IoT based Smart Cradle for Baby Monitoring System using Rasberry Pi

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***Abstract*—This paper presents an IoT-based Smart Cradle for Enhanced Baby Monitoring System using GrovePi sensors, Raspberry Pi and Azure Vision. The project aims to provide real-time monitoring of the baby's environment by leveraging these technologies. The system enables parents to promptly respond to abnormal conditions, enhancing the safety and security of the baby. With instant alerts and automated responses, parents can have peace of mind and remotely interact with their baby. The system stores sensor data over time, allowing for trend analysis and providing valuable insights into the baby's health and well-being. The intuitive interface enhances the user experience, making it easy for parents to monitor their baby's environment and access historical data analysis.**

***Index Terms*—IoT-based Smart Cradle, GrovePi sensors, Raspberry Pi, Azure Vision, real-time monitoring, sensor data analysis, trend analysis, edge computing, cloud services, computer vision, data analysis, visualization, Node-RED, machine learning, automation, system architecture, sensor monitoring, alerting, gas sensor simulation, camera integration, motion detection, cradle mechanism, automatic cradling**

I. Introduction

Infant monitoring is essential for ensuring their safety and well-being. This project introduces an IoT-based Smart Cradle for Enhanced Baby Monitoring System using Raspberry Pi and Azure Vision. The motivation behind this project is to provide parents with real-time monitoring capabilities and peace of mind, knowing they will be notified of any issues in their baby's environment. The goals of the project include providing enhanced safety and security for the baby, enabling remote interaction between parents and the baby, and facilitating data analysis to gain insights into the baby's health and well-being. The specific contributions of this project include:

- Integrating sensors, cloud computing, and computer vision technologies to create an IoT-based Smart Cradle for Enhanced Baby Monitoring System.
- Providing real-time monitoring of the baby's environment and enabling prompt responses to abnormal conditions.
- Enabling remote interaction between parents and the baby through automated responses.
- Facilitating data analysis to gain insights into the baby's health and well-being.

II. Related Work or Concepts

A. Sensor Technology

Previous research has explored the use of various sensors for monitoring infant vital signs and environmental conditions. These sensors may include temperature sensors, humidity sensors, motion sensors, sound sensors, and air quality sensors. Different sensor types are employed to provide comprehensive monitoring of the baby's environment and detect abnormalities or changes in conditions that may affect the baby's well-being.

B. Edge Computing

Edge computing plays a crucial role in IoT-based infant monitoring systems by enabling real-time data processing and analysis at the edge of the network, closer to the data source. This reduces latency and allows for faster response times to detected abnormalities or events. Edge computing platforms, such as Raspberry Pi, are commonly used in these systems to process sensor data locally and trigger alerts or actions as necessary.

C. Cloud Services

Cloud computing services are utilized to store, manage, and analyze large volumes of sensor data collected from IoT devices. Cloud platforms, such as Azure, AWS, and Google Cloud Platform, offer scalable and reliable infrastructure for hosting IoT applications and processing sensor data. Cloud services enable features such as data storage, analytics, visualization, and remote access to monitoring systems.

D. Computer Vision

Computer vision technologies are increasingly integrated into IoT-based infant monitoring systems to analyze visual data captured by cameras. Computer vision algorithms can be used to detect specific events or objects, such as a crying baby, facial expressions, or gestures, enabling more advanced monitoring capabilities and automated responses.

E. Data Analysis and Visualization

Data analysis techniques are applied to sensor data collected over time to identify patterns, trends, and anomalies in the baby's behavior and environment. Time-series databases, such as InfluxDB, are commonly used for storing and querying sensor data. Data visualization tools, such as Grafana, are employed to create visual representations of sensor data, enabling caregivers to gain insights into the baby's health and well-being.

F. Dashboards

User-friendly interfaces, such as mobile applications or web dashboards, provide caregivers with easy access to monitoring systems and real-time data insights. These interfaces allow caregivers to remotely monitor the baby's environment, receive alerts, and access historical data analysis from their smartphones or other devices.

