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Review Article

Systematic Review of Sleep Monitoring Systems for Babies: Research Issues, Current Status, and Future Challenges

Neda Khan,[1] **Duaa Zuhair Al-Hamid**,[1] **Peter H. J. Chong**,[1] **Farhaan Mirza**,[2] **and Arun Kumar**[3]

[1]*Department of Electrical and Electronics Engineering, School of Engineering, Computer and Mathematical Sciences, Auckland University of Technology (AUT), Auckland 1142, New Zealand*
[2]*Department of Information Technology and Software Engineering, School of Engineering, Computer and Mathematical Sciences, Auckland University of Technology (AUT), Auckland 1142, New Zealand*
[3]*Department of Computer Science & Engineering, National Institute of Technology (NIT), Rourkela, Odisha 769008, India*

Correspondence should be addressed to Neda Khan; neda.khan@autuni.ac.nz

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Recently, baby healthcare monitoring systems have emerged as a key research area. However, numerous research studies have been conducted on babies and their state of either awakening or sleeping. But there is a lack of comprehensive and systematic review in this area of research. The existing research considers mostly the children's monitoring vital health parameters, in turn, giving relaxation to the parents in caring of their babies. Still, the fundamental practical issues related to daily life are missing. As a result, the safety of babies against suffocation and falling hazards for employed parents or mothers involved in the workforce has been overlooked. Only a few studies exist that cover the age range of 0 months to 4 years, with further focus on the age range of 6 months to 4 years. In response to these gaps in previous research and existing technologies, this review work proposes a vision for a baby safety system that utilizes various sensors and technologies like machine learning and image processing to ensure a safer environment for babies.

1. Introduction

In recent decades, working mothers have represented a significant part of the labour force, accounting for nearly one-third (32%) of all working women. According to the American Community Survey conducted by the United States Census Bureau, two-thirds of the 23.5 million employed women with children under 18 work full-time [1]. Thus, it has significantly impacted contemporary society [2]. Nowadays, with the increased demands of life and busy lifestyle, taking care of infants is becoming extremely difficult [3]. According to a survey by the Centre for American Progress, half of U.S. families face childcare difficulties [4].

Due to the duo's work culture, infants suffer from a regrettable lack of maternal care and nurturing, leading to serious health issues. About 19% of parents encounter difficulty because childcare is expensive, and approximately 38% do not even have access to childcare facilities [5]. Furthermore, babysitting does not fulfil parent's natural feelings and desires for baby upbringing, and in extreme cases, it may result in infant mortality. According to the World Health Organisation (WHO), substantial progress has been made in reducing child mortality worldwide since 1990. The overall number of deaths among children under the age of five worldwide has fallen from 12.6 million in 1990 to 5 million in 2020. The global under-5 mortality rate has fallen by 60%, from 93 deaths per 1000 live births in 1990 to 37 in 2020. This is equivalent one in every 11 children dying before the age of five in 1990, compared to one in every 27 in 2020 [6].

According to the report of the New Zealand Ministry of Health, the risks to the safety of babies have increased due to the increase in COVID-19 cases, resulting in 497 deaths in the last two years [7], affecting almost the whole world.

Because of this, opening childcare facilities that rely on nannies who may not practice good hygiene and grandparents as caregivers could pose a risk.

All of these challenges highlight the importance of incorporating cutting-edge technologies in providing a smart healthcare system and improving the safety of babies during their sleep-in order to avoid dangerous situations and enhance parents' experience caring for their babies. In light of recent advancements on The Internet of Things (IoT) technology and its applications, which have surpassed traditional environment sensing techniques, wireless sensor networks (WSNs) become essential for various applications such as health monitoring systems. IoT has the potential to communicate sensor data over the Internet without human interaction. The IoT architecture helps control devices, real-time monitoring, autonomous operations, and optimize data analysis. Therefore, it is widely considered to be the most convenient technology designed to make individuals' lives easier. It has been noticed that machine learning and deep learning are also playing an important role in building up the smart and intelligent healthcare system [8] and to improve the quality of service [9], respectively. Here in, the development of smart devices such as wearable sensors can bring intelligence to healthcare systems that can be useful in a variety of fields such as infant safety and health-tracking, care for the elderly, healthcare monitoring [10], military and law enforcement, sports, and preventive medicine [11]. Even these days, mental health disorders are being depicted in not only adults [12] but in children [13] and adolescents who have been taken into challenge to resolve using machine learning and deep learning algorithms. Wearable sensor-based technologies for infants have also been introduced to warn of life-threatening situations [14].

Several ongoing studies have encountered various technical challenges such as limited visibility of only one side of the face, alignment issues, and the baby sucking their thumb while sleeping [15]. In particular, there are specific scenarios that are known to be dangerous, such as skull fractures, dislocated bones, and head injuries that can result in death due to falling hazards. Moreover, risky postures may lead to fall [16] and become the serious reason for the babies' death. Cold temperatures and nose blockage can also lead to suffocation, adding to the potential dangers. Additionally, some studies have faced hardware constraints to achieve optimal accuracy in their results. However, there is a noticeable lack of research that tackles privacy concerns. Consequently, parents and caregivers must constantly monitor babies, and ensuring their care and safety has become an everyday challenge.

The remainder of the article is organized as follows: Section 2 provides literature review. The vision of the Baby Health Monitoring System (B.H.M.S.) and open research issues are discussed later. Finally, the paper is concluded with the discussion.

2. Related Work

The advanced IoT technologies and wearable sensors underpinning the B.H.M.S. are active research areas. Henceforth, there have been 14 articles selected after reviewing several research works. This review concentrated solely on the risky scenarios faced by the baby in a sleeping state. Furthermore, the review has been restricted to children aged 6 months to 4 years. These dangerous scenarios are further subdivided into three major ones: continuous cry, safety hassle/environment issues, and health problem, and are explained in two ways: single scenario and mixed scenarios summarised in Tables 1 and 2, respectively. The overview of literature review is shown in Figure 1 in the form of a tree diagram. The health risks faced by babies who are put under the care of childcare, nannies, or even grandparents have been considered in the literature analysis. In addition to the risks, current technological solutions have been highlighted.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) technique has been used for systematic reviews and meta-analyses as the systematic review methodology [17]. Scopus, Web Science, Science Direct, Springer Link, Google Scholar, and the IEEE Xplore Digital Library are among the databases searched.

