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Development of an IoT-Enabled Smart Baby Cradle for Enhanced Infant Monitoring and Parental Control

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ABSTRACT

Traditional infant monitoring systems are evolving into intelligent solutions, offering real-time notifications and automation to cater to the demands of multitasking parents. However, most IoT solutions in parental care focus solely on monitoring, lacking automatic smartphone control. In response to this gap, we developed an IoT-based system for automatic cradle monitoring. This system not only enables smartphone-based monitoring but also allows parents to control the cradle's swing speed and receive notifications through a mobile application. Our solution integrates PIR and sound sensors, an ESP8266 microcontroller, and a Wi-Fi module to create a robust monitoring system that tracks a baby's movements and sounds, sending instant notifications to the smartphone. The user can activate the system and adjust the cradle's motion using a slider based on sensor data. This IoT-enabled smart baby cradle enhances convenience and reduces parental stress, ensuring infant well-being and safety. A survey conducted among Universiti Teknologi MARA instructors revealed that 70% preferred automatic swing cradles over traditional ones, and 80% expressed the need for IoT integration in infant cradles, highlighting the growing demand for such advanced solutions.

1. INTRODUCTION

In an era marked by profound technological advancements, the integration of the Internet of Things (IoT) into everyday life has revolutionized the way we interact with our environment (Alshammari, 2023; Dadhaneeya et al., 2023). Among the countless applications of IoT, there exists a growing interest in the domain of infant care monitoring especially for their health, well-being and safety. These applications are implemented in their body, incubator, stroller, baby's room and cradle for easily monitored and controlled by parents and adult (Kapen et al., 2019; Lorato et al., 2020; Markom et al., 2023; Sawant et al., 2023). In today's fast-paced and increasingly digital society, parents find themselves juggling various responsibilities and struggling to allocate sufficient time and attention to their children. This scenario has given rise to a

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pressing need for technological solutions that can bridge the gap and offer parents an enhanced sense of security and control in caring for their infants. Traditional infant care often entailed vigilant parental oversight, with the ability to physically attend to an infant's needs around the clock. In contrast, the demands of modern life frequently led to parents grappling with increasingly busy schedules and competing obligations (Ishtiaq Salehin et al., 2021). As a consequence, parents find themselves in a precarious balancing act, torn between professional responsibilities, household tasks, and the constant care required by their infants. This dilemma prompts a critical question: How can caregivers harness technology to bridge the gap between the demands of contemporary living and the essential, round-the-clock care infants require?

The early stages of an infant's life are characterized by their vulnerability to various health risks and conditions, making constant monitoring and prompt responses to their need’s imperative. Inadequate or inconsistent care during this period may lead to adverse outcomes, ranging from developmental delays to safety hazards. The IoT-enabled cradle system addresses the core predicaments of contemporary parenting by introducing a novel platform that harmonizes the age-old concept of an infant cradle with cutting-edge IoT technologies (Elsisi et al., 2021). It aims to redefine parental care by offering a comprehensive, data-driven solution that transcends geographical boundaries, enabling parents to be virtually present and responsive to their infant's needs at all times. The core principle of this innovation revolves around the concept of IoT, a network of interconnected devices that communicate and share information over the internet. In the context of infant care, the cradle becomes the central hub of this network, equipped with a range of sensors and devices (Karanjkar & Kumawat, 2022; Tupkar et al., 2020). These sensors, capable of monitoring an infant's vital signs, temperature, and even the cradle's motion, continuously transmit data to a centralized control unit. In real-time, parents can access this information through their smartphones or other connected devices, granting them an unparalleled level of insight into their child's well-being. This data-driven approach provides parents with an added layer of confidence in caring for their infants, particularly during the early months when their vulnerability is at its peak.

Moreover, the IoT-enabled cradle system is not solely limited to passive monitoring. It includes a responsive control system that allows parents to actively engage with the cradle and their infant's environment. Parents can remotely adjust the cradle's motion, ambient temperature, and even play lullabies or white noise, providing comfort and security to their infant from any location (Rajendran et al., 2022; Sun et al., 2021). The convenience and flexibility offered by this system make it a powerful tool for parental care, allowing parents to attend to their infant's needs promptly, regardless of their physical presence. The IoT-enabled cradle system also recognizes the importance of a supportive community in raising children. Through the platform, parents can share and access information with other caregivers, paediatricians, and family members, fostering a collaborative approach to childcare. Such collaboration extends to real-time alerts and notifications, ensuring that caregivers remain informed and connected, even during emergencies. Furthermore, in the realm of data privacy and security, the IoT-enabled infant cradle system addresses concerns with robust encryption, access controls, and secure cloud storage. The system is designed with the utmost care to safeguard sensitive information and protect the privacy of both infants and parents.