III. System Architecture and Design

A. Objective and Features

The project aims to revolutionize baby care by leveraging advanced technology for enhanced monitoring of the baby's well-being and behavior, ensuring caregivers receive timely alerts and assistance as needed. Through automation, routine tasks associated with baby care are streamlined, alleviating the burden on caregivers and enhancing overall convenience. By seamlessly integrating with IoT devices and sensors, the system creates a smart and responsive environment tailored to the baby's needs. Additionally, a user-centric design approach prioritizes ease of use and accessibility for caregivers, ensuring a seamless and intuitive experience.

The main features of the Smart Cradle are as follows:

- Enable voice-controlled operation of the baby crib's cradling mechanism, offering hands-free convenience and customization options.
- Activate distracting lights to entertain and soothe the baby, with customized patterns and brightness levels tailored to their preferences.
- Utilize infrared cameras and custom vision models for real-time monitoring of the baby's behavior, automatically triggering the cradling mechanism if crying is detected.
- Convert spoken commands into text for processing, ensuring accurate interpretation and seamless execution of user instructions.
- Integrate with external services like Azure Custom Vision for enhanced image classification and access to additional functionalities through APIs.
- Log and analyze data related to user interactions and baby-related events, presenting insights and trends for informed decision-making.
- Interface with hardware components such as GPIO pins and servo motors to control the cradling mechanism, ensuring smooth operation.
- Offer customized settings for cradling intensity, light patterns, and voice recognition sensitivity, allowing caregivers to tailor the system to their preferences.
- Design the system architecture to be scalable and expandable, supporting future integration of new features and upgrades to meet evolving user needs.

B. System Architecture

Before presenting the system architecture, let's introduce the physical components of our IoT baby monitoring and cradling system. These components include the Raspberry Pi, Grove Pi+ board, RPi infrared camera, servo motor, LED lights, and the 3D printed crib. These elements work together seamlessly to provide a comprehensive solution for monitoring and caring for infants.

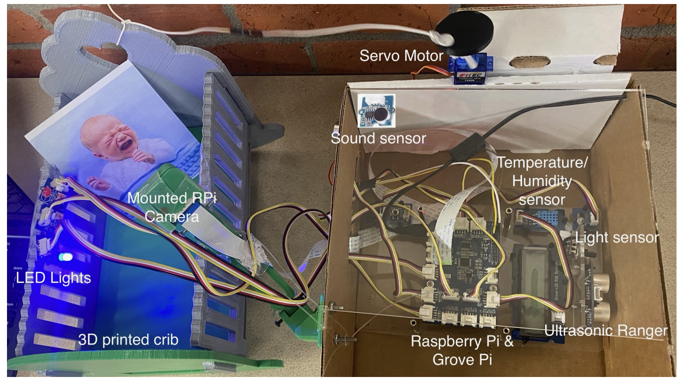

Fig. 1. Components of the Baby Monitoring System

The system architecture of the IoT baby monitoring and cradling system comprises the following components:

- Raspberry Pi: Serves as the central processing unit and connects to all sensors and actuators.
- Grove Pi+ Board: Acts as an interface between the Raspberry Pi and the Grove sensors, facilitating easy connection and communication.
- Sensors:
  - DHT11 Sensor: Measures temperature and humidity levels in the baby's environment.
  - Sound Sensor: Detects sound levels, enabling the system to respond to the baby's cries.
  - Light Sensor: Measures ambient light levels for controlling the LED lights.
  - Ultrasonic Range Sensor: Determines the distance between the sensor and nearby objects, useful for detecting the baby's presence near the crib.
- RPi Infrared Camera: Captures images of the baby for visual monitoring and analysis.
- Servo Motor: Controls the rocking motion of the crib, providing gentle movement to soothe the baby.
- LED Lights: Three LED lights are used for entertainment purposes, creating visual stimuli for the baby.
- 3D Printed Crib: Connected to the servo motor, the 3D printed crib provides a platform for the baby's comfort and movement.

