green arrows represent correct shot identification with a safe shot being called safe and an unsafe shot called unsafe. The red areas of the below diagram show shot identification failure. Here a real or actual Safe Shot determined dangerous by the system is considered allowable redundancy. An unsafe shot that has been identified as safe by the system should not be allowed however are an inevitability due to a system never being able to be 100% accurate.

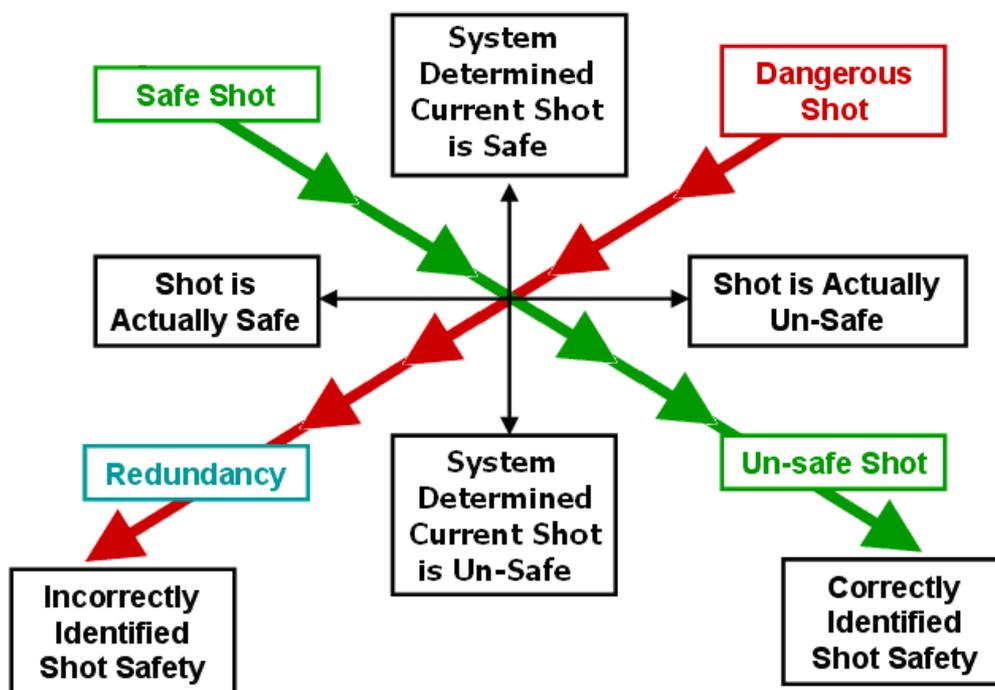


Figure 3.1c: All Possible Shot Determinations by System

Finally the complete communication and sensor overview can be seen in figure 3.1d. In this image the Global Positioning Satellites can be seen with the direct interaction to each hunter. Also the inter-hunter communication is labelled as short range radio with the link shown between the two hunters in the hunting field. Each hunter also has a digital compass through which directional data can be acquired. With the combination of these three interfaces it can be seen how messages can be passed around obvious objects such as trees.

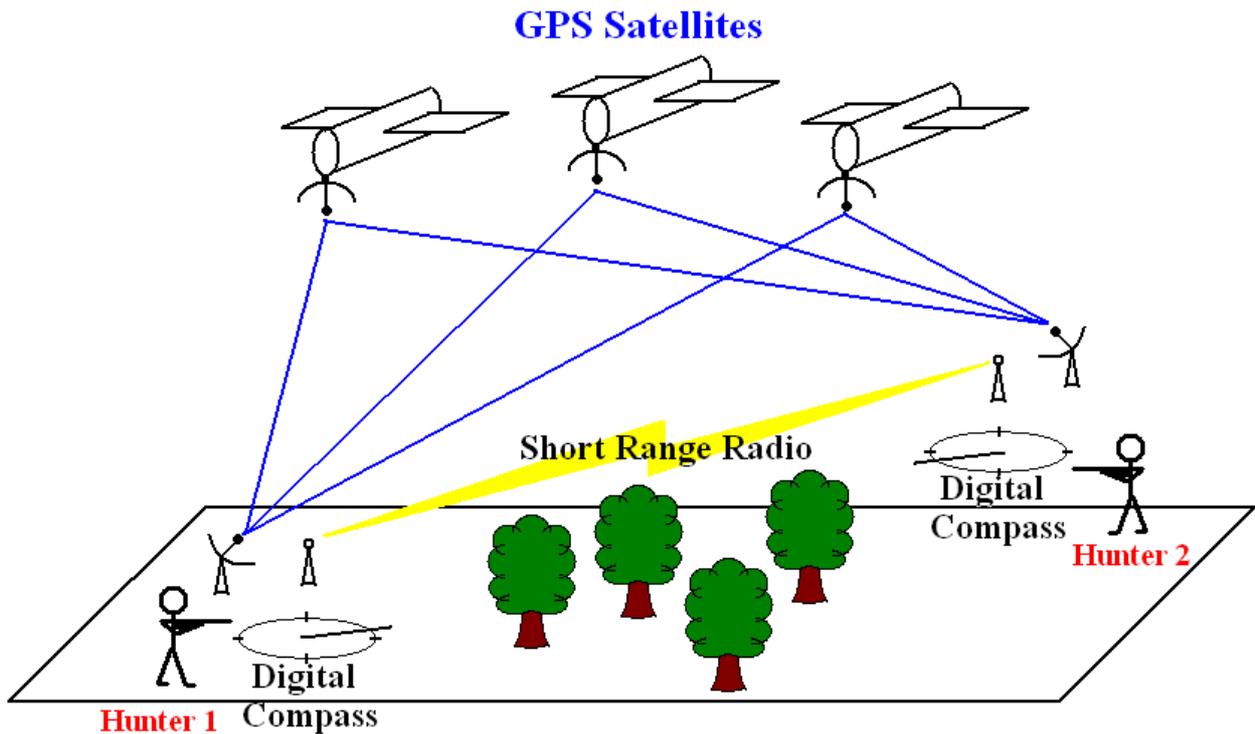


Figure 3.1d: Complete communication overview

3.2 Suggested System Process

To deeper understand the operation of this concept the tasks to be undertaken need to be examined and the order of task processing explained. The principle operation of this system is to receive positional data and gun data and via communication establish a safe or unsafe shot condition. These tasks need to be further broken down to show a new layer of complexity.

The first and most important operation of the concept hardware is to establish its own location but also to establish a record of this location once found. By saving a copy of the previous received location each time a location is received, the new location can be compared to the most recently saved location in order to check for positional movement of the hunter. This becomes the first rule of the communication between hunters hardware. The radio communication is based on the follow rules:

- If this hardware has changed location Transmit the new location.
- If received data from any hunter is different Transmit my location.
- Listen to Radio On Loop.

From these rules a flow of operations can be established in where first the hardware as said becomes aware of its own location and then communicates followed by a

decision cycle in which the direction of the hunters gun is received also including the calculation of a safe or unsafe shot and finally the illumination of an indication light.

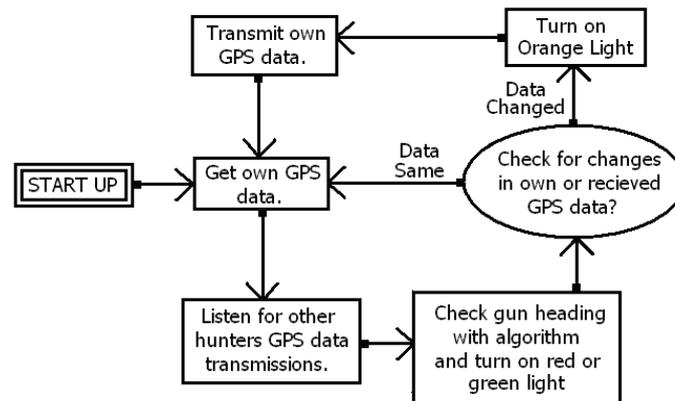


Figure 3.2: Concept System Flow - Non Specific

The first cycle of this operation is simple in that from start up the hardware learns its location and then receives any other hunters locations. From this an immediate red or green condition is determined. A critical decision in the cycle is made here if the hunters list of positions has changed or contains new data (as it is during start up cycle), then the hardware is to transmit its location before beginning the cycle again. If the list of position contains nothing new since last cycle then the hardware skips the orange light cycle and the light remains illuminated red or green. In figure 3.2 the upper two process boxes are considered the orange light cycle.

3.3 Inclusion of Chosen Hardware

In order to understand the next level of complexity it is important not only to understand the previous cycle that is now explained here in more detail but also to understand something of the physical chosen hardware used in this concept.

Remembering that the positional data is derived from a GPS unit and that the directional data for the gun from the magnetometer, the final piece of the puzzle is the radio microprocessor. The next cycle of operation shown in figure 3.3 is a broken down version of figure 3.2 as seen by its similar form. The only variance in the structure of figure 3.3 is the decision of a red or green light which are now their own sub process.

In figure 3.3 the process of figure 3.2 are broken down into sub processes. These smaller tasks are resembled in both the embedded code in the prototype hardware and in the modelling application. The acquisition of the gun heading is now a clear individual block at the bottom middle of the diagram as is the GPS data acquisition acting as the entry point into the process cycle.

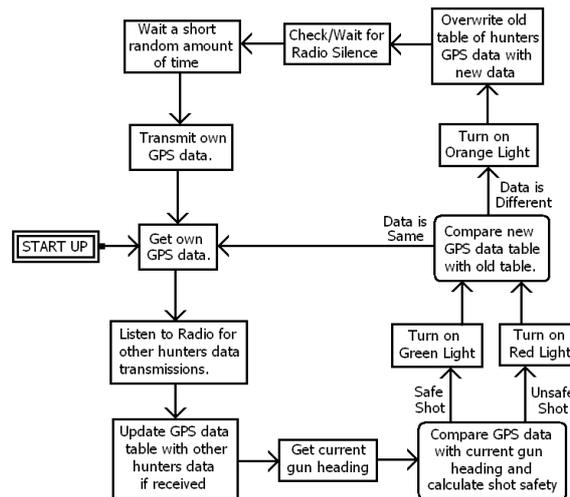


Figure 3.3: Concept System Flow - Detailed

The orange light is used in the top return cycle of the process shown in figure 3.3. This is where additional processes are included due to the orange light being used to indicate that the system is busy. Shortly after the illumination of the orange light to indicate to the hunter that the hardware is processing the data in the hunters list found to be different is updated with the newer version that had been received. The next two processes aid in the radio modulation and alignment of the network. Borrowed from standard network theory a simple collision avoidance technique is used where each individual radio will wait for radio silence before trying to talk. This is followed by each radio waiting a random amount of time before talking to randomly distribute the different systems transmissions over a short time interval. The orange cycle is again concluded with the retransmission of the hardware's own position.

The red and green light cycle being the lower half of figure 3.3 more sub processes have been added specifically dealing with the computation of the microprocessor. Entering again with listening to the radio, the desired intention is that each hardware spend the majority of its time in this process with only quick cycles through the rest of the diagram. It is important to note here that there are two lists of hunters positions stored in each hardware, an old and a new. When a hunters position is received or when positional data is received over the radio it is written into the new list of positions. At the end of the red and green light cycle the old list is compared to the new list to establish if an orange cycle and positions retransmission is required.

4. System Modelling of Interacting Wireless Nodes

One of the fundamental outputs of this research is to demonstrate a functional model to test the operation of the desired friendly fire prevention concept under different conditions and with different hardware. Covering the modelling process, this chapter will focus on the constituent parts of the model and how they are merged together to test the functionality of the desired friendly fire prevention method. This chapter subsequently continues on to show how the model can aid in design or determination of a measure of protection given by concept under test.

4.1 Explanation of Modelling Purpose

While the concept of a friendly fire prevention system seems most reasonable and the generation of an example node as discussed in later chapters is testable, there is still a need to test such a system and generate results on its performance. The production of many example hardware units is very costly for preliminary testing and the organisation involved in conducting field-tests can prove very time consuming for a single set of results. A common method for generating such mass unit results without the need for excess finance, time and participants is to generate a computer simulation of the concept under test.

Models are used to test many concepts in engineering, science and mathematics. Some classic examples of problems to be tackled by computer models are; long term climate change estimates, structure earthquake assessments and plate tectonic movement of the earths crust. A hunter simulation is needed specifically to test not only the concept of a friendly fire preventions system but also to test the effect of changing different hardware elements within a system. Such a model would need to be able to simulate a few hunters but should also simulate various effecting conditions such as foliage, animal movement and should take into account such variable as gun range and sight. Also variances in positional and directional data should be simulated within a model to add complexity.

In order to generate good size data sets the desire of a hunting simulation is to setup many random and different shooting scenarios as it runs. Each shooting situation involving the hunter taking a shot at an animal should be assessed in terms of how it would seem to the concept system under test as well as the actual danger level of the shot taken in accordance with real world physics. A log or graph over time is made of the shots taken, the number of dangerous shots missed or correctly identified by the concept system forms a trend of percentage accuracy. By this method it becomes easy to identify the effect of changes in hardware, such as a more accurate position acquisition equipment or changes in real world variables such as a shorter range gun.

4.2 Model Actors and Players

The desire is to create a hunting model that will generate random shots to measure the performance of simulated friendly fire prevention system. The area of coverage for any given system can be calculated based on gun range and radio range. This is not what the model is trying to establish. The aim of the model is to allow shots or shooting situations to be established based on the principles of how hunters and prey move in a hunting area. Because of this it is important to first establish each of the type of actors in the model.

It is impossible to have a dangerous shot without at least two hunters in the hunting area, the hunter shooting and the hunter being shot. Sometimes other factors are in play such as foliage or trees and sometime an animal being hunted. For this model there are 3 main actors, the tree which resembles any kind of foliage preventing vision, the animals in the area that are being hunted, and finally the hunters.

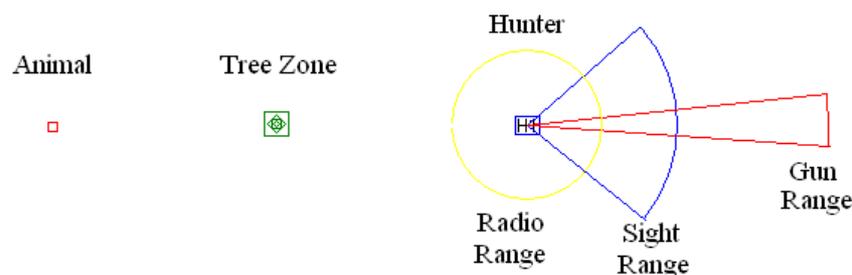


Figure 4.2a: Actors & Players Images Used in Model

The hunter is probably the most complex of the actors and when resembled in programming code his object class has a number of variable pertaining to his actor object within a simulation. When drawn a number of hunters properties from the setup of the simulation are used to generate the image of the hunters as he moves around the field. In figure 4.2a, a representative image is shown as it would appear within the simulation including hunters sight, radio and gun ranges or zones all highlighted.

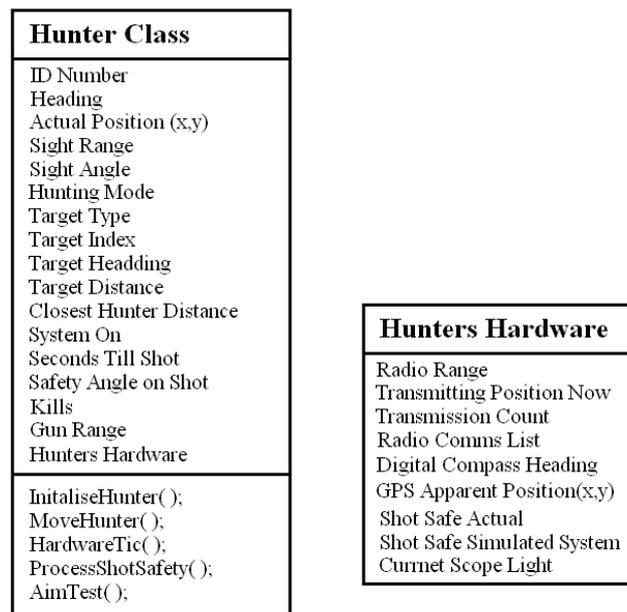


Figure 4.2b: Hunters and Hunters Hardware Classes

As the hunter and the hunters hardware are different entities under test they are kept as separate objects. The hunters hardware due to this is an object within the hunter class so once created the hardware object belongs to the hunter object. The variables for the hunter class are representative of real life properties of a hunter within a hunting zone. The hunter has a unique ID number which is sequentially given as hunters are created. The heading and the actual position values stored in the hunter class are the real and actual position and heading of the hunters gun. Sight range and angle are the range that a hunter is able to see then track an animal with the angle of sight being behind the hunters field of view. Target data speaks for itself with its index being unique. Kills is a tally of total animals shot by this hunter, and hunters hardware as mentioned is an instance of the Hunters Hardware object that is owned by this instance of the hunter class.

The procedures contained with the hunter class allows for setup, movement, target acquisition and shot processing. The Initialise Hunter process is used to fill the hunter class variables with start up and system values and is called shortly after a hunter object is created. The Move Hunter procedure is self explanatory. Hardware Tic is a procedure used to simulate a cycle of the hunters hardware and contains most of the operational code of the hardware object. Like wise process shot safety and Aim test are procedures used to process hunters hardware tasks such as finding a target. The process shot safety command is most important and is used to check if a shot is currently actually safe and weather the system under test has determined the shot as safe or unsafe.

The hunters hardware is the symbolic object of the system under test as would be carried by the particular hunter. Under this class are the variables used by the system. The radio range is an obvious item in the class and the Transmitting Position Now variable is used to indicate that this radio device is currently transmitting for any other listening

radios. The Radio Comms List or communication list is the list of all received positions of other hunters stored along with the hunter ID number. Digital Compass Heading and GPS Apparent Positions are used to store heading and position inclusive of errors to be used in radio and system calculations. Safe Shot Actual is the safety level of the shot in accordance with real world physics with any knowledge available to the system whereas Shot Safe Simulated System is a shot safety level as it appears to a system under test. Finally Current Scope Light is either Red, Green or Orange as set by system under test safety checks.

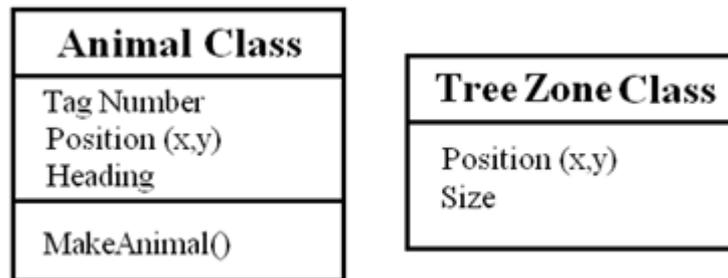


Figure 4.2c: Animal and Tree Zone Classes

As can be seen from the above class diagrams the animal and tree classes are much simpler than those of the hunter and his hardware. The tree class being the most simple with only a position and size property, it simply occupies a area of the hunting field. It should be noted here that originally tree object were exactly that, used to represent a single tree. Following this the tree size property of the tree class was included to allow for different sizes of trees to be placed within a field. Untrue to real life this lead to a variety of tree sizes from around 2-3m wide up to around 30m wide. Following this the tree object were viewed as tree zones representative of small pockets of foliage within a hunting zone. The tree sizes were set to max as it was found with more tree zones generated within a simulated hunting area at max tree size lead to an acceptable randomised forest layout. The tree zones were used within both radio code and hunter aim code in the following ways: If a tree object existed within a small tolerance of the line of sight of the radio communication then the radio range would be reduced to simulate a foliage effect. If the tree object was between two hunters then the hunters are able to consider each other a target due to the inability to identify what is being aimed at.

The animal class may be slightly more complex in structure, however its use is simpler than the tree zones. An animal object does little other than being required to move around the field. It has a heading or direction to which it wanders at a constant speed and has a stored position being its location at any given time. Also the Animal Class has a tag number being a unique number to identify this animal. The final property of the animal class and objects is that animals can be destroyed during simulation operation as a logged kill. The number of animals within the field is kept constant by spawning a new animal in a random position within the field. This animal killing and spawning code was

extended to allow for the shooting of hunters by hunters on the condition that a tree zone was prohibiting view. Likewise a shot hunter object is re-spawned at a random location.

To generate a large number of shots both dangerous and safe, more hunters in a smaller hunting area is ideal. For this simulation while the scale of the field is alterable the maximum number of hunters aimed for is around 10-20 however the simulation setup allows for 50. The simulated hardware loaded setup values for gun range, sight range and radio range with all operating within a set field size should safely generate enough statistics to show the effectiveness of the concept as well as differences between different systems under test.

Due to the need to complicate the shots taken by the hunters and to enable a large number of shots to be taken to generate data, the numbers of tree zones and hunters are a variable setting in the configuration of the simulation. A number of tests were undertaken to simply find the ratio of hunters to animals that would produce the most dangerous shots taken by the simulated hunters without overcrowding the field. This is covered in more detail in the results section.

4.3 Model Process Flow

The principle operation of the simulation is to allow hunters and animals to move around a simulated hunting field, and shots to be taken by these hunters at the animals and other hunters mistaken for animals. The desired outcome is to produce logs of shots taken evaluated in terms of safety from a physics point of view with knowledge of the entire field compared to safety from the point of view of a simulated system under test. The principle of changing system variables allows for testing of different systems. The simulation is run with changes only in the system variables governing the safety check results.

One of the first most important things to understand is that the simulation must run individually from the system or simulated hardware under test. While hardware in the field operates at phenomenal processing rates able to perform so many hundred or thousand of calculations per second the reality of the hunting environment is that the hunters don't move that fast as mentioned above in movement speed. For this simple reason the simulated hardware process is run on an independent event timer to the timer running the overall model.

The simulation or overall model timer is responsible for such tasks as moving animals and hunters, repainting the graphical simulation elements and updating text boxes of representative data. For this reason the simulation run timer being a timed event performing the above mentioned tasks, seemingly should be run for around every 1 second. This not only produces a very slow graphical representation with very little movement but would also lead to much fewer kills. Since the desire is to speed up any

such field tests to produce faster results it makes more sense to increase the timer repeat rate to a value as fast as 0.1 of a second. This increases the process speed 10 fold.

Figure 4.3a is the actual process diagram for the Simulations System Timer. The system timer along with the Hardware Simulation Timer are started when the Start Simulation Button has been clicked. The order of events as they appear is as so: With Each Hunter the follow procedure is repeated, Move the Hunter, Test to see if the Hunter is Searching, Aiming or Shooting, if Shooting remove the Animal or Hunter object shot then spawn a replacement Animal or Hunter. Once all the hunters have been moved and are processed for shots taken this cycle finishes by moving the Animals and Repainting the field (including filling in the text data boxes and updating graphs). Finally if the Simulation has a stop time setup the system timer will check to see if the elapsed time matches the desired simulation duration and if so the system timer disables itself.

The second independent event timer is the system under test timer or the simulated hardware timer. This timer is used for simulating hardware code and is run much faster. The principle tasks of a single hardware cycle is to emulate the flow diagrams of the embedded code shown later on. This tasks involve processing the radio communications, gathering the hardwares position, reading direction, checking for dangerous targets and then finally setting green, yellow or red lights to indicate the shot safety level. In reality this process would be occurring 1000s of times a second however in the simulation due to the still relatively slow speed of the simulation timer at 0.1s, this timer event process is run every 0.05 seconds allowing for 20 simulated hardware cycles per simulation timer cycle.

Figure 4.3b is a Process Diagram describing the flow of operations of the Simulated hardware timer called HardwareTic().

