IoT Enabled Smart Baby Cradle System

Revolutionizing Child Safety & Monitoring

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1. Introduction

The origins of the Internet can be traced to the early 1960s, with foundational research on packet switching theory by Leonard Kleinrock and colleagues at MIT, which established the theoretical basis for data communication across networks (Leiner et al., 2009). This work culminated in the development of ARPANET under the U.S. Department of Defense's Advanced Research Projects Agency (ARPA), designed to ensure resilient communication during the Cold War, particularly in the context of potential nuclear threats (Review of the ARPA, 2025). The adoption of the TCP/IP protocol suite in 1983 marked a pivotal moment, as it standardized communication across diverse computer systems and signified the official birth of the Internet (Leiner et al., 2009).

Subsequent technological advancements further accelerated the Internet's evolution(Johnson et al., 2015) from a specialized military project to a global infrastructure. Innovations such as the Domain Name System (DNS)(Ishioka, 2025), the emergence of public data networks based on X.25(Deasington, 1986), and the NSFNET project(Kazumori, 2025) in the 1980s expanded network access to academic and research communities, setting the stage for widespread commercialization and global adoption in the 1990s.The introduction of the World Wide Web by Tim Berners-Lee in 1989 fundamentally transformed the Internet, enabling user-friendly information sharing and multimedia content, which in turn spurred the rapid growth of online services and digital applications (The World-Wide Web, 2025).

Building upon this robust digital foundation, the concept of the Internet of Things (IoT) emerged in the late 1990s, first articulated by Kevin Ashton to describe a network of physical objects embedded with sensors and connectivity for data exchange and automation (Ashton, 2009). IoT represents a paradigm shift in which everyday devices become interconnected, intelligent agents capable of sensing, processing, and communicating autonomously (Atzori et al., 2010). While IoT has enabled significant advancements across sectors such as healthcare, smart homes, and industrial automation (Gubbi et al., 2013), it also introduces pressing challenges related to interoperability, security, and privacy, highlighting the need for robust frameworks as the technology continues to proliferate (Roman et al., 2013).

2. Literature Review

The application of Internet of Things (IoT) technologies in baby monitoring systems represents a significant advancement in the domain of infant safety and caregiving. Traditional baby monitors, which were historically constrained to basic audio or video transmission, have evolved into sophisticated platforms that integrate a variety of environmental and physiological sensors, including those for temperature, humidity, air quality, motion, and sound (Al-Fuqaha et al., 2015). These modern systems utilize cloud connectivity and mobile applications to facilitate remote, real-time access and to deliver intelligent alerts, thereby enabling caregivers to respond proactively to adverse conditions such as hazardous environmental factors or prolonged episodes of infant distress (Miorandi et al., 2012). Empirical studies have demonstrated that the deployment of smart baby monitors contributes to enhanced parental confidence and improved infant safety by providing continuous monitoring and data-driven insights into the well-being of the child (Rahman et al., 2021).

Despite these technological advancements, several critical challenges persist. Foremost among these are concerns regarding data security and privacy, given the sensitive nature of the health data collected and the imperative to safeguard such information from unauthorized access (Security, privacy and trust in IOT, 2015). Furthermore, the reliability of these systems is of paramount importance, as uninterrupted operation is essential to maintain user trust and ensure the effectiveness of the monitoring solution. Looking ahead, future research and development efforts are expected to focus on the integration of advanced machine learning algorithms for anomaly detection and pattern recognition(Lane and Poole, 2016). Such enhancements have the potential to further improve system responsiveness to infant needs, while also addressing existing challenges related to scalability and interoperability within current IoT-enabled baby monitoring frameworks(IoT-BBMS: IOT-Smart Cradle, 2025).

2.1. Research Gap

Although the proposed smart baby monitoring system incorporates multiple sensors—such as PIR for motion detection, temperature, gas, and moisture sensors, along with automated cradle movement—there are still notable gaps. The system does not monitor vital health parameters like heart rate or breathing, lacks advanced data integration for holistic analysis, and does not offer personalized responses based on individual baby behavior. Additionally, user interface design and data privacy measures require further development to ensure safety and ease of use.

2.2. Statement of Problem

Traditional baby cradles and basic monitoring systems are limited in their ability to ensure infant safety and comfort. They often fail to detect environmental hazards, lack real-time response mechanisms, and do not provide comprehensive monitoring of the baby's status. This can lead to delayed responses to risks such as overheating, exposure to harmful gases, or prolonged discomfort due to wetness, potentially compromising infant well-being.

2.3. Plan for Solving the Problem

To address these issues, the proposed system will integrate a suite of sensors (PIR, temperature, gas, moisture) to continuously monitor the baby's environment and condition. The system will automate cradle movement in response to detected motion or unfavorable temperature, and send instant alerts to caregivers when abnormal conditions are detected. Future enhancements will focus on improving data analysis, personalizing responses, and strengthening user interface and data security for a safer, smarter baby monitoring solution.

3. Materials and Methodology

3.1. Materials

The design and simulation of the Smart Baby Cradle System were carried out using Tinkercad(Tinkercad, 2025), an online platform for electronic circuit simulation and 3D design. The project was developed on a Lenovo LOQ (Laptops | LOQ, 2025) laptop equipped with 20 GB RAM, 512 GB storage, and an NVIDIA (NVIDIA Marketplace, 2025) RTX 3050 graphics card with 8 GB VRAM, providing the necessary computational power for smooth simulation and design processes (Laptops | LOQ, 2025). Additionally, the Fritzing application(Fritzing, 2025) was reviewed for prototype design and circuit visualization, but Tinkercad (Tinkercad, 2025) was ultimately selected due to its greater ease of use and flexibility for simulating the integrated sensor-based smart cradle system.

3.2. Methodology

The project was developed following the **Engineering Design Process**, which provided a systematic approach to problem-solving and innovation (Haik and Shahin, 2011).