The Raspberry Pi communicates with the components through the Grove Pi+ board, processing sensor data like temperature, humidity, sound, light, and distance. Based on predefined thresholds and user preferences, it triggers actions such as activating the cradling mechanism, adjusting LED lights, and sending alerts. The infrared camera captures images for computer vision analysis to detect the baby's presence and emotions, ensuring seamless integration for efficient baby monitoring and care.

The overall system architecture can be illustrated as follows:

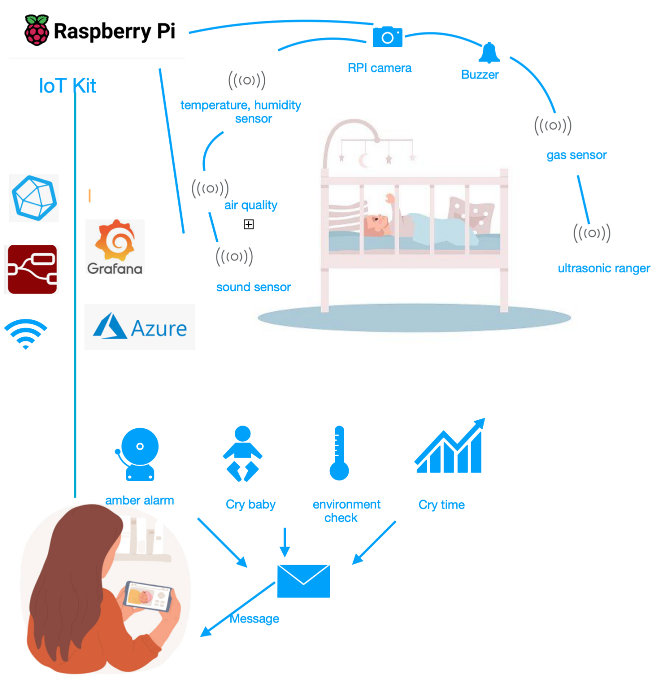

Fig. 2. System Architecture

C. Tools and Frameworks

*1) **Node-Red**:* The Node-RED dashboard provides a comprehensive overview of the baby's environment and status, facilitating real-time monitoring and interaction for caregivers. It includes temperature and humidity gauges, offering insights into the ambient conditions essential for the baby's comfort. The noise gauge indicates sound levels, providing feedback on the baby's activity and surroundings. Additionally, the heat index chart provides a graphical representation of the combined effects of temperature and humidity, aiding in assessing the overall comfort level.

Furthermore, the live feed from the camera allows caregivers to visually monitor the baby's activities and well-being remotely, ensuring constant supervision. The dashboard also features interactive elements such as a command interface to cradle the baby on demand, enabling caregivers to soothe the baby promptly. Moreover, the option to entertain the baby with lights adds a playful element to the environment, enhancing the baby's experience.

By integrating data from sensors and the camera, the Node-RED dashboard offers a centralized platform for comprehensive baby monitoring and interaction, empowering caregivers with valuable insights and control over the baby's environment.

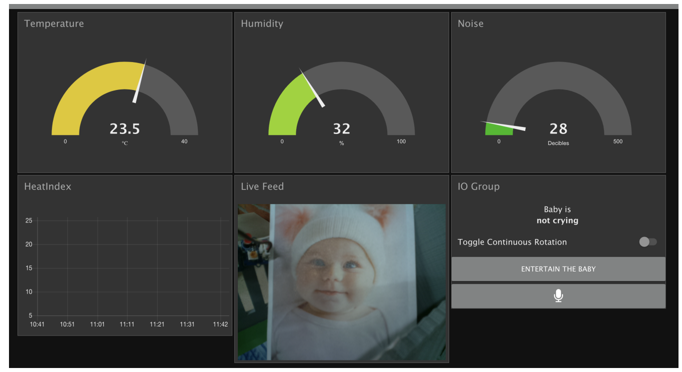

Fig. 3. Node-Red Dashboard

*2) **Microsoft Azure**:* The IoT dashboard implemented using Microsoft Azure IoT Hub offers a comprehensive analysis of various environmental parameters and baby-related metrics. It includes trend analysis charts for room temperature, humidity, and heat index, providing insights into the ambient conditions crucial for the baby's comfort. Additionally, data from gas sensor simulators, measuring alcohol, CH_4, CO, H_2, LPG, propane, and smoke levels, are analyzed to ensure a safe environment for the baby.