2. LITERATURE REVIEW

Thopate et al. (2023) designed a smart cradle that uses IoT to modernize traditional cradle systems, providing enhanced safety, comfort, and convenience for babies and caregivers. It uses sensors to monitor the baby's environment, collect real-time data, and send it to a cloud-based server for analysis. Caregivers can remotely monitor the baby's condition, control features like automated rocking, and customize the cradle's settings. The system also integrates with other smart home devices, providing insights and recommendations for baby's health and well-being. The findings demonstrate the detection of sound and water, but there is no proof of a completed circuit or a working prototype. The studies demonstrate sound

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and wetness detection, but there is a lack of a full circuit and finished prototype as evidence, and most of the other research presented is similar.

Then, an IoT-powered intelligent cradle system for baby monitoring using an Android application has been developed by Joshi and Mehetre (2017). In their solution, the cradle responds to a baby's cries by initiating automatic swinging. The associated mobile applications provide real-time alerts regarding the duration of the baby's crying episodes and the moisture level within the mattress. On a similar note, Joseph et al. (2021) have introduced a smart cradle equipped with a variety of sensors, including an additional gas sensor component. However, it is important to note that both prototypes suffer from certain shortcomings. They lack comprehensive development, as their components are disorganized and positioned on top of a board, resulting in an absence of observable hardware output.

Saude and Vardhini (2020) developed an IoT-driven intelligent system, which empowers parents to oversee the well-being of their children, even when they are physically distant. This innovative device enables parents to track their child's movements, listen to their cries, and view live video feed of the child's current position and activities on a screen monitor. In addition to monitoring ambient temperature and humidity, which provides insights into the infant's sleep conditions, this system has been designed. However, it is important to note that this project primarily focuses on monitoring capabilities and exhibits shortcomings in terms of the user interface of the mobile application and the development of the prototype.

An IoT-based cradle that places a strong emphasis on continuous live surveillance, ensuring that parents can monitor their infants even when they are not at home has been presented (Rekha et al., 2020). This system incorporates features that respond to the infant's crying and moisture levels in the bassinet, as well as an entertaining rotating toy to soothe the baby. It offers a holistic approach to infant care and remote monitoring, addressing the challenges faced by working parents. Chao et al. (2015) contribute to the discourse by introducing an energy-efficient electric cradle with infant cry recognition. By leveraging the principles of resonance and innovative sensor placement, this design seeks to save energy while providing effective cradle motion. Furthermore, the incorporation of infant cry recognition technology, a rare feature, enhances the cradle's functionality, aligning with the growing need for comprehensive infant care.

The most effective and automated method for monitoring a baby's movements and sounds, while also sending instant updates to the user's smartphone, is the approach introduced by Jabbar et al. (2019). The system includes various sensors that monitor the baby's vital signs, the room temperature, moisture levels on the mattress, and crying. A prototype of the system uses red meranti wood to construct the baby cradle. Within the system's design, the cradle is equipped with a motor that allows it to swing automatically in response to the baby's cries. It's also possible to remotely activate the lullaby toy on the cradle using a smartphone, and parents can even monitor their babies' well-being via an external web camera. The system provides smart monitoring features and a user-friendly interface, with the only drawback being the absence of control through the smartphone.

Other than IoT, there is deeper research using artificial intelligence. A smart baby monitoring system based on IoT and machine learning is designed to help working mothers monitor their babies' condition in real-time is developed by Alam et al. (2023). The system uses sensors to monitor room temperature, humidity, cry detection, and facial emotions. Parents can monitor their child's activities through an external web camera, remotely swing the baby cradle, and check room temperature and humidity levels. If abnormal actions are detected, the system alerts the parent's mobile app, allowing efficient time management. The research study by Kumar et al. (2022) also using a similar method of machine learning introduces a smart cradle that allows video monitoring of infants. The rise in high-speed internet and mobile phones has led to a growing concern about working parents monitoring their children's behaviour while babysitting. An infant's scream triggers the cradle's automatic swinging, and if the baby's cry persists, a buzzer and text message are sent to the phone. The cradle also features an automatic spinning toy for entertainment. The system uses a microcontroller and sensors to monitor the baby's vital signs and environmental conditions. A prototype was created using NX Siemens software and made of red meranti wood. Parents can use an

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external web camera to monitor their children's health while away. The network has been tested to ensure its effectiveness and safety.

