BabyGuardian: Smart Bassinet to Promote Safer Sleep Practices, Reducing Risks for SIDS

Design Sensor Systems Individual Report

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ABSTRACT

BabyGuardian is a smart bassinet designed to promote safer sleep practices and reduce the risk of SIDS by leveraging IoT and AI technologies. This report details the motivation, system design, implementation, and individual contributions to the project, highlighting key innovations such as facial expression recognition, cry analysis, and environmental monitoring for ensuring infant well-being.

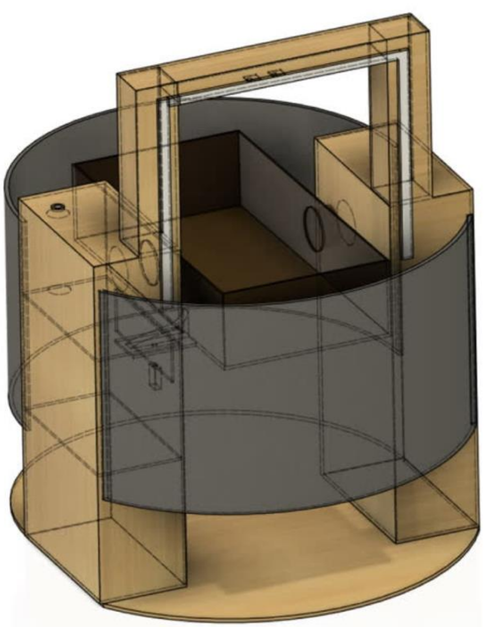

Figure 1: 3D model of the BabyGuardian smart bassinet, illustrating its design structure, the integration and positioning of essential components.

1 INTRODUCTION

Motivation: The "BabyGuardian" smart bassinet project addresses the critical issue of Sudden Infant Death Syndrome (SIDS), an unexplained and unpredictable cause of death among infants. This project aims to prevent SIDS and reduce newborn mortality by leveraging IoT and AI technologies to monitor and ensure safe sleep practices. This innovation complies with the project brief [1] and aligns with the United Nations Sustainable Development Goals [2] 3.2 and 3.4, which focus on ending preventable deaths of newborns and promoting overall child health and safe sleep practices.

Current Problems in Approaches to Prevent SIDS: SIDS is an unexplained and unpredictable cause of death in seemingly healthy infants. The primary challenge in preventing SIDS is the lack of identifiable symptoms and clear causes, making it difficult to predict and avoid. Current market solutions often involve wearable monitors and basic camera systems, which can be invasive and anxiety-inducing for parents, and they lack comprehensive monitoring capabilities. The Lullaby Trust recommends following safer sleep practices to mitigate the risk of SIDS, such as placing babies on their backs to sleep, ensuring a smoke-free environment, using a firm, flat mattress, and keeping the baby's sleep area clear of soft objects and loose bedding [3] These guidelines aim to create a safer sleep environment, but the effectiveness of existing solutions is limited by their inability to offer continuous, non-invasive monitoring and actionable insights for parents. [4]

Importance and Relevance: Traditional approaches to monitoring infants, such as wearable monitors and basic camera systems, often fall short due to their invasive nature and limited functionality. Current market solutions, including wearable devices like socks or clips, can cause discomfort and anxiety among parents. Additionally, standalone camera monitors lack comprehensive environmental monitoring and do not provide actionable insights for parents [5] [6].

BabyGuardian addresses these gaps by integrating multiple sensors, actuators, and AI to continuously monitor an infant's position, emotion, and environmental conditions. It ensures that infants sleep on their backs, the safest position to reduce SIDS risk, and maintain optimal room temperature and humidity. By offering non-invasive, real-time monitoring and automated interventions, smart bassinets promote safer sleep practices recommended by pediatric health authorities and thus mitigate the risk of SIDS.

Figure 2: BabyGuardian smart bassinet in a real-life setting, demonstrating its seamless integration into a modern living space and highlighting the aesthetic and functional aspects of the bassinet.

