IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

AI-BASED SMART CRADLE SYSTEM FOR INFANT MONITORING AND AUTOMATION

[1]Rachana R, [2]Soundarya H L, [3]Varsha R K ,[4]Yashaswini D

[1,2,3,4] UG Scholar, Department of Electronics and Communication, Sri Siddhartha Institute of Technology, SSAHE, Tumkur, Karnataka , India

Doi: https://doi.org/10.56975/ijcrt.v14i7.309981

Abstract: The growing demand for intelligent and automated solutions in daily life has led to the development of smart systems that enhance convenience, safety, and efficiency. One such critical area is infant care, where continuous monitoring and timely response are essential for ensuring the well-being of a baby. In many modern households, caregivers often face difficulty in maintaining constant supervision due to work commitments and other responsibilities. This situation creates a need for a reliable system that can assist in monitoring infants and responding appropriately without continuous human intervention. The proposed work presents the design and development of an AI-based smart cradle system that combines embedded technology, sensor networks, and intelligent decision-making to improve infant care.

The system is designed to observe various conditions related to the baby and its surroundings using multiple sensors. A digital microphone is utilized to capture sound signals and identify crying patterns, which are key indicators of discomfort. Environmental parameters such as temperature and humidity are continuously monitored using a dedicated sensor to ensure that the surroundings remain suitable for the baby. In addition, a capacitive moisture sensor is used to detect wet conditions in the bedding, which helps maintain hygiene and prevents discomfort. All these inputs are processed by a central microcontroller, which acts as the decision-making unit of the system.

Based on the analyzed data, the system performs automatic actions to provide comfort to the infant. When a crying condition is detected, the cradle is gently moved using a servo motor to mimic natural rocking, and soothing audio is played through an audio module and speaker. The system also includes a camera module that enables real-time video streaming, allowing caregivers to observe the baby remotely through a web-based interface. Alerts are generated whenever abnormal conditions such as high temperature or wetness are detected, ensuring timely attention.

The proposed system focuses on simplicity, cost-effectiveness, and practical usability, making it suitable for real-world applications. By integrating monitoring, automation, and remote accessibility, the system reduces manual effort while improving the safety and comfort of the infant. This work demonstrates how emerging technologies can be effectively applied to create supportive solutions for everyday challenges in childcare.

Index Terms - Artificial Intelligence, Smart Cradle, Infant Monitoring, Internet of Things, Embedded Systems, Automation

I. INTRODUCTION

The The advancement of technology has significantly transformed the way everyday tasks are performed, introducing intelligent systems that improve efficiency, safety, and convenience. Among various application domains, healthcare and personal assistance systems have gained considerable attention due to their direct impact on human well-being. Infant care is one such critical area where continuous monitoring and timely response are essential to ensure the safety, comfort, and healthy development of a baby. However, in modern society, the increasing pace of life and changing family structures have made it challenging for caregivers to provide constant attention to infants.

Traditionally, babies are placed in simple cradles or beds that serve only as resting spaces without any capability to monitor or respond to the baby's condition. In such setups, caregivers must frequently check whether the baby is crying, uncomfortable, or exposed to unsuitable environmental conditions. This manual monitoring approach is not only time-consuming but also prone to delays, especially when caregivers are occupied with other responsibilities. In households where both parents are working or managing multiple tasks, maintaining continuous supervision becomes even more difficult, increasing the risk of unnoticed discomfort or distress in infants.

With the emergence of embedded systems, Internet of Things (IoT), and artificial intelligence, it has become possible to design smart devices that can sense, analyze, and respond to real-world conditions autonomously. These technologies enable the development of intelligent monitoring systems capable of collecting data through sensors, processing it using microcontrollers, and taking appropriate actions without constant human involvement. By applying these advancements to infant care, a smart cradle system can be developed to provide both monitoring and automation, thereby assisting caregivers in managing their responsibilities more effectively.

The proposed AI-based smart cradle system is designed to address the limitations of traditional cradles by incorporating multiple sensing and control mechanisms. The system continuously monitors the baby's condition using sensors such as a digital microphone for detecting crying, a temperature and humidity sensor for environmental monitoring, and a moisture sensor for identifying wet conditions. These inputs are processed in real time by a microcontroller, which determines the appropriate response based on predefined logic and basic intelligent behavior. When a need is detected, the system automatically performs actions such as gently rocking the cradle and playing soothing sounds to comfort the baby.

In addition to automated responses, the system also provides remote monitoring capabilities through a camera module and a web-based interface. This feature allows caregivers to observe the baby from a distance and stay informed about the baby's condition at all times. Alerts are generated whenever abnormal situations are detected, ensuring timely intervention when necessary. The integration of monitoring, automation, and remote accessibility makes the system a comprehensive solution for infant care.

The primary objective of this work is to develop a cost-effective, reliable, and easy-to-use smart cradle system that enhances infant safety and reduces the burden on caregivers. By combining sensing technologies with intelligent control, the system aims to create a supportive environment where the baby's needs are addressed promptly and efficiently. This approach not only improves comfort for the infant but also provides peace of mind for parents, making it a practical solution for modern lifestyles.

II. LITERATURE SURVEY

The development of smart cradle systems has gained significant attention in recent years due to the increasing demand for intelligent infant monitoring solutions. Researchers have explored various approaches by integrating Internet of Things, embedded systems, and artificial intelligence to improve baby care and reduce caregiver workload. This section reviews some of the major contributions in this domain and highlights their advantages and limitations.