3. METHODOLOGY

Before developing the product, two important software tools are used. The first is Proteus 8 Professional, a program utilized to design the circuit for the project. It allows for the placement of components such as the ESP8266, PIR sensor, and sound detection sensor on the PCB board. Proteus 8 Professional is essential for professionals in electronics and embedded systems as it provides a comprehensive range of features for circuit design, simulation, microcontroller development, virtual prototyping, PCB layout, and troubleshooting. It simplifies the design process, enhances productivity, and reduces time-to-market for electronic products and systems. Secondly, there is Blynk, which is a platform for developing IoT applications by providing a user-friendly interface as well as a set of tools and libraries. It makes it easier to link hardware devices like Arduino to the internet and create mobile apps to control and monitor them remotely. Furthermore, Blynk is used in this project with the integration to a mobile app, which enables for a customized interface with buttons, sliders, graphs, and other interactive components. This app may then interface with the Arduino board via the Blynk server, allowing the hardware and the software to communicate in both directions.

According to Fig. 1, the program now includes the ESP8266 WI-FI module and Blynk library. The auth token is used to connect the hardware component to the templet (software) in the apps. The platform via which both software and hardware communicate is the ssid and pass. Fig. 2 (left) shows the speed control has been stated in V2 (virtual pin 2) and the LED and cradle rotation has been declared in V3 (virtual pin 3). When the slider is at its maximum position, the data is passed to "param.asDouble()" at V2 and then transferred to the speed variable. The analogWrite function sends the data variable speed to the motor driver, which controls the voltage supply to the gear DC motor. The data from the applications will be sent to "param.asInt()" at V3, and the role of digitalWrite is to deliver the data to the microcontroller and the motor driver, so the LED will turn on and the cradle will rotate clockwise. Then, Fig. 2 (right) shows the PIR sensor has been assigned to V1 (virtual pin 1) and the sound sensor has been assigned to V0 (virtual pin 0). When the sensors are triggered, the data is sent to the variable. The variable then uses "Blynk.virtualWrite" to deliver the data to its Virtual pins in the apps. If both sensors are triggered, a notification will be delivered to the smartphone through "Blynk.logEvent".

```
#define BLYNK_PRINT Serial
#include <ESP8266WiFi.h>
#include <BlynkSimpleEsp8266.h>

#define BLYNK_TEMPLATE_ID "TMPLSodhILrk"
#define BLYNK_DEVICE_NAME "IOT BABY CRADLE"
#define BLYNK_AUTH_TOKEN "41gHxaVC_H0bB6bcIA5E9N7aBK4j17AG"

char auth[] = BLYNK_AUTH_TOKEN;
char ssid[] = "Redmi Note 10S";//Enter your WIFI name
char pass[] = "madputeh";//Enter your WIFI password
```

Fig. 1. Code snippet of Wi-Fi module connection to a smartphone

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```
BLYNK_WRITE(V2) {
  double speed = param.asDouble();
  analogWrite(enA,speed);
  Blynk.virtualWrite(V2, speed);
  Serial.print("V2 Slider value is: ");
  Serial.println(speed);


}

BLYNK_WRITE(V3) {
  digitalWrite(in1, param.asInt());
  digitalWrite(LED, param.asInt());
}
```

```
BLYNK_WRITE(V2) {
  double speed = param.asDouble();
  analogWrite(enA,speed);
  Blynk.virtualWrite(V2, speed);
  Serial.print("V2 Slider value is: ");
  Serial.println(speed);