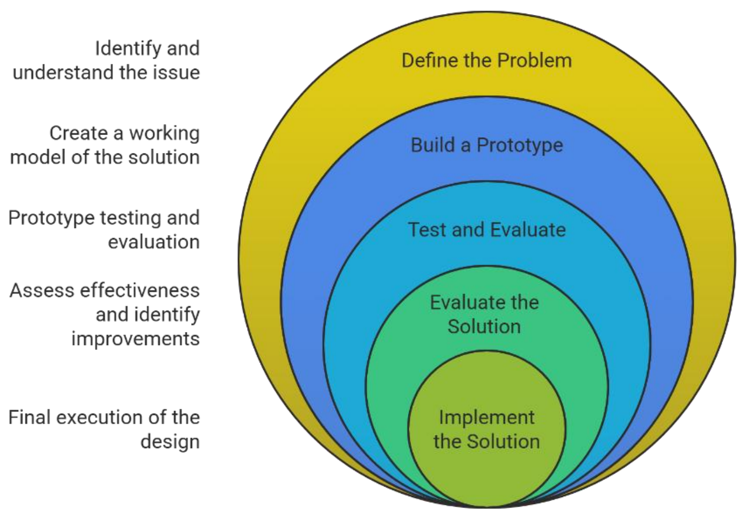


Fig. 1. Engineering Design Process

1. **Problem Identification:** The need for a safer, smarter baby cradle was established, focusing on real-time monitoring and automated responses.
2. **Research and Requirements Gathering:** Sensors and system requirements were identified based on literature review.

3. **Conceptual Design:** The system architecture was conceptualized, specifying the integration of motion, temperature, gas, and moisture sensors.
4. **Simulation and Prototyping:** Tinkercad (Tinkercad, 2025) was used to virtually assemble and simulate the electronic circuits, enabling real-time testing of sensor integration and automated cradle movement.
5. **Design Iteration:** Multiple design iterations were performed in Tinkercad (Tinkercad, 2025) to optimize the layout and ensure reliable sensor communication.
6. **Comparative Analysis:** Fritzing was reviewed as an alternative, but Tinkercad (Tinkercad, 2025) was preferred for its user-friendly interface and robust simulation capabilities (Fritzing, 2025).
7. **Documentation:** All design and simulation processes were thoroughly documented for reproducibility and future reference.

4. Technical development and analysis of IOT Enabled Smart Baby Cradle System

In the initial phase of developing the Smart Baby Cradle System, research was conducted using keywords such as "smart baby cradle," "IoT baby monitoring," and "automated cradle system." The research prioritized identifying innovative solutions that improve upon traditional baby cradles by leveraging IoT technologies, while also focusing on uncovering gaps in existing systems. Based on the analysis of prior work and identified gaps, an initial system layout was designed. Feedback was then sought from professors and peers to gain valuable insights. Their feedback, combined with considerations of resource availability and technical feasibility, guided iterative refinements in the design before progressing to the development and simulation phases.

A. Proposed System Demonstration using Flowchart Diagram

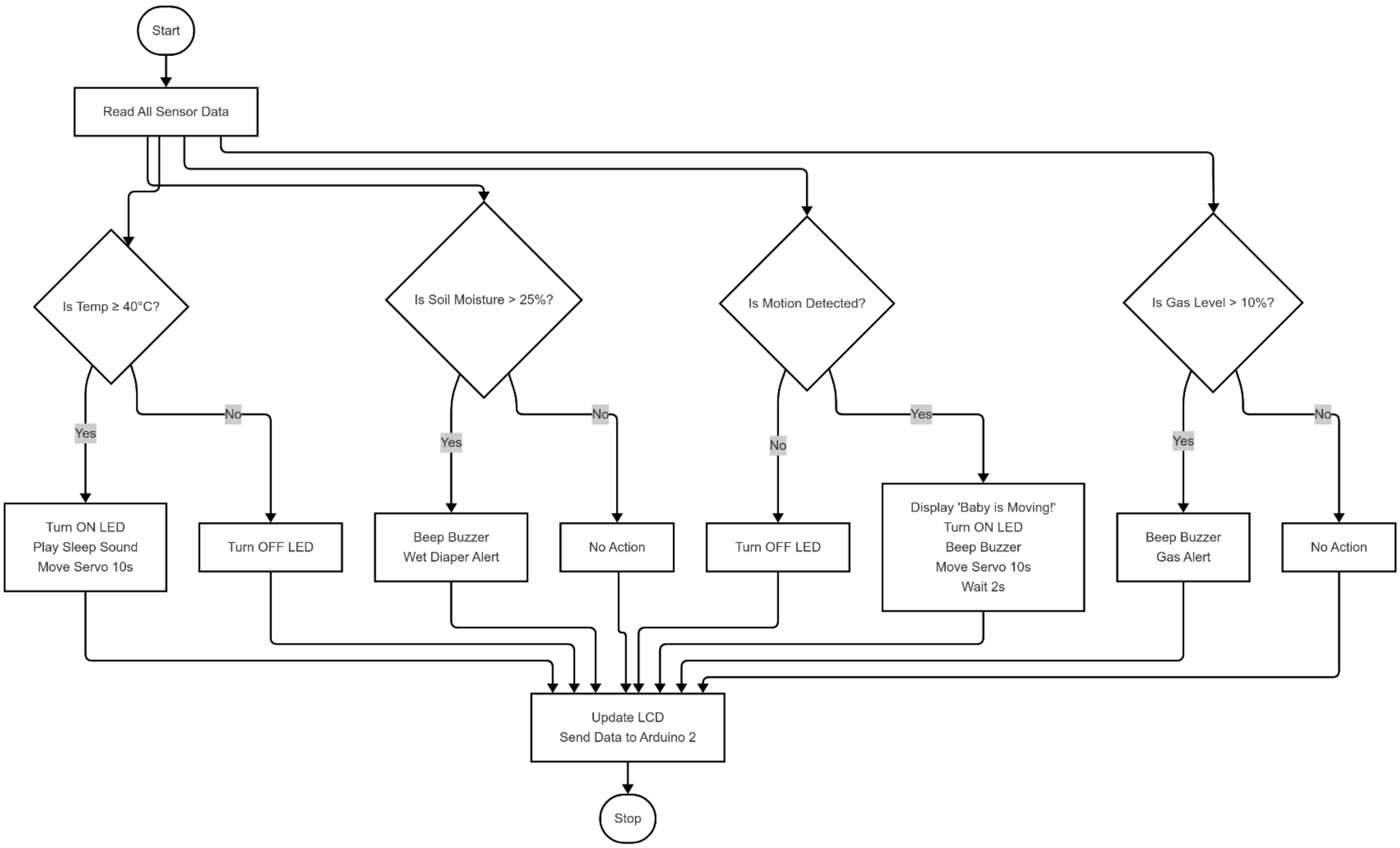


Fig. 2. System Design (Bird Eye View) of IOT enabled Smart Baby Cradle System

B. Boolean Logic Table, operation and circuit design for System Functionality and Fault Detection

i. Symbol Interpretation for Truth Table Demonstrating Baby Monitoring System

Gas Sensor		Temperature Sensor	
0	Gas Below Threshold (≤ 10%)	0	Temperature Below Threshold (< 40°C)
1	Gas Above Threshold (> 10%)	1	Temperature Above Threshold (≥ 40°C)
Soil Moisture Sensor		**PIR Sensor (Motion)**	
0	Dry (≤25%)	0	No Motion
1	1: Wet (>25%)	1	Motion Detected