Early research in this area focused on basic IoT-based monitoring systems that utilized sensors to track environmental conditions and baby activities. Several systems were designed to monitor parameters such as temperature, humidity, and sound levels, and to notify caregivers when abnormal conditions were detected. These systems provided a foundation for remote monitoring by enabling communication through mobile devices or web interfaces. However, most of these early implementations relied on simple threshold-based detection and lacked the capability to perform intelligent decision-making or automated responses.

In one approach, a smart baby monitoring system was developed using a camera and sound detection mechanism to observe the baby's condition. The system was capable of streaming live video and detecting crying patterns, thereby improving supervision. While such systems enhanced monitoring capabilities, they often required continuous internet connectivity and consumed higher power due to constant video processing. Additionally, these systems did not always provide automated actions to comfort the baby, making them partially dependent on human intervention.

Further research introduced automated cradle systems that could respond to crying by initiating a rocking motion. These systems used sound sensors to detect baby cries and triggered motors to swing the cradle. Some designs also included alert mechanisms to notify parents when the baby was crying for an extended period or when abnormal conditions were detected. Although these systems improved convenience, they were typically based on simple rule-based logic and did not incorporate advanced intelligence to analyze different types of baby behavior or environmental factors.

Recent advancements have focused on integrating artificial intelligence and machine learning techniques into smart cradle systems. These approaches aim to analyze baby behavior more effectively by identifying patterns such as crying intensity, movement, and sleep cycles. AI-based systems provide improved decision-making by distinguishing between different types of cries and predicting potential discomfort. However, such systems often require higher computational resources, larger datasets for training, and more complex implementation, which can increase system cost and design complexity.

Some studies have also explored the use of additional features such as hygiene monitoring and automated cleaning mechanisms to enhance infant safety. Moisture detection sensors have been used to identify wet bedding conditions, enabling timely alerts and improved comfort. In certain designs, multiple sensors were combined to provide a more comprehensive understanding of the baby's condition. Despite these improvements, challenges such as sensor accuracy, system reliability, and integration complexity still remain.

Another important aspect observed in existing systems is the dependence on network connectivity. Many IoT-based solutions require stable internet access for data transmission and remote monitoring. In environments with poor connectivity, system performance may be affected, leading to delays in alerts or incomplete monitoring. Additionally, some systems are designed with high-end components, making them less affordable for general household use.

From the analysis of existing literature, it is evident that although significant progress has been made in the development of smart cradle systems, there are still several limitations that need to be addressed. Many systems lack proper integration of multiple sensing parameters, resulting in incomplete understanding of the baby's condition. Some solutions are overly complex or expensive, while others rely heavily on manual intervention or internet connectivity. There is also a need for a balanced approach that combines simplicity, affordability, and intelligent automation.

The proposed system aims to overcome these limitations by integrating multiple sensors with a centralized microcontroller and implementing efficient decision-making logic. It focuses on providing real-time monitoring, automated response, and remote accessibility while maintaining low cost and ease of use. By addressing the gaps identified in existing systems, the proposed approach contributes toward the development of a more practical and reliable smart cradle solution.

III. PROBLEM STATEMENT

In recent years, the demand for reliable and efficient infant care systems has increased due to changes in lifestyle and family structures. In many households, caregivers are required to manage multiple responsibilities simultaneously, making it difficult to provide constant supervision to infants. Babies require continuous attention, as even small changes in their condition such as discomfort, hunger, or environmental imbalance can lead to distress. However, manual monitoring is not always practical, especially in situations where caregivers are engaged in work or other activities, which may result in delayed responses to the baby's needs.

Traditional cradles are designed only to provide a resting space for infants and do not include any mechanism for monitoring or responding to the baby's condition. These cradles lack the ability to detect crying, identify environmental changes, or recognize wet conditions in the bedding. As a result, caregivers must frequently check on the baby, which increases both physical effort and mental stress. In some cases, delays in noticing discomfort may affect the baby's well-being and overall safety.

Although several modern baby monitoring systems have been developed, many of them have limitations that reduce their effectiveness in real-world scenarios. Some systems only provide alert notifications without performing any corrective actions, which still requires immediate human intervention. Other systems rely on a single type of sensor, such as sound or temperature, which does not provide a complete understanding of the baby's condition. This lack of multi-parameter monitoring reduces the reliability and accuracy of the system.

Another significant issue in existing systems is the lack of proper integration between different components. In many cases, sensors, processing units, and actuators are not efficiently coordinated, leading to delays in response or inconsistent performance. Additionally, some solutions are designed with complex architectures and expensive components, making them less accessible for general household use. Systems that depend heavily on continuous internet connectivity may also face challenges in environments with unstable network conditions.

Furthermore, the absence of intelligent decision-making in many systems limits their ability to provide appropriate responses based on different situations. Basic rule-based systems may not effectively distinguish between various types of baby behavior, such as mild discomfort and serious distress. This can result in unnecessary actions or delayed responses, reducing the overall efficiency of the system.

Therefore, there is a clear need for a smart and integrated system that can continuously monitor the infant using multiple sensors, process the collected data in real time, and automatically perform suitable actions without requiring constant human supervision. The system should be capable of detecting different conditions such as crying, temperature variations, and wetness, while also providing remote monitoring capabilities for caregivers. In addition, it should be cost-effective, easy to implement, and reliable for practical use in everyday environments .