}

BLYNK_WRITE(V3) {
  digitalWrite(in1, param.asInt());
  digitalWrite(LED, param.asInt());
}
```

Fig. 2. Code snippet of the LED switch and the slider that control the speed (left); Code snippet to send the notification (right)

Fig. 3 shows the project flowchart, which is aligned with the objectives of developing an IoT baby's cradle. The IoT WiFi module, internet, and Blynk applications will be activated automatically when the device is turned on. The project's first objective is to create a smart monitoring infant cradle with PIR and sound sensors for baby reaction detection utilizing the ESP8266 as a microcontroller. When activated, the monitoring system uses both a PIR sensor and a sound detection sensor to send data to the user's phone. This information is shown on the phone, and a notification is triggered to notify the user. The second objective is to integrate an IoT system that uses a WiFi module to automate moving and controlling the speed of a swing using a smartphone. The cradle system is powered by the motor driver (L298N) voltage regulator and a gear DC motor. The user can regulate the motor's speed using a slider on their phone and enable current flow by turning on the LED. When both notifications are activated, the user can change the speed of the motor to ensure the baby's comfort or receive an active alert indicating that their baby is awake. Meanwhile, if the baby stops crying and moving, data will be sent to both sensors for detection. When this happens, it means the baby is asleep again, and the slider will stop.

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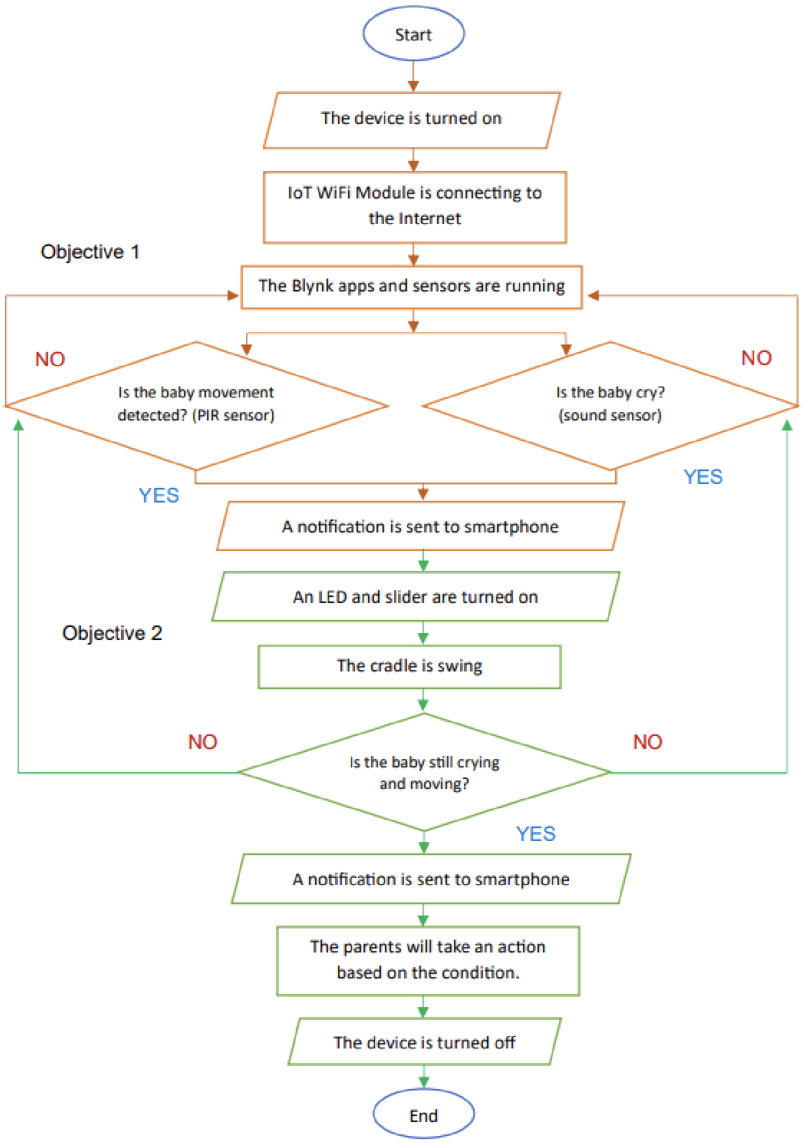

Fig. 3. Flowchart of the proposed system

Finally, there is the integration between the software and hardware of the device. Fig. 4 depicts a functional block diagram of the inputs, microcontroller, and outputs components used in the system. The system collects data using a PIR sensor and a sound detection sensor, which is then transferred to a microcontroller when sound or movement is detected. On a smartphone, the ESP8266 microcontroller is utilized to communicate data to the cloud. The ESP8266's motor driver (L298N) manages the voltage supplied to the gear DC motor, which outputs an LED, a gear DC motor, and a motor driver (L298N). The technology is activated by the smartphone's "ON" button and a slider that adjusts the DC motor's speed based on sensor data, allowing the user to customize the cradle's motion to the needs of the infant.

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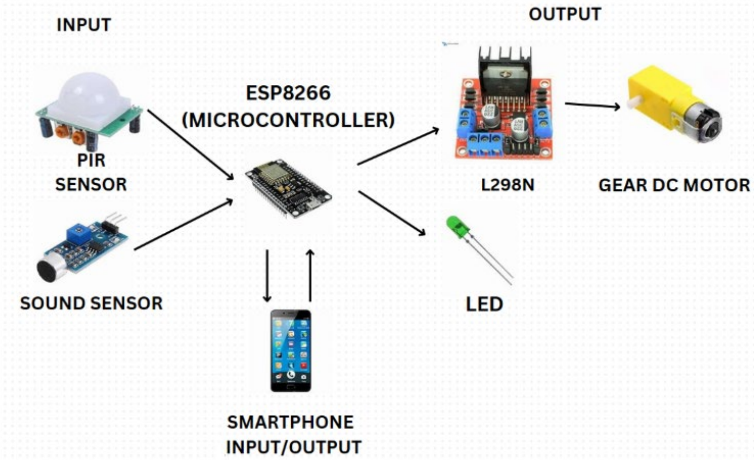

Fig. 4. Block diagram of the project

4. RESULTS