The following keywords are used in the literature review: "infant care," "child care," "baby healthcare monitoring," "smart wearable system," "IoT-based healthcare system," "wearable sensors," "dangerous scenarios," and "scientific technology." Additional search terms such as "baby" to avoid excluding papers on infants, toddlers, and combinations such as dangerous scenarios/baby/HMS/IoT/sensors/scientific technology/up to 4 years' age group are recommended. At the start, 80 publications are identified from the databases. Five duplicates' publications are removed after the initial screening. Furthermore, 20 articles are removed after skimming through the abstracts and the initial screening. Thus, 65 full-text publications were retrieved and included to be evaluated for eligibility based on the exclusion criteria (Table 3). Following the exclusion of irrelevant studies, 14 publications are chosen for the final review. Figure 2 presents the study selection process, while Tables 1 and 2 depict a comprehensive illustration of the included publications.

2.1. Health Risks

2.1. Health Risks. Parents often take on multiple roles as essential economic or domestic family support, whether they live in developing or developed countries. As a result, parents may leave their infants or toddlers in the care of grandparents, nannies, or childcare centres. This may expose babies to a variety of health risks that may have been preventable at home. The risks of baby safety exist while the baby is moving, awake, or asleep. Problematic situations may arise, such as colic, electric shock, falling downstairs, seizures, swallowing objects, or rolling over. While some of these can be prevented, numerous dangerous and potentially fatal scenarios can occur when a baby is asleep, including falling from an elevated crib, bed, sofa, or couch, intense or continuous crying, accidental asphyxia, seizures, suffocation, sudden infant death syndrome (SIDS) [18, 19], chest compression, severe cold and cough, high fever, abnormal posture and gestures, and others. The next subsection that follows looks at available technology solutions to similar challenges.

Table 1: Monitoring of single scenario while baby is sleeping using B.H.M.S.

Dangerous scenarios	Specific situations	Scientific technology/IoT devices or sensors	Benefits (result accuracy)	Limitations
Continuous cry	Pain, discomfort [20]	Acoustic signal processing/Camera and microphone	No accurate result analysis is mentioned	Data transmission frequency by the sensor's module should be at face value with the data reception frequency in the signal processing unit. No delay must be there in the transmission of the message to the parents
Continuous cry	Loud cry [21]	Audio signal processing and convolutional neural network (CNN)/not used	98.6% in identifying background noise and 92.2% in detecting cries from other nonbackground sounds	Detection of the duration of crying and the strategy of triggering relevant alarms should be further investigated. Reasons for crying must also be included to help parents provide effectual and liable parenting
Safety hassle/ environment issue	Falling from bed/couch/crib [22]	Image processing/Pi camera, M.I.C. condenser	Result accuracy is not mentioned. The non-contact-based monitoring system is designed. Haar cascade classifier is made for the prototype, and the dataset is trained with it	The alert system must be updated from mail to call
Health problems	Breathing troubles/ suffocation/asphyxia [23]	Image processing (motion detection mechanism based on handcrafted features)/not used	Response time and % accuracy, respectively, of 15 frames per interval for 30 F.P.S. (720p) with the given methods: (1) frame difference: 0.4 and 84.51 (2) Background subtraction: 0.89 and 84.51 (3) Hybrid method: 0.89 and 84.51	Light weight CNN model can be used to effectively present actions/patterns
	Cerebral palsy and autism spectrum disorders [24]	CNN and support vector machine (SVM)/accelerometer and gyroscope	For posture: CNN gives 80% and SVM gives 70–75% accuracy	To allow the hand or leg movements, an analysis must also be included separately for different posture contexts
	High fever and hypothermia [25]	Not used/pulse rate sensor and humidity sensor	% of pulse rate accuracy is 88–92.5% and successful threshold level system for humidity	Global data transmission network must be used, i.e., Internet to make the system more effective and efficient
	Skin allergy and rashes [26]	Not used/moisture sensor, sound sensor, and methane sensor	Multiple sensors with additional features for securing toddlers. No accurate result analysis is given	Alert updating system can be improved implementing cry threshold too
	Wet mattress/dampness on the baby bed/nature calls [27]	Not used/temperature sensor, humidity sensor, gas sensor, pulse rate sensor, microphone, and camera	Multifunctional system and updating baby's healthcare-related data to the mothers and caretakers from time to time	Frequent sneezing and coughing must also be sensed to give better healthcare updates
	S.I.D.S. [28]	Artificial intelligence/Cameras	AI algorithms accurately detect unsafe baby sleep postures with an accuracy of 87.8%	Face masks and alignments of the body are to be covered to get more effective results

Table 2: Monitoring of mixed scenarios while the baby is sleeping using B.H.M.S.