The proposed AI-based smart cradle system is designed to address these challenges by combining sensing, processing, and automation into a unified solution. It aims to reduce caregiver workload, improve response time, and enhance the overall safety and comfort of the infant through intelligent monitoring and control.

IV. PROPOSED SYSTEM

The proposed AI-based smart cradle system is designed to provide an intelligent, automated, and reliable solution for infant monitoring and care. The system integrates multiple sensors, embedded processing, and actuation mechanisms to continuously observe the baby's condition and respond appropriately without requiring constant human intervention. The main objective of this system is to ensure the safety, comfort, and well-being of the infant while reducing the workload of caregivers.

The overall design of the system is based on a modular architecture, where each component performs a specific function such as sensing, processing, communication, and actuation. Multiple sensors are placed around the cradle to collect real-time data related to the baby and its environment. A digital microphone is used to capture sound signals and detect crying, which is one of the primary indicators of discomfort. The DHT11 sensor continuously monitors temperature and humidity levels to maintain a suitable environment for the infant. In addition, a capacitive moisture sensor is used to detect wetness in the bedding or diaper area, ensuring hygiene and comfort.

All the sensor data is transmitted to the central processing unit, which is the ESP32 microcontroller. This microcontroller acts as the brain of the system and is responsible for analyzing the incoming data and making decisions. The system uses predefined logic along with basic artificial intelligence concepts to interpret the data and identify the baby's condition. For example, if the system detects continuous crying along with normal environmental conditions, it identifies the need for soothing actions. Similarly, if abnormal temperature or wetness is detected, it triggers alerts to notify caregivers.

Based on the analysis, the system performs automated actions to comfort the baby. A servo motor is used to provide gentle rocking motion to the cradle, simulating natural movement that helps calm the infant. At the same time, a DFPlayer Mini module connected to a speaker plays soothing music or lullabies to enhance comfort. These actions are triggered automatically, reducing the need for manual intervention and ensuring immediate response.

The system also incorporates a visual monitoring feature using an ESP32-CAM module. This allows real-time video streaming of the baby, which can be accessed by caregivers through a web-based interface. The microcontroller hosts a local web server that displays live video along with sensor data such as temperature, humidity, and system status. This enables remote monitoring, allowing parents to check on their baby even when they are not physically present near the cradle.

Another important feature of the proposed system is its ability to generate alerts in critical situations. If the system detects abnormal conditions such as excessive temperature, high humidity, or wet bedding, it sends notifications to the user through the web interface. This ensures that caregivers are informed in real time and can take necessary action if required.

The proposed system focuses on achieving a balance between functionality, cost, and ease of implementation. By using readily available components and a simple yet effective control strategy, the system remains affordable and practical for everyday use. At the same time, the integration of multiple sensors and automated responses enhances reliability and efficiency.

Overall, the proposed AI-based smart cradle system provides a comprehensive solution that combines monitoring, automation, and remote accessibility. It addresses the limitations of traditional cradles and existing systems by offering intelligent features that improve infant care while reducing caregiver effort.

V. SYSTEM ARCHITECTURE

The architecture of the proposed AI-based smart cradle system is designed to ensure efficient data collection, processing, and response through a structured and modular approach. The system is divided into three major layers, namely the input layer, processing layer, and output layer. Each layer performs a specific function and works in coordination with the others to achieve continuous monitoring and automation.

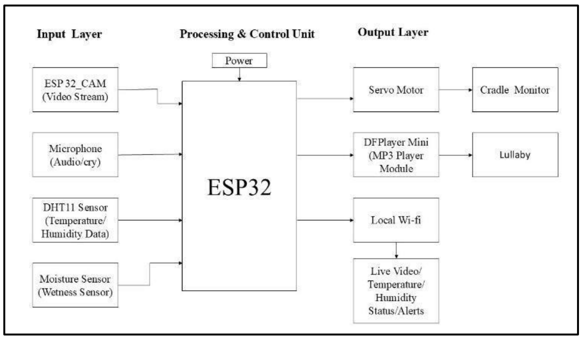
The input layer consists of multiple sensors that are responsible for capturing real-time data related to the baby and its surroundings. A digital microphone continuously monitors sound signals to detect crying, which is a primary indicator of discomfort. The DHT11 sensor measures environmental parameters such as temperature and humidity, ensuring that the baby remains in a comfortable environment. A capacitive moisture sensor is used to detect wet conditions in the bedding or diaper area, which is essential for maintaining hygiene and preventing irritation. Additionally, the ESP32-CAM module captures live video of the baby, providing visual monitoring capabilities.

The processing layer is centered around the ESP32 WROOM-32DA microcontroller, which acts as the main control unit of the system. All sensor data collected from the input layer is transmitted to this microcontroller, where it is processed in real time. The system uses predefined logic combined with basic artificial intelligence concepts to analyze the data and determine the baby's condition. The microcontroller also manages communication between different modules and ensures synchronized operation of the entire system.

The output layer consists of components that perform actions based on the decisions made by the processing unit. A servo motor is used to gently rock the cradle when the system detects that the baby needs soothing. The DFPlayer Mini module, along with a speaker, is used to play calming sounds or lullabies to comfort the baby. In addition to physical actions, the system also provides digital output in the form of alerts and notifications through a web-based interface. This allows caregivers to stay informed about the baby's condition in real time.