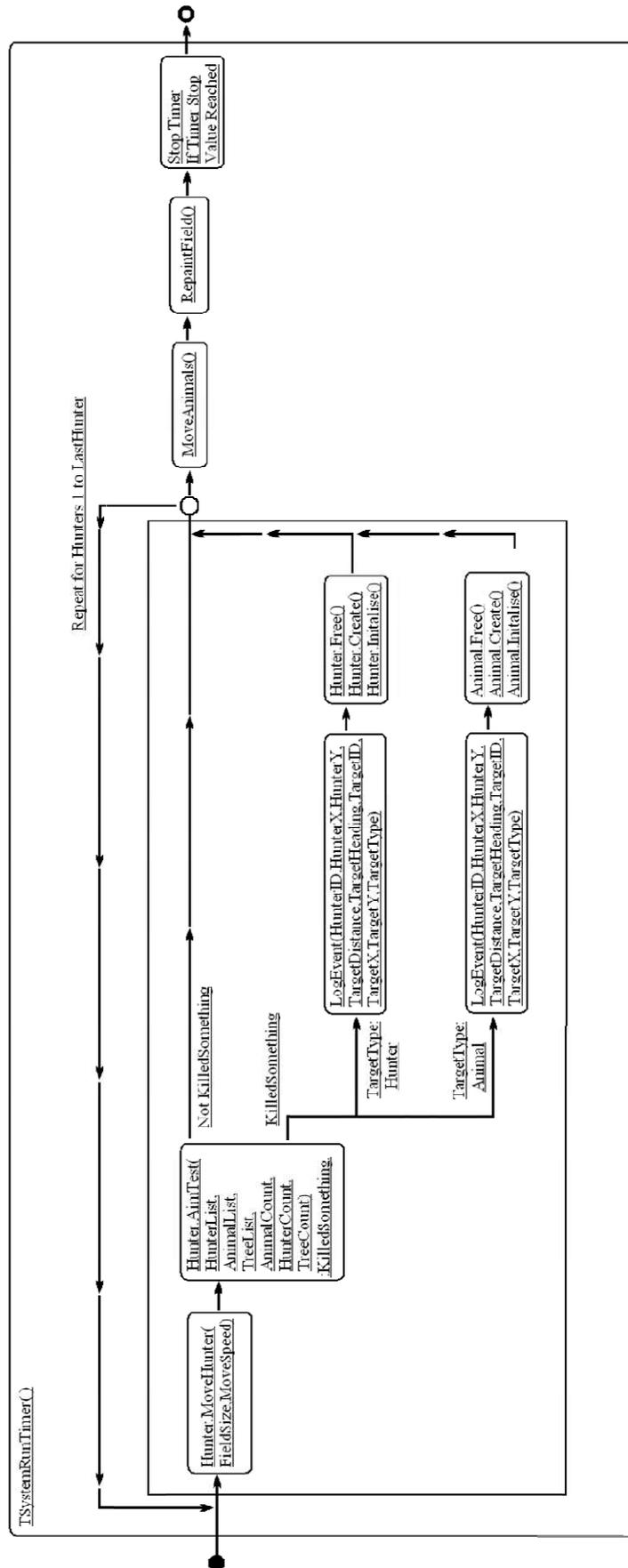


Figure 4.3a: Overall Model Control Process Diagram

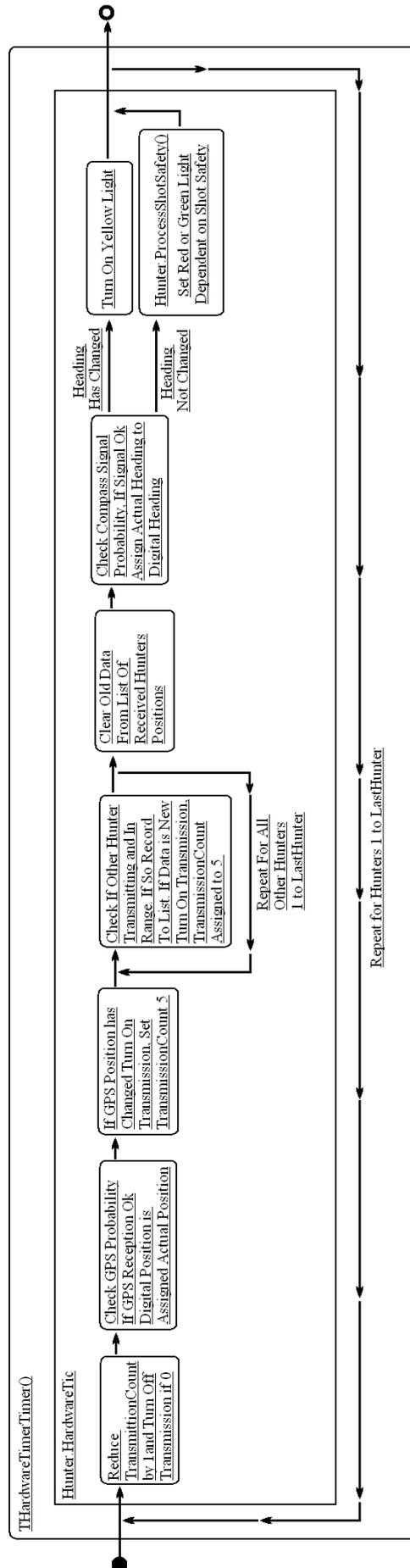


Figure 4.3b: Concept System Under Test Process Diagram

4.4 Network Principles and Interconnectivity

In order to simulate a radio based hunter friendly fire prevention system, code is needed to simulate the radio process. The complexity of this code can vary from some advanced simulations having signal fade around objects and signal strengths calculations for different distances. The code for this model however is much simpler involving point to point, non relaying communication between hunters of position, specifically with rules to determine radio arbitration within a system.

As mentioned this concept has not been extended to include relaying or repeating nodes so the radio is limited to point to point within range communication. Repeating nodes would increase the advantage of this suggested solution however drastically increase the complexity of the research. Before the radio code for the model is discussed in any detail it makes more sense to explain the radio process in the actual hardware to which we are replicating.

The hardware as it would be carried by a hunter operates at a frequency of 433MHz and is an embedded software operated device. In principle the requirement of the radio code is to update other hunters hardware with ones own location. There are two situations where this is required, the first being when a hunter changes his or her location secondly when he or she has received new data from other hunters. These two concepts form the basis of the radio communication rules used and in this way every hunter is made aware of any hunters changing location.

The order of the radio process within the microprocessor involves switching entirely to a listening mode for a duration during a section of its hardware tic cycle. Any data collected from this listening section is recorded in a variable which is used for dangerous shot processing. Another section of the hardware tic cycle checks for any changes in data received either via GPS directly or via Radio. Any new positional data of a hunters own hardware or another hunters hardware requires a simple radio transmission of the hunters own location.

To emulate this within higher level code than used within the microprocessor a set of radio functions were written for the simulation. Exactly like the microprocessor operation the radio will be listened to after checking its own GPS position. This radio listening is done by polling any other hunter within radio communication range (tree zones factored in) and if any of the polled hunters has a currently transmitting flag set, the radio message is passed between units. Alternatively on the transmission side, once a hardware has received any of its own data and other hunters data, if any of this data is new the hunters hardware will set its own "Need to Transmit" flag. The transmission flag is maintained for a few cycles of the hunters hardware to ensure that it is detected. This is different to the microprocessor code however has been done so to allow for many more units to be communicating without problems.

Specifically, in order to include tree zones and animal objects into the radio code two approaches are taken. The first approach is to check for tree zones between two radio objects. This check is performed when the radio code determines that a radio communication is to occur. This tree zone check has a tolerance as checking a direct line between radio objects may miss the centre point of the tree zone. By using this tolerance, tree zones are included that have only their outer perimeter communicated through. The second approach involves checking for tree zones between a target and hunter. This check is performed in order to treat a targeted hunter behind a tree zone, as an animal target. Hunters in direct sight are disregarded as targets. This is a fundamental process to simulate as shooting accidents often occur due to trees blocking a hunter's view of a target.

Interesting to note here is that the timing of the process allows for several hardware tic updates within a single model or simulation update. This is to represent radio and logic processing occurring much more regularly and faster than simulation changes such as animal and hunter position updates. In this way the hardware simulated has time to fully assess the field as it is presented in the data and still has time to settle before field changes occur.

4.5 Model Development

The final version of the application as shown in figure 4.5a has been generated through many versions of itself each containing more features than the last. This final version is the eighth edition of the application. The setup screen on the left side of figure 4.5a is used to enter initial values of parameters of the simulations. The final list of parameters that can be changed has evolved along with the application version.

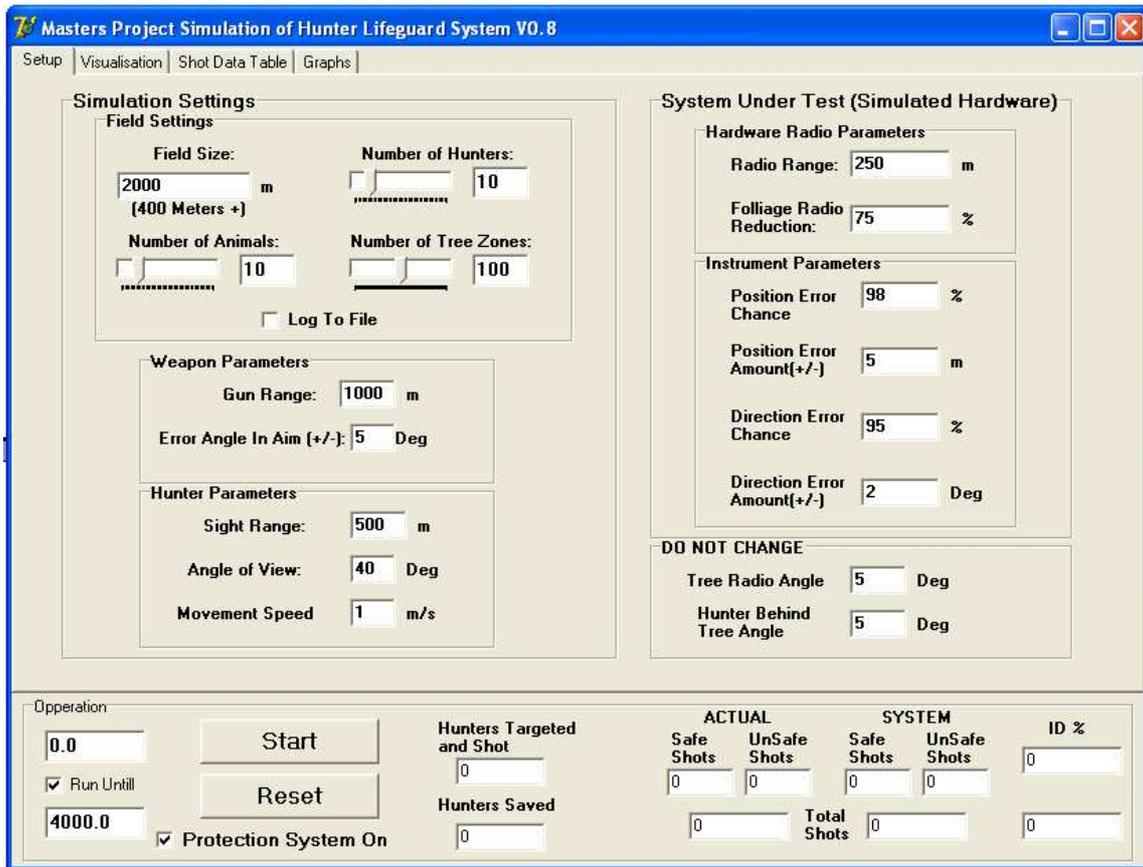


Figure 4.5a: Final Model Application Version 0.8 Setup Screen

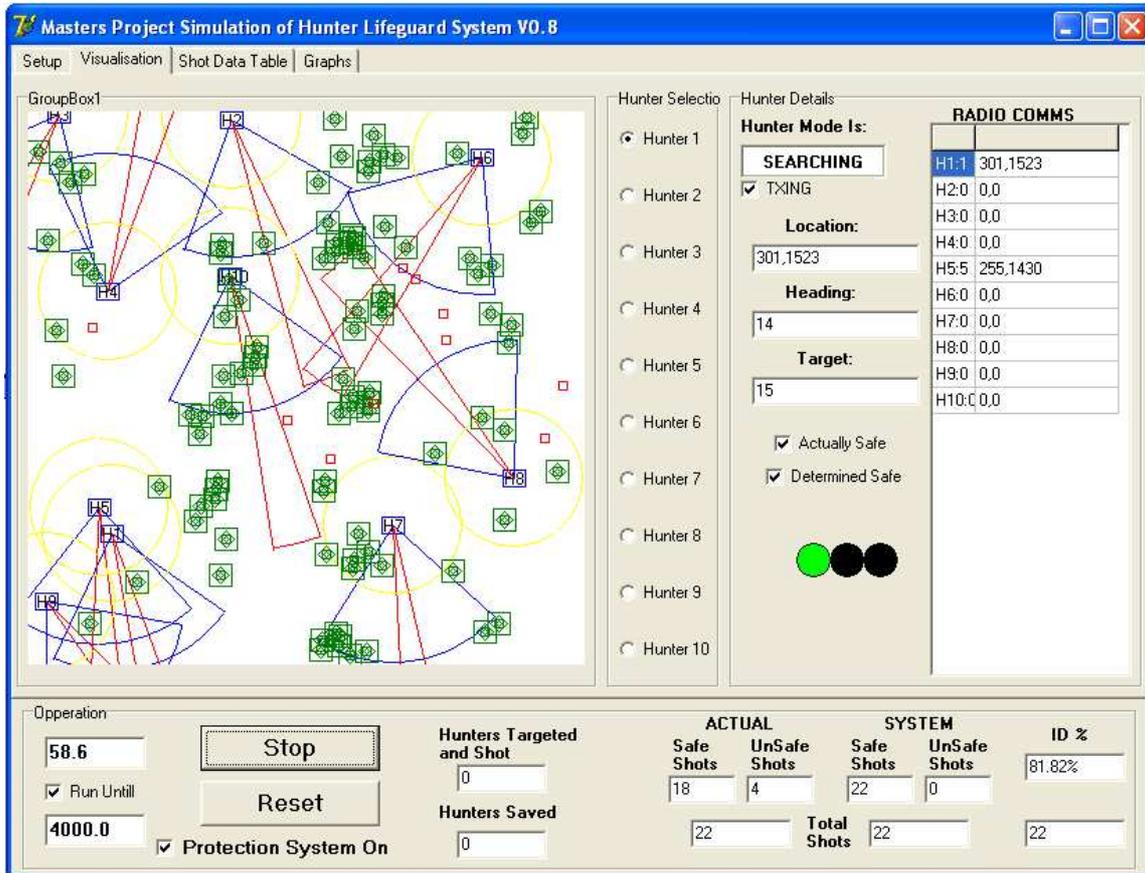


Figure 4.5b: Final Model Application Version 0.8 Running

The right hand screen shot in figure 4.5a and 4.5b shows the graphic of the hunting field during operation. Lights can be seen as three connected circular object, these represent the hunters LED lights mounted within the scope and are changed along with the current selected hunters hardware. The final number of hunters who's data is viewable is ten and the maximum number of possible hunter within the simulation is fifty however original version of the application started with only 2 hunters maximum. Through the different versions of the application the number of hunters was first changed from 2 to 3 in version 0.5 but following this the application was drastically changed from dealing with individual hunters to generically being able to process a hunter n in a list of hunters $1, \dots, n$. Version 0.6 of the application was the first to include number of hunters as a setup parameter to the simulation.

Original setup parameters were hard coded into the simulation however as the application evolved though its different versions different characteristics of the simulation were established into a setup screen. The second version of the application was the first to contain this setup screen and as shown in figure 4.5c. The initial parameters were simply number of animals, number of trees, radio range and gun range.

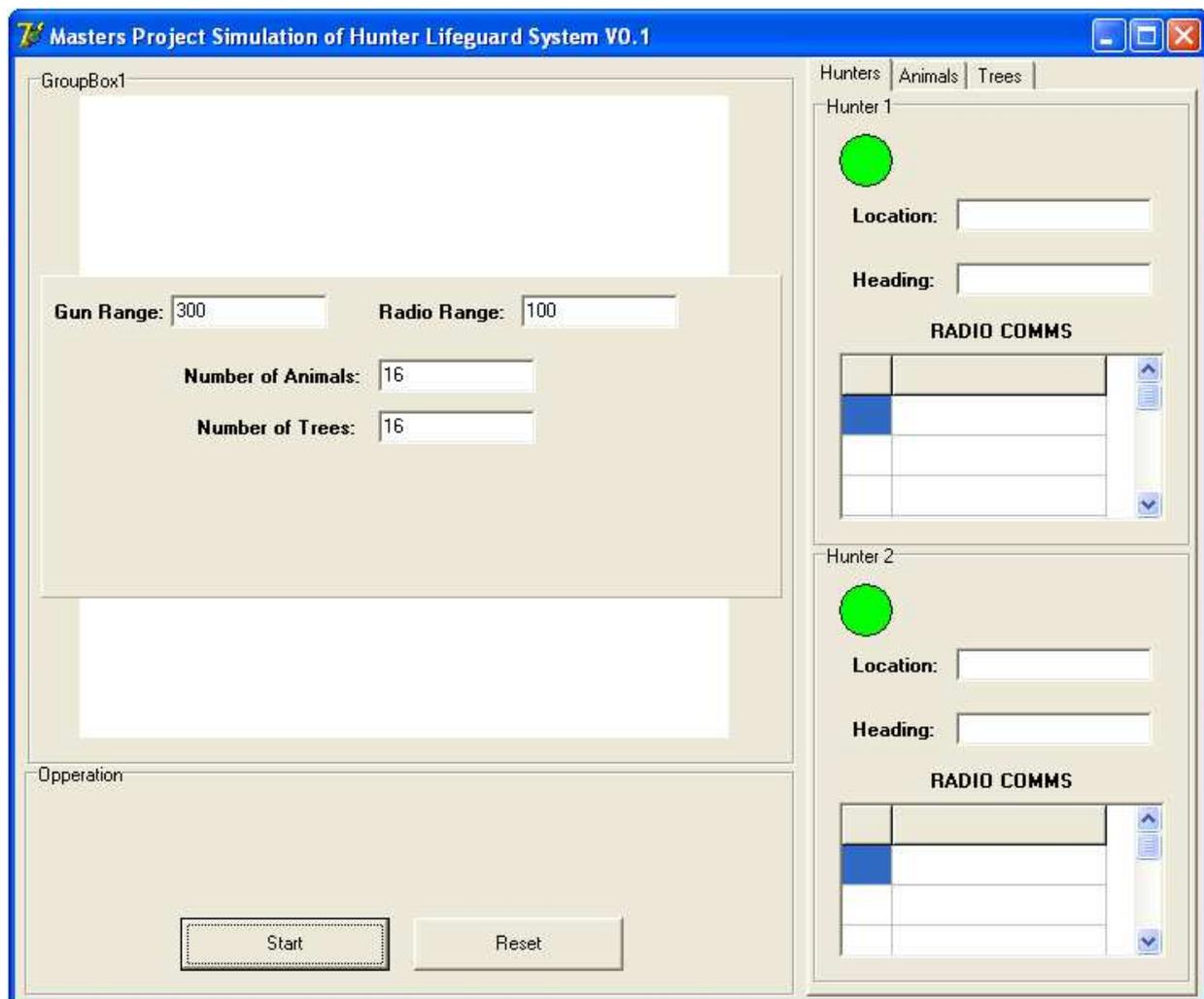


Figure 4.5c : Application Version 0.1 Setup Screen

Part of the reason for the lack of parameters in the original versions is the lack of detail in the simulation. As more detail was incorporated more models parameters can be set. Other parameters added along the way include sight range, sight angle, gun range and gun safety margin as an angle. Some parameters are used to aid in the scale of the simulation such as field size and movement speed however these two parameters were only included in version 0.8.

System reliability setup values such as Compass and GPS reception reliability as a percentage have been added in the final version, along with a tolerance or the size of error input, used when an erroneous signal occurs. There is a tolerance input for both GPS and Compass readings. The radio range is visible at the top of the setup page in figure 4.5a but is now joined with a value for percentage of radio range with foliage interference. A value of 100% here would mean no reduction of radio range due to a tree zone being in between radio units. At the bottom of the setup page are values in degrees for calculating radio tree zone interference and a variance for misidentifying a hunter as a target due to a tree zone blocking vision. These rough values have been established by monitoring the simulation for line of site between hunters during misidentification targeting.

The graphical detail and the movement process of the hunters and animals has likewise progressed with redevelopment of the application. The original version V0.0 simply has a hunter like object moving around a blank field, the second version likewise was simple by having a single arc drawn for view range, radio range and gun range without separation of these properties. It was not until version v0.3 that the drawn yellow radio range arc was introduced to the simulation and separated from the gun and sight drawn arcs. This can be seen in figure 4.5d containing version 0.2 without and figure 4.5e containing version 0.3 with the radio arc. Finally in version 0.6 all three arc, red for gun, blue for vision and yellow for radio, have been included.

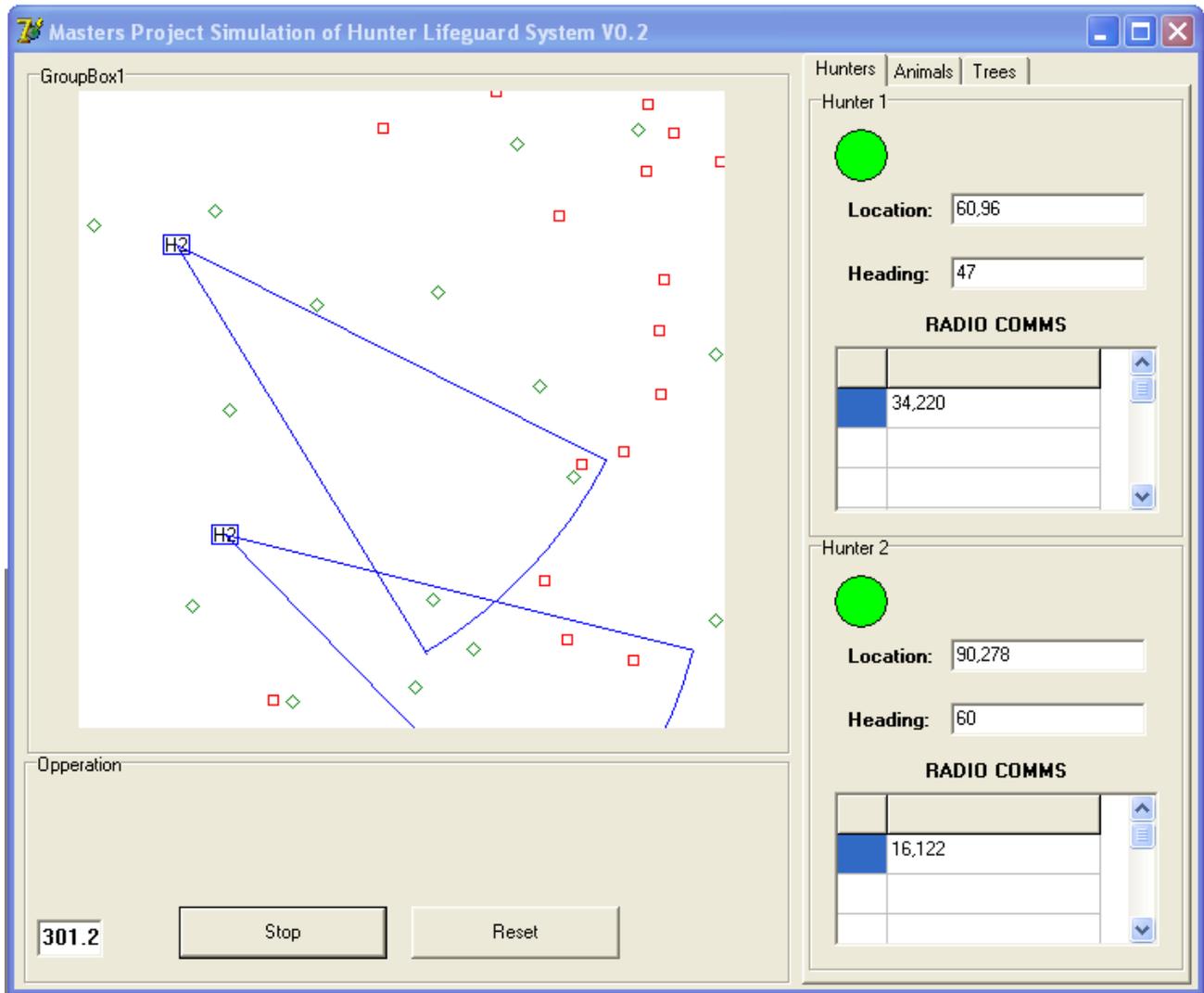


Figure 4.5d: Model Application Versions 0.2 Running

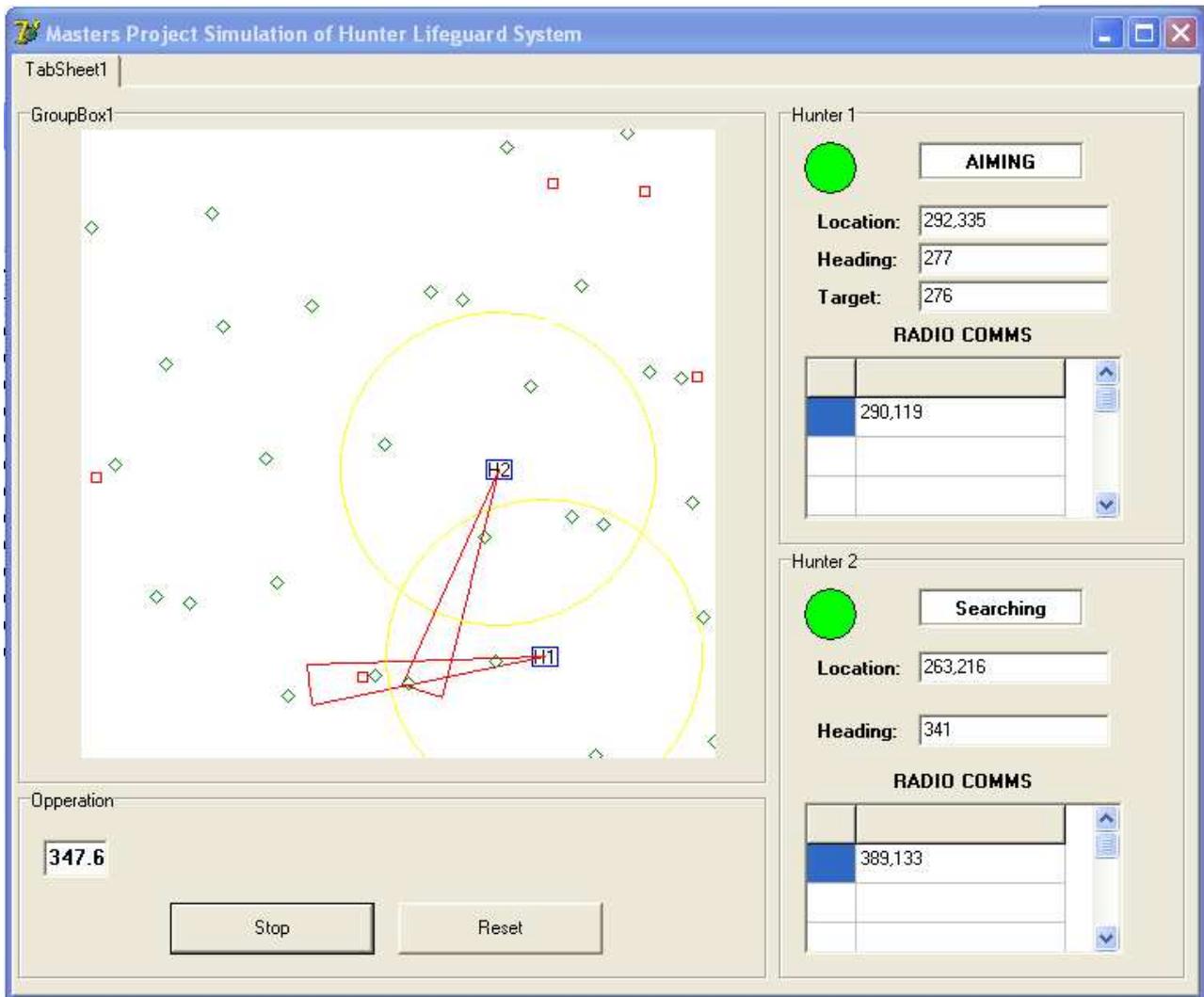


Figure 4.5e : Model Application Versions 0.3 Running

Since version 0.2 of the application a system run timer has been included in the bottom left of the application. This timer value is used in both the data logging and graphic functions of the application. Quickly the desire arose to run the application for a set duration. This was done by way of a "run until" checkbox and an input box for a timer value. These adds are visible in the bottom left of the screenshot of final application version 0.8 in figure 4.5a. Using the same checkbox input method an option has been included to either use the protection system under test or weather to disregard it. The reason for this last addition is to allow for testing of the field properties without influence from any protection system under test.