Moreover, the dashboard displays trend analysis for the number and types of alert messages received from the app, enabling caregivers to track and respond to critical events effectively. A pie chart depicting the status of whether the baby is crying or not offers immediate feedback on the baby's emotional state.

Furthermore, miscellaneous values from sensors such as the ultrasonic ranger, noise, and light sensors are presented for additional context and monitoring. Leveraging Azure Custom Vision model, the dashboard predicts the baby's crying status based on visual cues, enhancing the system's monitoring capabilities.

Overall, the Azure IoT dashboard provides caregivers with actionable insights and real-time monitoring of various parameters, ensuring the baby's safety, comfort, and well-being.

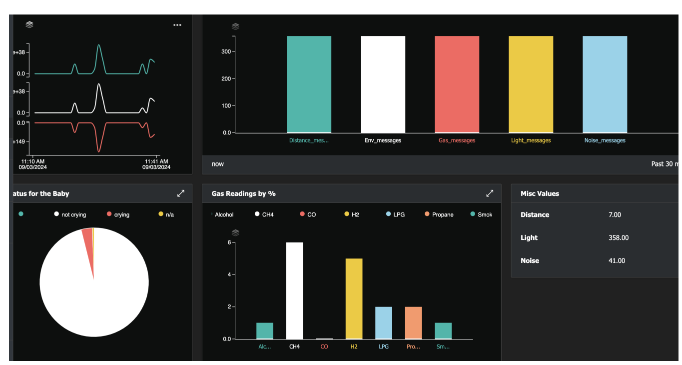

Fig. 4. Microsoft Azure Dashboard

*3) **Grafana**:* The Grafana dashboard offers a comprehensive overview of environmental conditions and baby-related metrics, providing caregivers with valuable insights and real-time monitoring capabilities. It includes visualizations for ambient light and sound levels, allowing caregivers to assess the baby's surroundings for optimal comfort. Additionally, gas values such as alcohol, CH4, CO, H2, LPG, propane, and smoke are graphically represented, ensuring a safe environment for the baby.

Moreover, the dashboard features a status indicator for whether the baby is crying or not, providing immediate feedback on the baby's emotional state. The movement distance of the baby is also tracked and displayed, enabling caregivers to monitor the baby's activity levels effectively.

Furthermore, trend analysis graphs for temperature, humidity, and heat index provide insights into the ambient conditions in the baby's environment, helping caregivers maintain a comfortable atmosphere. Additionally, charts for temperature and gas levels offer detailed monitoring of these critical parameters.

Overall, the Grafana dashboard serves as a valuable tool for caregivers, offering comprehensive monitoring and analysis of environmental conditions and baby-related metrics to ensure the baby's safety, comfort, and well-being.

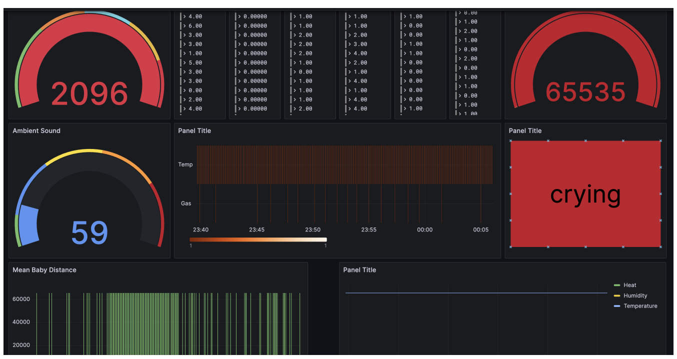

Fig. 5. Grafana Dashboard

*4) **InfluxDB**:* The InfluxDB database plays a crucial role in storing and organizing various measurements related to the baby's environment and well-being. It consists of multiple tables, each representing different aspects of the monitoring system:

- *Alcohol*: Stores data related to alcohol levels in the baby's environment, ensuring a safe atmosphere free from harmful substances.
- *Ambient_Light*: Records ambient light levels, allowing caregivers to adjust lighting conditions for the baby's comfort and visual stimulation.
- *Ambient_Sound*: Stores data on ambient sound levels, enabling caregivers to monitor noise levels and ensure a peaceful environment for the baby.
- *Baby_Distance*: Tracks the distance of the baby from the sensors, providing insights into the baby's movement patterns and activity levels.
- *Baby_Room_Conditions*: Stores comprehensive data on various room conditions, including temperature, humidity, and gas levels, ensuring optimal environmental conditions for the baby's well-being.
- *Baby_Status*: Records the status of the baby, including whether the baby is crying or not, providing caregivers with real-time alerts and insights into the baby's emotional state.
- *CH4, CO, H2, LPG, Propane, Smoke*: Each of these tables stores data related to specific gas levels in the baby's environment, ensuring safety and monitoring for any potential hazards.
- *Movement_Count*: Tracks the number of movements made by the baby, providing insights into the baby's activity levels and behavior.
- *Not_Gas_Conditions*: Stores data related to gas levels that deviate from ideal conditions, enabling caregivers to take prompt action to address any safety concerns.
- *Not_Ideal_Env, Not_Ideal_Light, Not_Ideal_Noise*: These tables record data indicating environmental conditions that are not ideal for the baby, allowing caregivers to make necessary adjustments for the baby's comfort and well-being.

Overall, the InfluxDB database serves as a central repository for storing and managing crucial data related to the baby's environment and status, enabling caregivers to make informed decisions and ensure the baby's safety and comfort at all times.

IV. NODE-RED IMPLEMENTATION

Node-RED serves as the backbone of our IoT baby monitoring and care system, providing a visual programming environment for easily integrating various sensors, actuators, and external services. With its intuitive interface and extensive library of pre-built nodes, Node-RED simplifies the development and deployment of complex workflows, allowing us to efficiently manage data flows, process sensor data, and trigger actions based on predefined conditions, ultimately enhancing the overall functionality and user experience of our system.

*1) **Sensor Monitoring**:*

- Utilizing sensors including DHT11 for temperature and humidity, a sound sensor for ambient sound levels, and light and ultrasonic ranger sensors for ambient light levels and distance monitoring.
- Displaying real-time data from these sensors on a Node-RED dashboard using gauges and charts.
- Storing the collected data in an InfluxDB database for long-term storage and visualization in Grafana.
- Flow components: DHT11, sound sensor, light sensor, and ultrasonic ranger sensor nodes for data collection, function nodes for data processing and formatting, and InfluxDB nodes for data storage.

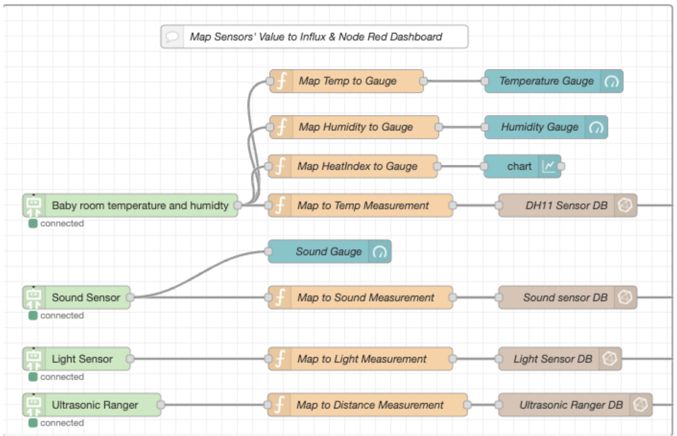

Fig. 6. Sensor Monitoring module

*2) **Alerting and Updating Baby State**:* This functionality monitors the room conditions where the baby is located and triggers alerts if conditions fall below or exceed certain thresholds. It also adjusts the baby's state based on detected conditions.