The architecture also includes a communication module that enables remote monitoring. Using built-in Wi-Fi capabilities of the ESP32, the system hosts a local web server that displays live video and sensor data. This feature allows caregivers to access the system through a web browser, providing flexibility and convenience.Overall, the system architecture ensures smooth data flow from sensing to decision-making and action execution. The modular design improves scalability, reliability, and ease of implementation, making the system suitable for real-world applications.

VI. BLOCK DIAGRAM



The block diagram of the proposed system represents the overall working flow from input sensing to output actions. It provides a clear understanding of how different components interact with each other within the system.

The input section includes sensors such as the microphone, DHT11 sensor, moisture sensor, and ESP32-CAM module. These components continuously gather data related to the baby's condition and surrounding environment. The microphone captures sound signals for cry detection, while the DHT11 sensor measures temperature and humidity. The moisture sensor detects wetness, and the camera module provides live video input.

All collected data is forwarded to the central processing unit, which is the ESP32 microcontroller. This unit processes the incoming signals using programmed logic and basic intelligent decision-making. It determines the appropriate response based on the current condition of the baby.

The output section includes actuators and communication modules. The servo motor controls the rocking motion of the cradle, while the DFPlayer Mini module and speaker are used to play soothing sounds. At the same time, the system sends data and alerts through Wi-Fi, allowing users to monitor the system remotely using a web interface.The entire system operates in a continuous loop, where sensing, processing, and response occur repeatedly in real time. This ensures that the baby's condition is constantly monitored and appropriate actions are taken without delay.

VII. METHODOLOGY

The methodology of the proposed AI-based smart cradle system describes the step-by-step process through which the system monitors the infant, analyzes the collected data, and performs appropriate actions. The overall working of the system is based on a continuous cycle of sensing, processing, decision-making, and response. This structured approach ensures that the system operates efficiently in real time and provides reliable assistance in infant care.

The process begins with data acquisition, where multiple sensors continuously collect information related to the baby and its surroundings. The digital microphone captures sound signals and converts them into electrical data that can be processed by the microcontroller. This data is analyzed to identify crying patterns, which serve as an important indicator of the baby's needs. At the same time, the DHT11 sensor measures temperature and humidity levels in the environment to ensure that the conditions remain suitable for the infant. The capacitive moisture sensor detects the presence of wetness in the bedding or diaper area, helping maintain hygiene and comfort. Additionally, the ESP32-CAM module captures visual data, allowing real-time monitoring of the baby's movements and condition.

Once the data is collected, it is transmitted to the ESP32 microcontroller, which performs the processing and analysis. The system uses predefined logic combined with simple artificial intelligence techniques to interpret the incoming data. For example, if the sound intensity exceeds a certain threshold for a specific duration, the system identifies it as a crying event. Similarly, temperature and humidity values are compared against predefined safe ranges to detect abnormal environmental conditions. The moisture sensor output is also evaluated to determine whether the baby's bedding is wet.

After analyzing the data, the system proceeds to the decision-making stage. In this stage, the microcontroller determines the appropriate action based on the identified condition. If crying is detected, the system initiates soothing actions such as rocking the cradle and playing calming audio. If abnormal temperature or humidity is detected, the system generates alerts to inform the caregiver. In the case of wetness detection, notifications are sent to ensure timely attention. The decision-making process is designed to be fast and efficient, allowing immediate response to changing conditions.

The next stage involves action execution, where the system performs the required operations based on the decision made. The servo motor is activated to provide gentle and controlled rocking motion to the cradle, simulating a natural soothing effect. The DFPlayer Mini module plays pre-recorded lullabies or soft music through the speaker to calm the baby. These actions are carried out automatically without requiring manual intervention, ensuring continuous care.

In addition to automated actions, the system also supports remote monitoring through a web-based interface. The ESP32 hosts a local web server that displays live video and sensor data, allowing caregivers to observe the baby in real time. The interface also provides status updates and alerts, ensuring that users are informed about any abnormal conditions.

The entire methodology operates in a continuous loop, where data is repeatedly collected, analyzed, and acted upon. This real-time operation ensures that the system remains responsive and reliable. By combining sensing, intelligent processing, and automated response, the methodology provides a comprehensive solution for infant monitoring and care.

VIII. HARDWARE REQUIREMENT

The implementation of the proposed AI-based smart cradle system requires a set of carefully selected hardware components that work together to perform sensing, processing, communication, and actuation functions. Each component plays a specific role in ensuring accurate monitoring, efficient processing, and reliable system performance. The selection of hardware is based on factors such as compatibility, cost-effectiveness, power efficiency, and ease of integration.

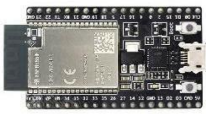


Figure 1: ESP32 Microcontroller

The central component of the system is the **ESP32 WROOM-32DA microcontroller**, which acts as the main control unit. It is responsible for collecting data from all sensors, processing the information, and controlling the output devices. The ESP32 is widely used in embedded systems due to its high processing capability, built-in Wi-Fi and Bluetooth support, and low power consumption. Its ability to handle multiple tasks simultaneously makes it suitable for real-time applications such as infant monitoring.

Figure 2: ESP32-CAM

For visual monitoring, the system uses an **ESP32-CAM module equipped with an OV3660 camera**. This module enables real-time video streaming, allowing caregivers to observe the baby remotely. The ESP32-CAM is compact, cost-effective, and capable of transmitting video over Wi-Fi, making it an ideal choice for IoT-based monitoring systems. The **ESP32-CAM-MB programming shield** is used to simplify the process of uploading code to the module through a Micro-USB interface.