Specific dangerous situations	Scientific technology/IoT devices or sensors	Benefits (result accuracy)	Limitations
Discomfort [29] Wet mattress [29]	Voice signal processing/moisture sensor, microphone, and camera	Sleep disturbance rate reduces from 50%, i.e. of the traditional system to 35%, i.e. of the proposed one	The system can be upgraded with the night vision camera
Loud/middle-night cry [31] Dangerous surrounding environment [31] S.I.D.S., nauseous, wet mattress [31]	Not used/web camera, temperature sensor, condenser M.I.C., DHT22 (temperature and humidity sensor)	Tested with 10 kg ballast successfully to stimulate the baby Sound detection has some time delay probably due to the loop process in programming codes	The level of the baby's crying must be distinguished as a low, medium, or high dB crying. To vary the speed of the swing process according to the measured dB(s), the motor attached to it can be coded. Additional wearable sensors can be installed for advanced monitoring
Pain [32] Cerebral palsy [32]	Not used/E.M.G. sensors, vibration motors, accelerometer	A good outcome for better sleep by providing a massage effect to avoid muscle spasms and safety by detecting seizure attacks	Only by using accelerometer sensors, that measure changes in positions, introduce drift error
Face mask and roll-over [15] S.I.D.S., hypothermia/hyperthermia [15]	Artificial intelligence and image processing/camera	Accuracy is not mentioned, but the results of the algorithms implemented showed successful attempts in real time with low latency	A new dataset of baby images having complex sleeping postures such as baby sucking thumbnail while sleeping, only side face visible, alignment issues, etc., may need to be developed
Dangerous/sharp objects around the baby and face mask [30] High fever, hypothermia, breathing troubles, and milk vomiting [30]	CNN and Gaussian mixture model (G.M.M.)/camera, body temperature sensor, heartbeat sensor, and temperature and humidity sensor	The delay between events occurring and receiving the alarm signal is 3-4 seconds. The false alarm rate is about only 0.5%. The detection failure rate is zero	Events of low-level warning must also be taken into a priority to avoid further risk

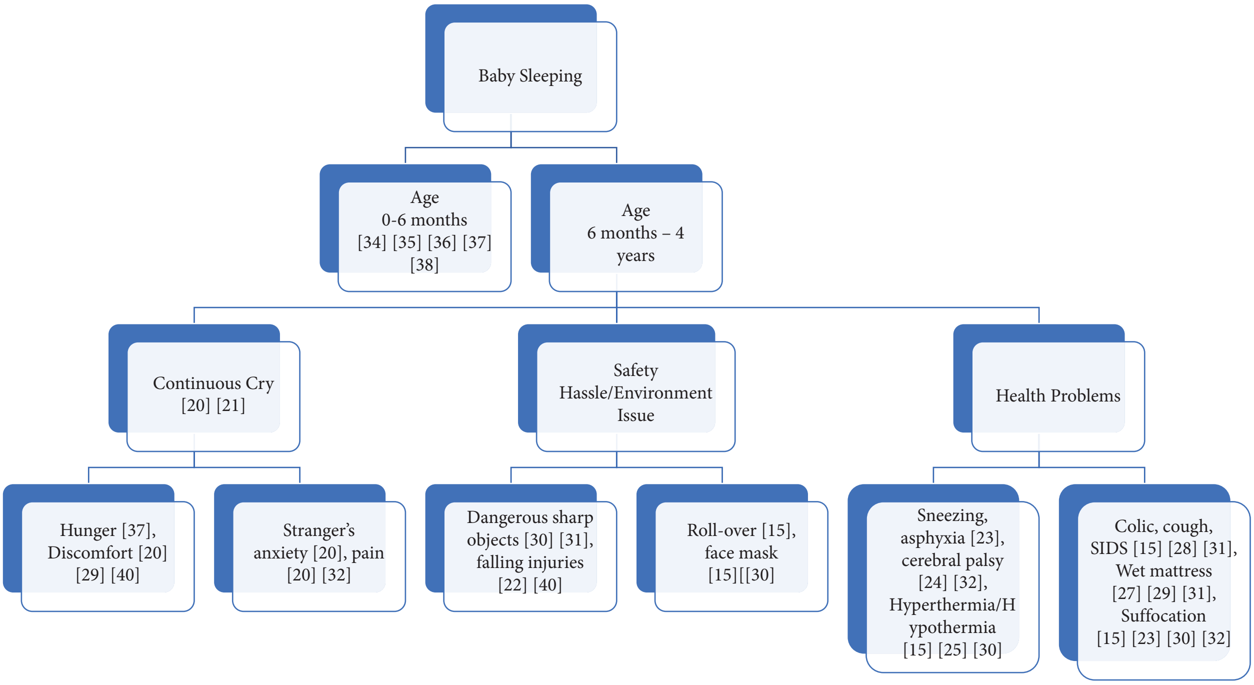

Figure 1: Tree diagram depicting leading risks and dangerous scenarios while the baby is sleeping.

Table 3: Exclusion criteria.

	Exclusion criteria
1	Articles that are not in English
2	Studies with a less technological focus
3	Articles solely on generic healthcare activities
4	Articles published ten years ago
5	Smart home studies for elderly healthcare
6	Articles with more emphasis on infants of 0–6 months
7	Articles with a commercial focus only
8	Studies with a high focus on computer networking, protocols, connectivity, and designs

2.2. Existing Technological Solutions. The following subsections present solutions to a variety of scenarios: these are single and mixed scenarios. Single scenario direct towards the designed system which has found the solution for any of the single situation that can be either continuous cry or safety hassle/environment issue or health problems faced by the baby as shown in Figure 1, whereas mixed scenarios depict the designed system that has found solutions for multiple situations that can be mixed issues of continuous cry, safety hassle/environment issue, and health problems faced by the baby.

2.2.1. Single Scenario

(1) Continuous Cry. Myakala et al. [20] proposed an Intelligent Cry Monitoring and Cry Detection System to monitor the cause of a child's cry in real time. Cry detection employs signal processing methods such as autocorrelation and modified zero-frequency filtering. The cry signal is also used to extract parameters such as instantaneous fundamental frequency (F0), strength of excitation, and signal energy. These extracted features detect the cause of the cry, such as discomfort, vaccine pain, anxiety, hunger, and thirst. Thus, it resulted into the behaviour of quantifying output parameters of the extracted parameters. These parameters are reported to be substantially larger in the pain category than in the discomfort category. In the future, the system must alleviate the delay in relaying the alert message to the parents. The system must maintain the sensors' module's data transmission frequency at face value with the signal processing unit's data receipt frequency. This could assist in the prevention of data loss. Xie et al. [21] proposed a two-step approach for detecting continuous infant cries. First, using a volume-based thresholding algorithm, background segments are detected. This algorithm is considerably more efficient in terms of computation. The second step is extracting cry detection features using advanced convolutional neural network (CNN) models. These models operate on the log linear-scale filter bank energies of audio signals. The proposed approach attained an accuracy of 98.6% in identifying background noise and 92.2% in