In Fig. 5, the comprehensive system connection implemented in Proteus software is illustrated. This system encompasses various components, including the Arduino Uno, PIR sensor, sound detection microphone sensor, LED, breadboard, resistor 10k, and LOGICSTATE. These components are interconnected according to the block diagram, and to power up the sensors, the "POWER" terminal mode is employed. To initiate the simulation, the code is uploaded to the Arduino Uno, and then the sensors are activated using "LOGICSTATE." Notably, the LED illuminates when both the PIR sensor and the sound detection microphone are either in a high or low state.

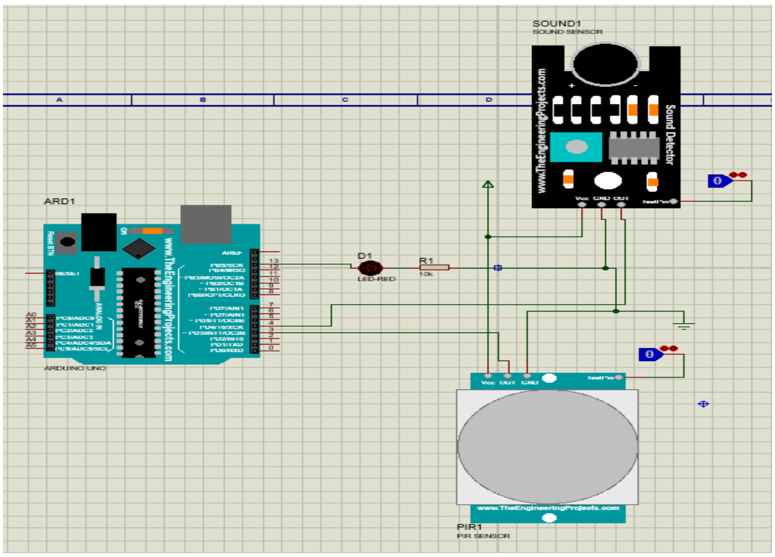

Fig. 5. Simulation circuit using Proteus 8

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The physical prototype of the project is crafted using a combination of black and white mountain boards, as showcased in Fig. 6. The cradle's primary structure is formed by overlapping and shaping five mountain planks into a pillar-like configuration. The cradle itself consists of a blue mountain board, fashioned as a cuboid. A gear and a stick are joined and linked to a gear DC motor, constituting the rotational mechanism. Lastly, a label is created using paper and double-sided tape. The system is built around the ESP8266 microcontroller and integrates an IoT system through a WIFI module to enable automated swing control via a smartphone. The ESP8266 microcontroller is being used for IoT-based infant monitoring because it provides a dependable and cost-effective solution with wireless connectivity, allowing real-time monitoring, remote control, and integration with other IoT devices or platforms.

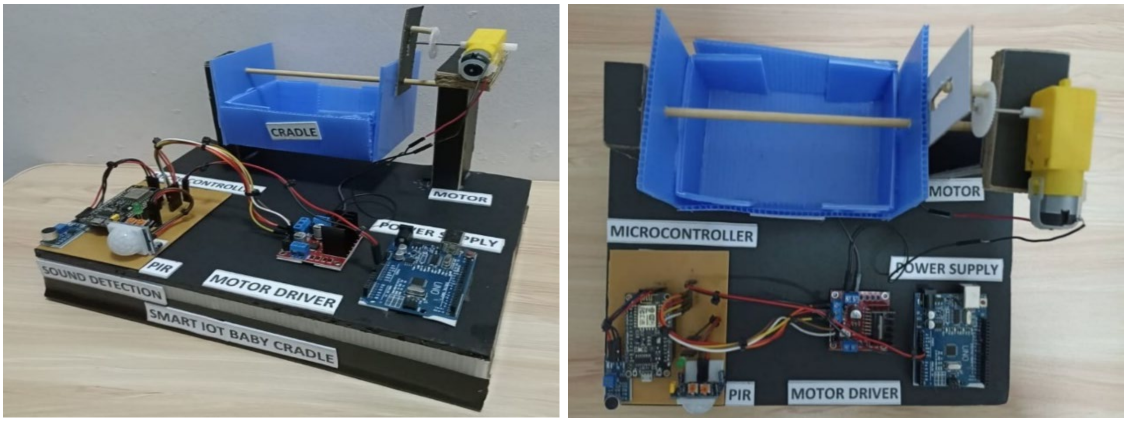

Fig. 6. Prototype of the project from the front view (left); prototype from the upper view (right)

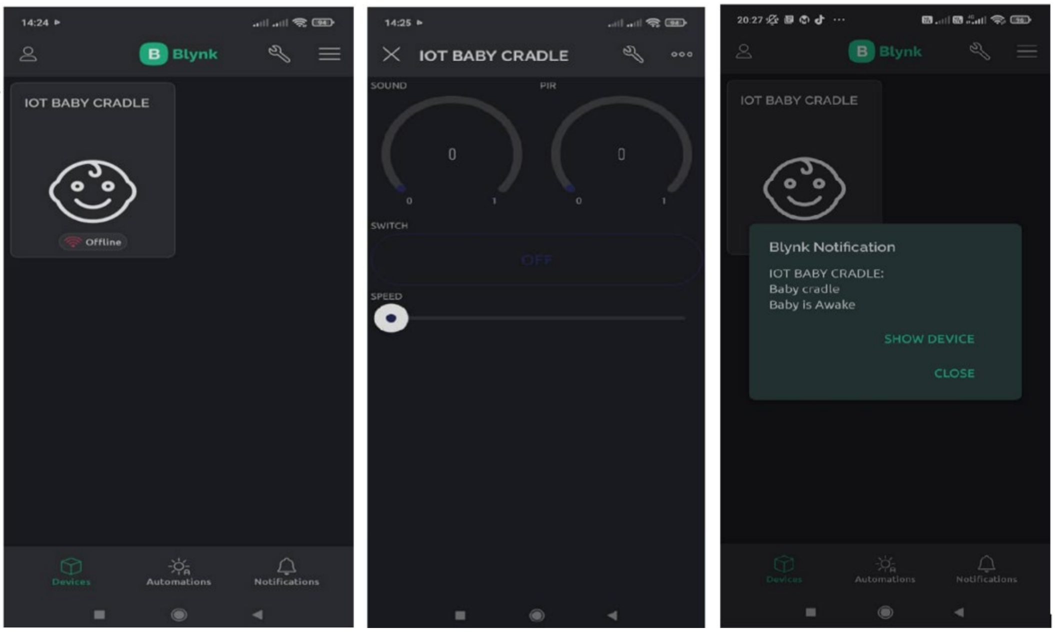

Fig. 7. Mobile apps interface using Blynk (left) main page (middle) dashboard with switch and speed bar (right) baby awake notification

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The project's design accounts for the PIR and sound sensors, which activate when the baby wakes up or makes noise. In response, the microcontroller sends notifications to the user's smartphone, allowing the user to soothe the infant by adjusting the cradle's speed control. If the sensors persistently trigger, a user intervention is required to attend to the infant. Fig. 7 (left) shows that after turning on the device, the template in the app will be available online. When the PIR and sound sensors are triggered, the gauge will display a value of 1, indicating that the infant is moving or making a sound, as shown in Fig. 7 (middle). If none of the sensors are triggered, the gauge will