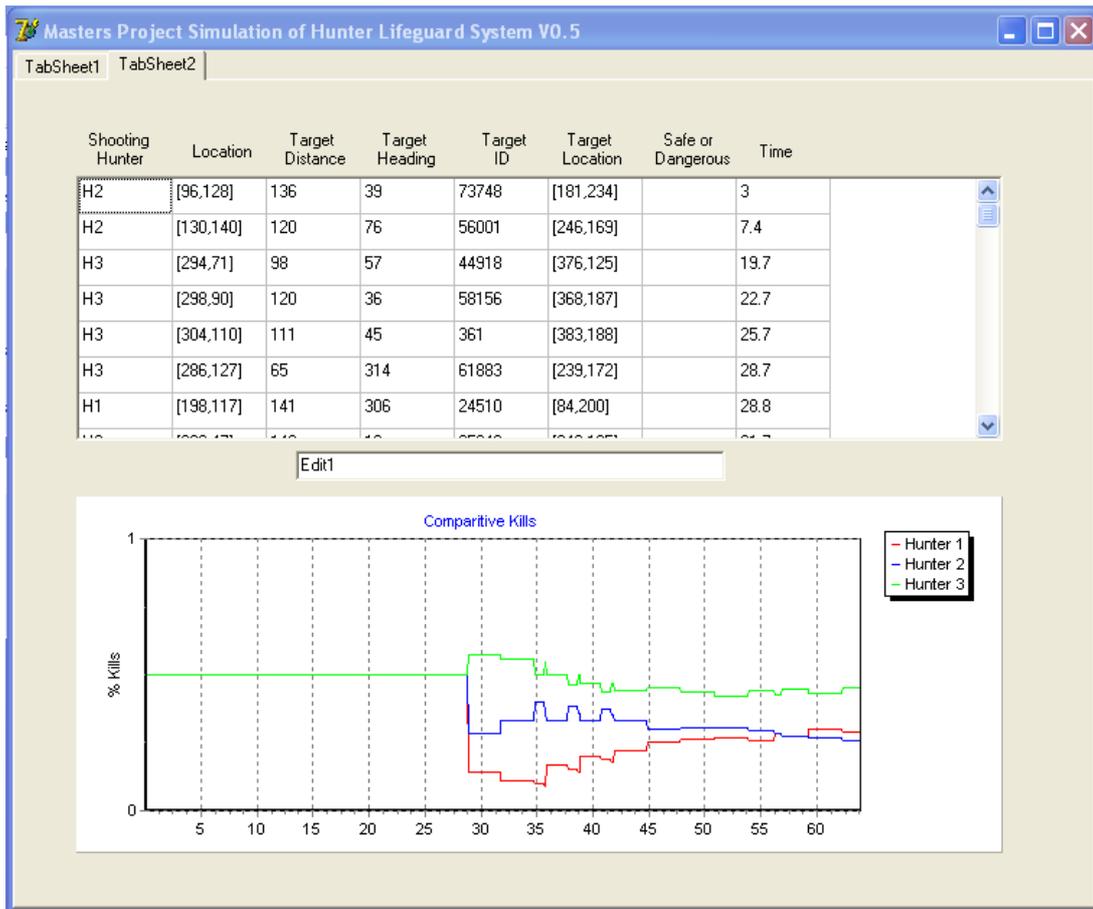


Figure 4.5f: Model Application Version 0.5 Results

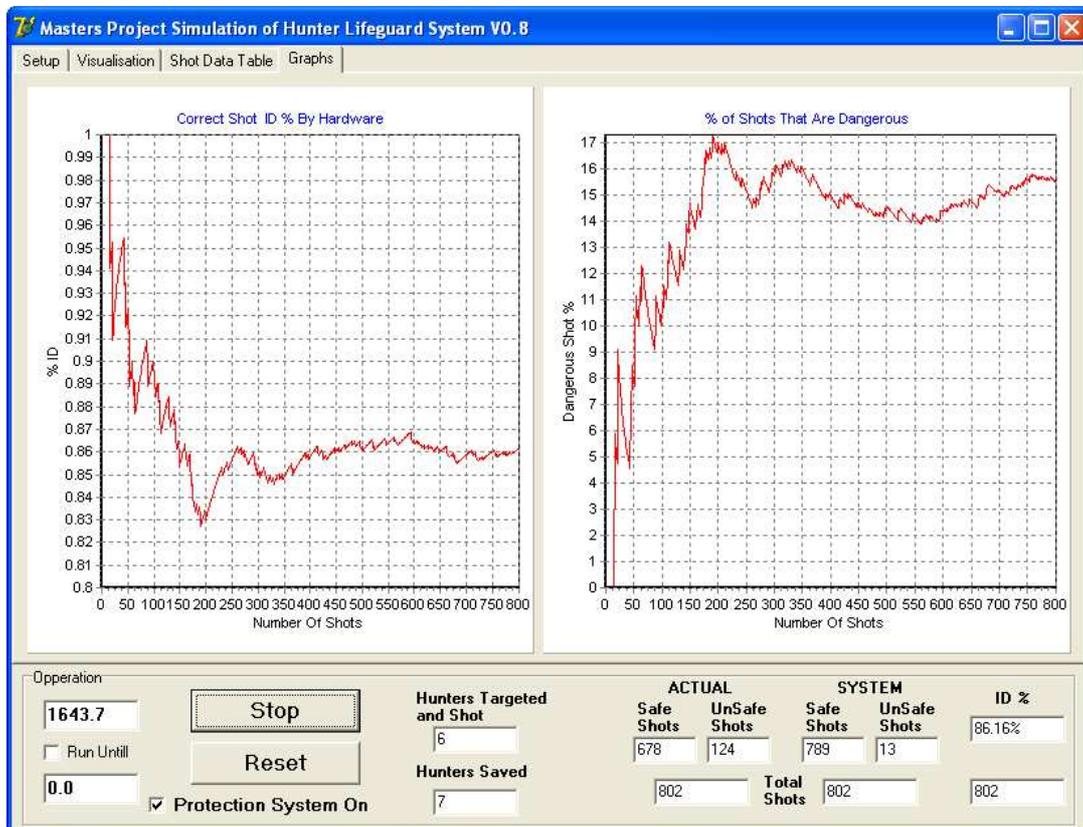


Figure 4.5g: Model Application Version 0.8 Results

An obvious requirement of the simulation is to produce outputs that can be compared against other tested systems. Of the versions of the application, V0.5 was the first to include a graphical chart type option. This graph was originally used to test the number of shots taken by each hunter during the simulation. While any one hunters can lead from time to time, a good simulation over time tends towards an even number of shots for each hunter hinting at a balance of ground coverage and share of animals between hunters. This graphical chart was quickly adapted to graph two properties of the simulation, the first being the percentage of shots that are dangerous and the second being the percentage shots properly identified by the system under test.

4.6 Real Vs. Ideal Modelling

It can be said that nearly all models are developed based on ideal operation and gradually have more complex factors worked into their operation to bring it closer to reality. This model is no different and its development through different versions shows it move from an ideal simulation to a more real one. In original versions of the model some simpler sections of the model such as simulated radio code that originally had infinite range have been replaced in the later versions with an input parameter for radio range. More specifically the gun range, dangerous angle on shot, sight range, sight angle and radio range were represented in a single blue arc in previous versions of the model, the later versions have three independent arcs, red for gun, blue for sight and yellow for radio.

On a more practical basis such factors of the simulation as the field size and the speed of the hunter were originally all left as unit values to match the application development. The Image of the field was 400 pixels wide and tall so the field in code and all the positions of the objects must conform to this 400 by 400 limit. This was unacceptable as it mimicked reality very little. In order to achieve some form of scale, the variable types of all the positional data were changed from integer being a whole number to extended type being a floating point number. Along with this change the field size could now be entered along with hunter movement speed as parameters in the model setup screen. These values along with some smart scaling code maps the position of any hunter, tree zone and animal to a floating position within the field.

Some of the advantages of the change to a variable field size is that now the ranges entered to setup the hunting simulation could now also adhere to this scale. Now able to be entered in Meters, Gun range, Radio range, Sight range and field size are all to scale with one another and to the desired hunting field simulation. Hunters speed, being used for both animal and hunter speed can be a floating point value that is scaled along with clock speed to ensure a correct change in position as time progresses.

It should be noted that even though the hunters movement speed was generated to be in scale to the field size, faster values than what an actual hunter can travel at on

foot are used but this is covered later. In order to achieve a larger number of simulated shots in a shorter amount of time, besides increasing number of hunters and animals within a set field size, the speed of the hunters can be increased allowing a hunter to cover more ground in a shorter time.

Along with establishing proportion within the model other real world effects are desired to be simulated to bring the model closer to reality. Specifically these effects are the reliability of the Position sensing equipment and the Digital compass direction sensing equipment. While these instruments work quite well most of the time there is a desire when trying to estimate the performance of such a system to incorporate or simulate the errors these instruments produce to see how a system would react. In the model the most common error is for the position data to be slightly off position, likewise once a calibration is established for the digital compass the only variance should be a slight error in reported direction. The effectiveness of reception of these wired devices is presumed to be 100%.

Finally in an attempt to produce a more real hunting example with accidental shootings due to mistaken identity, code was added to use the tree zones in the hunters hunting routine. This meant that instead of searching for animals, tracking animals and shooting animals, hunters would now hunt hunters as long as a tree zone object was in-between. Because of the statistical chance of having a tree zone on a strait line between hunters is very low a variance was added to search for a tree zone within an amount of degrees of the heading from hunter and target. As usual to the hunters behaviour the target will be followed for a short time called "Aiming" before the hunter will stop moving and "Shoot". If at any time during this process no tree zone objects exist in-between a shooting hunter and the target hunter then the target will be cancelled and the shooting hunter will return to searching mode. If the target hunter is obscured by tree zone object throughout the hunters process of searching, aiming and shooting then the hunter will be shot.

Adding to the use of tree zones in the simulation is the effect on radio. It's a well known and studied fact that vegetation reduces the range of effective radio transmissions. To incorporate this factor, code was created that like the hunters hunting routine is used to search for a tree zone that exists between hunters when processing radio communications. The detection of a tree zone between hunters within a variance leads to a percentage reduction in radio range between these two hunter objects when radio code is processed. The value used can be changed in the setup parameters.

It is important not to lose focus of the factors effecting the inaccuracy of the model. Part of the error is due to various assumptions in the model operation that were not pushed closer to reality such as the movement of the target animals around the hunting field specifically not reacting to avoid hunters. Other errors in modelling are due to variances in setup parameters such as gun aim error in degrees not being varied as the level of foliage in view changes. Finally it can be assumed that although a large number of

dangerous shot setups are being generated and evaluated, it is an unnatural occurrence to have so many shots fired in a hunting zone in such a short duration. While this over generation of shots varies from reality it does however achieve the desired outcome of pushing a friendly fire prevention method to a measurable and comparable level of results.

4.7 Use of Parameters in Model Initialisation

As mentions through this discussion on the model there are two distinct processes taking place. The model running the hunters and animals and effectively running the entire simulation. Secondly the hunters simulated hardware process is continuously running along side the model. As such in order to both change the setup of the model to be run as well as the important data of the system to under go testing. The setup screen of the final test edition of the model can be seen in figure 4.7.

Figure 4.7: Final Model Application Setup Screen With Values

The two different sets of setting fill the left and right side of the model. The left hand side contains model setup parameters including the field size and numbers of animals, hunters and tree zones, also weapon parameters and hunters parameters. The right hand side have setup values specific to the system or hardware simulated. These include Radio Parameters and Digital Direction and Position Equipment Parameters. Finally the last values labelled "Do not change" are used to govern the variance on tree zones being within radio perception and the variance of hunters view being blocked when

hunting other hunters. These values have been determined from tests and are based on the size of the tree zones.

As mentioned earlier and detailed in the result section the simulation settings for any run of the model can be varied to generate more or less dangerous shots. By changing sight range, field size and number of hunters and animals we can effectively create a room with 100 blindfolded hunters shooting randomly. It is not the intention to push the model to these extremes. However, the larger number of shots that are properly identified the better the system so the larger the number of shots taken the better the test data.

The hunters parameters including sight range and angle of view change the ability of the hunter to detect a target as he patrols. Increasing the view angle to 180 degrees would simulate a hunter that can see perfectly sideways at distance with the same quality he or she is able to see looking straight ahead. A more realistic view angle such as 40 degrees is used to generate a relatively large field of view in front of the hunter in which targets are detected. Also to remember is that the hunters view arc randomly sweeps left and right as he moves around the simulated hunting field.

4.8 Desired Model Outcome

The original desire for the model output was to produce text files as can be seen by the log to file checkbox provided in the application. While this was effective it did generate a long list of shooting situations as can be view in the text table within the application during a models operation. This list would involve post test processing in a spreadsheet application such as excel to quantify results. Due to the adaptability of the package used to generate the model it was possible not only to place more onscreen displays of running statistics but also to generate a graph page containing the two specific graphs that were of interest.

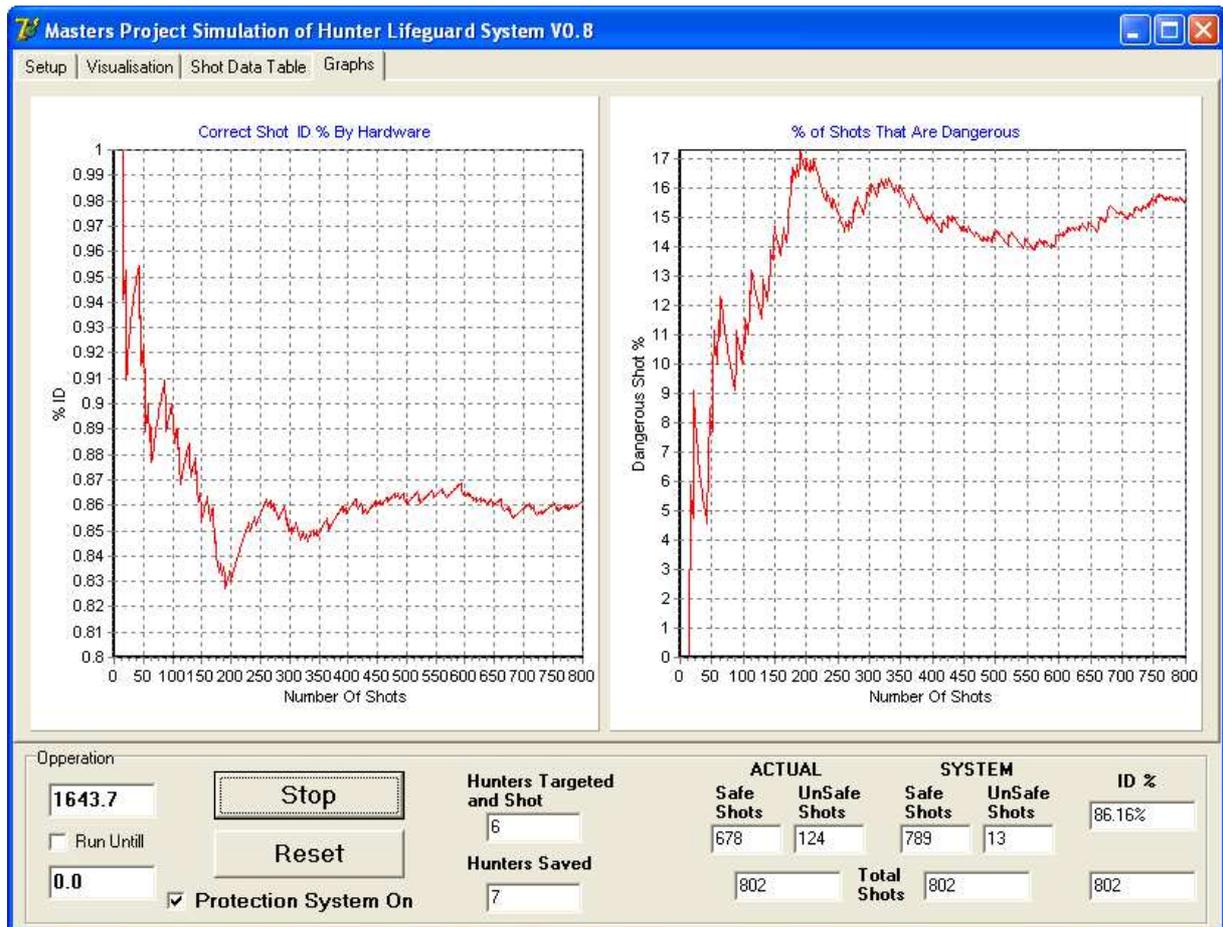


Figure 4.8a: Final Model Application Output Graphs

In the screen shot that is figure 4.8a, the two main graphs as well as the informative output text boxes at the bottom of the screen can be seen. The graph on the right is primarily to understand the current field setup. As shown in results when choosing to setup the model tests different field properties generate a different percentage of dangerous shots over time.

The left hand graph in figure 4.8a is more important for the system under test results. This second graph is used to show the correct shot identification percentage. The value here is the number of shots that the system under test determined the safety level of correctly, as a proportion of total shots taken. An example of this would be if ten shots were taken, nine of these shots has the safety level of reality and system modelled the same however the tenth shot was actually unsafe but has been determined by the system under test as safe, then the system would have a 90% correct shot ID rate.

As a measure of output the primary calculation shown in the right graph in figure 4.8a is a measure of the percentage of shots taken by all hunters simulated that are dangerous. This percentage is gained simply by dividing the number of shots that are actually dangerous by the total count of shots taken. This percentage is based on the field setup and has no reflection on the hardware or prevention method under test. The left hand graph in figure 4.8a shows the number of shots correctly identified by the system

under tests. This percentage reflects all four possible determinations shown in figure 3.1c. The specific calculation involves taking the number of shots with a mismatched safety determination between the system under tests and the models reality and dividing this number by the total shots taken. Post modelling data processing will be used to gain a final figure of amount of dangerous shots correctly identified by the system.

Contained within the edit boxes at the bottom of the application are a few text readouts of a few different readings within the system. These readings contain, Number of actual safe shots, number of unsafe shots, total number of shots, number of hunters shot behind a tree or hidden from view, number of hunters aimed at but not shot due to safety system under test. The most important of these text readouts is the Hunters Targeted and Shot and the Hunters Saved. This is a direct tally of the number of hunters that were mistakenly targeted and ether shot or saved by the friendly fire prevention logic programmed into the model.

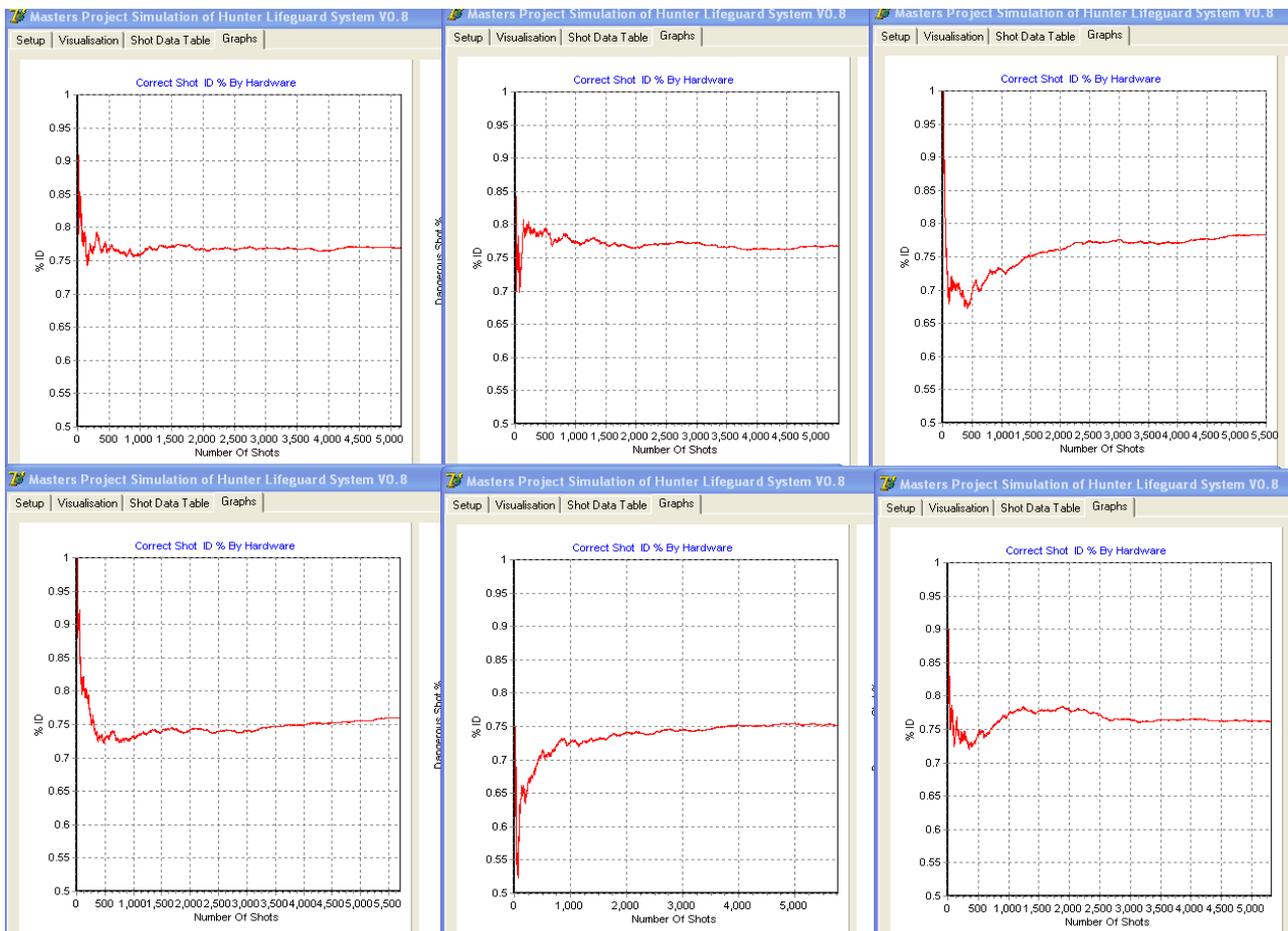


Figure 4.8b: Multiple Percentage Correct Shot ID Output Graphs

5.0 Hardware Implementation

Besides the generation of a model to test the concept it is important to gain insight into how such a concept can be converted into hardware. By doing such, it is also possible to incorporate data gathered from hardware field tests which will aid in bringing the generated model application closer to reality. This chapter details an embedded example of how the concept would be produced into a real system. Support is also given to the methodology of friendly fire prevention used within the model proving the possible real world operation of such a concept.

5.1 Generation of an Example Hardware Node

In order to demonstrate the possible functionality of an electronic friendly fire prevention system, a prototype system has been generated. This prototype system or example node is used primarily to test the functionality and limitations of the various hardware elements comprising this system, however this prototype also allows for the testing of a simulated completed unit to demonstrate proof that this is a viable concept.