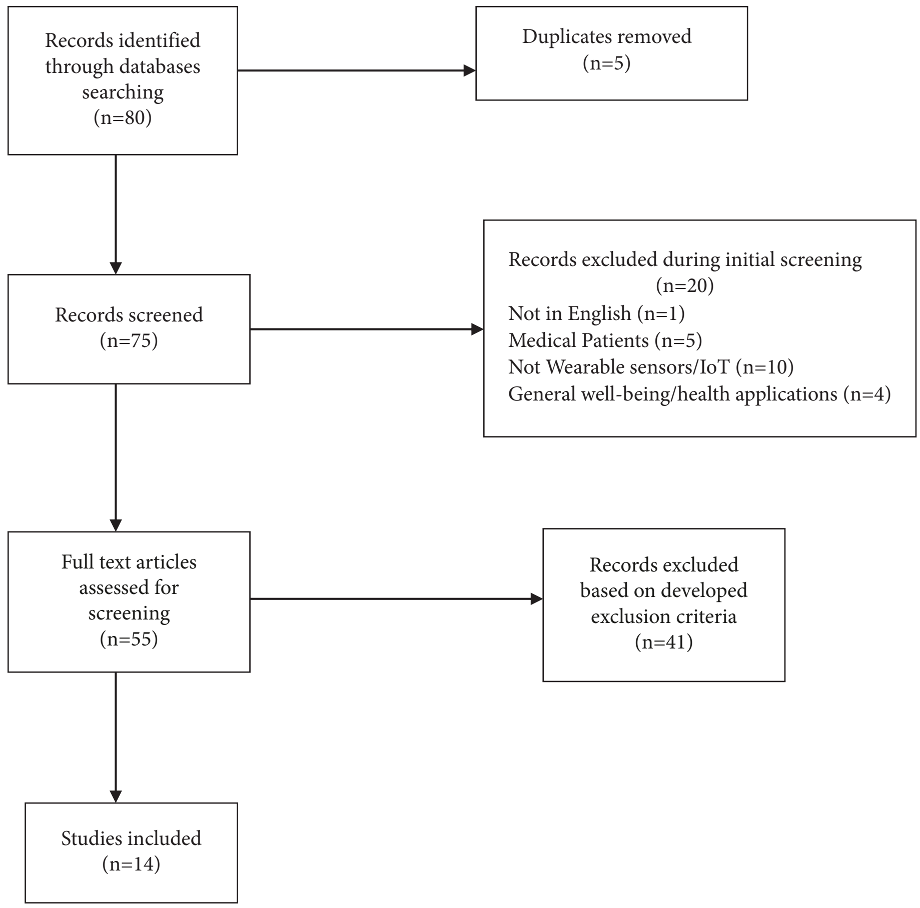

Figure 2: The study selection process.

detecting cries from other irrelevant sounds. While future work should focus on detecting the duration of crying and the strategy for triggering relevant alarms, the reasons for crying must also be taken into consideration to enable parents provide effectual and liable parenting.

(2) Safety Hassle/Environment Issue. Khan et al. [15] proposed an intelligent baby monitor to detect potentially dangerous or undesirable settings for the baby. In their work [15], the monitoring device uses artificial intelligence (AI) and image processing techniques to detect scenarios such as face masks and incorrect sleep postures, including roll-over, sleeping on the stomach, etc. The implemented algorithms show successful real-time efforts with low latency. Hence, a dataset of a new image with complex sleeping postures of babies, such as a baby sucking thumbnail while sleeping, only the side face visible, alignment issues, etc., may be required in the future. These data are then labelled, and the models are retrained using transfer learning with the new dataset. Dubey et al. [22] toiled over a non-contact-based baby monitoring system that detects crying, real-time motions and positions of newborns, and boundary conditions of the bed using image processing to reduce the probability of falling hazards. The face detection algorithm is trained using the Haar classifier to detect positive and negative nonfacial images. The system responds at the desired time interval of 120 seconds in the form of an e-mail to alert the parents about the current status and the baby's snap. Despite this, the alert system must be through calls or messages to the parents and family doctor/paediatrician for prompt actions.

(3) Health Problems. Hussain et al. [23] proposed a new vision-based baby monitoring framework in which control charts were employed as a process improvement technique to analyse a baby's breathing behaviour. In this scenario, the upper control limit (UCL) refers to highly intense motion, while the lower control limit (LCL) refers to no motion in control charts. If certain limitations are exceeded for a certain number of frames in a single interval, an alarm is generated. The frame difference and background subtraction (Gaussian mixture-based background/foreground segmentation) algorithm is used to compute baby motion. Response time and accuracy in percentage of 15 frames per interval for 30 F.P.S. (720p) using the following methods:

(1) Frame difference: 0.4 and 84.51
(2) Background subtraction: 0.89 and 84.51
(3) Hybrid method: 0.89 and 84.51

Lightweight CNN models can be used to efficiently present actions/patterns. Airaksinen et al. [24] described a smart multisensory jumpsuit as a wearable device for infants. The developed infant wearable used machine learning algorithms based on deep CNNs to screen and identify infants. These infants may be at a high risk for neurodevelopmental disorders such as cerebral palsy and autism spectrum disorders. Thus, the algorithm is trained to detect posture and movement classes using the data and annotation. Hence, CNN has an accuracy of 80% and support vector machine (SVM) has an accuracy of 70–75% for automatic posture detection. Furthermore, a new method for analysing hand or leg movements' indifferent posture contexts is to be introduced. Ishak et al. [25] introduced an improved outlook for the Neonatal Intensive Care Unit (NICU). It focuses on designing a monitoring system that includes an incubator equipped with the required sensors to measure the pulse rate and humidity. A survey of various sensors and actuators has been conducted to implement an intelligent cradle alerting to prevent unsanitary situations from becoming significant issues for the newborn [26]. Pratap et al. [27] developed an IoT-based smart cradle that monitors hygienic conditions to ensure babies' well-being. Huang et al. [28] demonstrated an accuracy of 87.8% in detecting safe newborn sleep postures to avoid fall injuries and SIDS.