- **Inject Nodes:** Trigger the flow at specific intervals to fetch room conditions and noise levels.
- **InfluxDB Nodes:** Retrieve data from the InfluxDB database regarding room conditions, ambient sound, and light levels.
- **Function Nodes:**
  - **Set Thresholds:** Determine acceptable ranges for temperature, humidity, heat index, sound, and light levels.
  - **Map Baby Status:** Extract the baby's status from the fetched data.
  - **Create Alerts:** Generate alerts for conditions not meeting thresholds.
- **Join Node:** Combine multiple alerts into a single message.
- **Twilio Out Node:** Send SMS alerts to the user's phone number using the Twilio API.
- **UI Text Node:** Display the current baby state on the user interface.

*3) **Gas Sensor Data Simulation**:* This Node-RED flow simulates gas sensor data, generating random values for gases like H2, LPG, CH4, Alcohol, CO, Smoke, and Propane, which are then mapped to a database and converted into percentages. If any gas level surpasses predefined thresholds indicating danger, an SMS alert is sent to the user. The flow includes inject nodes for triggering data simulation, random nodes for generating gas values, threshold nodes for checking dangerous levels, function nodes for converting values and mapping them, a join node for aggregating alerts, a Twilio node for sending SMS alerts, and InfluxDB nodes for storing data. Recommendations include ensuring simulation accuracy, fine-tuning thresholds, and implementing additional alerting mechanisms. This system provides a cost-effective solution for gas monitoring, enhancing safety and security through timely alerts.

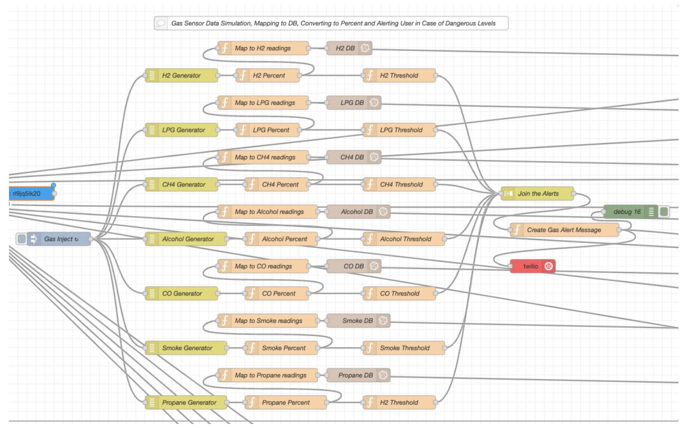

Fig. 7. Gas Sensor Simulation

*4) **Camera Integration and Live Feed**:* The Node-RED flow incorporates camera integration to capture images at regular intervals. Through HTTP communication, it retrieves the latest captured image from the camera module. Subsequently, the image data is processed and converted into a Base64 encoded format. This encoded image is then displayed on a Node-RED dashboard, providing users with a live feed. The process is automated to continuously update the live feed on the dashboard in real-time. This functionality allows users to conveniently monitor a live feed from the camera module directly on the Node-RED dashboard, facilitating efficient image monitoring.

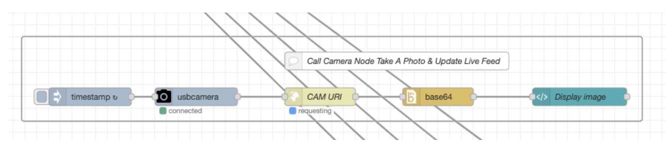

Fig. 8. Camera Integration

*5) **Motion Detection**:* The Node-RED flow implements motion detection to monitor the movement of a baby. It measures the distance traveled over time and retrieves current and previous distance data from an InfluxDB database using queries. By comparing these distances and applying a predefined threshold (set at 10 units), the flow identifies significant movement indicative of the baby's activity. Upon detecting significant movement, an alert message is generated and delivered to a predefined p