RGB LED		Buzzer	
ON	Fault or Status Indicated	ON	Fault Detected in the System
OFF	Normal	OFF	Normal

ii. Truth Table for Smart Cradle System

Cases	Temperature Sensor	Soil Moisture Sensor	Gas Sensor	PIR Sensor (Motion)	LED	Buzzer	Servo	LCD
	T	S	G	M	Output	ON/ OFF	Cradle Movement	Display
1	0	0	0	0	OFF	OFF	OFF	Available
2	1	0	0	0	ON	ON	ON	Temperature alert
3	0	1	0	0	OFF	ON	OFF	Wet Diaper
4	0	0	1	0	OFF	ON	ON	Gas alert
5	0	0	0	1	ON	ON	ON	Baby is moving
6	1	1	1	1	ON	ON	ON	All Faults
7	1	0	1	1	ON	ON	ON	Temp + Wet + Gas
8	0	1	1	1	ON	ON	ON	Temp + Wet + Gas
9	1	1	0	1	ON	ON	ON	Temp + Wet + Gas
10	1	1	1	0	ON	ON	ON	Temp + Wet + Gas

iii. Boolean Expression for Smart Baby Cradle System

a. Symbol Interpretation

All the symbolic expressions for the Smart Baby Cradle System is given below:

- T represents the Temperature Sensor (1 if High temperature ≥ 40°C)
- S represents the Soil Moisture Sensor (1 if wet diaper)
- G represents the Gas Sensor (1 if gas is detected)
- M represents the PIR Sensor (1 if baby is moving)
- ¬ represents NOT Operation
- ∧ represents AND Operation
- ∨ represents OR Operation

b. Boolean Expression for LED

LED turns ON when:

- Baby is moving and either temperature is high or gas is detected: $M \wedge (T \vee G)$
- OR all three faults: $T \wedge S \wedge G$

Final Expression:

$LED = (M \wedge (T \vee G)) \vee (T \wedge S \wedge G)$

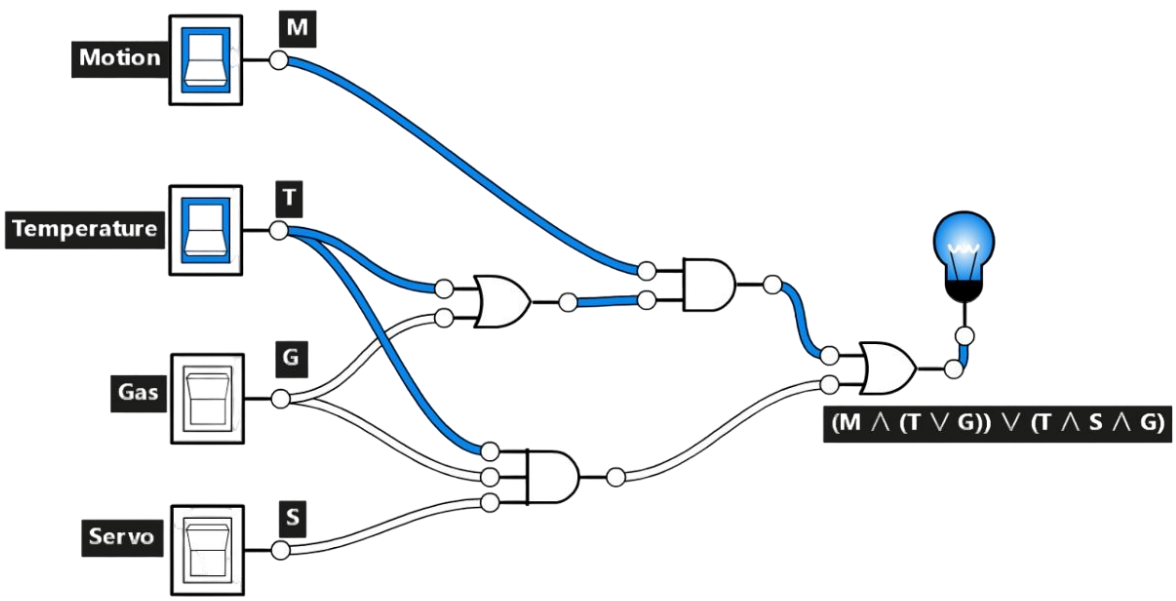


Fig. 3. Boolean Expression for LED

c. Boolean Expression for Buzzer

Buzzer turns ON when:

- Temperature is high: T
- OR wet diaper only: S ∧ ¬G ∧ ¬M
- OR gas detected only: G ∧ ¬T
- OR baby is moving: M

Final Expression:

Buzzer = T ∨ (S ∧ ¬G ∧ ¬M) ∨ (G ∧ ¬T) ∨ M

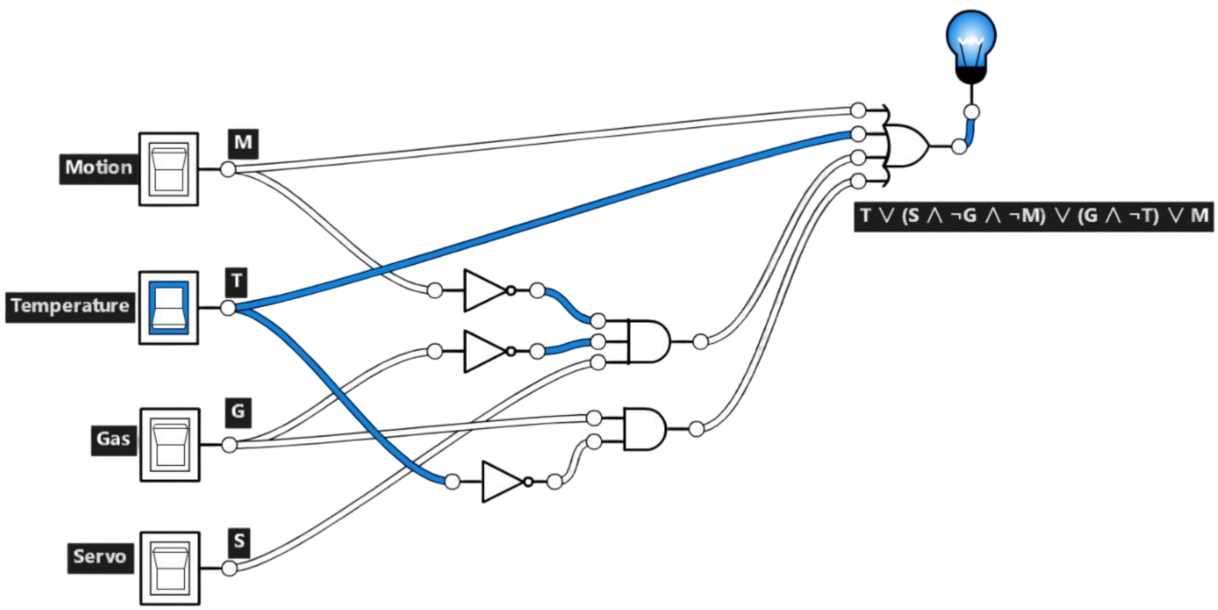


Fig. 4. Boolean Expression for Buzzer

d. Boolean Expression for Servo

Servo turns ON when:

- Any of Temperature high, Gas detected, or Motion detected is true

Final Expression:

Servo = T ∨ G ∨ M

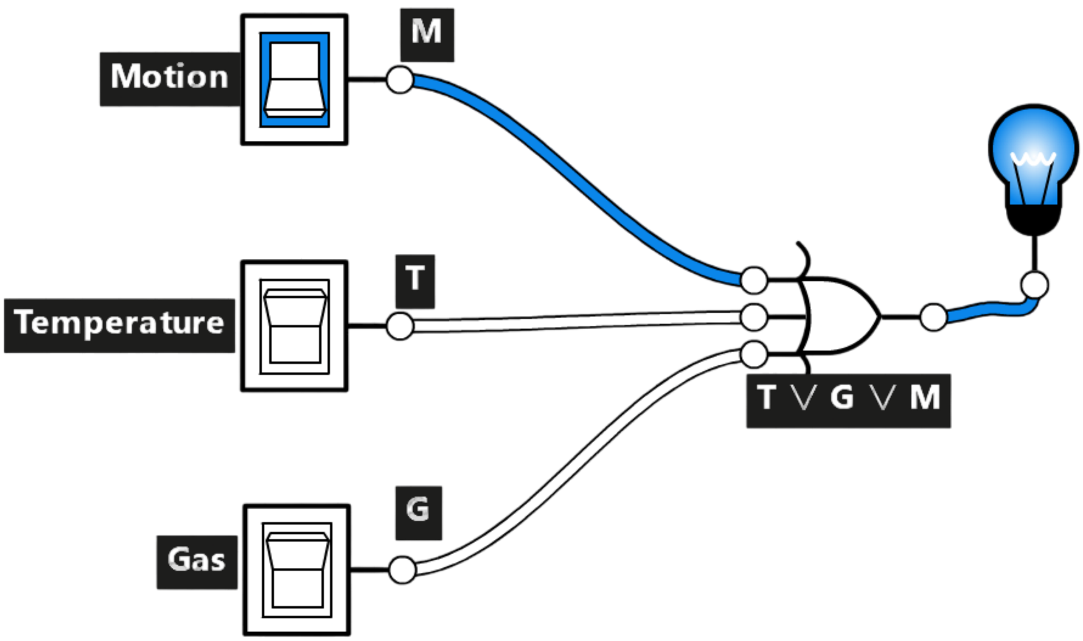
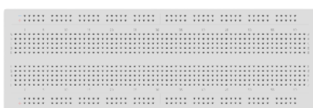
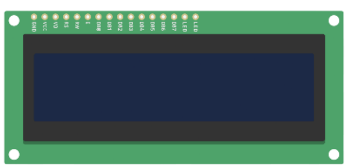
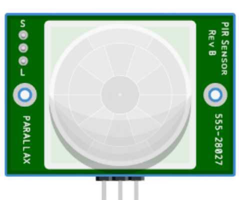
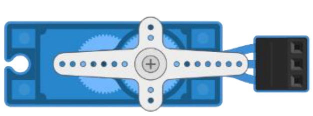
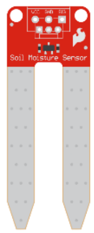
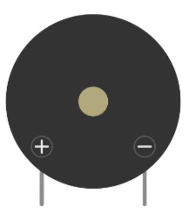


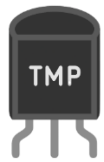
Fig. 4. Boolean Expression for Servo

C. Hardware Requirement Analysis for IOT enabled Smart Baby Cradle System

The system is developed for the implementation within the TinkerCad Simulation environment, utilizing available hardware components in TinkerCad. Below, a well-structured set of diagrams and a use case table provide a clear and detailed representation of the design :-

SN	Image	Name	Quantity	Use case
1		Arduino Uno	1	The Arduino Uno, a cost-effective and beginner-friendly microcontroller, is utilized to receive input signals from sensors and send appropriate commands to actuators, ensuring seamless interaction between components.
2		Breadboard	1	To enable seamless circuit connections and component integration without requiring soldering.
3		LCD 16x2	1	To deliver real-time system updates, ensuring users receive clear and easily accessible information.
4		PIR Sensor	1	To identify movements and promptly notify the user regarding detected activity.
5		Servo Motor	1	To activate the cradle system in response to detected motion or elevated temperature.

6		Soil Moisture sensor	1	A soil moisture sensor was utilized to identify the presence of moisture.
7		LED	1	A light bulb was utilized to represent the power source for the cradle system, functioning as a reference indicator that alerts users by emitting light.
8		Gas Sensor	1	A gas sensor was employed to detect the presence of fire or any hazardous gases near the cradle.
9		Potentiometer	1	A potentiometer was utilized to adjust the display, ensuring proper visibility on the LCD screen.
10		Buzzer	1	A buzzer was used to alert users to any sensor-detected activity while also producing a calming sound when the baby moves.

11		Temperature sensor	1	A temperature sensor was used to track the baby's and cradle's temperature, providing alerts for elevated temperatures and triggering cradle movement when necessary.
12		Resistor	4	Resistors were employed to control the electrical flow across all circuits, ensuring stable operation.