2.2.2. Mixed Issues and Scenarios. Mixed Issues and Scenarios. Of the research work and solutions that entail examining multiple health and safety issues at once are shown in Table 2, for example, tracking an infant's biofeedback monitoring, sleep position, respiratory rate, and body temperature. These data are considered the primary factor in the high risk of SIDS. [18]. Ferreira et al. [19] developed an approach that describes the use of a smart wearable system for SIDS. Monitoring with a wearable IoT device embedded into a chest belt provides critical key metrics for diagnosing SIDS scenarios and evaluating sleep quality. Joshi et al. [29] presented the design of a smart cradle, which reduces the sleep disturbances of the baby from 50%, i.e., of the traditional to 35%, i.e., of the proposed one. Lai et al. [30] integrated the CNN with the Gaussian mixture model (G.M.M.) to detect abnormal or harmful occurrences such as asphyxia, milk vomiting, dangerous or sharp objects in the vicinity, and sleeping on the stomach. Furthermore, using the time series analysis method, the false alarm rate was reduced to zero. Jabbar et al. [31] designed a smart cradle; it helps in the detection of crying and the surrounding environmental conditions to avoid risky situations such as SIDS. Divakaran et al. [32] designed a unique bed named "Bedstead" to save babies from dangerous situations such as cerebral palsy, which includes seizure attacks, discomfort, respiratory problems, muscle spasms, etc. The author ensures that babies can have profound and uninterrupted sleep with little or no disruption.

3. The Vision of B.H.M.S

B.H.M.S. is the system to give ease and comfort to the babies in any way either measuring vitals or finding the dangerous scenarios to avoid further life-threatening incidents. Many B.H.M.S. are being designed to provide better quality sleep by keeping eye on the babies' vital parameters. Thus, in this research work, the B.H.M.S. to be designed is an alert-based system for sleeping babies considering two cases:

Case (i): A camera captures the image, and the sensors detect breathing status in a suffocation state

Case (ii): A camera captures the image and movements in a falling state

The system architecture of case (i) of the proposed system is illustrated in Figure 3.

(a) Data collection: in this initial stage, various sensors such as the heart rate, SpO_2, body temperature sensor, and pi camera are used to detect the respiration details and capture images and transmission is done.
(b) Cloud storage: the collected data are stored via Wi-Fi or Bluetooth. This is the gateway to make the data available on a global platform.
(c) Analysis, face detection, and feature extraction: in this stage, the collected data are analysed further to detect the face and perform feature extraction using different algorithms.
(d) Decision system: based on the analysis over the detected face and extracted features of the baby along with the detected vital parameters, the decision is being taken in the form of alert.
(e) Alert to the parents: immediate alert is given to the parents/caregivers.

The vision of case (ii) of the proposed system is illustrated in Figure 4.

(a) Data collection: in this initial stage, a pi camera is used to capture images of babies during sleeping and further movement in the partial sleeping state.
(b) Cloud storage: the collected data are stored via Wi-Fi or Bluetooth. This is the gateway to make the data available on a global platform.
(c) Analysis, face detection, and motion detection: in this stage, the collected data are analysed and face detection is performed to identify the partial sleeping state of the baby. Then, motion is detected to retrieve the condition of crossing the threshold limits, reaching a nearby staircase using machine-learning-based algorithms.
(d) Decision system: based on the analysis over the detected face and motion of the baby, the decision is being taken in the form of alert.
(e) Alert to the parents: immediate alert is given to the parents/caregivers.

In Table 4, the B.H.M.S. vision depicting the two dangerous scenarios articulates the system's needs and findings, as well as the indication of priority-based warning events.

4. Discussion

The challenges and issues that have been addressed, in turn, stimulate the research with practical welfare. It has been analysed that the existing systems pose few practical

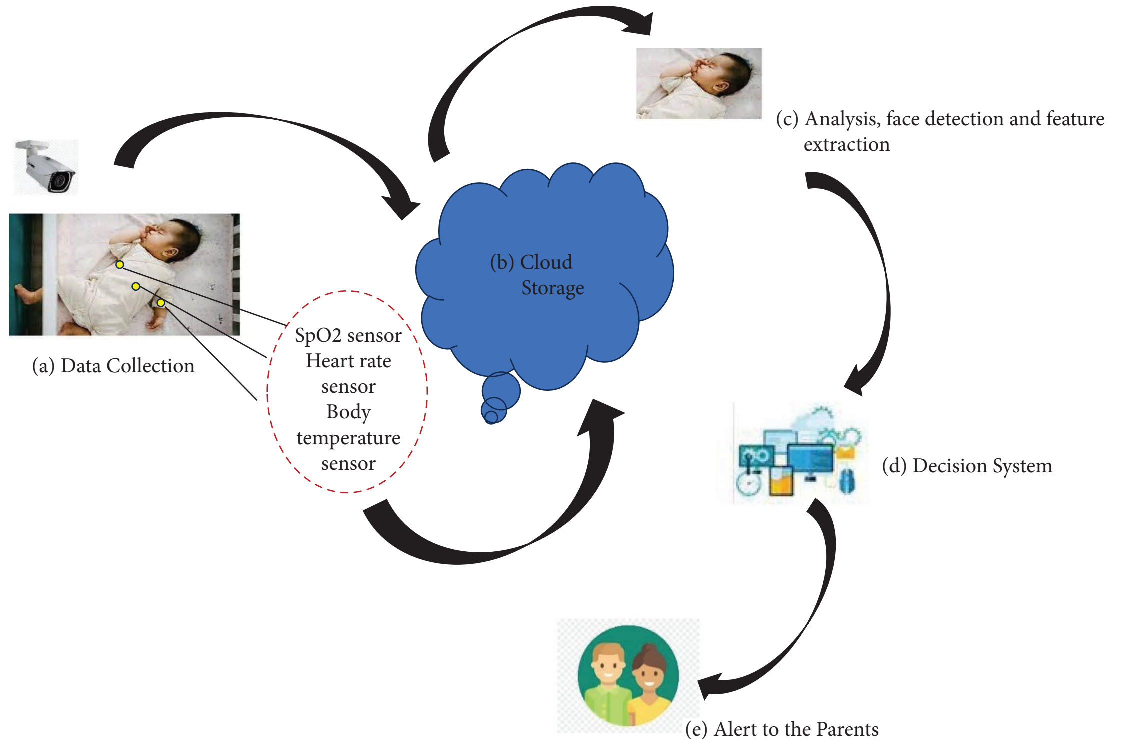

Figure 3: System architecture depicting the dangerous scenario of suffocation of a baby while sleeping.