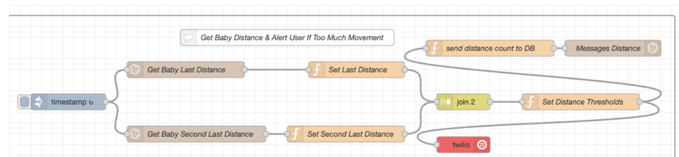

Fig. 9. Motion Detection

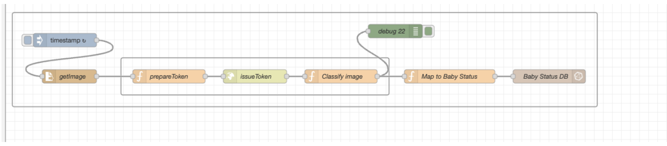

Fig. 11. Cry detection

*6) **Baby Crib Cradle Mechanism**:* The voice-controlled baby crib functionality enables caregivers to interact with the crib using voice commands, providing convenient and hands-free operation. The system comprises two main functionalities: cradling the baby crib and entertaining the baby with distracting lights.

- The UI microphone node (`ui_microphone`) captures voice commands from users, sending audio input to the system for processing.
- Speech-to-text conversion is performed using services like the Microsoft Cognitive Services Speech API. Extracted text is parsed to identify commands related to cradling the crib and entertaining the baby with lights.
- The `Cradle Toggle` function node interprets commands to activate or deactivate the cradling mechanism of the baby crib.
- The `Distract Toggle` function node controls the activation or deactivation of distracting lights based on recognized commands.
- External scripts, like `sooth.py`, are executed using the `exec` node to control distracting lights.
- GPIO pins and a servo motor interface with the Node-RED flow to physically control the cradling mechanism of the baby crib.
- The system retrieves sensor data using InfluxDB queries and provides feedback to the user regarding command execution and the current status of the cradling mechanism.

This functionality enhances caregiver comfort and improves baby care by providing convenient interaction with the crib, hands-free operation, and real-time feedback.

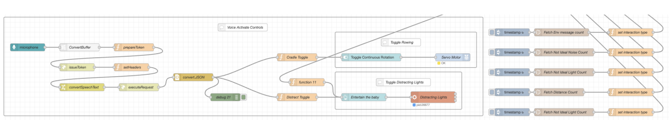

Fig. 10. Automatic Cradling

*7) **Automatic Cradling**:* The system incorporates a mechanism to automatically detect instances of the baby crying using a custom vision model deployed on Azure. When the model identifies the baby crying from the camera feed, it triggers the automatic cradling mechanism of the crib. Simultaneously, distracting lights are activated to entertain and soothe the baby. This functionality enhances caregiver responsiveness and provides timely comfort to the baby, improving overall care quality.

V. Future Works

In future iterations, potential areas for improvement and expansion of the smart cradle and baby monitoring system include: Integration of Additional Sensors: Consider incorporating more sensors, such as a heart rate monitor or air quality sensor, to enhance the system's monitoring capabilities. Machine Learning Integration: Explore the implementation of machine learning algorithms to predict and detect patterns in baby behavior, enabling more proactive caregiving. Mobile Application Development: Develop a companion mobile application to provide caregivers with remote access to the baby monitoring system, enabling real-time alerts and controls. Enhanced Automation: Further automate routine tasks by integrating voice recognition technology for more intuitive interaction with the system. User Feedback and Iterative Improvement: Gather feedback from users to identify areas for improvement and iterate on the system's design and functionality continuously.

VI. Conclusion

In conclusion, the development of the smart cradle and baby monitoring system represents a significant step towards leveraging technology for enhancing childcare. By integrating IoT devices, machine learning models, and automation, the system offers caregivers unprecedented insights and control over the baby's well-being. Throughout the project, valuable lessons were learned, and challenges were overcome, leading to a robust and user-friendly solution. As we look ahead, the potential for further innovation and improvement is vast, and we remain committed to advancing the field of smart childcare technology for the benefit of parents and caregivers worldwide.

Acknowledgment

We extend our heartfelt thanks to Professor Eyhab Al-Masri and Teaching Assistant Wenjun Yang for their unwavering support, insightful guidance, and dedication throughout this course. Their expertise and encouragement have been instrumental in shaping our project's development and success. We are also grateful to Don McLane for his invaluable assistance with 3D printing the prototype, which has greatly contributed to the realization of our vision. Their contributions have been invaluable, and we are truly grateful for their mentorship and support.

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