D. Software Requirement analysis while designing IOT based Smart Baby Cradle System

For Research and Analysis		
1	Google Scholar	For finding papers based on the assigned project
For Designing and Planning		
3	Mermaidchart	For designing block diagram before development
For Development and Programming		
4	Arduino IDE	For writing, compiling, and uploading code to Arduino boards.
5	C++	Programming language for writing Arduino firmware
For Simulation and Circuit Design		
6	TinkerCad	For designing and simulation of circuit diagrams virtually
For Debugging and Testing		
8	Serial Monitor	For debugging real-time sensor data
For Writing Article		
9	Microsoft Word	For writing the research paper
11	Zotero	For Citation and Referencing

E. *Final design of IOT enabled Smart Baby Cradle System*

Following extensive research, careful planning, and system design using a block diagram, logic was developed based on the diagram. Logic circuits were reviewed, and hardware requirements were analyzed based on availability. As a result, a fully constructed circuit diagram has been created in TinkerCad and is presented below:-

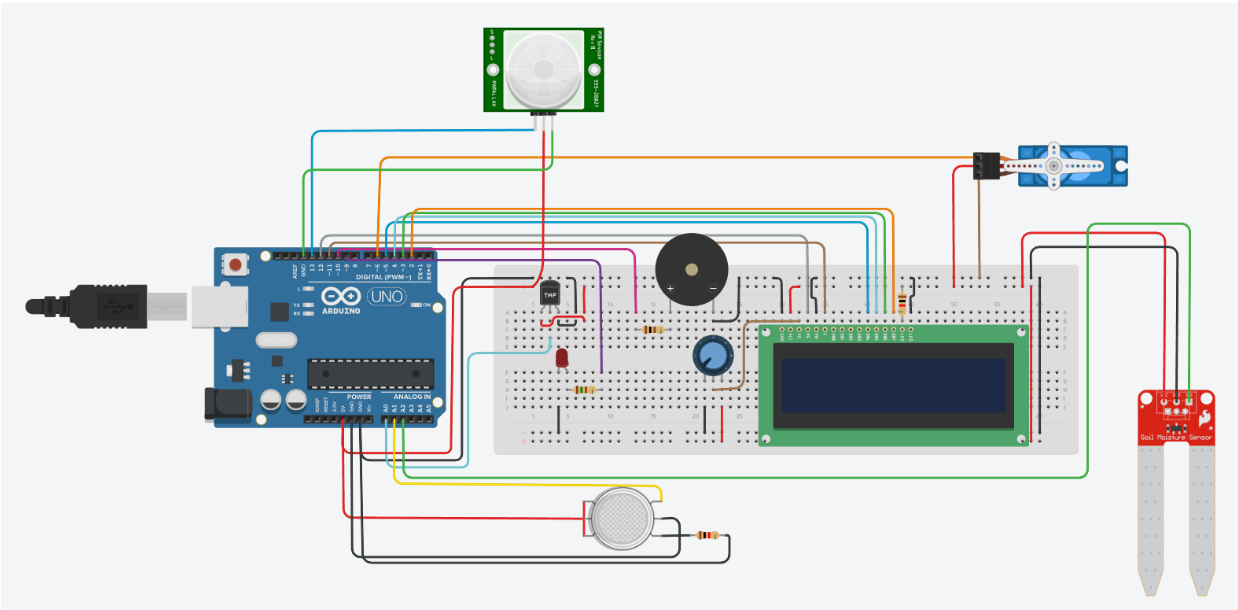


Fig. 5. Tinkercad demonstration of IOT enabled Smart Baby Monitoring System

F. Schematic diagram of IOT enabled Smart Baby Cradle System

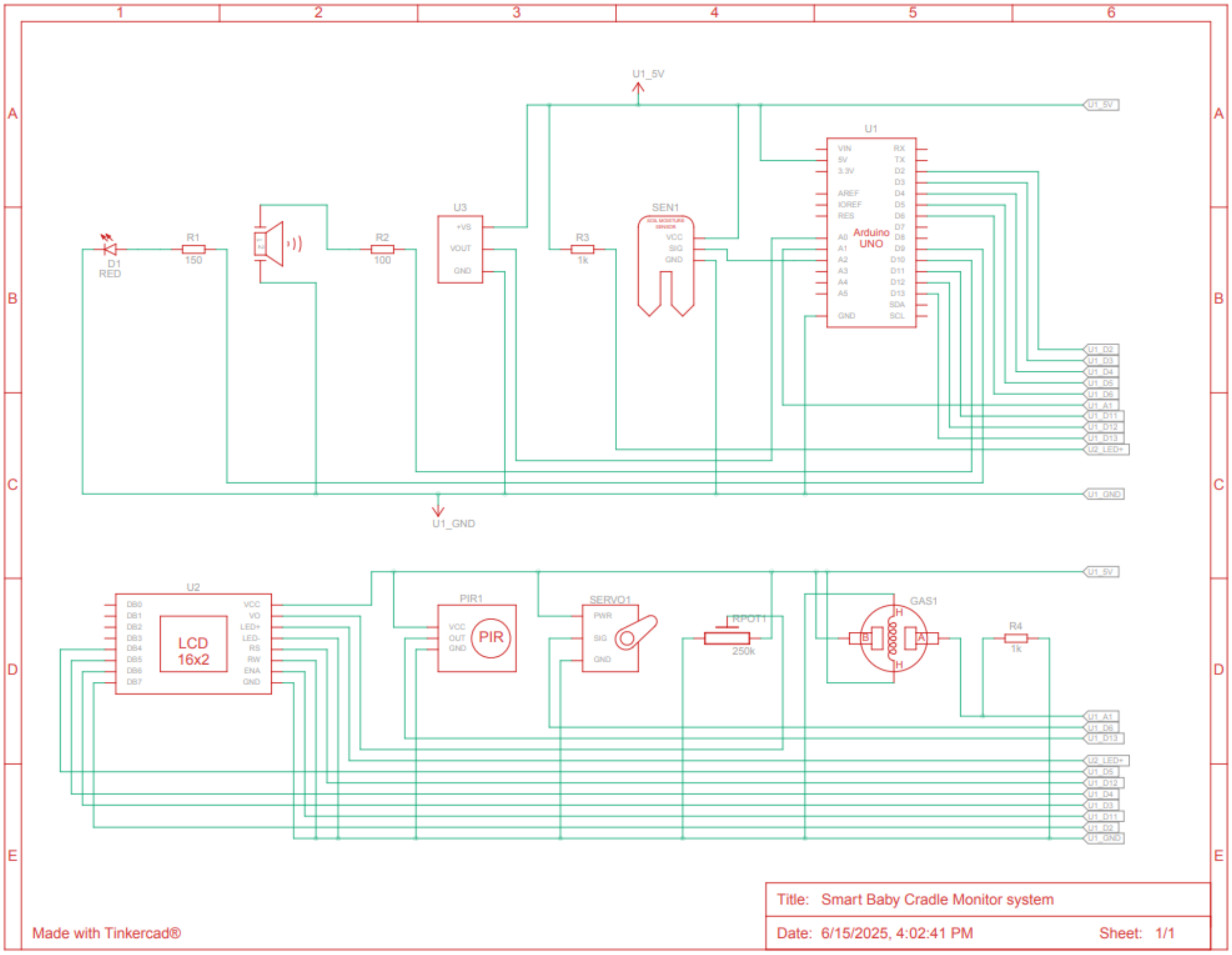


Fig. 6. Schematic layout demonstrating IOT enabled Smart Baby Cradle System

G. Code of IOT enabled Smart Baby Cradle System

```
#include <LiquidCrystal.h>

const int buzz = 10;
const int soilMoisturePin = A2;

const int rs = 12, en = 11, d4 = 5, d5 = 4, d6 = 3, d7 = 2;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);

void setup() {
  pinMode(buzz, OUTPUT);
  lcd.begin(16, 2);
  Serial.begin(9600);
}

void loop() {
  int soilRaw = analogRead(soilMoisturePin);
  int soilMoisture = constrain(map(soilRaw, 300, 1023, 0, 100), 0,
100);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Moisture:");
  lcd.setCursor(0, 1);
  lcd.print(soilMoisture); lcd.print("%");

  Serial.print("Soil Moisture: ");
  Serial.println(soilMoisture);
  if (soilMoisture > 25) {
    beepBuzzer(3);
  }

  delay(2000);
}

void beepBuzzer(int seconds) {
  unsigned long start = millis();
  while (millis() - start < seconds * 1000) {
    tone(buzz, 1000, 200);
    delay(400);
  }
  noTone(buzz);
}
```

Fig. 7. Snapshot of the Aurdino code of the moisture sensor of IOT enabled Smart Baby Cradle System

Including the entire code within this document is not a professional approach. To ensure clarity while meeting the requirements, the snapshot above represents only one-third of the complete code file, specifically focusing on the motion sensor. Since the system integrates multiple sensors, each with its own distinct code, I have provided only the code relevant to the motion sensor. **Complete code is available at: https://github.com/Rozeen-Baniya/IOT-Enabled-Smart-Baby-Cradle-System**