Figure 3: Microphone

To detect sound signals, the system incorporates an **SPH0645 I2S digital microphone**. This microphone captures audio data with high accuracy and converts it into digital signals that can be directly processed by the microcontroller. It plays a crucial role in identifying crying patterns, which are essential for determining the baby's needs.

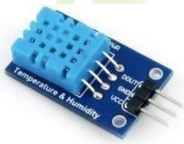


Figure 4: Temperature & Humidity Sensor

Environmental conditions are monitored using the **DHT11temperature and humidity sensor**. This sensor provides real-time measurements of ambient temperature and relative humidity, ensuring that the baby is kept in a comfortable environment. Maintaining appropriate environmental conditions is important for the baby's health and well-being.

Figure 5: Moisture Sensor

A **capacitive soil moisture sensor (version 1.2)** is used to detect wetness in the bedding or diaper area. Unlike traditional resistive sensors, capacitive sensors are more reliable and less prone to corrosion. This component helps in maintaining hygiene by detecting wet conditions and triggering alerts when necessary.

Figure 6: Servo Motor

For actuation, the system uses an **SG90 servo motor**, which is responsible for providing gentle rocking motion to the cradle. The servo motor offers precise control over movement and operates based on pulse width modulation signals generated by the microcontroller. This controlled motion helps in soothing the baby effectively.

Figure 7: Audio Module

To enhance comfort, the system includes a **DFPlayer Mini MP3 module**, which is used to play soothing audio or lullabies. This module works in conjunction with a **4-ohm 3-watt speaker** to produce clear and audible sound. The audio files are stored in a **16GB micro SD card**, which allows easy storage and playback of multiple sound tracks.

The system is powered using an **MB102 breadboard power supply module**, which provides regulated 5V and
3.3V outputs required for different components. A **5V 2A power adapter** is used as the external power source to ensure stable and sufficient current supply for all modules. Proper power management is essential to prevent system instability and ensure continuous operation.

Supporting components such as a **full-size breadboard** and **jumper wires** (male-to-male and male-to-female) are used for establishing electrical connections between different modules. These components facilitate easy prototyping and testing of the system.

IX. SOFTWARE REQURIMENTS

The functionality of the proposed AI-based smart cradle system is achieved through a combination of embedded programming, communication protocols, and web-based technologies. The software components play a crucial role in enabling data acquisition, processing, decision-making, and user interaction. The system is designed using a set of development tools and libraries that ensure efficient integration with the hardware components and provide reliable real-time performance.

The primary development environment used for programming the system is the **Arduino IDE (version 2.3.6)**. This platform provides a simple and user-friendly interface for writing, compiling, and uploading code to the ESP32 microcontroller and ESP32-CAM module. The Arduino IDE supports a wide range of libraries and hardware platforms, making it suitable for rapid development and testing of embedded applications.

To enable compatibility with ESP32-based hardware, the **Espressif ESP32 Board Core** (version 2.0.18) is installed within the development environment. This package provides the necessary drivers, configurations, and libraries required for programming ESP32 modules. It allows developers to access features such as Wi-Fi connectivity, GPIO control, and peripheral interfaces.

The system uses the **WiFi.h library** to establish wireless communication between the ESP32 and the user interface. This library enables the microcontroller to connect to a local network and host a web server, allowing real-time data transmission and remote monitoring. Through this communication channel, users can access live video streams and sensor data using a standard web browser.

For controlling the actuation mechanism, the **ESP32Servo.h library** is used to operate the servo motor. This library simplifies the generation of pulse width modulation signals required for precise control of the servo's position and movement. It allows the system to implement smooth and controlled rocking of the cradle.

The **DHT sensor library** is used to interface with the DHT11 sensor and retrieve temperature and humidity data. This library handles communication with the sensor and provides accurate readings in a format that can be easily processed by the microcontroller.

To manage audio playback, the system utilizes the **DFRobotDFPlayerMini.h** library, which enables serial communication with the DFPlayer Mini module. This library allows the microcontroller to control functions such as play, pause, volume adjustment, and track selection. It ensures smooth playback of soothing sounds and lullabies stored on the micro SD card.

The **driver/i2s.h library** is used to interface with the SPH0645 digital microphone. This library supports the I2S communication protocol, which allows high-quality digital audio data to be captured and processed efficiently. It plays an important role in detecting crying patterns and analyzing sound signals.

For the user interface, web technologies such as **HTML5** and **CSS3** are used to design a responsive and user-friendly dashboard. The interface displays live video, sensor readings, and system status in a structured format. **JavaScript** and **XMLHTTPRequest** are used to handle dynamic data updates, enabling the system to fetch new data from the server without refreshing the entire page.

To achieve real-time communication, **AJAX (Asynchronous JavaScript and XML)** is implemented. This technique allows continuous data exchange between the client and server in the background, ensuring that sensor values and system updates are displayed instantly. This enhances the user experience by providing smooth and uninterrupted monitoring.

The system can be accessed through any standard **web browser**, which acts as the interface for viewing and controlling the smart cradle. This eliminates the need for additional applications and makes the system easily accessible across different devices.