If we again look at a system overview we can see the required hardware elements but also the specific hardware chosen for each function and its position within the system, (for now the connectivity has been left out with arrows showing an interaction):

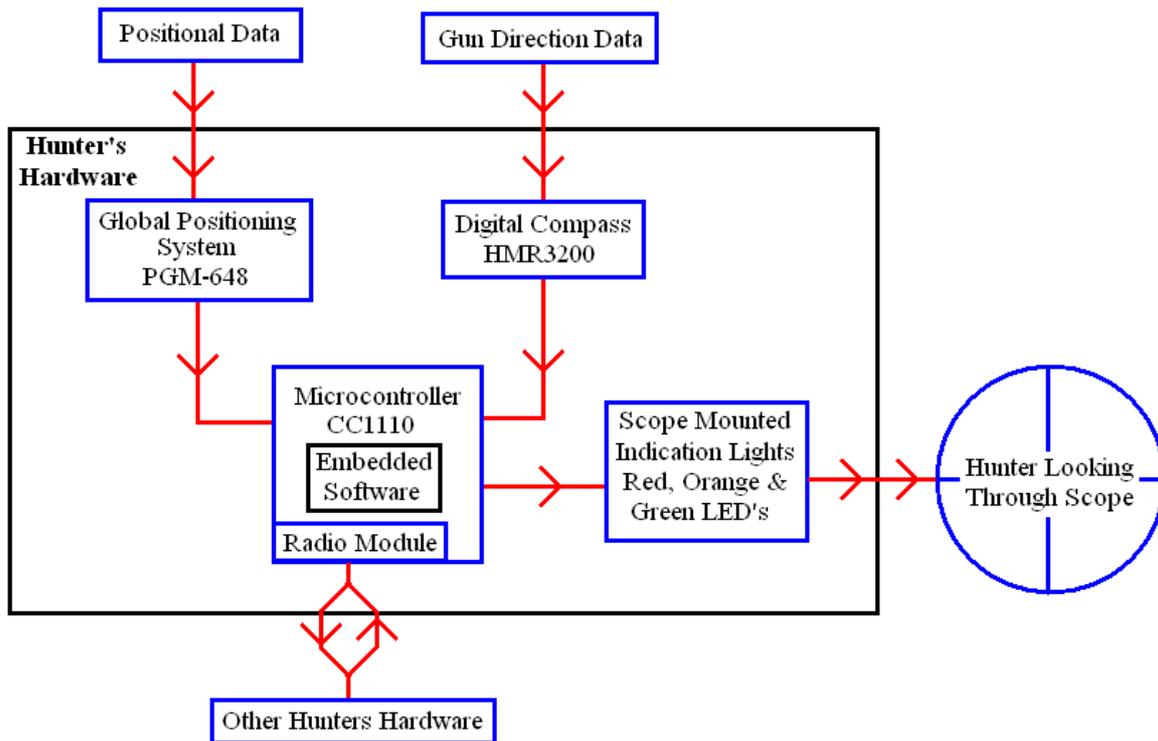


Figure 5.1: Concept System Hardware Overview

In figure 5.1 the four elements of the prototype system are clearly shown. Firstly the microcontroller is at the centre of the diagram, the second and third constituent parts are the global positioning system and digital compass shown at the top of figure 5.1. Finally the fourth element, the Indication lights, is shown to the right of the diagram. The connectivity of the elements along with the direction data is shown, giving completion to the plan for an example node.

5.2 Hardware Block Diagram

An overview of the hardware layout without specific detail on the communication protocols would be as shown in figure 5.2:

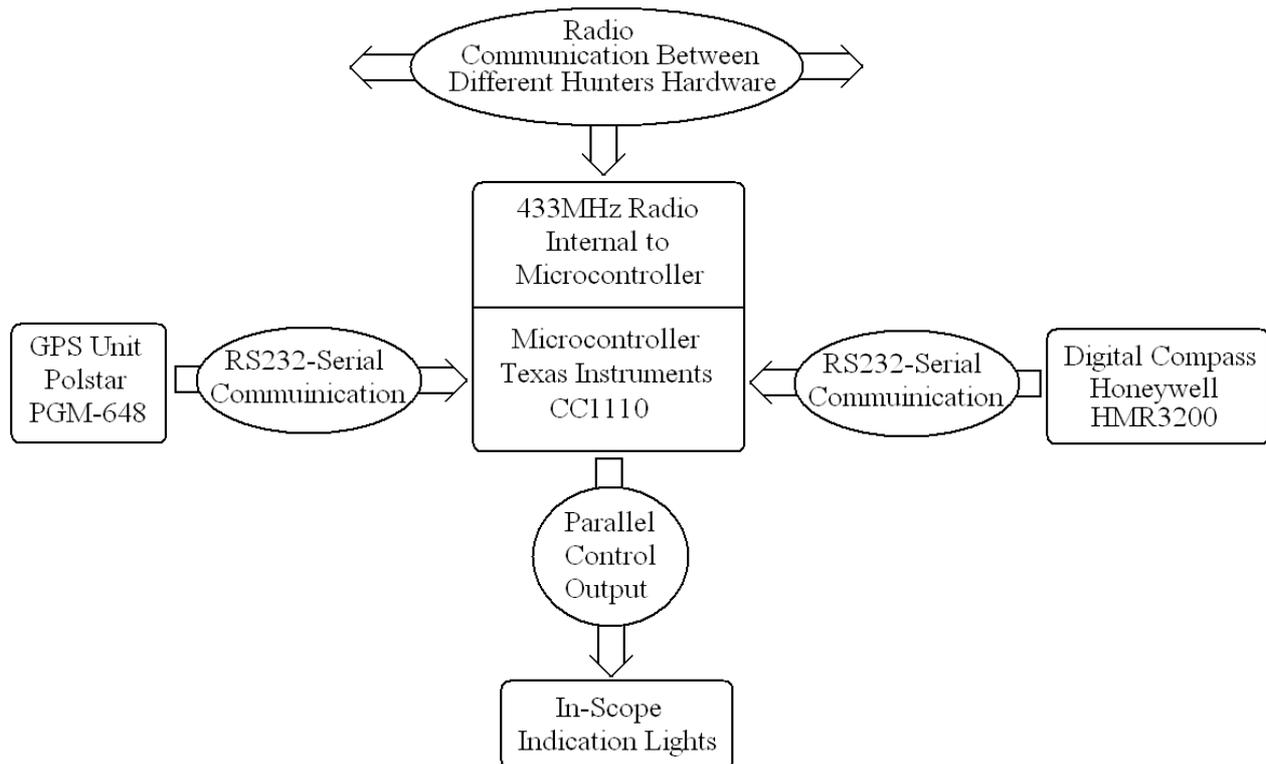


Figure 5.2: Concept Hardware Interactivity

In the above block diagram the various hardware components selected are shown along with the interaction between these elements of the system. As an overview it can be seen that the microcontroller in the middle of the diagram receives data from the Digital Compass and from the GPS unit by way of serial communication, it can also be seen that the microcontroller controls the In-scope Indication Lights by way of a parallel control lines.

The microcontroller receives nothing from the scope indication lights and likewise the Digital Compass and the GPS unit are not controlled by the microprocessor. This is why all the communication arrows in the above diagram show communication in a single direction. The exception to this would be the communication from the radio transmitter which is used to both send and receive data between different hunters systems within range.

As mentioned in the System Overview chapter earlier, the underlying function of the hardware is to first become aware of its own location but to then share this information with other hunters systems and to gather a list of other hunters locations. This is achieved via radio communication. Again in the middle of the above diagram both the microcontroller as well as its radio segment can be seen as a single entity. It should be noted that the radio module is an internal part of the microprocessor and hence no connection is shown as all radio usage is handled inside of the embedded software.

5.3 Hardware Interfaces and Protocols

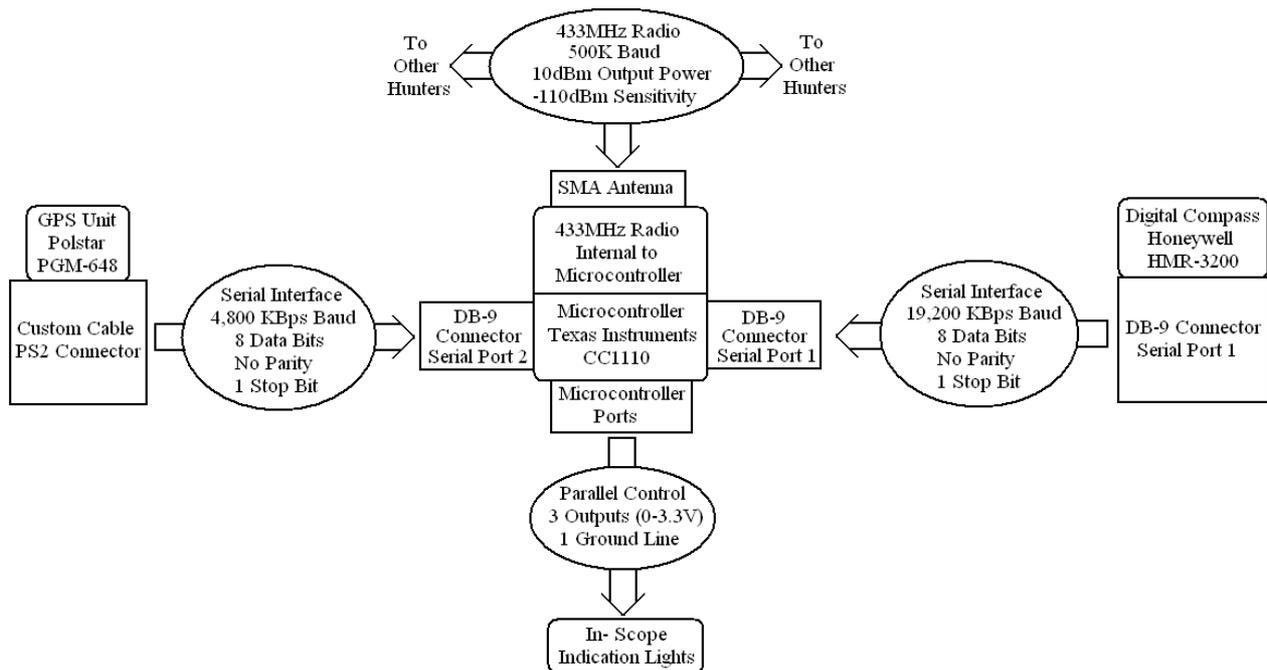


Figure 5.3: Concept System Communication Details

In figure 5.3 the interfaces between the hardware elements have been refined. Each section of hardware now has its interface type connected to it as well each actual interface having the specifics of the protocol used. It should be recapped at this point that the reason for segregating each of the hardware elements and connecting them via cable in contrast to building all onto a single printed circuit board is to allow for the swapping of the components to test different hardware. Another reason for this is that electromagnetic and magnetic interference between the hardware elements would be possible.

The GPS Unit on the far left of the above diagram, is connected to the microcontroller via serial communication however its connection is a PS2 port on a custom cable connected to the GPS unit. To connect this to the DB9 serial port of the microcontroller an adapter was fabricated. The functional pins of the PS2 interface are identical to a simply RS-232 connection with the important pins being Transmit, Receive and 0V or Ground. The format of the text messages passed between the GPS unit and the Microcontroller are NMEA which stands for National Marine Electronics Association. NMEA messages follow specific formats depending on hardware. Here is a list of the most common NMEA string formats:

\$GPGGA (Global positioning system fix data)

This first output string is one of the more commonly used with Latitude, Longitude, Altitude and Number of Satellites in view.

\$GPRMA (Navigation data from present position)

This output string in a simpler version on \$GPGGA containing Latitude, Longitude, Number of Satellites and Vertical Position above sea level as well as some simple movement readings like speed over ground and course over ground.

\$GPGSA (GPS operating mode, Satellite View 7 DOP values)

This more complex string output contains information on which satellites are in view and Dilution of precision on satellites data.

\$GPGSV (Specific Satellite View, PRN number and Signal to Noise Ratios)

This is a more detailed satellite data string containing satellites ID's, Signal to Noise Ratios, Azimuths and elevations.

These are just a few of around 30 different output strings, all of which start with the prefix \$GP. Which strings are outputted is specific to the hardware, Specifically the PGM-648 outputs the following strings: \$GPGGA, \$GPGSV, \$GPGSA, \$GPRMC and with \$GPVTG and \$GPGLL optional. For the purposes of this application the only required data is latitude and longitude leading to the \$GPGGA string being the simplest to use.

The desire of this research project is for hardware to be able to determine its current location and to be able to receive and transmit position data wirelessly. For this purpose some of the GPS protocols are unusable. Firstly time and date specifics are not required such as available in the ZDA format. Also vector information such as course over ground and ground speed provided by the VTG format are again not needed. GSV and GSA are specific formats for satellite discovery with information like satellite direction and elevation all of which is information we will not need. The remaining protocols are RMC, GLL and GGA. Of these remaining 3 protocols RMC and GGA are larger message/packet sizes including information such as altitude above sea level and velocity. This information again will not be needed in a prototype system for research processed so the best matching protocol for this application would be the GLL format.

The GLL format specifically has information about latitude, longitude and message validity. This is one of the shorter more simplistic GPS data formats and will best suit this research requirement by minimizing the data to sort through in order to decipher a numerical representation of position.

The digital compass data as described in the system overview chapter, is used to measure the current heading of the gun. This value is used in the calculation of shot safety to which the output indication lights are based. The digital compass in figure 5.3 like the GPS has its communication properties described. Unlike GPS the data from the compass is much simpler in essence being that it simply transmits a compass bearing from 0.0 to 359.9 degrees. This short string is repeated in a quick loop. Also unlike the GPS the

connection has a DB-9 serial port on both sides meaning a standard serial cable can be used to connect the two sections of hardware.

Connecting the Microprocessor to the output indication lights built into the scope, are 3 parallel control lines coupled with an earth or 0V wire. This setup allows for either a red, green or orange light to be activated individually or concurrently. For the purposes of this application the lights are only used individually. The 3 control lines are fed directly from the port of the microcontroller and are controlled via the embedded software.

The radio module although completely internal to the microprocessor still relies on an SMA 433MHz antenna as well as a Balun circuit to interface with other hunters systems. More specific details on the radio setup and usage can be seen in the embedded software chapter following.

5.4 The Circuit

The Circuit that was designed is intended to add functionality to the wireless microprocessors motherboard shown in the figure 5.7e. The motherboard also known as the CC1110 Evaluation module contains all the required radio and external crystals required for the processor to operate and send radio messages. Two, twenty way ports connect the bottom of the Evaluation module to any desired daughter board. One such board comes with the development kit and is the SmartRF 04EB board which acts as a base interface board for a range of peripherals and allows for direct radio testing with a liquid crystal display screen.

The produced daughter board has little functionality other than what is required for the application. Primarily they supply power and reset functionality to the motherboard but dominating the circuit is the two line driver chips used for the dual serial communication ports. Unlike the SmartRF development board the intended circuit is required to receive information off two individual serial devices. Figure 5.4a is the circuit diagram generated for the task:

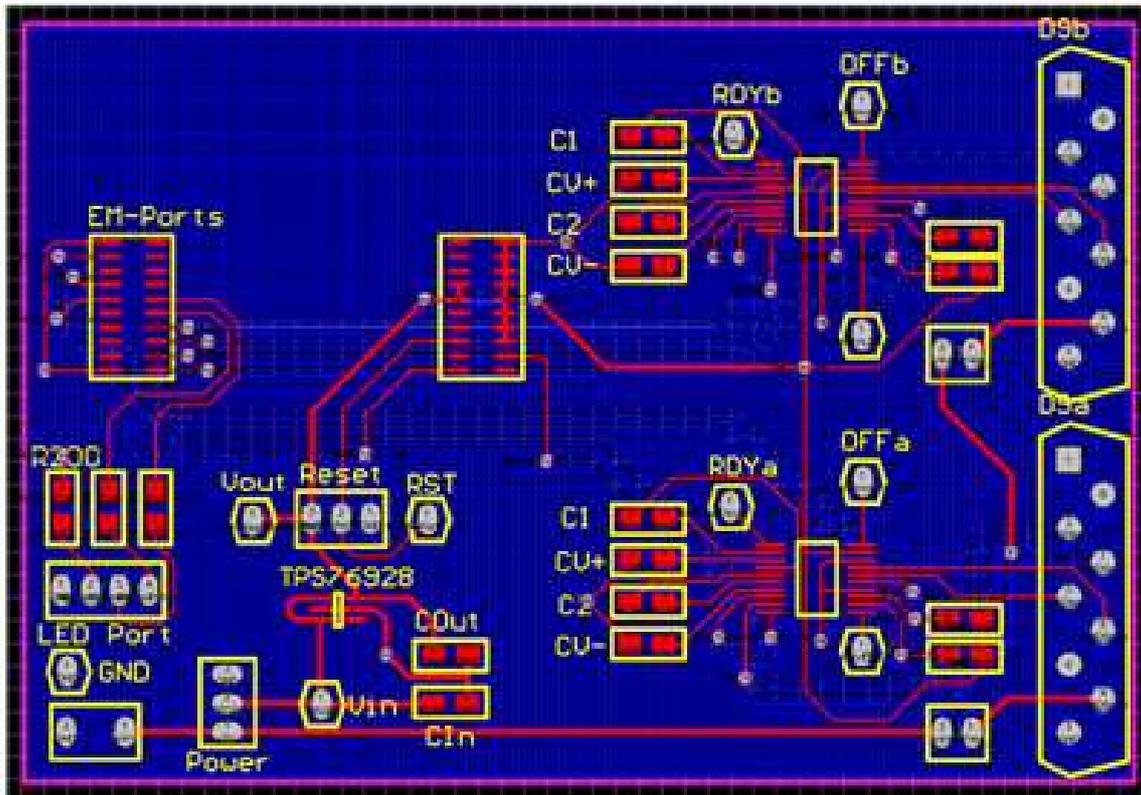


Figure 5.4b: Printed Circuit Board Design

The printed circuit board as usual looks very different to the schematic in terms of representative sizes of the components. Due to use of Surface mount technology for this build the components are much smaller. On the right hand side are two large DB-9 shaped connector outlines are the output solder terminals for the serial ports used. The top left of the printed circuit board has the two twenty way connectors on which to mount the Evaluation Module motherboard holding the processor. The largest feature on the printed circuit board are the test points and switch soldering points, these are the only other silver through hole components to be used. The LED port to connect the indication lights is on the left hand side just under 3 surface mount resistor pads and above the ground test point.

Hardly visible now are the integrated circuit chips, the power supply is extremely small and has been placed below the reset switch. The voltage regulator's surface mount capacitor pads are visible down and to the right of the reset button and voltage regulator and are called "Cin" and "Cout". The power supply chip is specifically a Texas Instrument TPS3319 and produces a fixed voltage output of 3 volts. Pin outs for the chip are identical to those of most power regulators in that there are the minimum three connections, Voltage in, Voltage out and Ground.

Finally in the middle right are the line driver chips used to facilitate the serial communications. The yellow outline of these integrated circuits can be seen clearly with a spider nest of red tracks leading away. Just to the left of the line driver chips are the eight

capacitors stacked vertically, four are needed per line driver chip. The line drivers are specifically MAX3318 line driver IC's produced by Texas Instruments. With low power consumption these chips work off of a 2.5 to 3 Volt supply. These line driver chips are very similar to others used in that the required connections are a few enable lines, power and ground, the four lines to drive in and out and the leads for four capacitors used to generate the line driving voltages.

5.5 Embedded Software Specifics

The software generated for this application is designed to be programmed into the CC1110 motherboard that will be then run while mounted to the daughterboard. The code is generated using IAR embedded workbench and uses the Embedded C language. Code structure is fragmented with each hardware element having its own C file and Header file for ease.

The first serial interface that was used is USART 0 in UART mode and was connected to the GPS receiver. This port set in its original configuration as in it is to be assumed to be Alternative 1 out of 2 and will use the pins P0.2, P0.3, P0.4, P0.5. This port will be used at 4.8kbps and will use 8 data bits, 1 stop bit and no parity.

The second serial interface USART 1 was configured slightly different due to its use with the digital compass and the need to not overlap with USART 0. This second USART 1 was set in configuration 2 of 2 and used the pins P1.4, P1.5, P1.6, P1.7. The baud rate for this port was 19.2kbps and with the same data format of 8 data bits, 1 stop but and no parity.

The radio code used was largely kept the same as the original Texas instruments example code. This is due to the large number of registers and flags required to be setup prior to radio usage. Another specific challenge is that it is suggested that DMA channels are used to read and write out of the radio buffers, this code again was not overly edited from the example code however was cut down in functionality to fit the required task at hand. As mentioned through the rest of this thesis the frequency being used is 433MHz.

The control of the LED scope lights was done directly through ports P2.0, P2.1 and P2.2. These ports were set in the general IO register as being outputs and are from that point controlled by statements that directly assigned to the port bit.

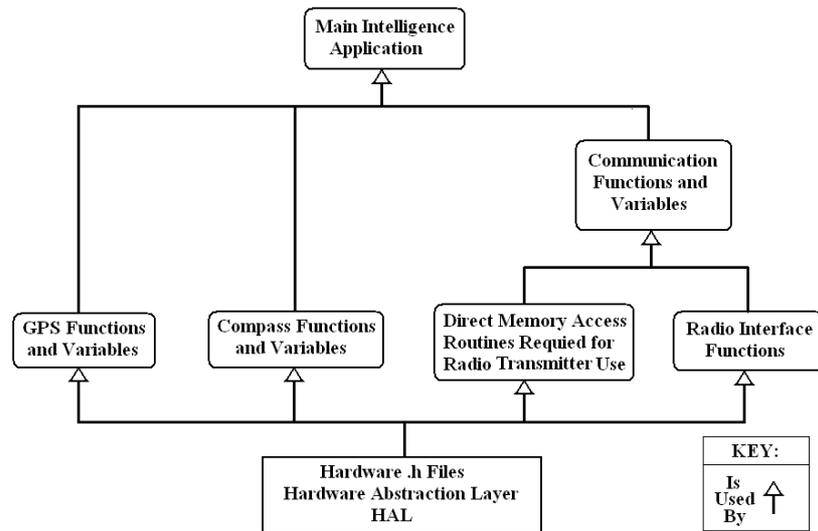


Figure 5.5a: Embedded Software Structure

The specific programming layout of the embedded section of this project can be seen in figure 5.5a. The functional sections of hardware have become the entitling section of code. From bottom to top of the diagram we can see the lower levels at the bottom containing most of the hardware abstraction layer. This bottom collection of header files contain the majority of the definitions of hardware bits and registers to be used in the code. The next layer up or the middle layer of the diagram shows the hardware functionality layer where C files written to handle the GPS, Compass, DMA and Compass are contained. While the GPS and Compass C and header files have been generated from scratch the radio code is a composition of generated and used example code.

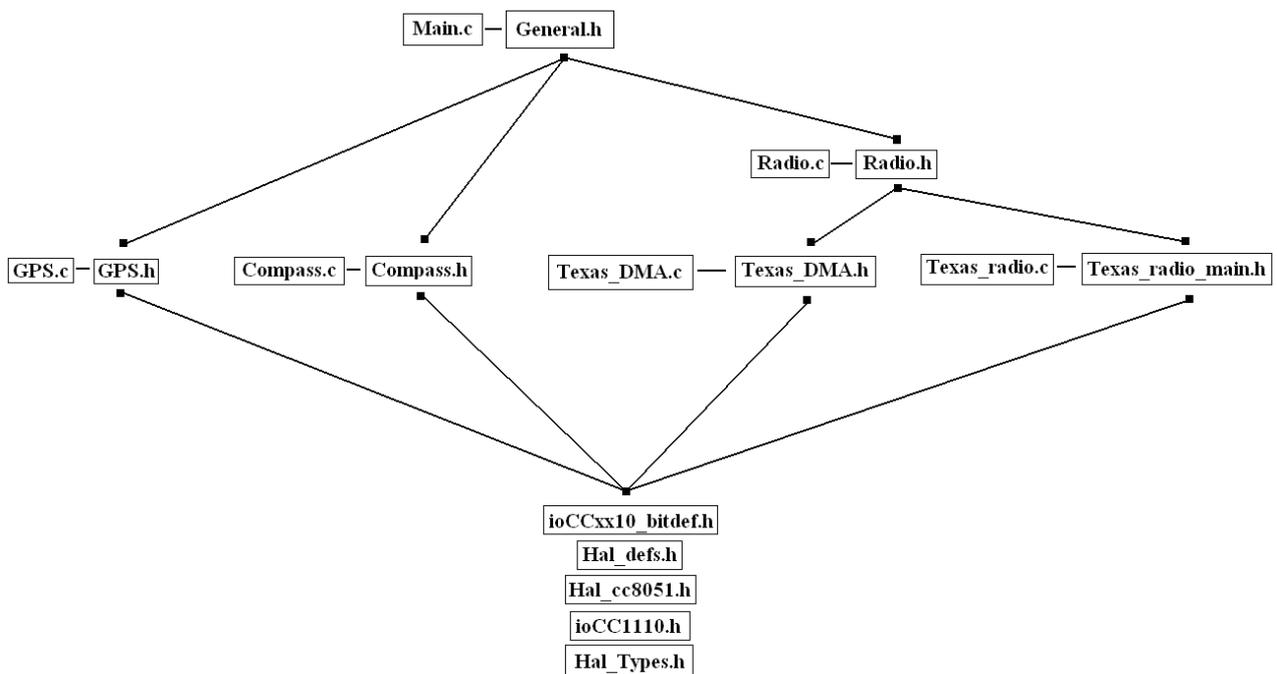


Figure 5.5b: Embedded Software File Linkage

The Texas DMA c and header file were used from example code however had been cut down in size from the original multi-chip support to only code that is specific to the CC1110 processor used. Likewise the lower level Texas radio C and header files are from the example code and contain the radio configuration commands and register settings. The radio C and header files above those provided by Texas Instruments were written from scratch and like the GPS and Compass files, provide radio functionality to the main program code.