5. Results and Discussion

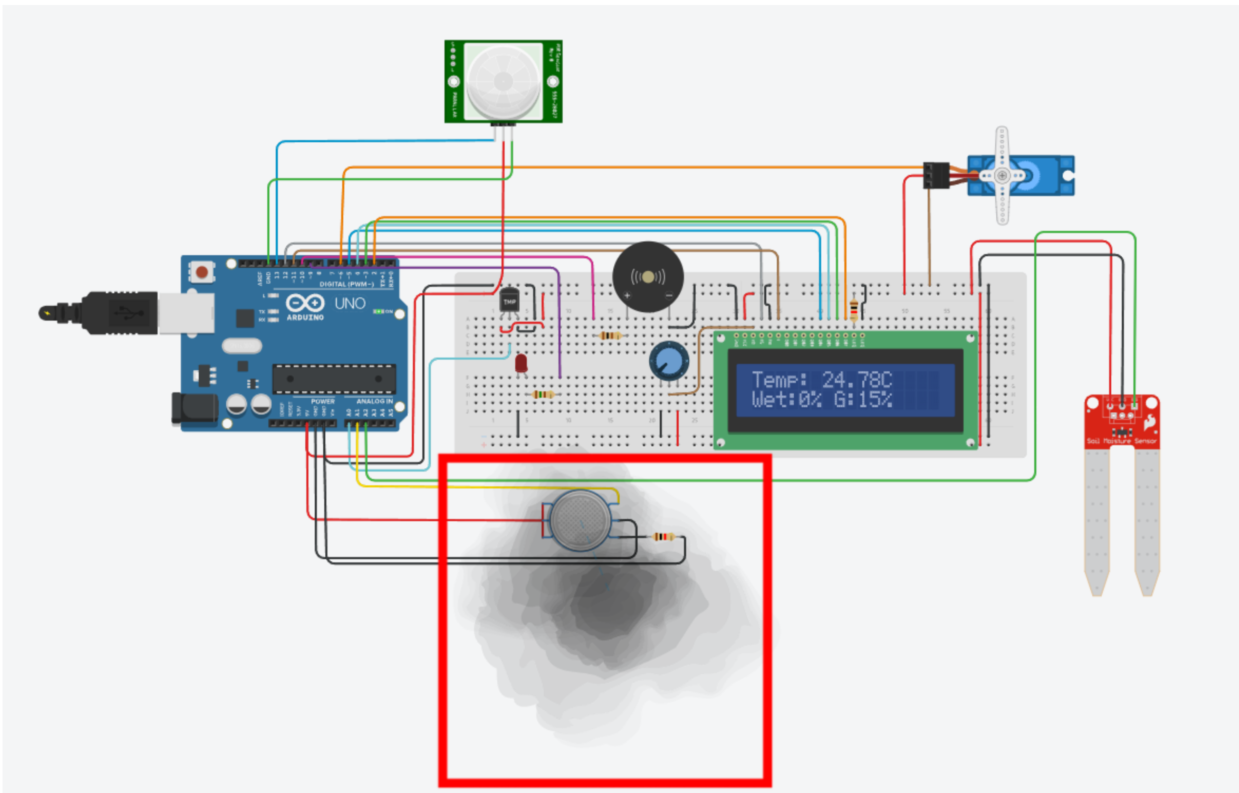


Fig. 8. **Simulation 1** *when smoke/gas is detected the buzzer buzzes*

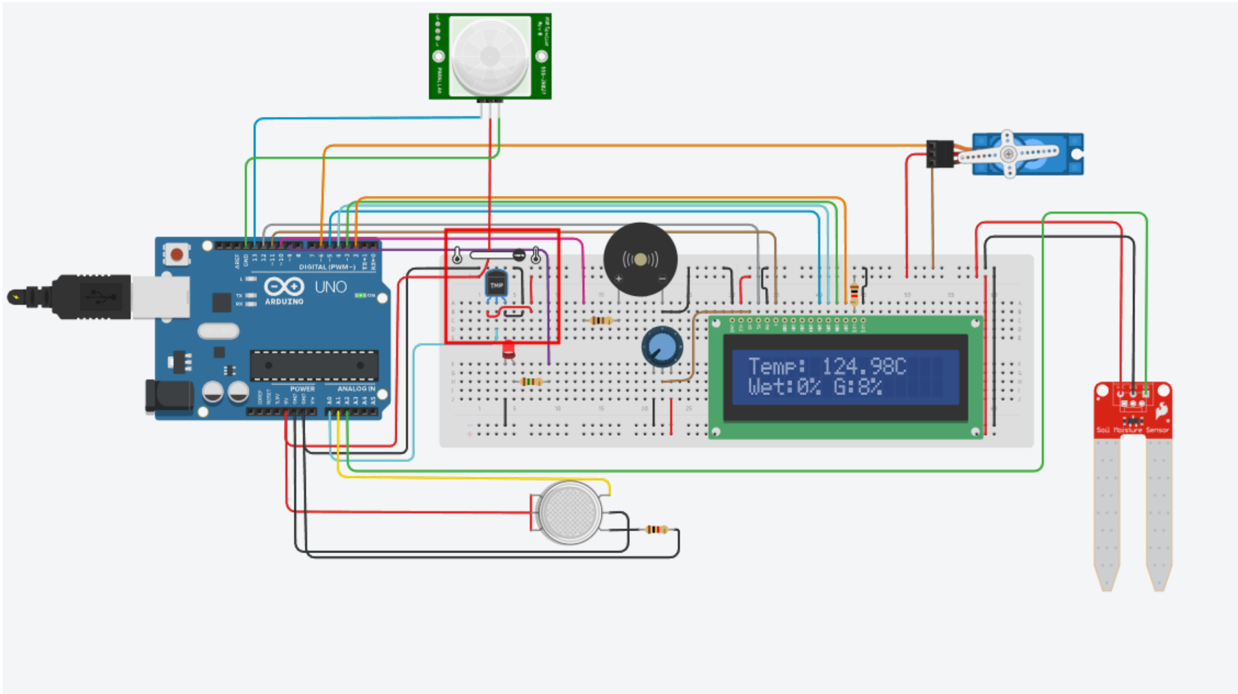


Fig. 9. **Simulation 2** *when Temperature is high the buzzer buzzes*

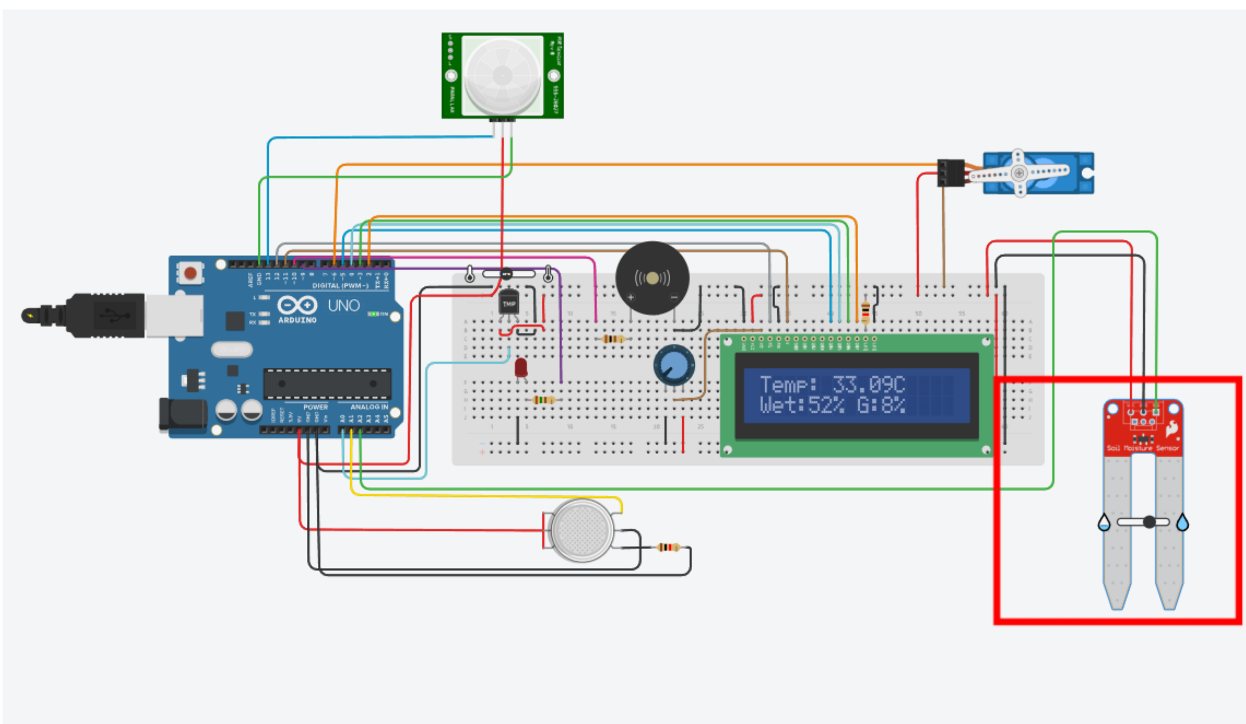


Fig. 10. **Simulation 3** *when the moisture is detected the buzzer buzzes*

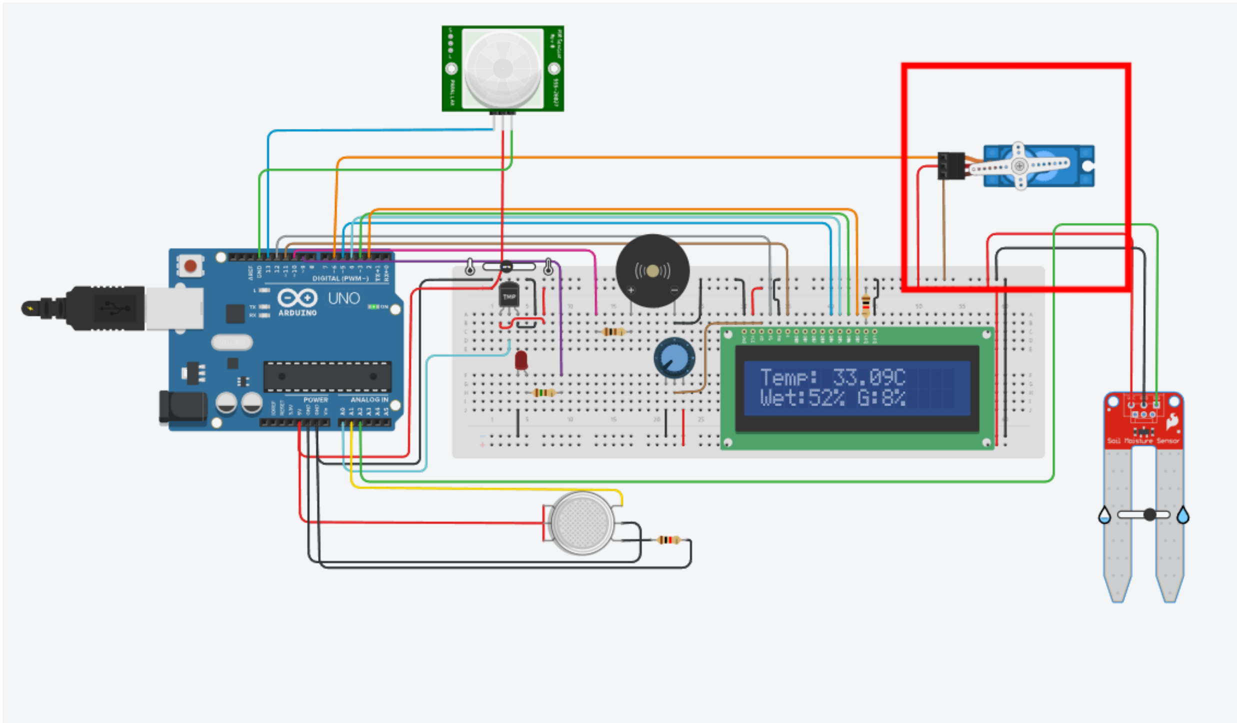


Fig. 11. **Simulation 4** *when the temperature is high or when the movement is detected the servo moves*

When the system detects any abnormalities based on sensor input (motion, gas, temperature, or diaper wetness), the Smart Baby Cradle responds immediately with appropriate actions to ensure the safety and comfort of the baby. The output behaviors during a test scenario are explained as follows:

- When smoke/gas is detected, the Gas Sensor triggers a safety response. The buzzer immediately activates with a sharp beeping sound to alert nearby caregivers of harmful air conditions around the cradle.
- When high temperature (≥ 40°C) is detected by the **Temperature Sensor**, the system triggers a soothing melody from the buzzer to calm the baby. Simultaneously, the LED turns ON, and the Servo Motor indicates the Cradle movement, gently rocking the baby for added comfort.
- When the PIR sensor detects movement, indicating the baby is awake or active, the LCD displays the message "Baby is Moving", and both the LED and buzzers are activated for notification. Additionally, the Servo Motor engages, mimicking natural cradle rocking.
- When the Soil Moisture Sensor detects a wet diaper (moisture level > 25%), the buzzer sounds a repetitive alert tone to inform parents or guardians that the diaper needs changing, ensuring the baby's hygiene and comfort.

All sensor status and readings are simultaneously displayed on the 16x2 LCD screen for real-time monitoring. Communications are handled by a single Arduino board, where all sensors inputs are processed, and outputs (LCD, buzzer, servo, LED) are triggered accordingly. The system is designed to operate autonomously and locally, making it reliable even without cloud or network dependency.