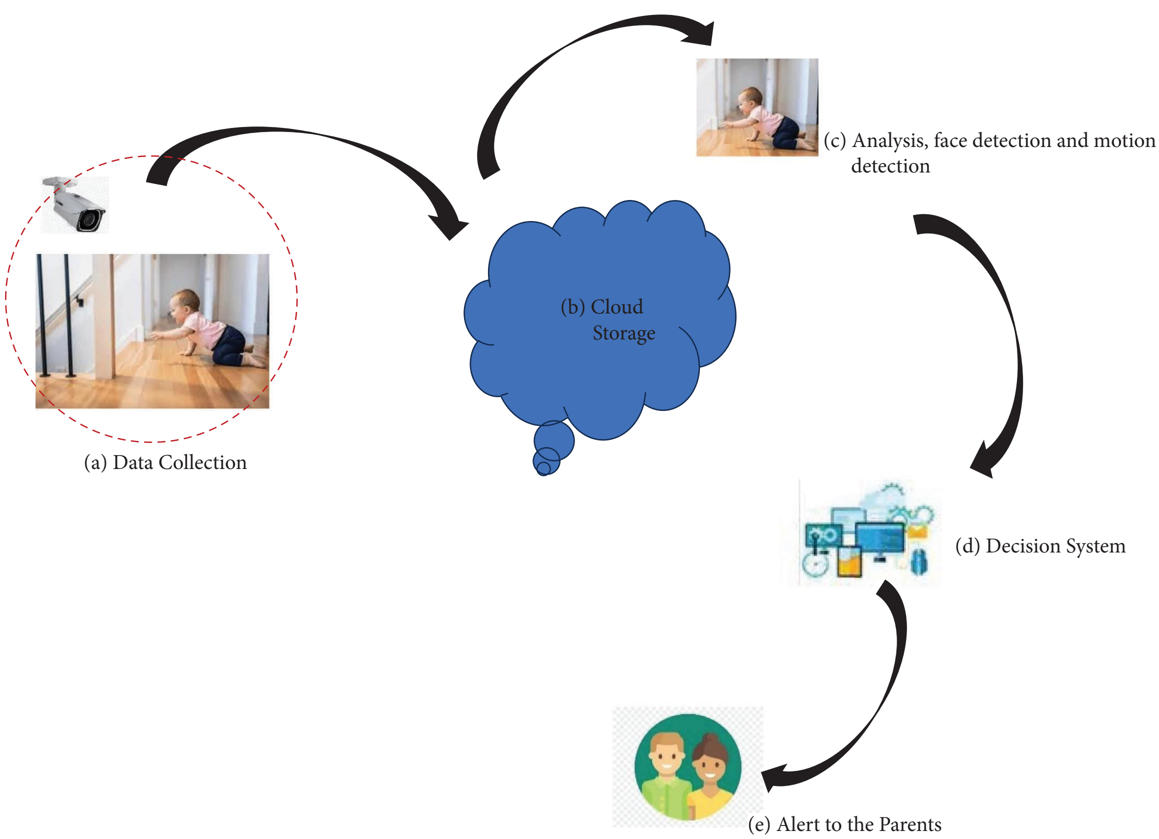

Figure 4: System architecture depicts the dangerous scenario of slipping over a staircase while a baby is partially sleeping.

Table 4: Vision of B.H.M.S. highlights the two dangerous scenarios for babies.

Scenario	Level of events (*)	Need of system	Platform/sensors used	Findings/outcomes
Suffocation	E1: cold	Baby gets nose blockage resulting in the cold	SpO_2 sensor, heart rate sensor, body temperature sensor, and pi camera	Sensor modules along with the implemented algorithms will alert the parents/caregivers about the discomfort and risk to the baby's life
	E2: asphyxia	Baby, along with cold sucking thumbnail, gets choked and results in suffocation	Pi camera, image processing	
Falling hazards	E1: partial sleeping state	Baby starts moving in a partial sleeping state	Pi camera and python	The implemented algorithms will alert the parents/caregivers about the baby crossing the threshold limit and reaching the staircase in a partial sleeping state
	E2: slip over a staircase	When the baby reaches the risk of slipping over a staircase	Pi camera and deep convolutional neural network	

*Level of events. E1: low-level warning event. E2: high-level warning event.

challenges, such as face masking [15, 30], falling hazard [30], intense loud crying [33, 37, 38], heart rate shooting up [39], accidental asphyxia, and SIDS [34–36, 40]. Moreover, the baby aged months to 24 months remains unsafe for the case of leaving in a crib alone. There is a chance of suffocation due to a tangled blanket or sleeping over the stomach. The head may get banged with the fences of the crib. When a baby is playing in a crib, their head, hands, or legs may get entangled in the slats of fences of the crib [1, 6]. These dangerous situations can further deviate the systems' concern towards more safety while the baby or child is sleeping.

This article reviewed 14 baby healthcare monitoring applications based on IoT [42], wearable sensors [41], and scientific technologies. The articles were reviewed following the eligibility criteria of the PRISMA technique. It has been taken into account that the selected studies were published between 2010 and 2022. Moreover, it has been aimed to select only the articles that worked on babies of 6 months to 4 years and babies' sleeping state as a prior consideration. These reviewed articles evaluated the technological advancements and the implementation of advanced devices supporting baby healthcare and the parents or mothers involved in the workforce. The articles have been assessed using single scenarios and multiple scenarios, monitoring systems to identify multiple challenges. Those research challenges have been considered to pin down the data detection and collection, techniques for processing, and practicality and appropriateness in a system. Thus, the focus was on briefing these challenges and articulating a solution-based system for the safety of babies in the identified dangerous scenarios, in turn, giving relaxation to the parents in their babies' care.