During development and testing, the **Serial Monitor** is used for debugging purposes. It helps in tracking system behavior, identifying errors, and verifying sensor readings in real time. This tool is essential for ensuring the proper functioning of the system before deployment.

Overall, the software components are designed to provide seamless integration with the hardware, efficient data processing, and a user-friendly interface. The combination of embedded programming and web technologies ensures that the system operates reliably and meets the requirements of real-time infant monitoring and automation.

X. SYSTEM IMPLEMENTATION

The implementation of the proposed AI-based smart cradle system involves the integration of hardware components with embedded software to achieve real-time monitoring and automated response. The system is developed in a structured manner, starting from individual component testing to complete system integration and validation. This approach ensures that each module functions correctly before being combined into the final system.

Initially, all hardware components are assembled using a breadboard setup to allow flexible connections and easy modifications during testing. The ESP32 WROOM-32DA microcontroller is used as the central control unit, and all sensors and actuators are connected to it through appropriate GPIO pins. The ESP32-CAM module is configured separately for video streaming and connected to the same network for synchronized operation. Power is supplied using a regulated 5V source to ensure stable functioning of all modules.

The implementation begins with testing individual sensors to verify their performance. The SPH0645 digital microphone is tested to capture sound signals and detect variations in sound intensity. The DHT11 sensor is used to measure temperature and humidity, and its readings are validated under different environmental conditions. The capacitive moisture sensor is tested by simulating wet and dry conditions to ensure accurate detection. The ESP32-CAM module is configured to capture and stream video, and its output is verified through a web browser.

After individual testing, all components are integrated into a unified system. The microcontroller is programmed using the Arduino IDE to continuously read data from all sensors and process it using predefined logic. The system operates in a loop where sensor data is collected, analyzed, and appropriate actions are triggered. The integration ensures that all modules work together seamlessly without conflicts.

The control logic of the system is designed to respond to different conditions. When the microphone detects continuous crying, the microcontroller activates the SG90 servo motor to gently rock the cradle. Simultaneously, the DFPlayer Mini module is triggered to play soothing audio through the speaker. These actions help in calming the baby automatically. If the DHT11 sensor detects abnormal temperature or humidity levels, the system generates alerts to notify the caregiver. Similarly, when the moisture sensor detects wet conditions, a notification is sent to ensure timely attention.

The ESP32 microcontroller also hosts a web server that provides a user interface for remote monitoring. The interface displays live video from the ESP32-CAM along with real-time sensor data. Caregivers can access this interface using a web browser, allowing them to monitor the baby from anywhere within the network. The use of AJAX ensures that data is updated continuously without requiring manual page refresh.

During implementation, debugging and testing are carried out using the Serial Monitor to verify sensor readings and system responses. Various test scenarios are created to evaluate the performance of the system under different conditions, such as continuous crying, changes in temperature, and wetness detection. The system is observed to respond accurately and promptly in all cases.

The final implementation demonstrates that the system is capable of performing real-time monitoring and automated actions effectively. The integration of sensing, processing, and actuation ensures smooth operation and reliable performance. The system provides a practical and efficient solution for infant monitoring, making it suitable for real-world applications.

XI. RESULT AND DISCUSSION

The performance of the proposed AI-based smart cradle system was evaluated by testing it under different real-time conditions to verify its functionality, reliability, and responsiveness. The system was tested by simulating various scenarios such as baby crying, changes in environmental conditions, and wetness detection. The objective of these tests was to ensure that the system could accurately detect different conditions and respond appropriately without delay.

During testing, the sound detection mechanism using the digital microphone was observed to effectively identify crying patterns based on sound intensity. The system was able to differentiate between normal background noise and significant sound levels associated with crying. When a crying condition was detected, the response time of the system was found to be minimal, with the servo motor activating almost immediately to initiate the rocking motion. At the same time, the audio module successfully played soothing sounds, demonstrating proper synchronization between different output components.

The environmental monitoring using the DHT11 sensor provided consistent readings of temperature and humidity. The system was able to detect variations in environmental conditions and compare them with predefined thresholds. When abnormal temperature levels were simulated, the system generated alerts through the web interface, allowing the user to take corrective action. This confirms that the system can maintain a comfortable environment for the infant by providing timely notifications.

The moisture detection functionality was also tested by introducing wet conditions near the sensor. The capacitive moisture sensor accurately detected the presence of moisture and triggered an alert. This feature is particularly important for maintaining hygiene and ensuring the baby's comfort. The system demonstrated reliable performance in identifying wet conditions without false triggering.

The video streaming functionality of the ESP32-CAM module was tested to evaluate remote monitoring capabilities. The system successfully streamed live video to the web interface, allowing real-time observation of the baby. Although minor latency was observed due to network conditions, the overall performance was satisfactory for monitoring purposes. The integration of video with sensor data provided a comprehensive view of the baby's condition.

The web-based interface was evaluated for usability and responsiveness. The interface displayed real-time sensor readings, system status, and live video in an organized manner. The use of asynchronous communication ensured that data was updated continuously without requiring manual refresh. This improved the overall user experience and made the system easy to operate.

From the observations, it is evident that the system performs effectively in real-time conditions and meets the intended objectives. The integration of multiple sensors improves accuracy and reliability, while automated actions reduce the need for manual intervention. The system demonstrates good responsiveness, with minimal delay between detection and action.

However, certain limitations were observed during testing. The accuracy of sound detection may vary depending on background noise levels, and the video streaming quality is influenced by network stability. Despite these minor limitations, the system performs efficiently and provides a practical solution for infant monitoring and care.