6. Addressing system limitations for Real World Deployment

a) **Simulation Constraints**
The current design is a simulation and has not been tested in real-world environments. When deploying hardware components like servo motors (for cradle movement), temperature sensors (baby temperature), soil moisture sensors (wetness detection), and gas sensors, challenges such as environmental interference (e.g., humidity affecting moisture detection), power fluctuations, and sensor calibration inaccuracies may arise. These factors could necessitate hardware upgrades or replacements, increasing overall system costs.

b) **Scalability Changes**
The system is designed for a single cradle setup. Expanding to multiple cradles in a household or integrating with broader smart home ecosystems (e.g., baby monitors, smart lights) would require architectural changes, optimized IoT communication protocols, and enhanced data synchronization to avoid latency in real-time alerts.

c) **Data Management and Privacy**
The system currently lacks a database for storing sensor data (e.g., temperature trends, gas leak incidents). For practical deployment, a secure cloud or edge-based storage solution is critical to log historical data while ensuring compliance with privacy regulations (e.g., GDPR) and protecting sensitive infant health information.

d) **Hardware Maintenance and Reliability**
- **Servo motors** requires periodic lubrication and alignment checks to ensure smooth cradle movement.
- **Temperature Sensors** may drift overtime, requiring recalibration to maintain accuracy.
- **Soil moisture sensors** are prone to corrosion or false triggers due to environmental contaminants.
- **Gas sensors** need regular testing to detect leaks reliably.

e) **Alert and Notification System**
A robust alert mechanism is essential to notify caregivers immediately in cases of abnormal conditions (e.g., high temperature, gas leaks, or prolonged wetness). False alarms (e.g., moisture sensors triggered by spilled water) or delayed notifications could erode caregiver trust and system effectiveness.