The highest level of the diagram in figure 5.5b the Main c file is visible. This is accompanied by a simple header file called general.h that declares global variables needed in more than one section of code. The main code who's functionality is detailed in the next section, uses all the hardware functionality files provided in the middle section of the diagram. The GPS.c and GPS.h files contain GPS hardware initialisation and sample functions that return a GPS value to the main code. Likewise the Compass.c and Compass.h files provide Compass initialisation functions and Compass value sampling functions. The functions contained within the sample radio code provided allow for initialisation of the radio and DMS where as the radio code written has a function for the transmission of a location and a function for the reception of a location.

5.6 System Block Diagram and Explanation

The easiest way to understand how the embedded code works is to look at a state diagram to describe the process and in which sections of code most of its processing time is spent. A very basic representation of the process would be as shown in figure 5.6a:

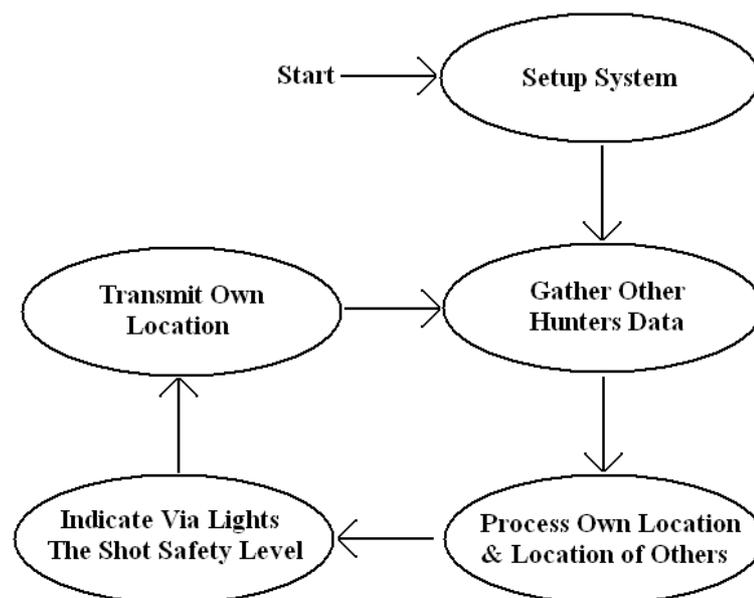


Figure 5.6a: Concept State Diagram

The concept behind the system starts with the initialisation code for the hardware. After the hardware is ready the code gathers data from the devices connected such as the

radio, compass and GPS. This data is then processed and the outputs being the indication lights are set accordingly . Finally the position of this hardware is sent via radio. If we are to add more detail to the process then figure 5.6b could be produced:

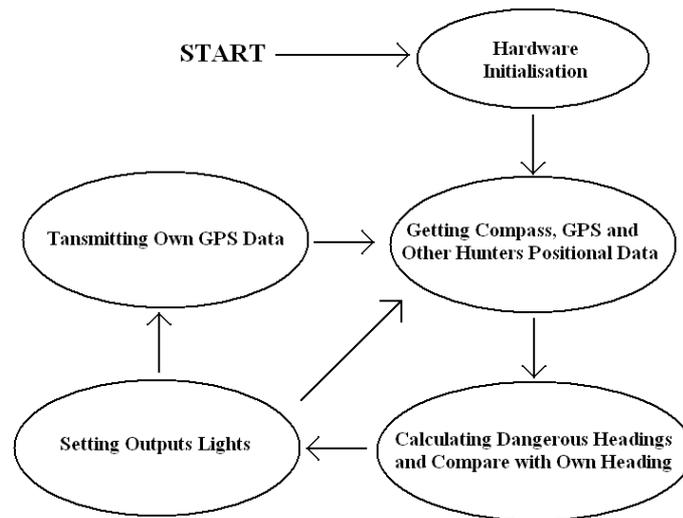


Figure 5.6b: Embedded State Diagram Minimal Detail

In diagram 5.6b it is clear to see the basic requirement of the embedded code. A new arrow has been added to this diagram allowing the transition from setting the output lights to the getting of new data. This transition forms the basis of the radio rules allowing the option to not transmit ones own GPS data to other hunters if no new hunters are within range and if the GPS data of the processing unit has not changed. The final diagram shown in figure 5.6c is a state diagram of the entire code with each of its exact processes shown as well as the simple functions of each stage to give an indication of time requirements.

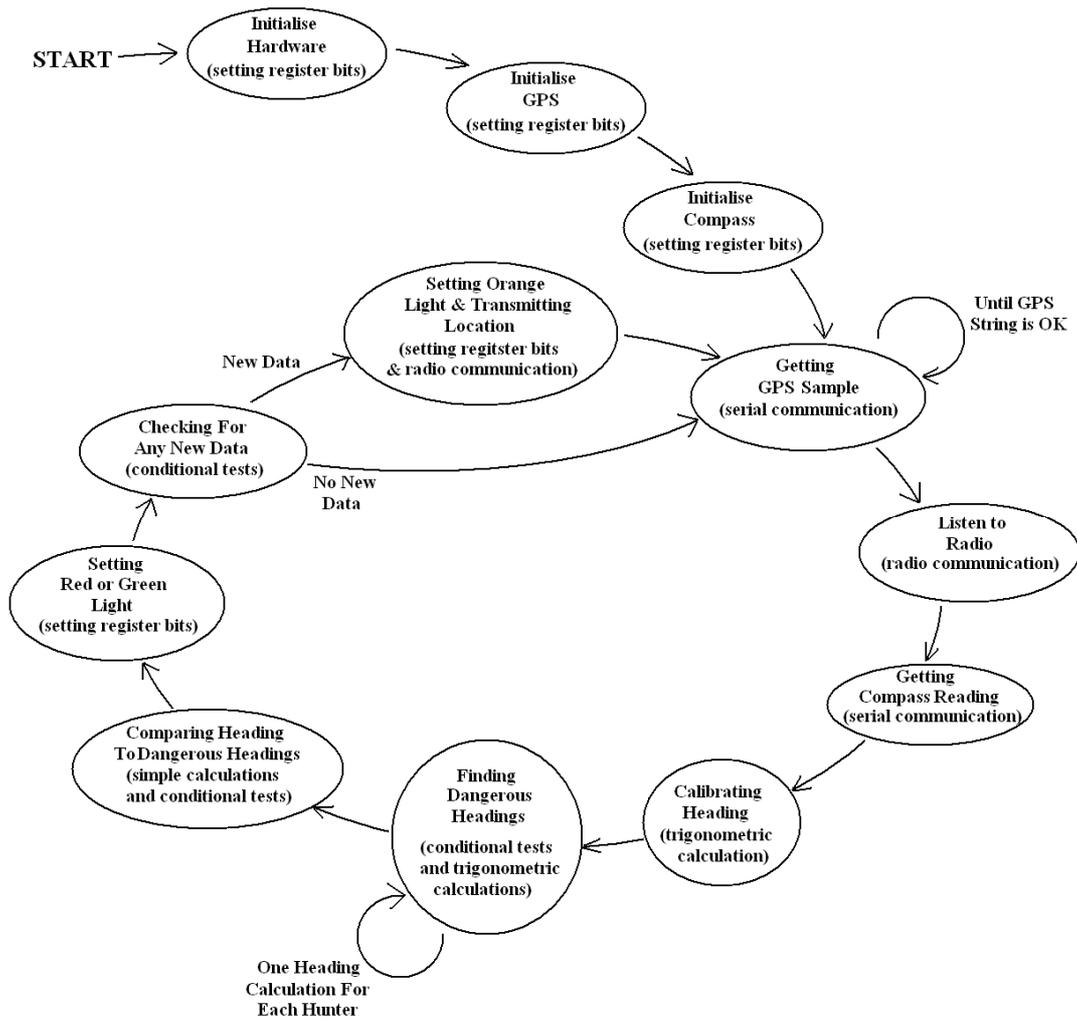


Figure 5.6c: Detailed Embedded State Diagram

The final process diagram is very specific and shows each of the functions for each hardware in each group. The overall flow runs from the initialisation code at the top, down to either the transmission code at the bottom or breaking out to repeat in the middle as indicated.

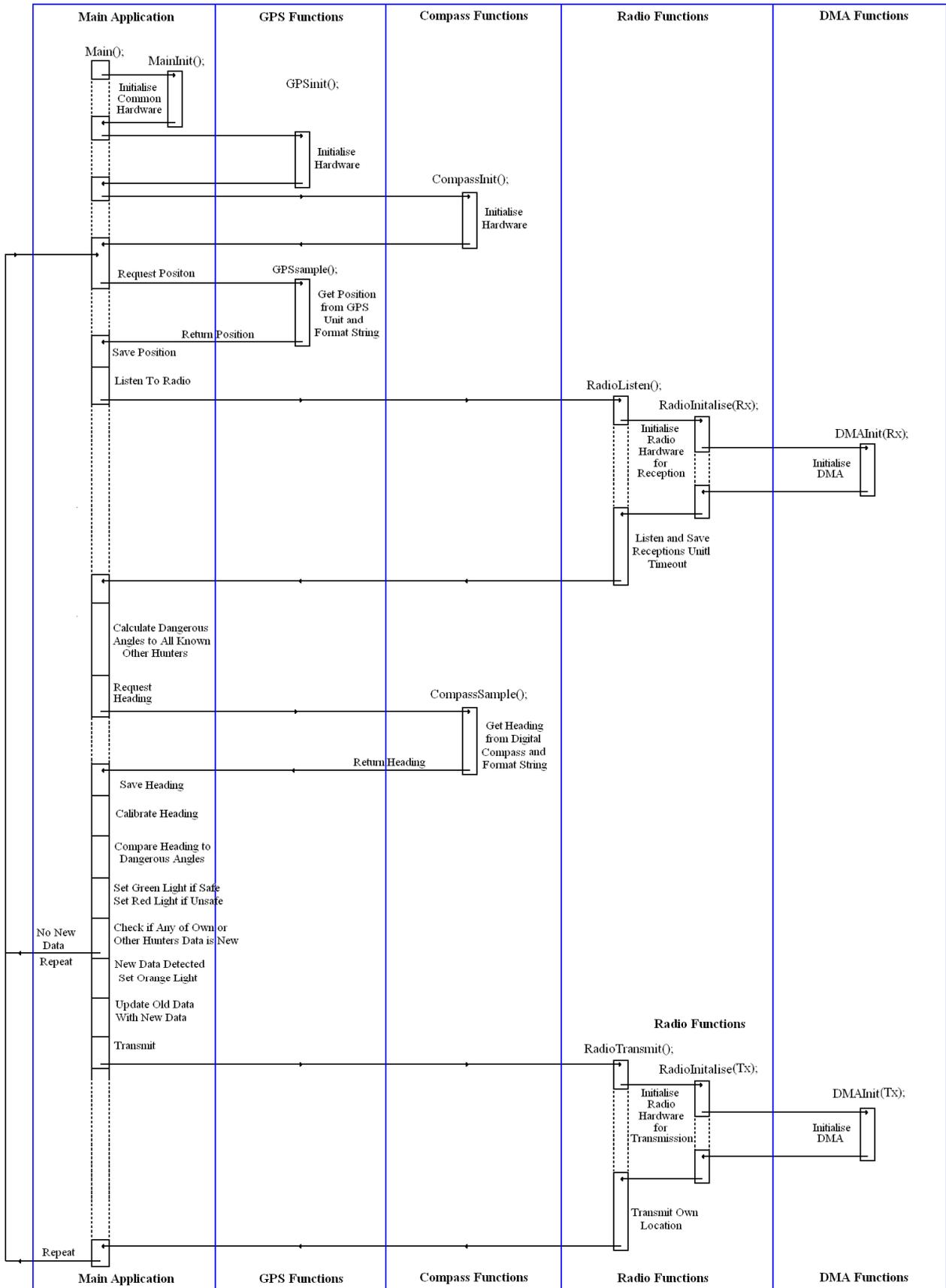


Figure 5.6d: Process Diagram of Complete Embedded Code

5.7 Assembly of Hardware

So far the application circuit as well as the code to be loaded on it have been discussed. In order to test and implement the setup two different test platforms were generated. The first of these test platforms was a mock-up rifle stock to which the radio hardware, scope, GPS and Compass were attached. This was to show that not only can this prototype hardware be mounted to a rifle but also to show that even in the bulky prototype form that it is in, it still is almost out of the way.

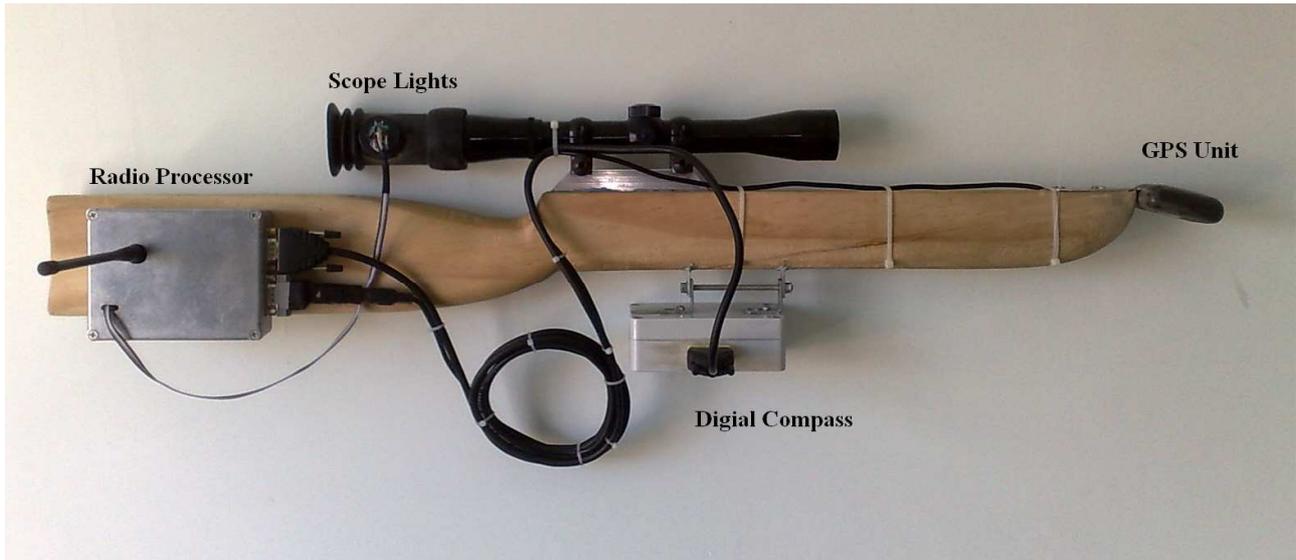


Figure 5.7a: Assembled Prototype System

The second test bed came about as a matter of test practicality and ethics. It was quickly decided on that walking around a field with a mock-up weapon could cause panic from all sorts of individuals. To counter this problem a simple section of wood formed the base of the second test bed to which all the required sensors were mounted to. This appeared much less threatening.

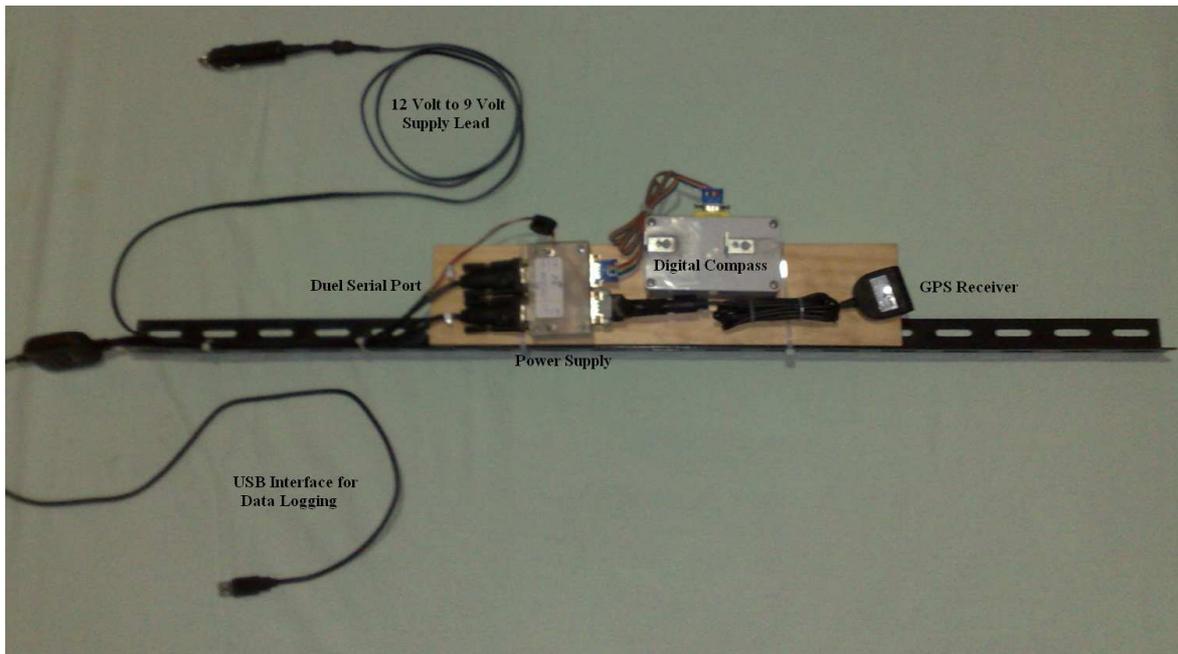


Figure 5.7b: GPS & Compass Test Rig

Only the GPS units arrived in their own enclosures however edits had to be made to remove mounting magnets from within the GPS receivers. The digital compass from Honeywell had no such enclosure so one had to be produced since the compass was the most expensive and sensitive hardware element. Due to the compass requiring 9 volts to be supplied over the serial cable an adaptation was made to use the same methodology to supply power to the GPS unit. While the GPS ran on a required 5 volts, the 9 volts that was made available required another power regulator chip installed inline to reduce the voltage.



Figure 5.7c: Prototype System Component View

The above image is the designed prototype base wooden form to which the test equipment is mounted. The far right tip of the barrel has the GPS receiver unit, the Compass enclosure (also shown in figure 5.7d) is opened from its lid which can be seen in the proper mounting position for compass operation. The left hand side of the prototype

base has its radio communication ports interfacing out of the right of the metal enclosure. The top left of the metal enclosure has the motherboard visible with the antenna connected to it.



Figure 5.7d: Digital Compass Enclosure

Again it is important to remember that this hardware was a first prototype of the system and for radio interference reasons it was important for testing to have the digital compass, GPS and Radio Transceiver Microprocessor separated. As the elements are sold with serial communication as a base protocol, serial cables were used to keep the 3 devices separate.

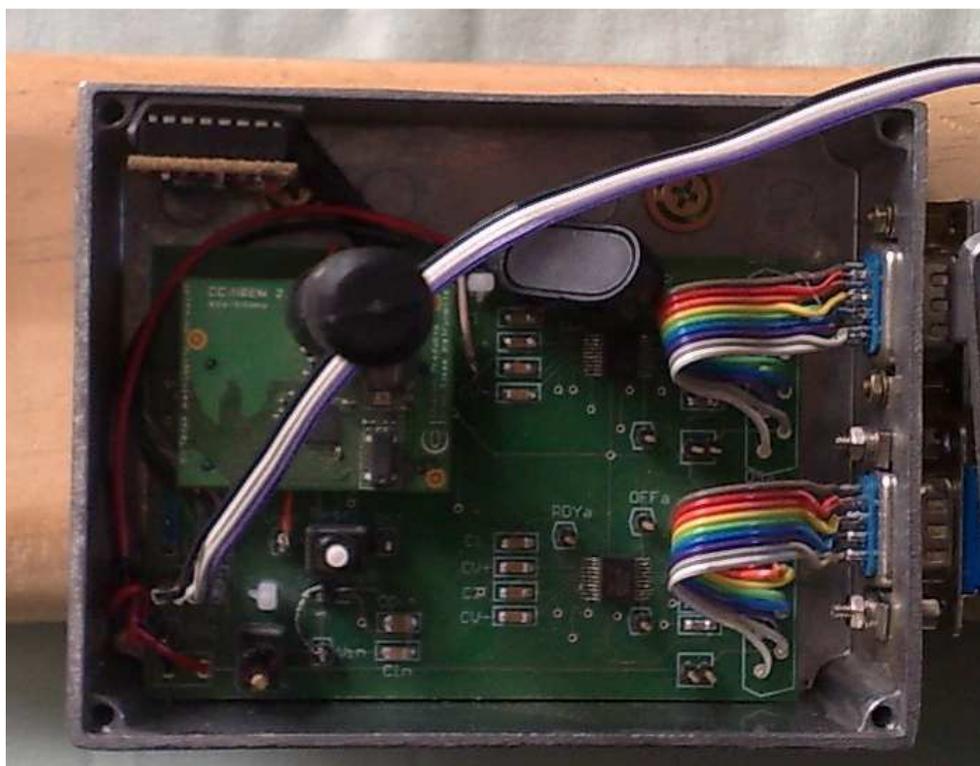


Figure 5.7e: Radio Model Enclosure

The soldering and mounting of the daughterboard for the radio processor involved careful planning. The daughter circuit boards were designed to have two serial ports onboard to allow for communication to the two remote units that had their DB9 ports mounted on the side of the daughterboard enclosure. Also to be included within this enclosure was the 9 volt battery intended to supply the entire system as well as a hole to mount the antenna and to run a cable to the indication lights mounted on the side of the scope. Again for ease of mounting a scope attachment was purchased being a rubber sleeve to prevent the scope impacting the eye while shooting. This scope attachment had a recess added and the 3 LED's installed. The LED's were located just out of direct sight to prevent any blinding signals however, to still allow the inside of the rubber sleeve to show a red, green or orange illumination.

6. Concept Testing and Results

With the system fully described, this next chapter focuses on the methods used for testing. Primarily the concept of field testing the elements of hardware individually is detailed. This in essence is equivalent to hacking into the signals used within the concept prototype in order to gain insight into how best to represent this data in the model application. Results provided in this chapter also show the operation of the model with focus on different hunting field setups, followed by the principle tests of the model application with included real factors from the hardware field tests.

6.1 Field Tests

The specific testing will fall into 4 main categories: It is important to test the radios independently to gain knowledge and measured results on the signal and data degradation as both distance and foliage are increased. It is also important to gain a measure of the reliability of the GPS hardware as well as the digital compass, both in ability to communicate reliability and readout accuracy. The specific data output from the radio testing that is desired is a basic radio range as well as the amount of range degradation due to foliage. The desired results from the GPS and Compass tests that will be used are the number of random misplaced data points as well as the tolerance of these misplaced points. These are the first two sections of tests.

The third section of tests involve as part of the concept the GPS data as well as the Compass data being analysed and the values for errors and variance be loaded into the model application that has been generated. From this point various models will be run to produce values for percentage of correctly identified shots. This will give a measure of the different performance characteristics of the model system tested.

The fourth and final stage of testing involves the field testing of the prototype hardware. This section will involve taking the sample hardware to a field and testing the ability of the system at accurately indicate a non safe shooting solution. This is a functionality test only and a qualitative opinion will be the result but no quantifiable data will be recorded.

6.2 Methodology of Tests

As mentioned in previous sections there are four stages of tests. The first stage been the radio tests were carried out in two different locations. Firstly the radio range and signal loss was tested in an open field with line of sight between the antennas. This is to produce the best case scenario. The field where the tests were to take place had a 350m straight line marked out in 50m increments. Each of the 3 radio frequencies available being 433MHz, 868Mhz and 915MHz were tested three times each at each of the 50 meter increments to give an average. This entire set of tests was performed again in a local forest area. Here a line of markers were again placed 350m total in 50m increments. Unlike last time, with the forest radio test the line of markers were placed in a open line of sight strip of terrain however the actual tests were performed 20m into the dense vegetation at a right angle to the distance markers.

The second set of tests performed were the GPS reception tests and Digital compass tests. For the GPS testing the easiest way to travel in a strait line without any variation was to use a vehicle. The second benefit of this operation is that later comparisons between logged data and satellite photos are easier due to the visibility of roads from the sky. Both a short range and a longer distance path were both logged, marked and compared. Google earth was very beneficial for this application in that specific GPS locations can be zeroed in on overlaid on satellite photos and a path of connective points created.