2 RELATED WORK

Computer Vision for Infant Facial Expression Recognition (FER) and Non-Contact Monitoring: FER plays a pivotal role in understanding and responding to an infant's emotional state.

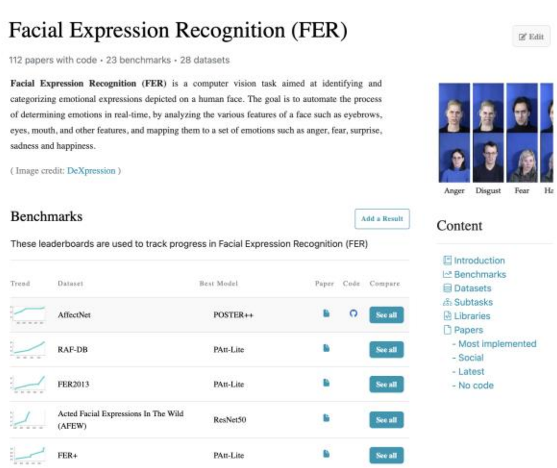

Figure 3: Current benchmarks in FER, such as AffectNet and RAF-DB, have demonstrated significant progress in emotion recognition, with models like POSTER++ and PAtt-Lite achieving state-of-the-art performance. [7]

Computer vision have enabled real-time emotion detection by analyzing various facial features such as eyebrows, eyes, and mouth, mapping these to a set of emotions like anger, fear, surprise, sadness, and happiness. Non-contact monitoring ensures continuous, unobtrusive surveillance of an infant's emotional well-being [8]. Systems utilizing Eulerian magnification techniques for motion detection can amplify subtle movements, aiding in the detection of abnormal breathing patterns associated with SIDS [9]. Such technologies not only enhance safety but also provide peace of mind for parents through reliable, non-invasive monitoring.

Infant Cry Reason Classification: Infant cry analysis is essential for identifying various needs and conditions of a baby. Studies have proposed systems using MFCC and machine learning algorithms like KNN to classify infant cries based on their acoustic features [10]. The ability to distinguish between different types of cries—indicative of hunger, discomfort, pain, or the need for sleep—enables timely and appropriate responses from caregivers. The donateacry-corpus on GitHub, for instance, offers a comprehensive dataset for training and validating cry classification models, demonstrating high accuracy in distinguishing cry types under various environmental conditions [11]. By integrating cry detection systems into smart bassinets, parents can receive precise alerts and insights into their infant's needs, reducing response time and improving care quality.

Use of Large Language Models to Provide Guidance for Parents: Large language models (LLMs), such as those developed by Google Gemini, hold substantial potential for providing personalized parenting guidance. These models can analyze extensive data sets and offer tailored insights and recommendations. For instance, in the domain of neonatal care, LLMs have shown good performance on medical licensing examination questions, indicating their potential to assist in clinical decision-making [12]. Integrating LLMs into smart bassinets like "BabyGuardian" can provide parents with real-time, evidence-based advice on infant care practices, interpreting cry patterns, and ensuring safe sleep environments. This capability aligns with research findings that emphasize the importance of accurate and accessible medical knowledge for improving neonatal care [12]. By leveraging the expertise embedded in LLMs, smart bassinets can evolve into comprehensive support systems, enhancing both the monitoring capabilities and the educational resources available to parents, ultimately contributing to the achievement of the UN SDGs related to child health and well-being.

Current Challenges: Despite the promising advancements in baby monitoring technology, several challenges remain. A significant issue is the accuracy and consistency of health information measurement. Most wearable devices lack FDA approval and are not substantiated by peer-reviewed research, raising concerns about their reliability [13]. False negatives can lead to critical conditions being overlooked, while false positives can cause unnecessary anxiety and overtreatment. Additionally, the integration of real-time data transfer and synchronization is crucial for accurate monitoring, yet current devices often struggle with delays and connectivity issues. Furthermore, the high cost of these devices limits their accessibility to financially constrained families [9]. Addressing these challenges through multidisciplinary research and development will be essential for the future success and adoption of wearable baby monitoring technologies, which is why we are focusing on the smart bassinet project rather than wearable devices for achieving our goal of enhanced infant care and lower risk factors for SIDS.