Overall, the results indicate that the proposed system is capable of delivering reliable performance, effective monitoring, and timely response, making it suitable for real-world implementation.

XII.ADVANTAGES AND LIMITATIONS

The proposed AI-based smart cradle system offers several advantages by combining monitoring, automation, and intelligent response into a single integrated solution. At the same time, certain limitations are observed due to practical constraints and system dependencies. Understanding both aspects is important for evaluating the effectiveness of the system and identifying areas for improvement.

One of the major advantages of the system is its ability to provide **real-time monitoring** of the infant's condition. By continuously collecting data from multiple sensors, the system ensures that important parameters such as sound, temperature, humidity, and wetness are constantly observed. This continuous monitoring helps in identifying changes in the baby's condition at an early stage, reducing the chances of discomfort going unnoticed.

Another significant advantage is the **automatic response mechanism**. Unlike traditional monitoring systems that only provide alerts, the proposed system performs actions such as rocking the cradle and playing soothing sounds when crying is detected. This reduces the need for immediate manual intervention and provides comfort to the baby without delay. The combination of sensing and actuation enhances the overall efficiency of the system.

The system also offers **remote monitoring capabilities**, allowing caregivers to observe the baby through a web-based interface. The integration of live video streaming along with sensor data provides a comprehensive view of the baby's condition. This feature is especially beneficial for working parents, as it enables them to stay connected with their child even when they are not physically present.

In addition, the system is designed to be **cost-effective and easy to implement**. By using readily available components such as ESP32 modules and basic sensors, the overall cost of the system is kept low. The use of simple hardware and software architecture also makes the system easier to develop, maintain, and deploy in real-world environments.

Despite these advantages, the system has certain limitations that need to be considered. One of the primary limitations is its **dependence on network connectivity** for remote monitoring and video streaming. If the network connection is unstable or unavailable, the performance of the system may be affected, especially in terms of remote access and data transmission.

Another limitation is related to **sound detection accuracy**. The system relies on sound intensity to detect crying, which may sometimes be affected by background noise or external disturbances. This can lead to false triggering or missed detection in certain situations. Improving the accuracy of sound analysis may require more advanced processing techniques.

The system also has **limited intelligence** compared to advanced machine learning-based solutions. While it uses predefined logic and basic intelligent behavior, it does not perform deep analysis of baby behavior such as distinguishing between different types of cries or predicting future conditions. Incorporating advanced AI models could improve the system's decision-making capabilities.

Additionally, the system is implemented using a **prototype setup**, which may not fully represent a real-world product. Factors such as durability, long-term reliability, and compact design need to be considered for practical deployment.

Overall, the proposed system provides a balanced combination of functionality, affordability, and ease of use. While certain limitations exist, they can be addressed in future improvements to enhance the system's performance and reliability.

XIII. APPLICATION

The proposed AI-based smart cradle system can be applied in various real-world environments where continuous infant monitoring and care are essential. Its ability to combine sensing, automation, and remote monitoring makes it suitable for both personal and professional use.

One of the primary applications of the system is in **home infant care**, where it assists parents in monitoring their baby's condition without the need for constant physical supervision. In households where caregivers are engaged in multiple tasks, the system helps in ensuring that the baby remains safe and comfortable at all times. The automated response features, such as rocking and playing soothing sounds, reduce the workload of parents and provide timely comfort to the baby.

The system can also be used in **healthcare environments**, such as hospitals and neonatal care units, where continuous monitoring of infants is critical. Nurses and healthcare staff can use the system to observe multiple infants simultaneously, reducing manual effort and improving efficiency. The ability to detect environmental conditions and generate alerts can help in maintaining a safe and hygienic environment for newborns.

Another important application is in **daycare centers**, where caregivers are responsible for managing several infants at once. The system allows caregivers to monitor multiple cradles and receive alerts when attention is needed. This improves overall supervision and reduces the risk of delayed response in busy environments.

The system is also useful for **working parents**, who may not always be physically present near their baby. Through remote monitoring capabilities, parents can check live video and sensor data using a web interface, providing reassurance and peace of mind. This feature is particularly beneficial in modern lifestyles where balancing work and family responsibilities is challenging.

Additionally, the system can be extended to **research and development** purposes in the field of smart healthcare and IoT-based monitoring systems. It provides a foundation for developing more advanced systems that incorporate intelligent decision-making and predictive analysis.

XIV. FUTURE SCOPE

Although the proposed system provides an effective solution for infant monitoring and care, there is significant scope for further improvement and enhancement. Future developments can focus on increasing system intelligence, improving accuracy, and expanding functionality.

One of the major areas for improvement is the integration of **advanced artificial intelligence and machine learning techniques**. By analyzing patterns in baby behavior, such as different types of crying or sleep cycles, the system can provide more accurate and personalized responses. This would allow the system to distinguish between different needs, such as hunger, discomfort, or sleep disturbance.

Another potential enhancement is the development of a **dedicated mobile application** for easier access and control. A mobile app can provide notifications, live video streaming, and control options in a more user-friendly manner compared to a web interface. This would improve accessibility and convenience for users.

The system can also be improved by incorporating **cloud connectivity**, which would allow data storage and remote access from any location. Cloud integration can enable long-term data analysis, helping caregivers understand patterns in the baby's behavior and environment over time.