Compass testing was originally intended to be performed at the same time as the GPS logging however it was quickly noticed that the compass reading was effected by mounting it in a metal composed vehicle. Alternatively as a second approach a path was walked with the compass hardware worn on a strap. Unfortunately another problem arose with the compass swaying by a couple of degrees every step taken due to a walking motion. Finally stationary tests were decided to be carried out within a field to avoid interference. Noting that the metal composition of a vehicle had an effect on the compass reading, a length of metal angle iron was mounted along side the compass as a surrogate gun barrel, introducing the desired interference in the reading.



Figure 6.2a: Compass Test Table & Setup

The above photo shows the test rig used to take readings of North South East and West. In the middle the white compass enclosure with the two metal tags mounted on top is mounted to the wooden board. Also attached at the right hand side of the wooden board is the GPS receiver unit. Both these devices are wired from right to left to the clear enclosure providing power. Connected to the power module trailing off the left hand side of the table is a Dual Serial to Single USB connection cable. This cable provides data directly to the Laptop where a custom application data logs the results.



Figure 6.2b: Dumb Node Setup

The final prototype tests were performed again at the chosen open field location where radio tests were first carried out. Specifically these tests involved placement of a dumb node that simply transmitted location to the gun hardware. This node is referred to dumb as it has a reduced intelligence compared to the prototype system. The test rig's power would then be enabled and the system tested in terms of being able to indicate a dangerous heading.

6.3 Effecting Conditions and Test Problems Found

The environments that these tests should be performed in are: An open empty field where line of sight between radio test platforms is possible as well as a location of dense forested where no view of the target is possible. Besides the density and distribution of vegetation, there are a number of other factors that have a small effect on both signal or reception ability, range and accuracy of the instruments. Rain and humidity are two factors however their effect is very small. Unfortunately due to the test equipment not being waterproof and the operation of tests performed requiring interfacing directly with the push buttons mounted on the board, testing in the rain was avoided. Another more sizeable effect on radio and the digital compass is the presence of fencing and transmission lines. The compass can be effected by large transformers and power lines so placement of radio equipment too close to any of these was avoided.

Initial perception of tests is that a radio range of 500m to maybe 700m might be required for the test. This lead to the search for a pair of local parks, without any of the obstacles to radio transmission discussed above. One of the parks was to be an open field and one a dense native forest. Initial on location tests prior to data recording showed that a range of 350m would more than suffice for complete radio signal loss due to being out of range.

6.4 Test Location Selection and Data Collection

In order to avoid both power lines, transformers and wire fences, two test locations were chosen that were void of these objects. The first test location was a large reserve in the district of Botany in East Auckland called Barry Curtis Park. This reserve provides over 800m of uninterrupted flat grass land with no crossing fences or power lines. The second chosen location was Murphy's Bush, also in Botany in East Auckland the Park is a small native bush reserve with walking trails and a definite over population of vegetation in every direction including a dense canopy. Murphy's Bush, like Barry Curtis Park is void of crossing fences or power lines however both are sounded by a wire fence at their perimeter and have a track of power lines along one edge.



Figure 6.4a: Open Field Radio Test Site & Hardware



Figure 6.4b Open Field Radio Test Positions

In order to gage a proper distance for transmission a meter wheel was used along with pegs to mark out 50m increments on a 350m line. The radio testing was performed along this 350m line in the open field however it was impossible to rule a strait 350m line through thick scrub. As a result a 350m line was marked out parallel to the edge of the forest to which each test was moved 20m into the forest perpendicular to the marked out line.



Figure 6.4c: Forest Environment Radio Test Site & Hardware



Figure 6.4d: Forest Environment Radio Test Positions

6.5 Radio Range and Error Rate Test Results

The results collected show two characteristics of the radio communication. The first property tested is the Signal Strength. These values give an indication of how well the radio communication is working at a specific distance in accordance with the radio hardware used. The second recorded property of the radio testing is called error rate and shows the quality of the data transmission in accordance with the embedded software and protocol.

Field Test Results for 433 MHz, both Open Field and Forrest:

Open Field Testing of Signal Strength in dBm 433MHz					
Range	50	100	150	200	250
Reading 1	-70	-79	-90	-91	No Rx
Reading 2	-69	-81	-91	-91	No Rx
Reading 3	-70	-79	-92	-90	No Rx
Average	-70	-80	-91	-91	No Rx

Forrest Testing of Signal Strength in dBm 433MHz					
Range	50	100	150	200	250
Reading 1	-68	-90	-95	No Rx	No Rx
Reading 2	-68	-92	-95	No Rx	No Rx
Reading 3	-69	-96	-94	-95	No Rx
Average	-68	-93	-95	-95	No Rx

Open Field Testing of Percentage Error Rate 433MHz					
Range	50	100	150	200	250
Reading 1	0.0	0.6	4.8	1.7	No Rx
Reading 2	0.0	0.0	15.7	4.5	No Rx
Reading 3	0.0	0.0	16.9	0.9	No Rx
Average	0.0	0.2	12.5	2.4	100.0

Forrest Testing of Percentage Error Rate 433MHz					
Range	50	100	150	200	250
Reading 1	0.0	68.8	87.3	No Rx	No Rx
Reading 2	0.0	82.1	88.0	No Rx	No Rx
Reading 3	0.0	68.7	79.4	99.9	No Rx
Average	0.0	73.2	84.9	99.9	100.0

Table 6.5a: Results of 433MHz Radio Tests

Field Test Results for 868 MHz, both Open Field and Forrest:

Open Field Testing of Signal Strength in dBm 868MHz					
Range (m)	50	100	150	200	250
Reading 1	-86	-93	-96	-100	No Rx
Reading 2	-86	-93	-97	-100	No Rx
Reading 3	-87	-93	-94	No Rx	No Rx
Average	-86	-93	-96	-100	No Rx

Forrest Testing of Signal Strength in dBm 868MHz					
Range	50	100	150	200	250
Reading 1	-81	-99	-98	No Rx	No Rx
Reading 2	-81	-96	-98	No Rx	No Rx
Reading 3	-81	-98	-99	No Rx	No Rx
Average	-81	-98	-98	No Rx	No Rx

Open Field Testing of Percentage Error Rate 868MHz					
Range	50	100	150	200	250
Reading 1	0.1	16.6	86.1	100.0	No Rx
Reading 2	0.3	7.1	80.4	100.0	No Rx
Reading 3	2.4	7.2	71.7	No Rx	No Rx
Average	0.9	10.3	79.4	100.0	100.0

Forrest Testing of Percentage Error Rate 868MHz					
Range	50	100	150	200	250
Reading 1	1.2	99.9	93.4	No Rx	No Rx
Reading 2	0.9	90.5	86.6	No Rx	No Rx
Reading 3	0.7	92.2	74.6	No Rx	No Rx
Average	0.9	94.2	84.9	100.0	100.0

Table 6.5b: Results of 868MHz Radio Tests

Field Test Results for 915 MHz, both Open Field and Forrest:

Open Field Testing of Signal Strength 915MHz					
Range	50	100	150	200	250
Reading 1	-83	-95	-94	No Rx	No Rx
Reading 2	-80	-93	-94	-100	No Rx
Reading 3	-77	-94	-95	No Rx	No Rx
Average	-80	-94	-94	-100	No Rx

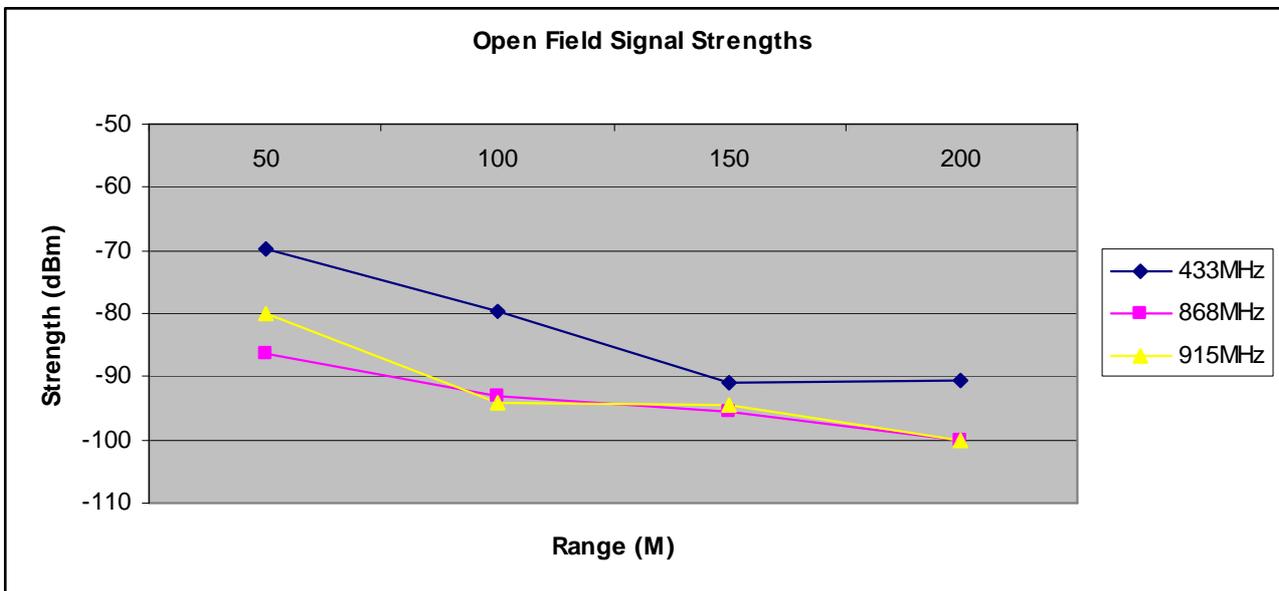
Forrest Testing of Signal Strength 915MHz					
Range	50	100	150	200	250
Reading 1	-91	-95	-97	No Rx	No Rx
Reading 2	-83	-96	-96	No Rx	No Rx
Reading 3	-93	-95	No Rx	No Rx	No Rx
Average	-89	-95	-97	No Rx	No Rx

Open Field Testing of Percentage Error Rate 915MHz					
Range	50	100	150	200	250
Reading 1	2.3	50.6	40.6	No Rx	No Rx
Reading 2	0.4	67.7	31.2	99.6	No Rx
Reading 3	0.1	59.7	22.1	No Rx	No Rx
Average	0.9	59.3	31.3	99.6	No Rx

Forrest Testing of Percentage Error Rate 915MHz					
Range	50	100	150	200	250
Reading 1	15.3	92.2	90.9	No Rx	No Rx
Reading 2	6.7	90.2	86.5	No Rx	No Rx
Reading 3	28.2	86.9	No Rx	No Rx	No Rx
Average	16.7	89.8	88.7	100.0	No Rx

Table 6.5c: Results of 915MHz Radio Tests

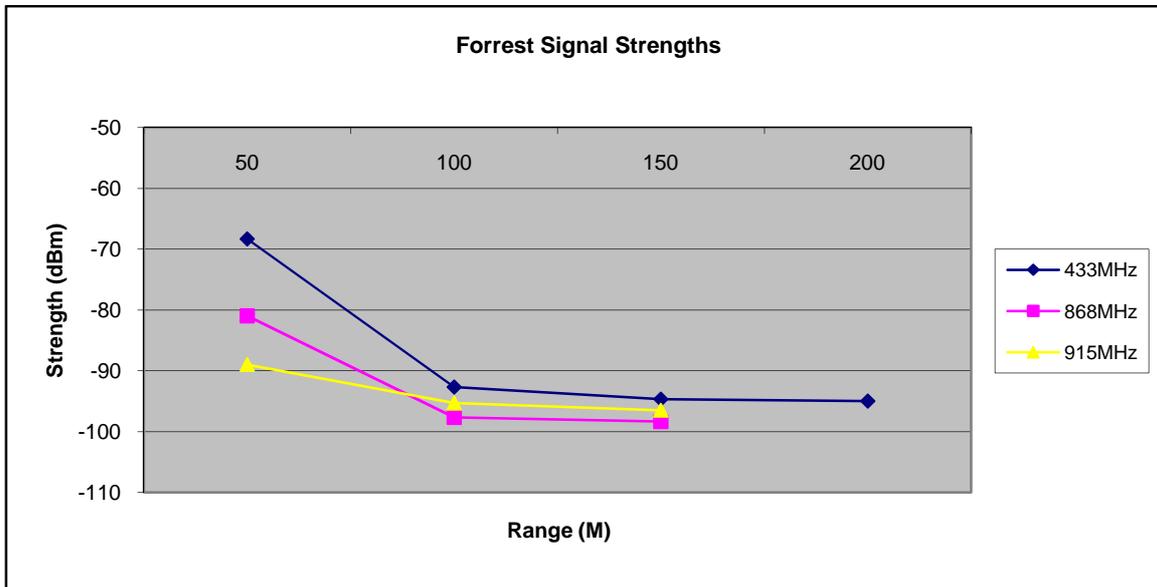
Presented in tables 6.5a, b and c the results are hard to visualise however if a graph is generated for each condition we can better see the reliability and forestry effect on each radio test. Firstly if we are to look at the Open field signal strength testing we can see the following:



Graph 6.5d: Graphed Open Field Radio Tests Signal Strength

The signal strength above clearly shows that over an open field in line of sight the 433 MHz radio tests manages to maintain an advantage in signal strength over the entire test range and also that it keeps this advantage until the signal completely drops out at 250m. It is particularly interesting that at 200m, the 433MHz transmission has approximately -90dBm of signal strength whereas the other higher frequencies have almost completely dropped out at around -100dBm.

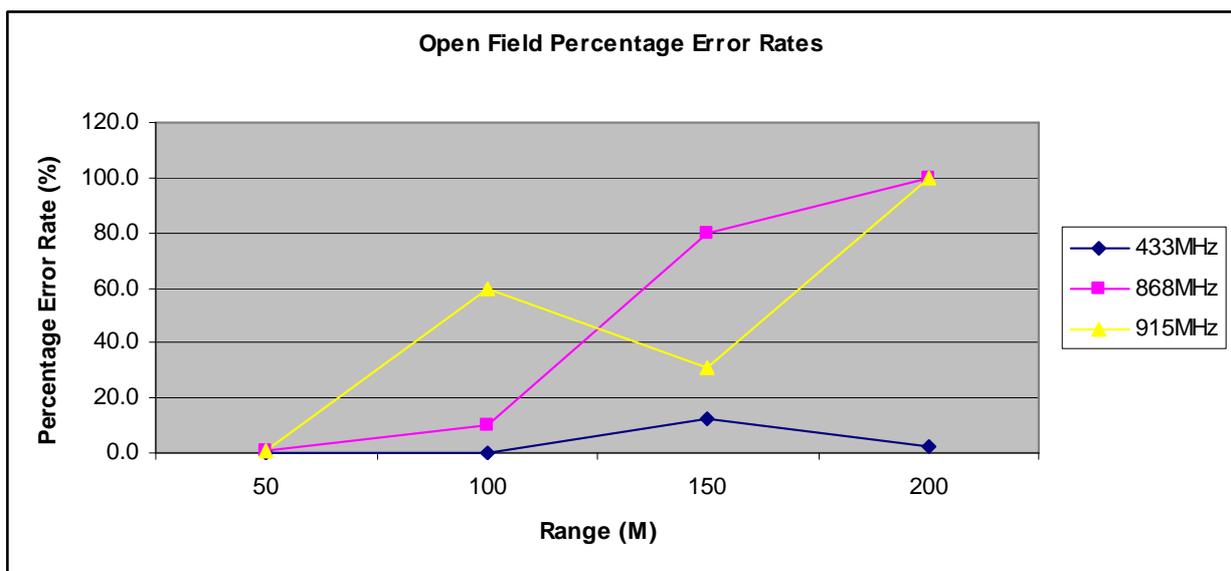
If the signal strength as measured in a forest is now graphed the advantage still belongs to the 433MHz transmission, as shown below:



Graph 6.5e: Graphed Forest Radio Tests Signal Strength

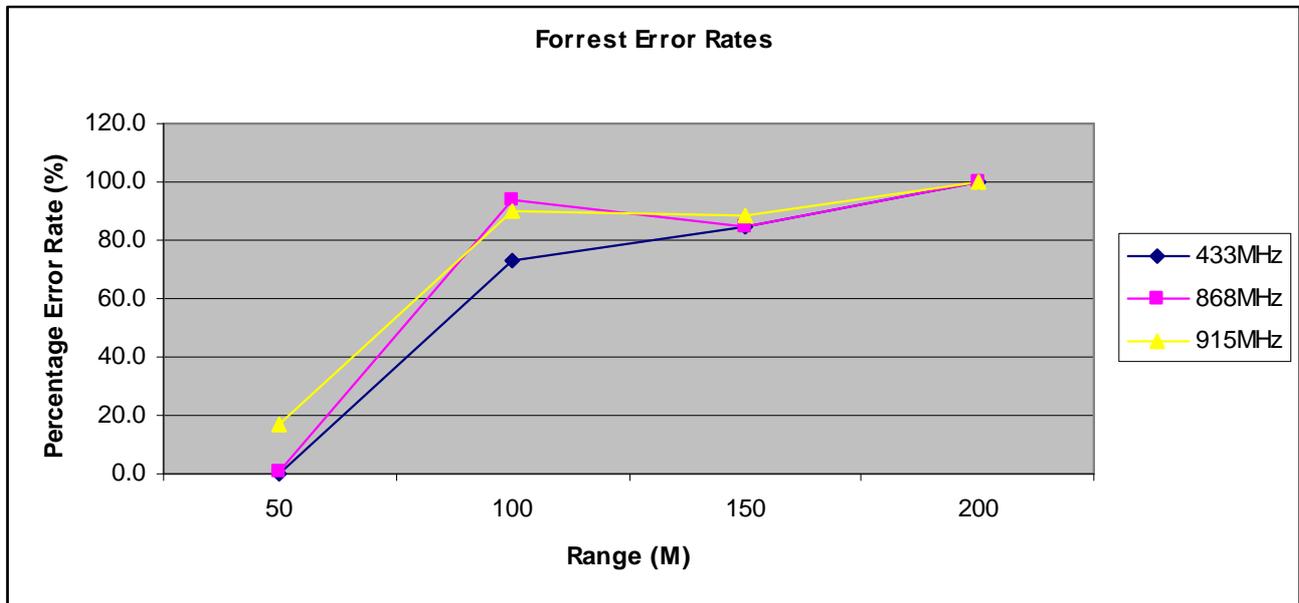
Again with an advantage in signal strength across the entire test range we can see that not only does the 433MHz connectivity exist at 200m holding a value of approximately -95dBm but also radio signal strength for the 868MHz and 915MHz tests were unable to yield a value at 200m.

From signal strength it is appropriate to follow with comparative graphs of Percentage Error Rates:



Graph 6.5f: Graphed Open Field Tests Error Rate

It is clear in this first Error Rate graph that the 433MHz again takes the lead with a less than 20% packet error rate across the entire test range. The two higher frequencies of 868MHz and 915MHz start with very low percentage error rates however they quickly increase in error as range increases. This can be further analysed by looking at the percentage error rates recorded in the forest tests:



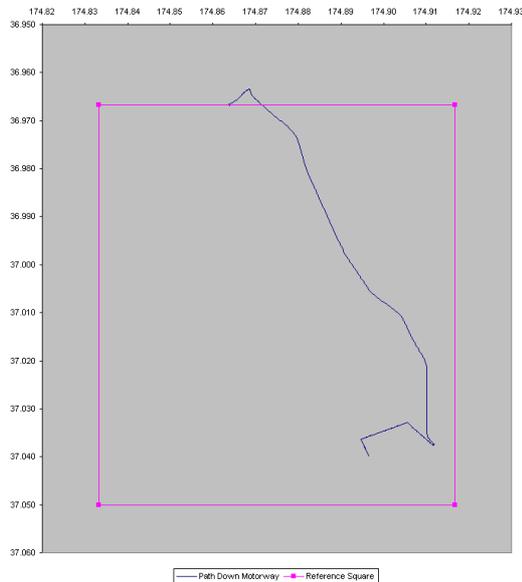
Graph 6.5g: Graphed Forest Tests Error Rate

In this final graph it is clear that almost all radio communications have higher percentage errors during communication through dense forest. There is an almost failure of the radio communication with percentage error rates over 80% at 150m however the best candidate for maintaining communication is obviously 433MHz. The lower frequency has an advantage of approximately 20% reception error over the higher two frequencies at 100m.

One factor not visible in these tests is the data rate. While the higher frequencies are suffering in their signal strengths and percentage error rates, they do allow for a much higher data throughput. This advantage is negligible for this conceptual system since the required radio messages to be transmitted are of very small size. While data error rates can be greatly changed by increasing the number of repeated transmissions (i.e. sending each message twice), the actual increase in data throughput of the higher frequency transmissions is insufficient to counteract the poorer signal quality. It should also be noted that increasing redundant or repeated message transmission will not have noticeable effect on range to which the 433MHz communications are clearly showing a 20%-25% advantage over the 868MHz and the 915MHz.

6.6 Digital Compass and GPS Test Results

For the first test a long distance run was undertaken from Papatoetoe Motorway on ramp to Takanini Motorway off ramp. The trip was data logged and converted into a graph producing the graphic on the left in figure 6.6a. Likewise Google earth's path drawing ability was used producing the graphic on the right below.



Results From Data Log



Results From Drawn Path

Figure 6.6a: Long Distance GPS Test Data Log and Drawn Path

When these two images (actual path travelled and one recorded path travelled) are overlaid we are able to see that there is almost no visible discrepancy in the data output by the global positioning system.

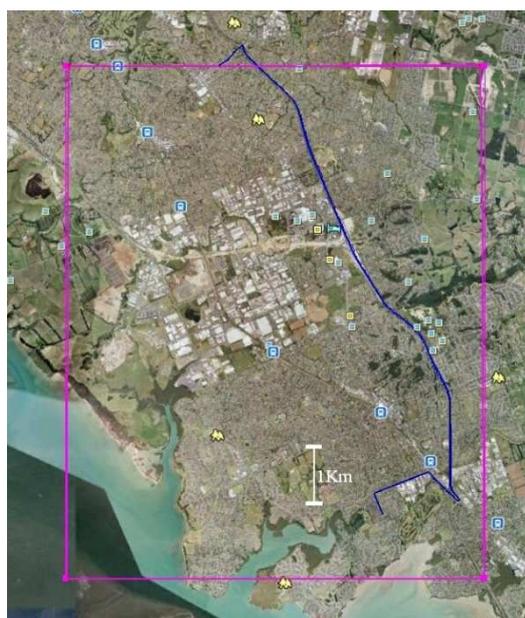
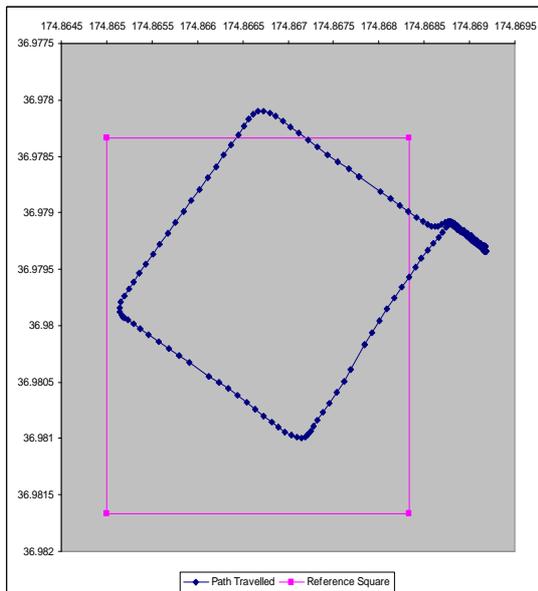


Figure 6.6b: Long Distance GPS Test Overlay

The possible reason for the lack of error in position could be due to the scale of the path travelled. This thick dark blue line from north to south actually completely obscures the three lane motorway underneath.

In order to generate a more accurate measure of small scale error another path was undertaken.



Data Logged Path



Path Drawn in Google Earth

Figure 6.6c: Short Range GPS Test Data Log and Drawn Path

When this smaller path is analysed it can be seen again that the global positioning system seems to follow almost exactly. In fact the dots are so regularly placed and accurate that travelling speed can almost be calculated from the logged movement data. Again if we are to overlay the above two images the follow graphic is the result.

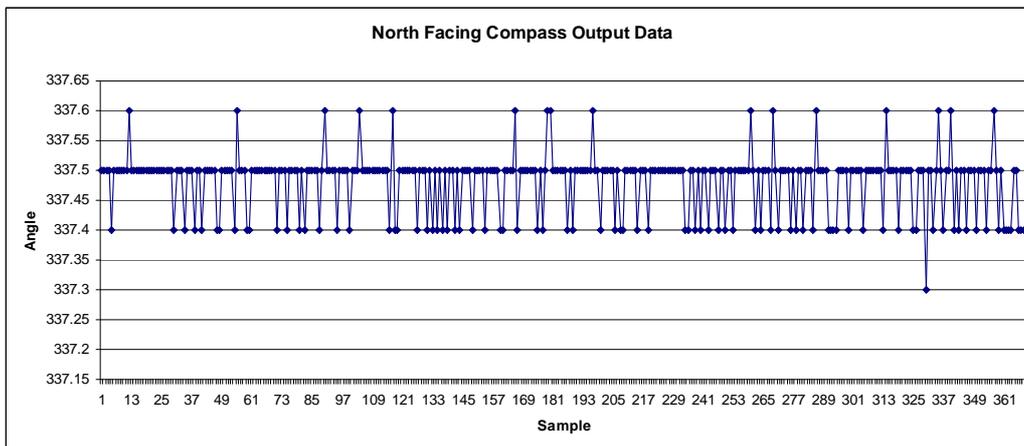


Figure 6.6d: Short Distance GPS Test Overlay

In this second overlay it is possible to see that the dots seem to follow the path with around 1 to 2 meters tolerance, estimated by the results ability to show the correct lane of the road that was travelled in for this test. This is a very high accuracy for an affordable, non military grade GPS and will mean embedded calculations made based on this data will have little error in the final safe/unsafe heading calculation.