f) **User Interface and Accessibility**
A dedicated mobile/web app with intuitive UI/UX is needed for caregivers to monitor real-time data (e.g., temperature graphs, moisture alerts) and control cradle movement remotely. Accessibility features (e.g., voice commands, multilingual support) must be included to accommodate diverse users.

g) **Power Management**
Uninterrupted power supply is critical for servo motors and sensors. Power outages or fluctuations could disrupt cradle automation or sensor functionality. Battery backups or low-power sleep modes must be implemented to ensure continuous operation.

h) **Environmental Adaptability**
The system may struggle in extreme environments (e.g., high humidity interfering with moisture sensors, cold temperatures affecting servo responsiveness).

Weatherproofing and adaptive algorithms would be necessary for reliable performance in diverse conditions.

7. Conclusions

The IoT-based Smart Baby Cradle System demonstrates a significant step forward in modernizing infant care by addressing the shortcomings of traditional cradles through intelligent monitoring and automation. By leveraging sensors for temperature, moisture, and gas detection, along with automated cradle movement, the system enhances both safety and comfort for infants while providing peace of mind for caregivers. Although the current design has proven effective in simulation, its real-world implementation will require overcoming challenges related to hardware reliability, data security, and adaptability to diverse environments. Looking ahead, integrating advanced health monitoring, developing a user-friendly mobile application, and incorporating robust data management and security measures will be essential for practical deployment. With continued innovation and refinement, this smart cradle system holds great promise for setting new standards in responsive, technology-driven childcare.

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