Further improvements can be made in **sensor accuracy and reliability**. Using more advanced sensors for sound detection, temperature measurement, and motion tracking can enhance system performance. Additional sensors such as heart rate or movement sensors can be included to provide more comprehensive monitoring.

The design of the system can also be optimized by developing a **compact and robust hardware structure** suitable for real-world deployment. Improving durability, reducing size, and ensuring safety standards are important factors for transforming the prototype into a commercial product.

Finally, the system can be extended with **voice control and smart assistant integration**, allowing caregivers to control the cradle using voice commands. This would further enhance user convenience and interaction.

XV.CONCLUSION

The development of the AI-based smart cradle system presents an effective approach to improving infant monitoring and care through the integration of modern technologies. The system successfully combines embedded systems, sensor-based monitoring, and automated response mechanisms to create an intelligent environment for infants. By continuously observing parameters such as crying, temperature, humidity, and wetness, the system ensures that the baby's needs are identified and addressed in a timely manner.

The implementation of the system demonstrates its ability to perform real-time monitoring and automatic actions without requiring constant human intervention. Features such as cradle rocking and soothing audio playback help in providing immediate comfort to the baby, while the integration of a camera module and web-based interface enables remote monitoring. These functionalities reduce the workload on caregivers and provide greater flexibility in managing infant care.

The system is designed to be cost-effective, simple, and practical, making it suitable for use in homes, healthcare environments, and daycare centers. The use of readily available hardware components and straightforward software implementation ensures ease of development and deployment. At the same time, the integration of multiple sensors improves the reliability and accuracy of monitoring.

Although certain limitations exist, such as dependence on network connectivity and basic decision-making logic, the overall performance of the system is satisfactory for real-world applications. The proposed solution effectively addresses the limitations of traditional cradles and existing monitoring systems by providing a balanced combination of automation, monitoring, and user convenience.

In conclusion, the AI-based smart cradle system demonstrates the potential of intelligent technologies in enhancing infant care. With further improvements and advancements, the system can be developed into a more advanced and comprehensive solution that provides even greater support to caregivers and ensures improved safety and comfort for infants.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to **Dr. Sharada Guptha M N**, Associate Professor, Department of Electronics and Communication Engineering, Sri Siddhartha Institute of Technology, Tumakuru, for her valuable guidance, continuous support, and encouragement throughout the development of this project. Her insights and suggestions played a significant role in shaping the overall design and successful implementation of the system.

The authors also extend their thanks to the faculty members and technical staff of the Department of Electronics and Communication Engineering for their assistance and support during the project work. Their cooperation and valuable inputs contributed to the completion of this work.

REFRENCES

[1] H. M. Ishtiaq Salehin, Q. R. A. Joy, F. T. Z. Aparna, A.T. Ridwan, and R. Khan, "Development of an IoT based smart baby monitoring system with face recognition," in Proc. IEEE World AI IoT Congress (AIIoT), 2021.

[2] H. Chauhan, D. Gupta, S. Gupta, and M. J. Haque, "A smart cradle system to monitor infants for healthcare baby wards based on IoT and blockchain," in Proc. Int.Conf. Advances in Computing, Communication Control and Networking (ICAC3N), 2021.

[3] R. Sonia, S. M. Jayadeva, S. D. P. Ragavendiran, R. N.,J. Arumugam, and S. S. Kumar, “IoT based smart cradle for neonatal monitoring,” in Proc. Int. Conf. Electronics, Communication and Aerospace Technology, 2022.

[4] C. N. Savithri, S. Sumathi, M. Bhuvaneshwar, G. Dheepak, and M. J, “Techno cradle,” in Proc. Int. Conf. Intelligent Computing and Control for Engineering and Business Systems (ICCEBS), 2023.

[5] S. S. S. Susarla, S. R. Sadaf, S. K. Harshitha, and N. Vijapur, “IoT and embedded based smart baby cradle,” in Proc. Int. Conf. Confluence of Advancements in Robotics, Vision and Interdisciplinary Technology Management (IC-RVITM), 2023.

[6] Sakthidevi, S. V. Shankar, R. S. Krishnan, S. E. Kuruvilla, M. Bharath, and S. Gopikumar, “Predictive parenting: An IoT-enabled cradle system with AI-driven sleep pattern analysis,” in Proc. Int. Conf. Mobile Computing and Sustainable Informatics (ICMCSI), 2024.

[7] S. Gupta, A. Aggarwal, and N. Khatri, “Smart care baby: Revolutionizing infant safety and comfort with the smart auto-cleaning cradle system,” in Proc. Int. Conf. Technological Advancements in Computational Sciences (ICTACS), 2024.

[8] M. R, U. V. Anbazhagu, R. S. Krishnan, K. Paulraj, E. E. Nithila, and R. Umesh, “IoT-enabled deep learning framework for smart infant health monitoring,” in Proc. Int. Conf. Intelligent Computing and Control Systems (ICICCS), 2025.

[9] S. D, S. P. A, V. S, and K. R, “Automated system for infant sleep pattern analysis and monitoring,” in Proc. Int. Conf. Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA), 2025.

[10] M. Mudda, A. M, G. K. G, M. L. Rupal, Y. Samitha, and S. Sreeharsha, “IoT-based smart cradle system using ESP32 for automated infant soothing and monitoring,” in Proc. Int. Conf. Inventive Systems and Control (ICISC), 2025.