To test the digital compass a different set of field results were recorded. This is due to two reasons being that firstly the GPS readings were recorded in a vehicle to enable larger distances to be covered and better results. It was found that mounting the compass into a vehicle drastically effects the reading due to both electronic effects and the steel chassis of the car. The second problem is that it makes little sense to data log a digital compass while it is being carried by someone even if they attempt to keep it pointing straight. Preliminary test of this method yielded results with a continual compass swagger generated by the walking motion.

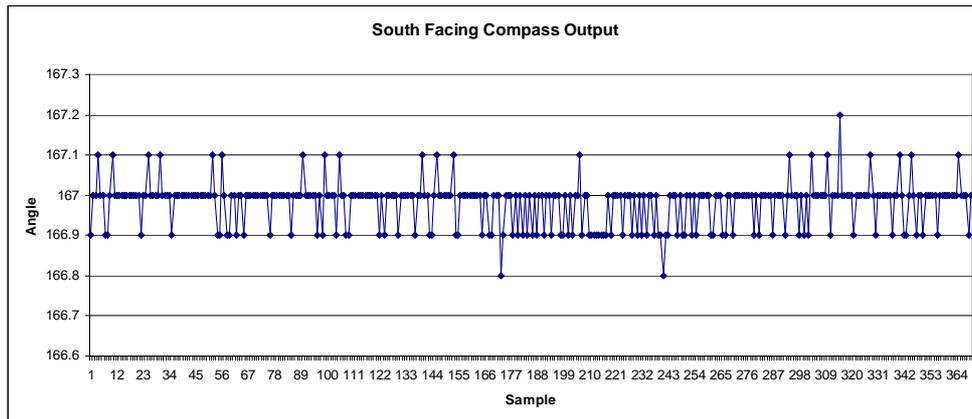
The final design for the compass test involved setting up a level table in the middle of a field and allowing the compass to sit idle on the table and generate data. These compass tests were performed with the compass facing north, south, east and west to show a 360 degree variance in compass readings. The indication of direction was achieved by installing more markers or pegs on the field in directions directly north and west of the test table, then looking through the two aligned eyelets mounts of the compass enclosure like a scope at the field markers it is easy to align the compass with a true direction.



Graph 6.6e: Graphed Compass Data North Reading

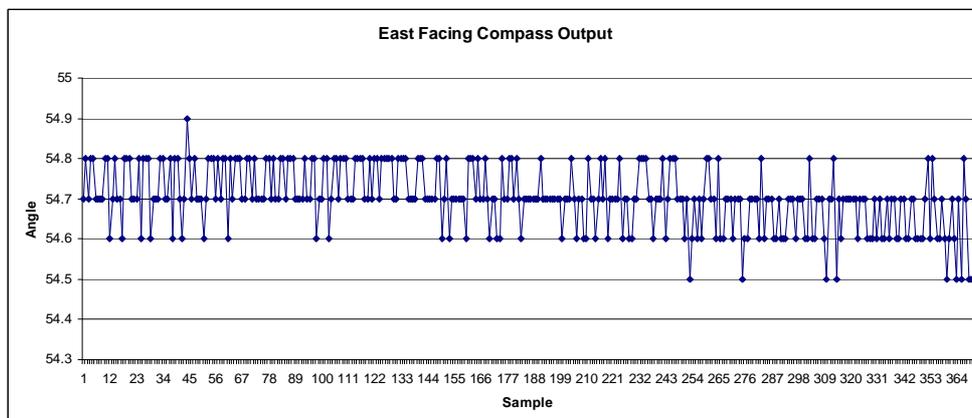
Graph 6.6e shows the logged output from the compass while facing north. It is clear to see in the data that the medium or average reading has a value of 337.5. The jitter or error in the signal again can be seen and read off the graph easily due to only four levels of signals. With a minimum value of 337.3 and a maximum value of 337.6 it can be safely said that this compass reports its heading at a rounded angle of 337 degrees while facing north.

Graph 6.6f shows the compass output while facing south. This method used that same markers as north however the entire equipment was reversed or turned around 180 degrees. The reason for this is that errors common to north and south if the same could be a result of placement of the field markers or due to a symbolic metal rod mounted down the side of the test equipment to simulate a gun barrel. The results specifically show a heading of 167 degrees when rounded with the medium being 167.0, the maximum being 167.2 and the minimum being 166.8 the reading of 167 degrees is very close to the average of this data set.



Graph 6.6f: Graphed Compass Data South Reading

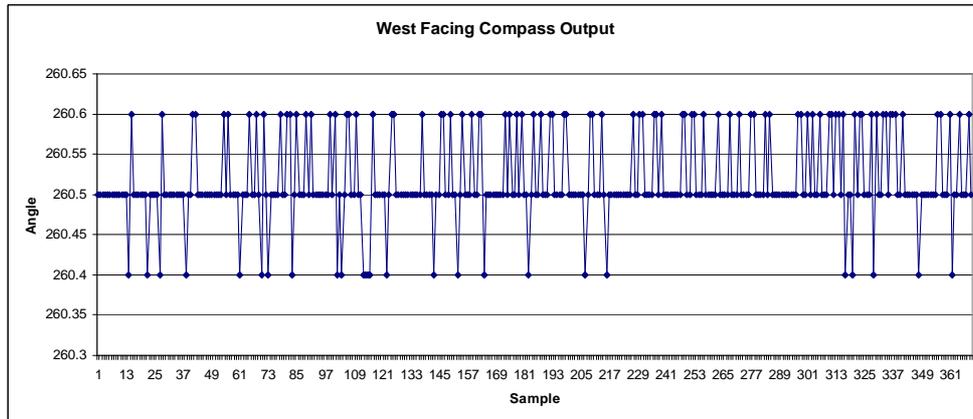
Likewise for the north reading a line of markers were placed in a straight line from the table outward in an exact westerly direction. This was achieved by use of the GPS unit to determine a set of locations with an identical north south reading. Again the compass was placed on a level table facing east and readings were logged over time. In the graph 6.6g it can be seen that the average reading is around 54.7 degrees with the medium being the same. The Maximum has value of 54.9 and a minimum of 54.6 leading to a reading of 55 degrees when rounded to a whole number.



Graph 6.6g: Graphed Compass Data East Reading

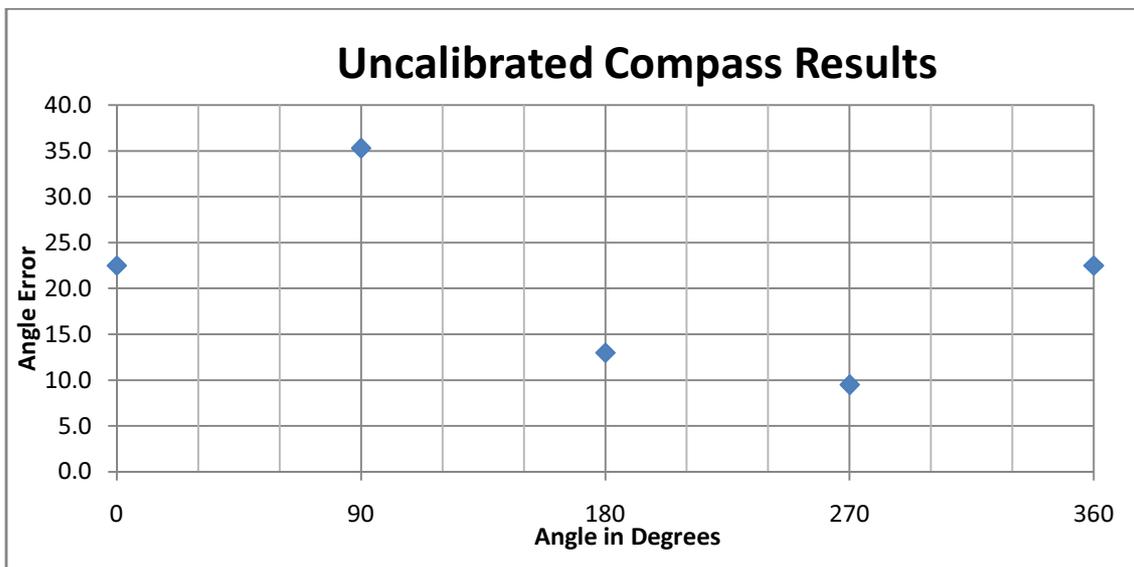
The final graph logged was an inverted version of east, having the equipment rotated 180 degrees to face west. In the results of graph 6.6h it is clear that the average and medium values are around 260.5 to a single decimal place. The maximum value is

260.6 and the minimum value is 260.4. This leads to a determination of a value of 261 degrees when rounded to zero decimal places.



Graph 6.6h: Graphed Compass Data West Reading

When the results of the four direction compass logs are compared graph 6.6i is produced. This image below along with the table of values shows the offset of each reading at any specific angle. An example of this would be that at 180 degrees we can see from the graph that the reading is around 12.5 degrees off, so the actually true south of 180 degree angle would be equivalent to an output of 167.5 degrees.



Graph 6.6i: Graphed Compass Error

Within both GPS and Compass results it has been noted that none of the recorded data points look unreasonable or completely chaotic or random. In fact with 0.1 degree resolution the compass (even with jitter) did not stray more than 0.5 of a degree from its reading produced. This is not to say these readings are without error, the offset can be seen in the above graph. The GPS reading likewise again was within 1-2 meters accuracy with no visible jitter and no erroneous points.

6.7 Calibration of Compass

Given that the error in graph 6.6i of compass output error is above 30 degrees in some sections it is required that this equation is calibrated. For this reason the follow equation was derived in MATLAB as a correction to graph 6.6i:

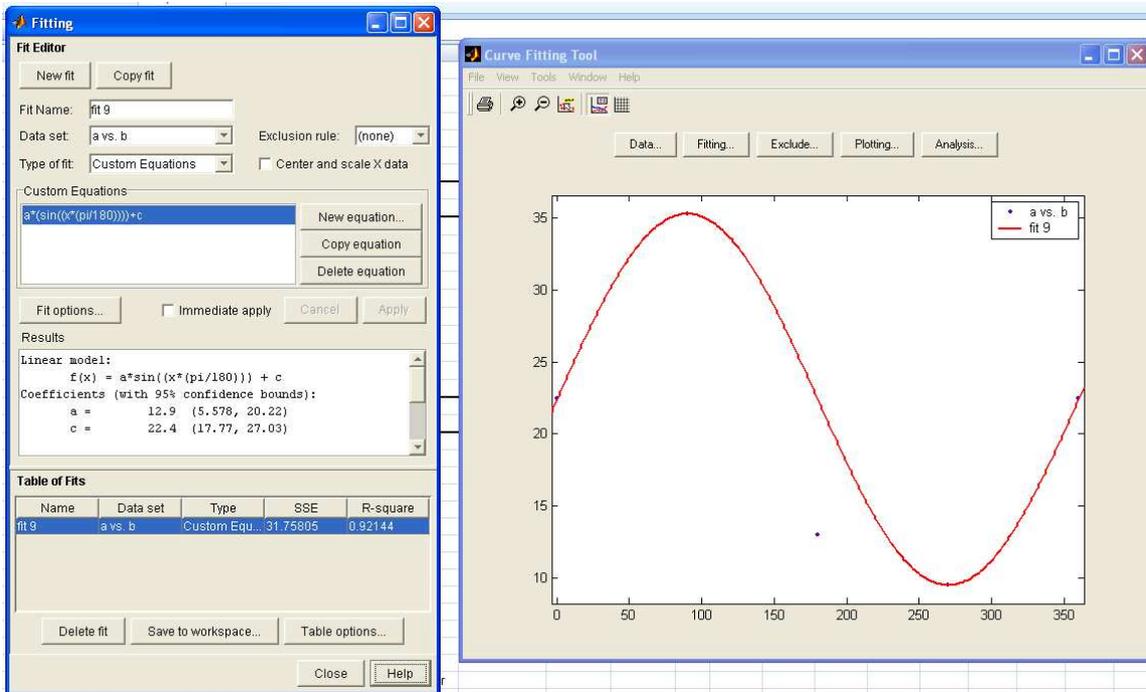
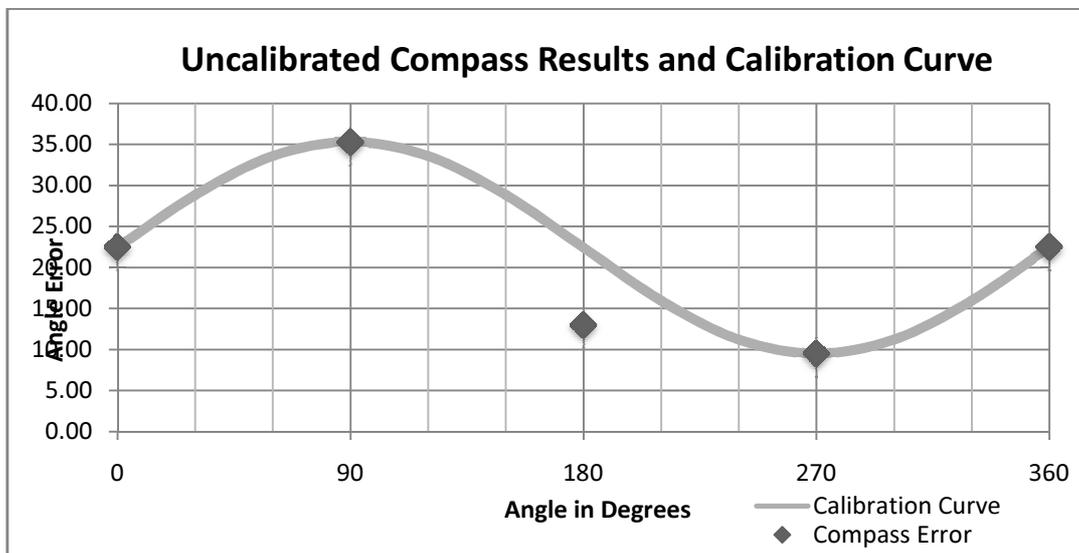


Figure 6.7a MATLAB Curve Fitting Toolbox

Resultant Calibration Equation :
Error = 12.9 * Sin(angle) + 22.4

When the above equation is graphed and fitted over the existing graph of compass output error the following graph is achieved:



Graph 6.7: Compass Error With Calibration Curve

While it can be seen that this graph is not perfect it can also be seen that it can quickly reduce the error from 15 degrees down to 2 or 3 degrees even in the worst matching sections.

6.8 Prototype Hardware Field Test Results

The field tests of the prototype hardware were performed at the same location as the original radio tests. This location offered a large open field in which a dumb node could be setup to transmit location. The gun hardware was then powered up and aimed in the direction of the dumb node and the scope indication lights tested.



Figure 6.8: Dumb Node Close Up View

The dumb node used in these tests was loaded with a reduced version of the main embedded software. This reduced code only used communication functions for the GPS and not the Compass. Also the dumb node was not set to receive any other hunters GPS data via radio. The aim of the prototype test was not to test the ability of the radio to establish a network but rather to test the ability of the microprocessor to use the compass, GPS and radio to indication the location of an alternative node.

The final prototype tests were performed at a time of year when rain and moisture in the air is at very high levels. Initial tests were problematic with one of the evaluation boards quickly developing a fault in the reset circuitry connected to the microprocessors reset pin. Following this problem one of the motherboards containing the microprocessor had its SMA antenna connection detach from the circuit board, while an initial solder reattached the connector the problem was quick to reoccur. Because of all these problems only one of three field tests to test the prototype system ended in a red light indication of a dangerous angle. One of the most problematic factors effecting these tests was the fact that the chips could not be programmed in the field and likewise the specific short range sensor network evaluation hardware proved too delicate for field work applications.

6.9 Model Testing

The tests that were run involved loading the model with values from the other field tests and setting the model to run. Specifically the tests performed were as follows: A perfect system was tested with no error and a maximum transmission distance, a symbolic 433MHz system with shorter than ideal range and included GPS and Compass error rates and a 868MHz system was tested including the same GPS error and Compass rates as the 433MHz tests. Finally a test was run with a much larger error in compass and GPS more symbolic of an un-calibrated compass heading and dense forest GPS reception. The final test's radio distance was based on the 433MHz system. Values used in these tests are quantified here:

Test Name	Radio Range	Radio Foliage Range	GPS Reception Chance	GPS Error Value	Compass Reception Chance	Compass Error Value
Test 1	250	75%	100%	0	100%	0
Test 2	200	75%	100%	0	100%	0
Test 3	200	75%	95%	5	100%	0
Test 4	200	75%	80%	20	100%	0
Test 5	200	75%	100%	0	95%	3
Test 6	200	75%	100%	0	80%	20
Test 7	200	75%	95%	5	95%	3
Test 8	200	75%	80%	20	80%	20
Test 9	150	50%	100%	0	100%	0
Test 10	150	50%	95%	5	100%	0
Test 11	150	50%	80%	20	100%	0
Test 12	150	50%	100%	0	95%	3
Test 13	150	50%	100%	0	80%	20
Test 14	150	50%	95%	5	95%	3
Test 15	150	50%	80%	20	80%	20

Table 6.9: Table of Setup Data for Model Testing

Each of the above tests was run 5 times for a duration of 4000 seconds per test. This generated more of an even average as some tests appear more random in their results than others. The results from these tests that will be compared against each other, are the percentage of hunters saved against those shot, The percentage identification rate of the system to identify every shot's safety level correctly and the percentage of dangerous shots detected.

6.10 Setting up Modelling Parameters and Notes on Scale

In order to generate the best results the system needed to be pushed to generate a larger number of shots in a shorter period of time without changing the setup values to absolute extremes. As a base line test to investigate an average number of shot, a working setup called a base line was used and then each parameter changed one at a time to look for any drastic increase in the number of dangerous shots produced as a percentage of shots taken. The values that were used were loaded into setup screen which is shown in the screen shot of figure 6.10a.

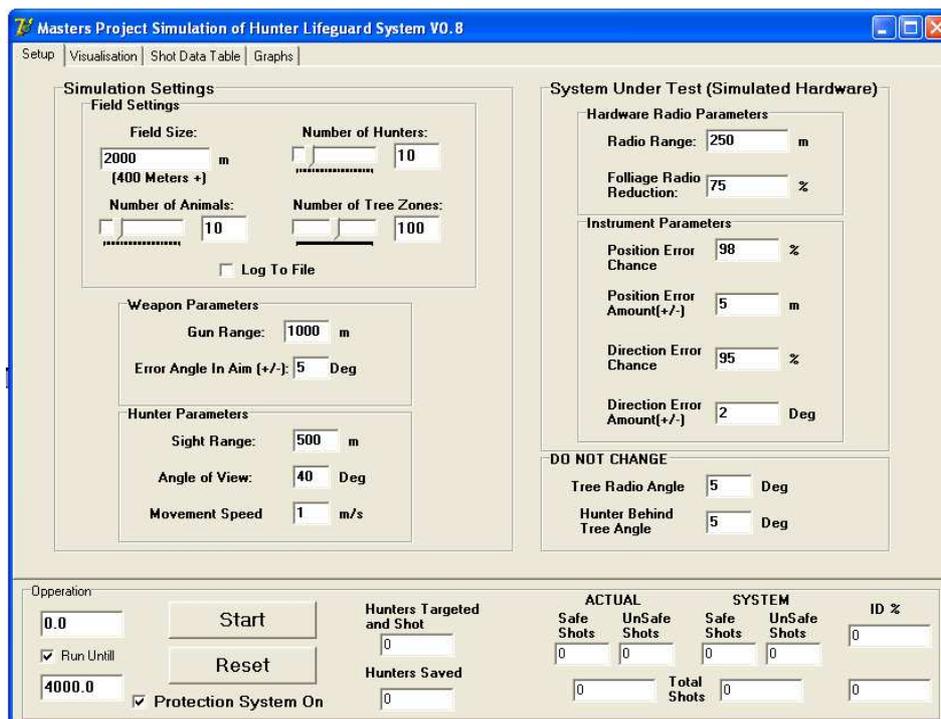


Figure 6.10a: Screenshot of Setup Screen In Final Model Application

The desire of the simulation is to generate a large number of every possible dangerous shot and then to log the conditions of the shot and how each shot is viewed or determined by the simulated solution. For this reason the field variable for running the model, not the simulated system variable, were experimented with to generate a very large number of dangerous shots in a shorter amount of time. The results from some testing of the model are provided in table 6.10b:

	Field	Run	Number	Number	Number	Angle					Total	Total	Percentage
	Size	Time	Of	Of	Of	Sight	Of	Move	Gun	Danger	Shots	Dangerous	Dangerous
	(m)	(s)	Animals	Hunters	Trees	Range	View	Speed	Range	Angle	Taken	Shots	Shots
			(#)	(#)	(#)	(m)	(Deg)	(m/s)	(m)	(deg)			
Baseline Tests	2000	4000	10	10	100	500	40	1	1000	5	1691	257	15
	2000	4000	10	10	100	500	40	1	1000	5	1551	182	12
	2000	4000	10	10	100	500	40	1	1000	5	666	85	12
# of Animal	2000	4000	5	10	100	500	40	1	1000	5	514	59	11
	2000	4000	15	10	100	500	40	1	1000	5	1783	298	16
# of Hunters	2000	4000	10	5	100	500	40	1	1000	5	47	0	0
	2000	4000	10	15	100	500	40	1	1000	5	1494	315	21
# of Trees	2000	4000	10	10	50	500	40	1	1000	5	998	109	11
	2000	4000	10	10	150	500	40	1	1000	5	1580	240	15
Sight Range	2000	4000	10	10	100	400	40	1	1000	5	725	89	12
	2000	4000	10	10	100	600	40	1	1000	5	1808	223	12
Angle of View	2000	4000	10	10	100	500	30	1	1000	5	722	100	13
	2000	4000	10	10	100	500	50	1	1000	5	1353	186	14
Move Speed	2000	4000	10	10	100	500	40	0.2	1000	5	961	122	13
	2000	4000	10	10	100	500	40	5	1000	5	1494	206	14
Gun Range	2000	4000	10	10	100	500	40	1	800	5	1410	138	10
	2000	4000	10	10	100	500	40	1	1200	5	1129	197	18
Danger Angle	2000	4000	10	10	100	500	40	1	1000	4	693	84	12
	2000	4000	10	10	100	500	40	1	1000	6	1288	220	17
Field Size	1800	4000	10	10	100	500	40	1	1000	5	1593	257	16
	2200	4000	10	10	100	500	40	1	1000	5	487	51	11
	2000	4000	20	20	200	600	50	5	1200	6	7118	2508	35
	2000	4000	30	20	200	600	50	5	1200	6	9263	3113	34

Table 6.10b: Table of Simulation Results Without Protection System Active

It can be seen in the above table that increasing each variable increases the number of dangerous shots while decreasing the variables leads to lesser dangerous shots. It should be Remembered that these variables are field setup values and have no relation to the system under test. The principle aim is not to simply increase the number of shots taken but to investigate the setup that produces the largest percentage of dangerous shots. It seems logical but the final setup included within a set area, more hunters, more animals, longer gun ranges as well as faster hunter and animal movement speeds. Shot safety angle being the tolerance in bullet travel left and right in degrees also specifically increases the number of dangerous shots.

It is still important however to not become excessive in increasing these values. While more data is usable more hunters introduces more randomness and starts to load up the system. At a point the number of hunters in a field would start to effect the ability of the radio code to arbitrate communication. For this reason and for the fact that in reality it is unlikely to have such a large number of hunters in a small area the hunter limit used for a 2 kilometre by 2 kilometre square will not be pushed over 20. Furthermore due to the hunting area being so large as in 2km by 2km it can take the hunter a great duration of time to travel around the hunting area at 1m ser second. In order to speed up the process the hunters movement speed was increased to 5m/s. This would more closely resemble a situation where hunters are on quad bikes or off road vehicles.

Gun range was set to a maximum of 1200m. This is to say that a missed shot at 200m could still be dangerous 1km later. This variable can be highly debated with the ability to fire at a 45 degree angle in the air making the possible deadly range of the gun much further and practical shots at targets being much shorter. This situation is most unlikely however with a powerful rifle aiming horizontal at a medium to long range target, having the bullet travel 500m to 1km past the target and to still have the altitude and momentum to cause injury is very rare.

Finally it should be noted that all the tests performed had very little effect on the percentage of dangerous shots other than animal count and hunter count. For this reason these are the two main changes to the baseline tests that will be used in the final tests. Table 6.10c is a summary of the intended values used for the field:

Common To All Tests		
Hunters	20	Count
Animals	20	Count
Tree Zones	200	Count
Gun Range	1000	Meters
Error in Aim	5	Meters
Sight Range	500	meters
Angle of View	40	degrees
Movement Rate	5	meters per sec

Table 6.10c: Setup Values Common to All Model Tests Run

6.11 Results from Model Tests with Real Parameters

Each of the desired tests, as mentioned was run 5 times to produce an average value. Table 6.12a shows example data collected from tests 2, 3 and 4 of 15.