remain unchanged, suggesting that the infant is sleeping and not crying. A slider is used to control the cradle's speed. When the slider is set to the maximum value, data is delivered to the microcontroller via the Wi-Fi module, allowing the motor driver to send a high voltage to the gear dc motor. As a result, the cradle moves at a tremendous rate. Similarly, if the slider is set to the minimum value, the data is transferred to the microcontroller via the Wi-Fi module, allowing the motor driver to send a low voltage to the gear dc motor. As a result, the cradle moves at a slow pace. When both the PIR and sound sensors are activated at the same time, a notification is delivered to the user's smartphone, as seen in Fig. 7 (right).

5. DISCUSSION

The Fig. 8 is one of a survey question that have been conducted using a google form to 30 lecturers in Universiti Teknologi MARA. The survey results clearly indicate that a substantial majority of the respondents, 70%, favor an automatic swing cradle over the traditional one. This preference can be attributed to the practical advantages offered by automated cradles, such as time-saving, energy efficiency, and enhanced flexibility for parents. Meanwhile, the remaining parents use a traditional swing because they already have one at home and do not need to purchase a new one for the automated.

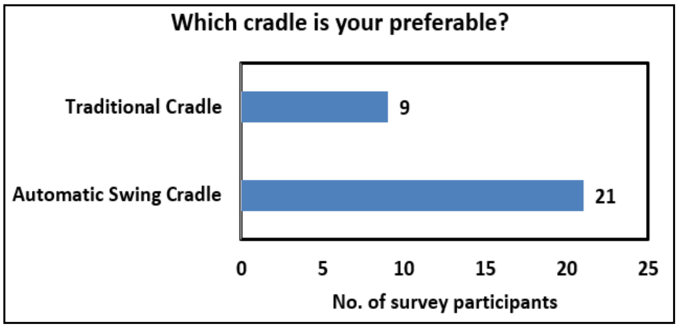

Fig. 8. Percentage of preferable type of cradle

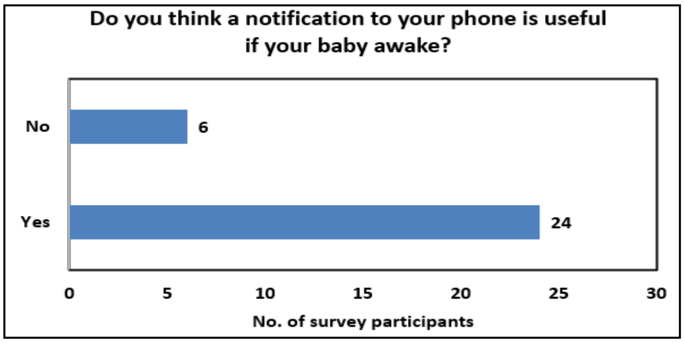

Fig. 9. The need to use IoT to receive a notification for baby's monitoring

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Automated cradles eliminate the need for manual rocking, allowing parents to attend to other tasks or rest while ensuring that their infants experience a soothing, consistent rocking motion. This finding aligns with the evolving lifestyle of contemporary parents who seek convenience and time-saving solutions. The project's decision to focus on the development of an automatic swing cradle is validated by this strong preference, highlighting its potential to cater to the needs and preferences of its target audience effectively. The survey further shown in Fig. 9 reveals that a significant 80% of respondents expressed a desire for IoT integration in baby cradles. This demand signifies a growing awareness and adoption of IoT technology, especially in the context of child monitoring. Smartphones have become ubiquitous in our daily lives, and the integration of IoT in baby cradles harnesses the smartphone's capabilities for real-time infant monitoring, remote control, and instant notifications. However, another 20% might say the IoT is not important as they can hear their baby's crying and experience parents.