5. Conclusion and Future Work

The research is directed towards identifying the dangerous scenarios for sleeping babies which leads to life risks. Hence, we intend to focus on two scenarios that may get proven as life-threatening: Suffocation (asphyxia) and falling hazards (slipping over a staircase). Both these scenarios can escalate the condition of the baby to mortality. This research envisioned an alert-based system that can find the possibility of two cases while a baby is sleeping:

(i) Suffocation: baby suffering from cold and concurrently started sucking thumbnail.

(ii) Slip over staircase: baby is in a partial sleeping state and has concurrently started moving and crossing the threshold limit of reaching the nearby staircase.

Henceforth, the system can be designed using computer vision techniques and sensing technologies. Moreover, this research framework can be taken as future scope.

Additionally, the research inculcates the challenge that needs to be considered in the cost-effectiveness, customer reliability, and compatibility with the commercial-based product.

Data Availability

The review article data supporting this systematic review are from previously reported studies and datasets, which have been cited. The processed data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] C. Christnacht and B. Sullivan, "The choices working mother makes," 2020, https://www.census.gov/library/stories/2020/05/the-choices-working-mothers-make.

[2] M. Kalaiyarasi, S. Kaushik, and R. Saravanan, "Infant health monitoring and security system using IoT. Smart technologies, communication & robotics," in *Proceedings of the 2021 Smart Technologies, Communication and Robotics (STCR)*, pp. 1–4, Sathyamangalam, India, October 2021.

[3] R. Cheggou, S. S. H. Mohand, O. Annad, and E. H. Khoumeri, "An intelligent baby monitoring system based on raspberry PI, IoT sensors and convolutional neural network," in *Proceedings of the IEEE 21stInternational Conference on Information Reuse &Integration for Data Science (IRI)*, pp. 365–371, Las Vegas, NV, USA, August 2020.

[4] Fast facts Mothers in the Workforce, "The American association of university women," 2019, https://www.aauw.org/resources/article/fast-facts-working-moms.

[5] N. Z. Stats, "Chilcare a challenge for 1 in 6workingparents," 2018, https://www.stats.govt.nz/news/childcare-a-challenge-for-1-in-6-working-parents.

[6] World Health Organisation, "Child mortality (under 5 years)," 2020, https://www.who.int/news-room/fact-sheets/detail/levels-and-trends-in-child-under-5-mortality.

[7] New Zealand Ministry of Health, "Covid 19: CaseDemographics," 2022, https://www.health.govt.nz/covid-19-novel-coronavirus/covid-19-data-and-statistics/covid-19-case-demographics.

[8] I. F. Zamzami, K. Pathoee, B. B. Gupta, A. Mishra, D. Rawat, and W. Alhalabi, "Machine learning-based algorithm for smart and intelligent healthcare system in society 5.0," *International Journal of Intelligent Systems*, vol. 87, pp. 11742–11763, 2022.

[9] D. Bordoloi, V. Singh, S. Sanober, S. M. Buhari, J. A. Ujjan, and R. Boddu, "Deep learning in healthcare system for quality of service," *Journal of Healthcare Engineering (Hindawi)*, vol. 2022, Article ID 8169203, 11 pages, 2022.

[10] A. Darwish and A. E. Hassanein, "Wearable and implantable wireless sensor network solutions for healthcare monitoring," *MDPI Journal*, vol. 11, no. 6, pp. 5561–5595, 2011.

[11] J. Casselman, N. Onopa, and L. Khansa, "Wearable healthcare: l," *Telematics and Informatics*, vol. 34, no. 7, pp. 1011–1023, 2017.

[12] S. Hassantabar, J. Zhang, H. Yin, N. K. Jha, and M. H. Deep, "MHDeep: mental health disorder detection system based on wearable sensors and artificial neural networks," *ACM*

Transactions on Embedded Computing Systems, vol. 21, no. 6, pp. 1–22, 2022.

[13] Z. Jiang, L. Lin, X. Zhang et al., "A data-driven context-aware health inference system for children during school closures," *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, vol. 7, no. 1, pp. 1–26, 2023.

[14] Z. Zhu, T. Liu, G. Li, T. Li, and Y. Inoue, "Wearable sensor systems for infants," *Sensors*, vol. 15, no. 2, pp. 3721–3749, 2015.

[15] T. Khan, "An intelligent baby monitor with automatic sleeping posture detection and notification," *MDPI Journal AI*, vol. 2, no. 2, pp. 290–306, 2021.

[16] R. Guo, Y. Fang, Z. Wang et al., "Deep learning assisted body area triboelectric hydrogel sensor network for infant care," *Advanced Functional Materials*, vol. 32, no. 35, pp. 1–7, 2022.

[17] D. Moher, A. Liberati, J. Tetzlaff, and D. G. Altman, "Preferred reporting Items for systematic reviewsand meta-analyses: the P.R.I.S.M.A. Statement," *Annals of Internal Medicine*, vol. 151, no. 4, pp. 264–269, 2009.

[18] A. M. Fonseca, E. T. Horta, S. Sendra, J. J. P. C. Rodrigues, and J. A. F. Moutinho, "A sudden infant death system for babies," in *Proceedings of the International Conference on E-Health Networking, Application and Services*, pp. 525–530, New York, NY, USA, January 2014.

[19] A. G. Ferreira, D. Fernandes, S. Branco et al., "A smart wearable system for sudden infant death syndrome monitoring," in *Proceedings of the International Conference on Industrial Technology (ICIT)*, pp. 1920–1925, Taipei, Taiwan, March 2016.