	Test Name	Hunters Targeted and Shot	Hunters Saved By System	Actual Number of Safe Shots	Actual Number of Unsafe Shots	System Determined Safe Shots	System Determined Unsafe Shots	Total Shots Taken
200m Range	Test 2 (a)	293	63	4575	1780	6127	228	6355
	Test 2 (b)	262	32	4572	1619	5989	202	6191
	Test 2 (c)	224	30	4514	1703	6043	174	6217
	Test 2 (d)	148	21	3756	1236	4882	110	4992
	Test 2 (e)	255	39	4627	1844	6251	220	6471
Position Error	Test 3 (a)	260	58	4680	1815	6280	215	6495
	Test 3 (b)	303	46	4188	1622	5608	202	5810
	Test 3 (c)	210	35	4040	1472	5320	192	5512
	Test 3 (d)	269	42	4682	1759	6227	214	6441
	Test 3 (e)	222	44	4818	1842	6469	191	6660
	Test 4 (a)	349	58	5027	2107	6870	264	7134
	Test 4 (b)	207	30	4291	1563	5686	168	5854
	Test 4 (c)	217	25	4212	1492	5551	153	5704
	Test 4 (d)	204	31	3966	1422	5262	126	5388
	Test 4 (e)	234	28	3972	1498	5300	170	5470

Table 6.11a: Sample Results from Model Tests Run

From these results, data processing can be performed to show a percentage of the actual danger level identified by the system in three categories. These categories include the correct identification of all shots, the correct identification of dangerous shots, the number

of hunters shot in comparison to those saved by the system. Table 6.11b contains average results from test 2, 3 and 4 of 15:

Test Name	Percentage of Correctly Identified Shots	Percentage of Dangerous Shots Correctly Identified	Percent of Hunters Saved Vs. Shot
Test 2 (a)	74.60%	12.81%	17.70%
Test 2 (b)	76.08%	12.48%	10.88%
Test 2 (c)	74.79%	10.22%	11.81%
Test 2 (d)	76.88%	8.90%	12.43%
Test 2 (e)	74.25%	11.93%	13.27%
Test 3 (a)	74.38%	11.85%	18.24%
Test 3 (b)	74.70%	12.45%	13.18%
Test 3 (c)	76.05%	13.04%	14.29%
Test 3 (d)	75.11%	12.17%	13.50%
Test 3 (e)	74.61%	10.37%	16.54%
Test 4 (a)	72.76%	12.53%	14.25%
Test 4 (b)	75.08%	10.75%	12.66%
Test 4 (c)	75.40%	10.25%	10.33%
Test 4 (d)	75.06%	8.86%	13.19%
Test 4 (e)	74.84%	11.35%	10.69%

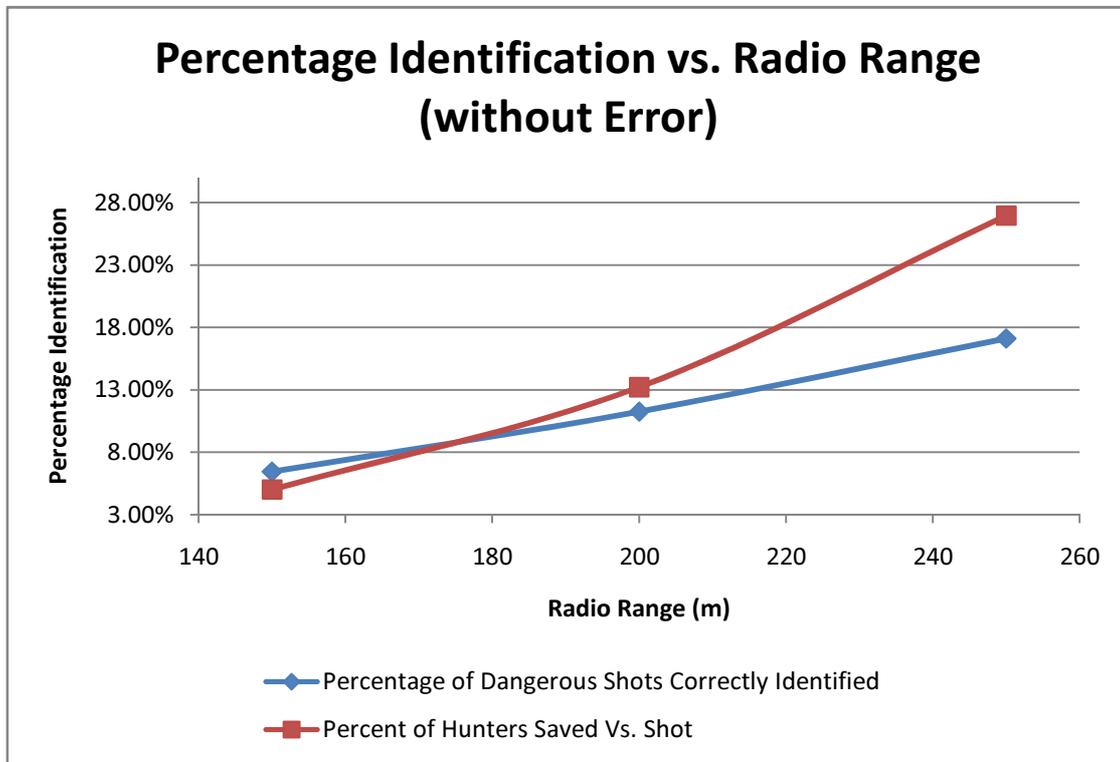
Table 6.11b: Sample Data Processing of Percentage Value Results of Model Tests

When these figures in table 6.11b are averaged we get the final much more manageable table 6.11c:

Test Name	Radio Range	Radio Foliage Range	GPS Reception Chance	GPS Error Value	Compass Reception Chance	Compass Error Value	Percentage of Correctly Identified Shots	Percentage of Dangerous Shots Correctly Identified	Percent of Hunters Saved Vs. Shot	Percent of Dangerous Shots Detected
Test 1	250	75%	100%	0	100%	0	77.17%	17.11%	26.95%	17.11%
Test 2	200	75%	100%	0	100%	0	75.32%	11.27%	13.22%	11.27%
Test 3	200	75%	95%	5	100%	0	74.97%	11.98%	15.15%	11.98%
Test 4	200	75%	80%	20	100%	0	74.63%	10.75%	12.22%	10.75%
Test 5	200	75%	100%	0	95%	3	75.30%	12.18%	15.09%	12.18%
Test 6	200	75%	100%	0	80%	20	75.06%	11.32%	16.51%	11.32%
Test 7	200	75%	95%	5	95%	3	75.95%	12.11%	15.07%	12.11%
Test 8	200	75%	80%	20	80%	20	74.56%	10.88%	13.36%	10.88%
Test 9	150	50%	100%	0	100%	0	74.18%	6.45%	5.02%	6.45%
Test 10	150	50%	95%	5	100%	0	74.18%	6.40%	4.35%	6.40%
Test 11	150	50%	80%	20	100%	0	73.58%	6.37%	4.87%	6.37%
Test 12	150	50%	100%	0	95%	3	74.83%	7.04%	5.68%	7.04%
Test 13	150	50%	100%	0	80%	20	73.89%	6.09%	4.14%	6.09%
Test 14	150	50%	95%	5	95%	3	75.30%	6.05%	3.97%	6.05%
Test 15	150	50%	80%	20	80%	20	74.14%	6.98%	4.09%	6.98%

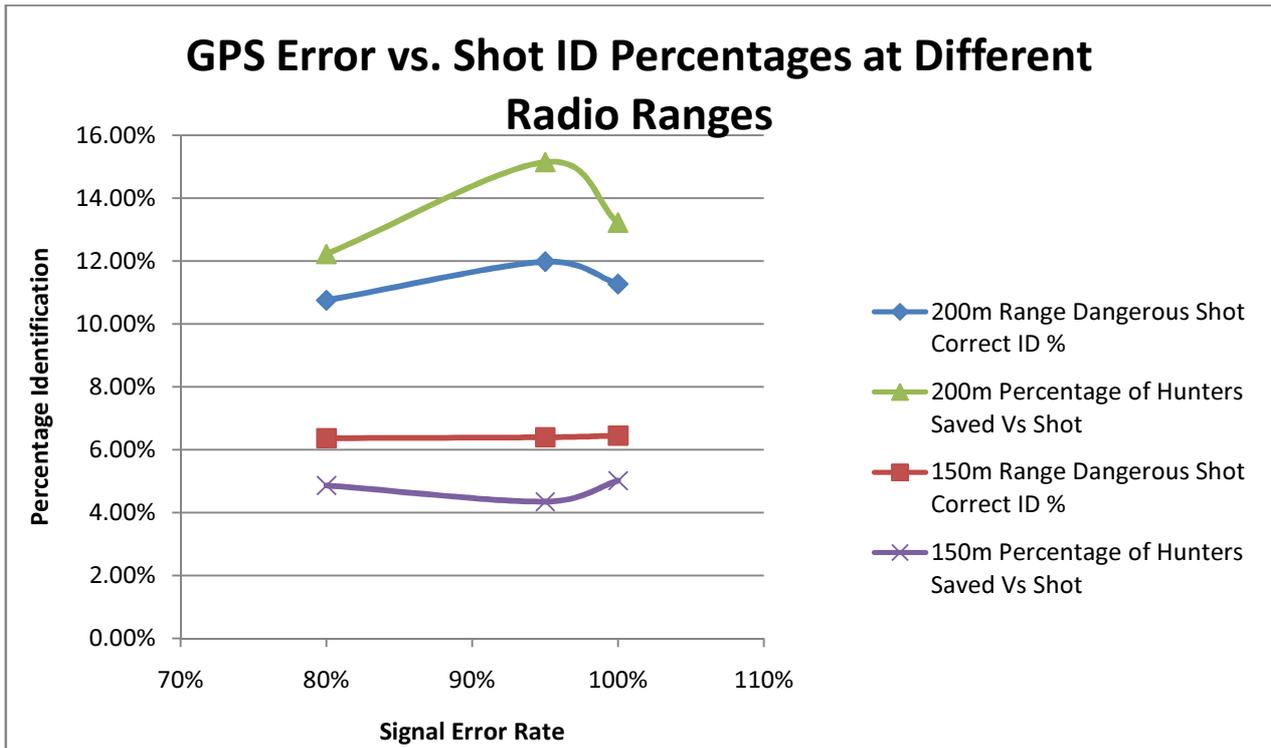
Table 6.11c: Accumulated Model Test Results

From table 6.11c a number of graphs can be generated to illustrate the difference in the figures. If we are to primarily compare the results for 0% error which is equal to 100% reception in both GPS and Compass readings, graph 6.11d can be generated:

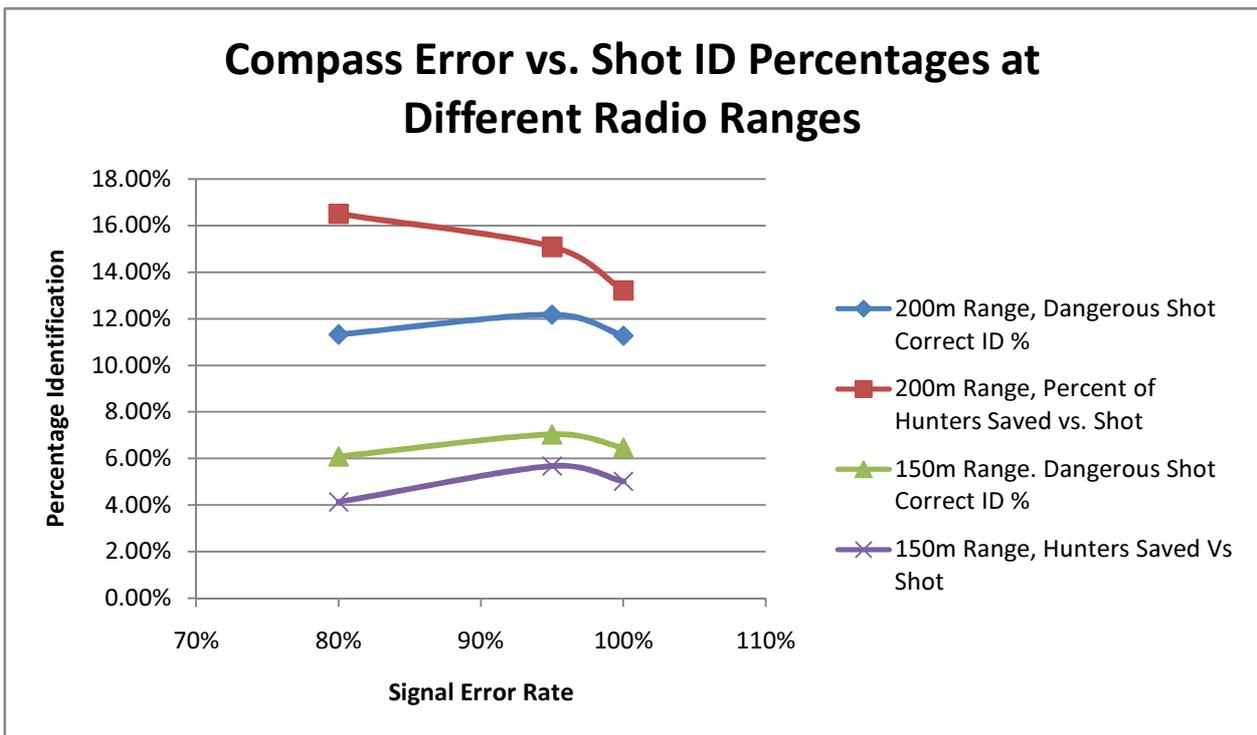


Graph 6.11d: Radio Range vs. System ID Percentages

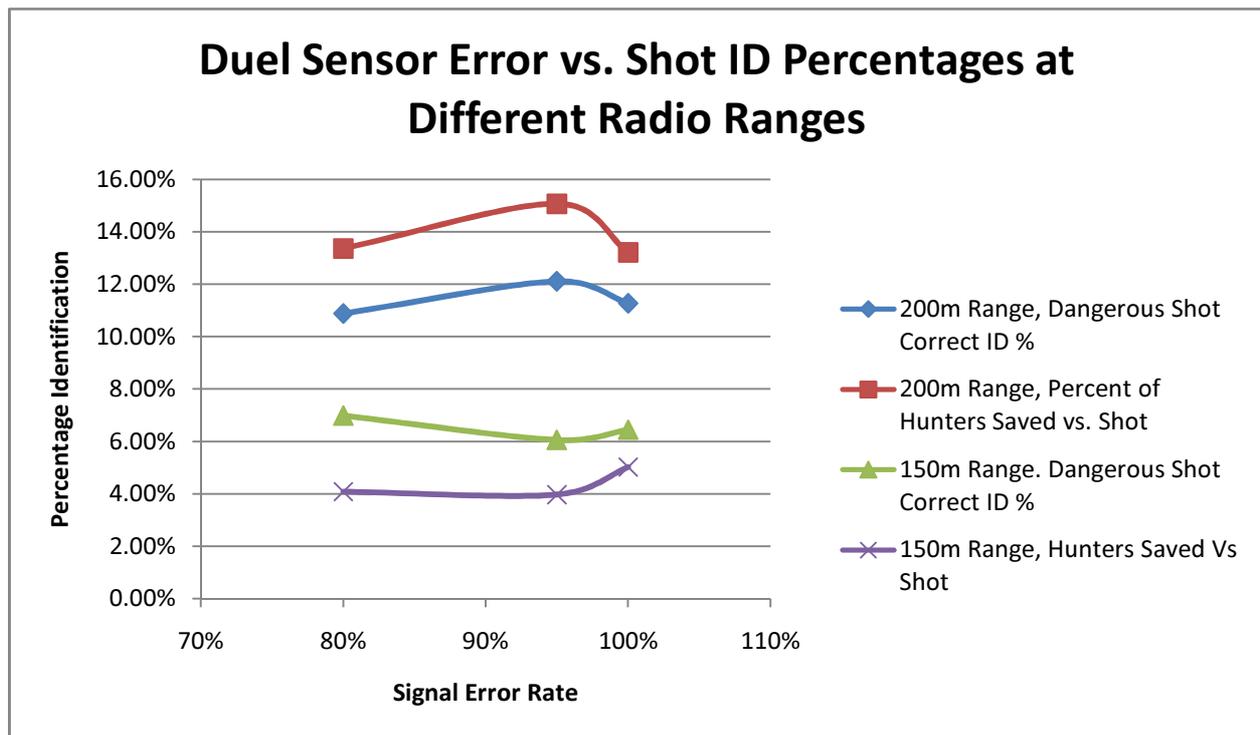
In the graph 6.11d it is easy to see that with an increase in radio range we receive an increase in system performance. What is not so clear and should be pointed out is that a small increase in radio range leads to a drastic increase in the amount of system protection provided. Further graphing of the results produces graphs 6.11e,f and g where the percentage change of GPS signal Reception is graphed against Dangerous Shot ID percentages and Hunters Saved vs Shot percentages:



Graph 6.11e: GPS Reception Chance vs. System ID Percentages



Graph 6.11f Compass Reception Chance vs. System ID Percentages



Graph 6.11g Duel Sensor Reception Chance vs. System ID Percentages

6.12 Analysis of Model Outputs from Real Parameter Tests

The final table of results for model testing are shown in figure 6.11c. If this table along with the graphs 6.11d, 6.11e, 6.11f, 6.11g were to be analysed the following could be said:

It can be seen from table 6.11c that the results have been generated at 3 different radio ranges with increasing levels of error in sensors of position and direction.

The first important note is that even with all the discrepancy in the setup values that approximately 75% of all shots were identified correctly in all tests. Unfortunately it is also notable that most of the dangerous shots exist in residual 25% of all shots fired.

The average percentage of hunters saved is a clear indication of systems performance. This value is only related to miss identification shootings as a result of foliage. From the values it can be seen that the perfect system (as in test 1) stopped about 27% of hunters that were miss-targeted from being shot. When the radio range is reduced by 50m for a system representative of 433MHz (test 2), it can be seen that the number of hunters saved by the system under test lowers to around 15% of all hunters miss-targeted. When a larger error rate and tolerance is introduced to the same symbolic system such as in test 7 and test 8, it lowers the number of hunter saved by a further 5%. This brings the equivalent of an erroneous 433Mhz system down to a total of 10% of miss-identified hunters as targets being saved. Finally when the shortest ranged system

tests were performed called test 9 to test 15 the value of hunters miss targeted that were prevented from being shot drops to an extremely low value of 6% with or without error.

The percentage of dangerous shots identified also shows a good indication of system performance. With dangerous shots including the entire gun range due to hunters in danger beyond a target, the systems under test managed to detect a measly 17.5% of all dangerous shots. This number still holds a little weight at 200m radio range tests being around 10% to 12% of all dangerous shots being correctly identified. This value however again falls to an extremely low level of 6% when the radio range is reduced further to that representative of an 868MHz and a 915MHz system.

It is noticeable that the higher frequency transmissions of 868MHz and 915MHz can maintain good connectivity, data rate and low percentage error rates at short range. For radio applications of approximately 50m distances the differences in error rate and signal strength are negligible between 433MHz, 868MHz and 915MHz. However due to the higher safety rate of the lower frequency 433MHz would be the best choice for this application. These frequencies fit within the UHF bandwidths that are free to use in most countries.

For communication over longer distances of around 150m +/-50m the best option for an application is again the lower frequency to 433MHz. This is because the 433MHz frequencies maintain better signal strength over distance in both open fields and forest, and have a lower percentage error rates at longer distances. The extremely high percentage error rates as well as the short range that were measured during the higher frequency transmissions only further support the 433MHz option.

6.13 Example Node, GPS and Digital Compass Performance

Example node field tests proved most frustrating with initial tests showing no dangerous angles what so ever and little more than a single green light illuminated. Some of the latter test performed did however show a red light indication of a dangerous angle however the angle indicated was significantly different from the direction of the Dumb node placed in the field. This is believed to exist due to no calibration of the compass angle as well as influential factors such as the attached metal angle iron in substitute for a gun barrel causing a shift in magnetic field direction.

Shortly after these tests the code was further edited to include the compass calibration and to slightly restructure the radio code to its current form. The final edition of embedded code clearly demonstrates that such a prevention methodology as in the model, can be implemented in a real hardware prototype. An alternative sensor network module or SOC system on chip could be chosen to again slightly increase range providing even more coverage. The GPS and Compass modules used would not be changed as the results

seemed acceptable for the basis of a prototype system however more investigation could be undertaken on the effects of a metal barrel on a digital compass.

The GPS road tests carried out proved to be most surprising. The tests that were performed showed no visible missing points and little more than +/- 2m from actual position. This leads to the conclusion that the GPS units chosen suit the job of accurate position location very well.

The digital compass tests were different again. The actual compass readouts proved to be very accurate with a reading to the nearest decimal point and a variance of around +/- .2 degrees at worst. What was interesting is how inaccurate the compass output was in terms of actual heading. As seen by results the calibration of the compass seemed quite far off and furthermore the addition of a mock up barrel attached to the data logging setup caused even more error between actual heading and compass readout.

It can be concluded that the GPS positioning equipment was both accurate, reliable and low cost and if further attempts at the system are made the same GPS units would be used without concern. Unfortunately the same cannot be said about the compass. While it can be calibrated it is suggested that any further development work is done when newer or more accurate and cheaper digital compass units are available.

7.0 To Conclude

Entering into this project the principle objectives firstly involved the attempted generation of a model to test friendly fire prevention methods. Further objectives include the conversion of this modelling application code into a simple hardware prototype in an attempt to show the feasibility of such a friendly fire concept as a real system. Final Objectives involved taking lessons learned from hardware development to further test the model and derive conclusions of how to better protect hunters with the method implemented. This section concludes on these issues and presents future work to be undertaken.

7.1 Final Conclusions

Overall I believe that the results from the testing prove that this method of friendly fire prevention is an effective technique to save hunters lives.

The model testing not only proved that a percentage of random dangerous shots can be stopped using the hardware tested, but more specifically an amount of wrongly identified targeted hunters will not be shot. The model as its own entity is amazingly useful not only in its ability to demonstrate the above claims but also in its ability to test any other possible solution systems that fit to this format.

It is easy to conclude here that a radio range of 150m failed in all tests to meet any reasonable levels of safety with the possibility of preventing one in every 20 hunting shooting accidents. The 200m radio range tests symbolic of the 433MHz system under tests still performed poorly however was more than twice as effective as the shorter radio range, saving approximately 1 in 10 up to 1 in 7 hunters. Finally the ideal test of 250m radio communication proved practical saving as much as 1 in 4 hunters from a shooting incident leading to the conclusion that this should be the minimal range for such a system if further developed.

It must be included in this argument that all dangerous shots calculated are not lethal, in fact most dangerous shots will miss a non aimed target however shots being intentionally aimed at a misidentified target are usually more fatal due to the included intention. Of these shots the systems tested showed that a radio range of 200m was almost acceptable as an entry level into effective friendly fire prevention systems and that the GPS discrepancy and compass calibration problems can be overcome and are not as influential on a system performance as radio range is (according to the model).

7.2 Effect of Foliage on Radio Range and Error Rate

Is it clearly visible for the radio field tests that foliage has a direct results on both signal strength at range as well as the percentage error rate. The effect of using radio equipment in a forest or wooded area is negative to both measurement criteria.

It shows from testing that for further transmission distances and higher quality transmission of small amounts of data in both radio friendly and non friendly environments it is best to chose a lower frequency if available to provide better protection.

7.3 Future Work and Further Development

Initial ideas for future work on this project, focus on keeping the concept the same however experimenting with different hardware is suggested. Slight issues were found with battery life in that it was noticed that during field tests batteries would regularly run out. Final concept units if produced as a product would require a full day of battery usage without changing batteries.

Changes in testing methodology for GPS could be established in that running multiple paths and overlaying multiple GPS data logs would indicate more discrepancy in data. Likewise compass testing would be better performed at a number of "magnetically noisy" locations and the data compared to establish the true susceptibility of the compass. Adding to this more compass data points can be recorded to allow for the generation of a better calibration curve.

Future work could include extending the project into the third dimension. This would involve investigation into the elevation of the gun barrel as well as its direction. The GPS output already contains an altitude reading however reliability of this value is very questionable.

One of the final sections of future work that might be undertaken is the real testing of a populated field with these devices. Such an investigation could be implemented as a scoring system for a paint ball match. These tests would give good comparative results against the model generated however would require many hardware units.

Another future application could be a scaled down version for people without weapons. Such a unit can be carried by both non target animals such as breeding stock and other non targets such as hikers and hunting dogs. Non target marker when mounted by a ranger onto specific animals would protect animal populations. If such a device were mounted around a perimeter they may be able to even prevent stray bullets fired out of the hunting area.

A suggested next stage of processing would involve moving the GPS, compass and wireless processor to a single PCB and enclosure. Along with this development upgrade, other future work could make use of a surface mount, on-board antenna for the radio module in order to reduce physical awkwardness and increase prototype durability.

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