The "normal crying curve" refers to a typical pattern or schedule of crying behavior in infants during the early months of life (Barr et al., 2006). It is a concept used in child development and pediatrics to describe the expected changes in an infant's crying frequency and duration as they grow and develop. The normal crying curve typically shows that infants cry more during the first few weeks of life, with crying peaking at a certain age, and then gradually decreasing as they get older as shown in Fig. 10. Monitoring a baby's crying patterns using an IoT-equipped baby cradle is crucial for ensuring the infant's safety and well-being. By detecting deviations from the expected curve and other signs of distress, the cradle can provide early warnings to parents, allowing for timely intervention and personalized care adjustments based on the baby's preferences. This monitoring approach not only helps prevent stress-related incidents like shaken baby syndrome but also ensures a more comfortable and secure environment for the infant.

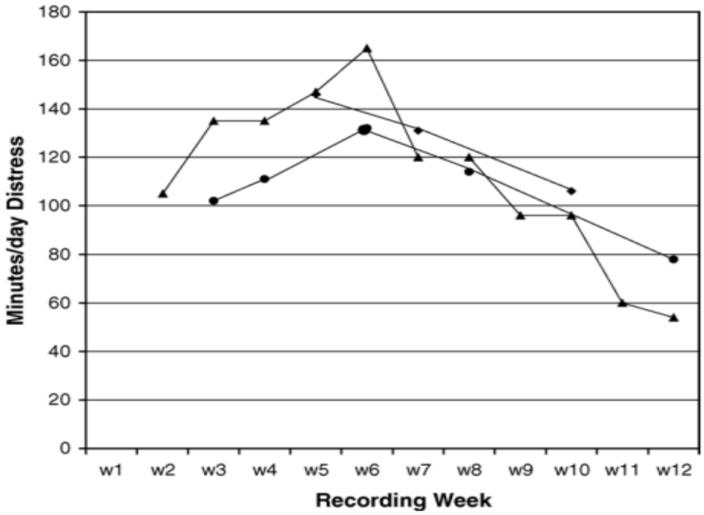

Fig. 10. Crying amounts and patterns from three North American studies illustrating absence of secular trend

Source: Barr et al. (2006)

Therefore, this innovative feature is seen as a valuable addition by parents, as it not only provides convenience but also offers peace of mind. The choice to incorporate an IoT system through the "BLYNK" app into the project aligns with this demand and positions the cradle as a modern solution that simplifies parenting and enables multitasking. It underscores the project's adaptability to current technological trends and its ability to address the evolving needs of parents in the digital age. There are several important elements to consider when developing an IoT baby cradle, including safety, comfort, and ease of use. In

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terms of safety, it is important to ensure that the cradle meets safety standards and regulations to prevent accidents and injuries. Comfort is also crucial, and the cradle should be designed to provide a soothing and calming environment for the baby.

Additionally, the cradle should be easy to use and operate, with features such as smartphone integration and adjustable settings to customize the motion and sound sensors. Therefore, the goal of the project is to enhance comfort by offering a swing that is automated to keep the infant calm and asleep while also being simple to use and integrated with a smartphone for parental management. The project's alignment with the Sustainable Development Goals (SDGs) is evident through its response to the evolving needs of parents in the digital age. By prioritizing an automatic swing cradle and IoT integration, the project contributes to SDG 3 (Good Health and Well-being) by enhancing infant care and parental well-being. Simultaneously, the project resonates with the principles of Industry 4.0 (IR 4.0), which emphasizes the smart, connected, and automated utilization of technology.