[20] P. R. Myakala, R. Nalumachu, S. Sharma, and V. K. Mittal, "A low-cost smart intelligent system for real-time infant monitoring and cry detection," in *Proceedings of the Region 10 Conference (TENCON)*, pp. 2795–2800, Penang, Malaysia, November 2017.

[21] J. Xie, X. Long, R. A. Otte, and C. Shan, "Convolutional neural networks for audio-based continuous infant cry monitoring at home," *IEEE Sensors Journal*, vol. 21, no. 24, pp. 27710–27717, 2021.

[22] D. Y. Dubey and S. Damke, "Baby monitoring system using image processing and IoT," *International Journal of Engineering and Advanced Technology*, vol. 8, no. 6, pp. 4961–4964, 2019.

[23] T. Hussain, K. Muhammad, S. Khan, A. Ullah, M. Y. Lee, and S. W. Baik, "Intelligent baby behavior monitoring using embedded vision in IoT for smart healthcare centers," *Journal of Artificial Intelligence and Systems*, vol. 1, pp. 110–124, 2019.

[24] M. Airaksinen, O. Rasanen, E. Ilen et al., "Automatic posture and movement tracking of infants with wearable movement sensors," *Scientific Reports*, vol. 10, no. 1, pp. 169–213, 2020.

[25] D. N. F. M. Ishak, M. M. Jamil, and R. Ambar, "Arduino-based infant monitoring system. International research and innovation summit (IRIS2017)," *IOP Conference Series: Materials Science and Engineering*, vol. 226, Article ID 012095, pp. 1–7, 2017.

[26] S. Kavitha, R. R. Neela, M. Sowndarya, M. Chandra, and K. Harshitha, "Analysis on IoT based smart cradle system with an android application for baby monitoring," in *Proceedings of the 1st International Conference on Advanced Technologies in Intelligent Control, Environment, Computing & Communication Engineering (ICATIECE)*, pp. 136–139, Bangalore, India, March 2019.

[27] N. L. Pratap, K. Anuroop, P. N. Devi, A. Sandeep, and S. Nalajala, "IoT-based smart cradle for baby monitoring system," in *Proceedings of the 6th International Conference on Inventive Computation Technologies (ICICT)*, pp. 1298–1303, Coimbatore, India, January 2021.

[28] Q. Huang and K. Hao, "The development of artificial algorithms (A.I.) to avoid potential baby sleep hazardsin smart buildings," in *Proceedings of Construction Research Congress 2020*, pp. 278–287, London, UK, November 2020.

[29] M. P. Joshi and D. C. Mehetre, "IoT-based smart cradle system with an android app for baby monitoring," in *Proceedings of the International Conference on Computing, Communication, Control and Automation (ICCUBEA)*, pp. 1–4, Pune, India, August 2017.

[30] C. Lai and L. Jiang, "An intelligent baby care system based on IoT and deep learning techniques," *International Journal of Electronics and Communication Engineering*, vol. 12, no. 1, pp. 81–85, 2018.

[31] W. A. Jabbar, H. K. Shang, S. N. I. S. Hamid, A. A. Almohammedi, R. M. Ramli, and M. A. H. Ali, "IoT-BBMS: Internet of things-based baby monitoring system for smart cradle," *IEEE Access*, vol. 7, pp. 93791–93805, 2019.

[32] S. Divakaran, B. J. Janney, T. Sudhakar et al., "A safe and comfort bed for cerebral palsy babies-bedstead," *Journal of Physics: Conference Series*, vol. 1937, pp. 1–7, 2021.

[33] A. F. Symon, N. Hassan, H. Rashid, I. U. Ahmed, and S. M. Taslim Reza, "Design and development of a smart baby monitoring system based on raspberry pi and pi camera," in *Proceedings of the 4th International Conference on Advances in Electrical Engineering (ICAEE)*, pp. 117–122, Dhaka, Bangladesh, September 2017.

[34] E. Abirami and S. Karthika, "Design of infant monitoring system to reduce the risk of sudden infant death syndrome," in *Proceedings of the International Conference on Communication and Signal Processing*, pp. 0180–0183, Chennai, India, April 2017.

[35] W. Lin, R. Zhang, J. Brittelli, and C. Lehmann, "Wireless infant monitoring device for the prevention of sudden infant death syndrome," in *Proceeding of the 11th International Conference & Expo on Emerging Technologies for a Smarter World(CEWIT)*, pp. 1–4, Melville, NY, USA, October 2014.

[36] R. Ganesan, A. Lakshman R, H. Prasad L, and C. Mouli R, "Baby monitoring system using wireless sensor network," *ICTACT Journal on Communication Technology*, vol. 05, no. 03, pp. 963–969, 2014.

[37] C. T. Chao, C. W. Wang, J. S. Chiou, and C. J. Wang, "An arduino-based resonant cradle design with infant cries recognition," *Sensors*, vol. 15, no. 8, pp. 18934–18949, 2015.

[38] S. A. Alswedani and F. E. Eassa, "A smart baby cradle based on IoT," *International Journal of Computer Science and Mobile Computing*, vol. 9, no. 7, pp. 64–76, 2020.

[39] M. A. Wahab and D. M. Nor, "Safety and health monitoring system for baby incubator using IoT," *Evolution in Electrical and Electronic Engineering*, vol. 2, no. 2, pp. 256–264, 2021.

[40] S. Dhumal, N. Kumbhar, A. Tak, and S. G. Shaikh, "Wearable health monitoring system for babies," *International Journal of Computer Engineering &Technology*, vol. 7, no. 2, pp. 15–23, 2016.

[41] M. M. Baig, S. Afifi, H. G. Hosseini, and F. Mirza, "A systematic review of wearable sensors and IoT-based monitoring applications for older adults: a focus on ageing population and independent living," *Journal of Medical Systems*, vol. 43, pp. 1–11, 2019.

[42] S. Y. Y. Tun, S. Madanian, and F. Mirza, "Internet of things (IoT) applications for elderly care: a reflective review," *Aging Clinical and Experimental Research*, vol. 33, no. 4, pp. 855–867, 2021.