For future improvement, the IoT baby cradle system could focus on enhancing sensor integration, including additional sensors like temperature, humidity, and sleep pattern monitors to provide a more comprehensive monitoring system. Incorporating a camera for visual monitoring would allow parents to observe their baby's condition in real-time, adding an extra layer of assurance. Moreover, exploring machine learning algorithms could optimize the cradle's responsiveness to the baby's needs, potentially predicting and preventing distress before it occurs. Future studies could also investigate more user-friendly interfaces and robust data security measures to ensure parents' ease of use and privacy. Additionally, expanding the system's capabilities to integrate with other smart home devices could create a more seamless and efficient home environment.

6. CONCLUSION

This project has successfully developed a smart monitoring system for baby cradles, achieving the objective of comprehensive monitoring. By integrating a passive infrared (PIR) sensor and a sound sensor with an ESP8266 microcontroller, the system can detect the baby's response, movement, and vocalizations, ensuring efficient monitoring capabilities. The integration of an IoT system using a WiFi module and Blynk allows for the automation of the cradle's motion and convenient control of the swing's speed through a smartphone. The design process involved flowcharting, simulations using Proteus software, PCB testing, and programming with the ESP8266 microcontroller. The resulting system provides continuous monitoring of the child for 24 hours a day using the sound and movement sensors, while enabling remote control of the cradle's motion via an IoT button and a gear motor. This innovative baby monitoring system prototype offers flexibility, time management, and peace of mind for parents and caregivers.

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8. CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

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9. AUTHORS' CONTRIBUTIONS

Abdul Samad Kamarul Ariffin: Conceptualisation, methodology, prototype development and writing-original draft; **Arni Munira Markom**: Conceptualisation, supervision, writing- review and editing, and validation.

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