3 SYSTEM OVERVIEW

The BabyGuardian smart bassinet is designed with a focus on reduced SIDS risk factors, safety, comfort, and real-time responsiveness. The system is built to detect and analyze various emotional states, cry reasons and environmental conditions, enabling automatic adjustments and notifications to ensure the well-being of the infant.

3.1 Edge Nodes: Sensors and Actuators

The BabyGuardian system is equipped with a variety of sensors and actuators that form the core of its monitoring and response capabilities.

Key sensors include:

- **Raspberry Pi Camera Module:** Utilized for facial expression and emotion recognition, the camera module is integral for visual monitoring, ensuring the baby is always positioned correctly and safely.
- **USB Microphone:** This sensor captures audio signals, which are analyzed to detect and classify different types of cries, helping to identify the baby's needs, such as hunger, discomfort, or tiredness.
- **Temperature & Humidity Sensor (DHT20):** This sensor monitors the ambient conditions within the bassinet, ensuring they remain within safe and comfortable ranges.
- **Infrared Thermal Imager (AMG8833):** This sensor provides detailed thermal imaging to detect temperature changes, crucial for identifying potential issues such as overheating or cold stress.
- **Gas Concentration Sensor (MQ-7 flyfish):** Ensures the air quality around the baby is safe, detecting harmful gases and alerting parents if intervention is required.
- **Motion Sensor (HC-SR501):** Detects movements within the bassinet, aiding in the monitoring of the baby's activity and potential distress signals.

Key actuators in the system include:

- **12V Linear Actuator:** Used for gentle rocking motions to soothe the baby when necessary.
- **5V Humidifier:** Automatically activates to maintain optimal humidity levels, ensuring a comfortable environment.
- **USB Speaker:** Plays white noise or soothing music to help calm the baby.
- **5V LED Strip:** Provides gentle illumination for the room and parents, contributing to a soothing sleep environment.

3.2 System Architecture

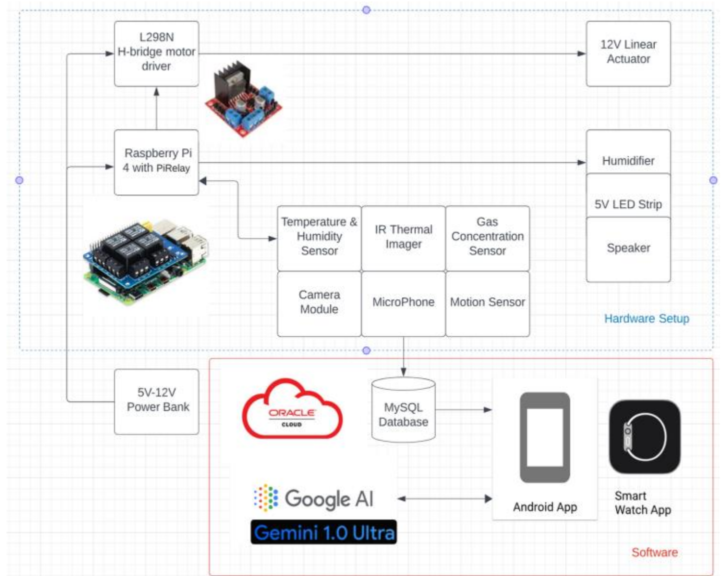

Figure 4: System Architecture Diagram for BabyGuardian

The BabyGuardian architecture consists of the following key components:

- **Edge Devices**: These include the sensors and actuators mentioned above, all connected to a central processing unit (Raspberry Pi 4 with a PiRelay and L298N Motor Driver). This unit processes the data locally to provide real-time responses.
- **Local Processing**: The Raspberry Pi 4 (2GB) acts as the primary processing hub, running lite versions of AI models for emotion and cry detection, and controlling the actuators based on the sensor inputs.
- **Cloud Infrastructure:** Data from the edge devices is also transmitted to Weicheng's personal cloud server (Oracle Cloud) for more complex processing and long-term storage. This setup allows for advanced analytics and integration with the Google Gemini AI, providing parents with insightful parenting advice.
- **Communication Protocols:** The system utilizes home Wi-Fi and use PHP protocol for data transmission between the edge devices and the cloud server. Secure communication protocols ensure data privacy and integrity.
- **Companion App:** Available on both mobile and smartwatch platforms, the companion app provides parents with real-time notifications and control over the bassinet.

4 INDIVIDUAL CONTRIBUTIONS

4.1 Ideation

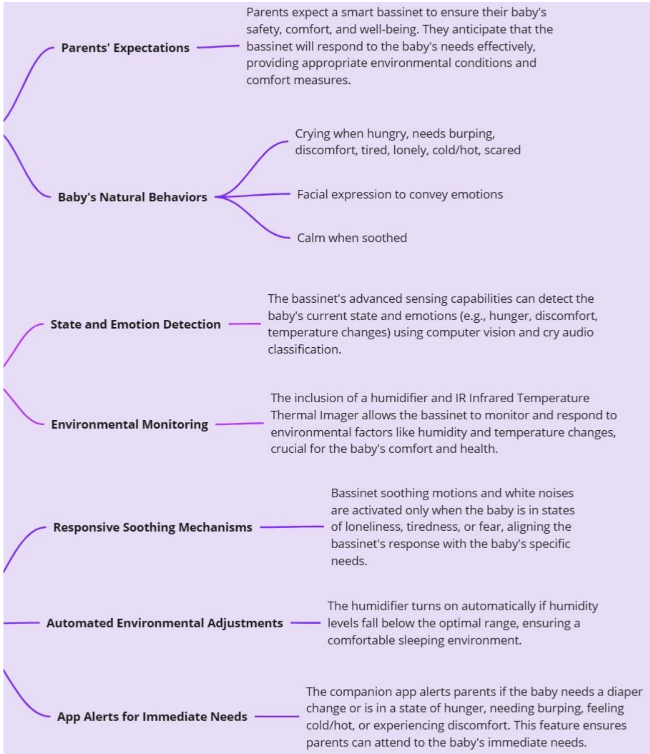

Figure 5: Part of the Expected, Sensed, and Desired Framework as guidance for designing the smart features of BabyGuardian

Responsibilities and Design Choices: During the initial phase of our project, my primary responsibility was to steer the ideation process towards a feasible and impactful IoT application. Recognizing the constraints of our small team, consisting of only five members, I advocated for targeting a niche yet proven category within the IoT market to maximize our chances of success. This strategic decision was based on a thorough analysis of past CES honorees over the last three years, which highlighted the rising trend and success of smart baby products. By focusing on a smart baby bassinet, we could innovate on existing concepts rather than venture into an overly competitive and broad market. I presented this idea to the team, emphasizing the potential to create a standout product with incremental innovations, which gained unanimous support from my peers.

Challenges and Solutions: One of the primary challenges encountered during the ideation phase was the underestimation of the difficulty in gathering a suitable dataset for infant facial recognition. Due to ethical constraints and the scarcity of open-source infant face databases, we faced significant hurdles in training our computer vision model. To address this, one team member dedicated substantial time to web scraping and manually labeling images to create a proprietary dataset. Additionally, the physical size of the bassinet posed logistical challenges, particularly since we couldn't rely on 3D printing for the entire structure. This necessitated careful planning and innovative design solutions to ensure the product was practical and within budget. To further refine our design ideas and enhance project management, I created the Expected, Sensed, and Desired framework flowchart (As illustrated in Figure 5) according to Benford's theory [14]. This tool proved invaluable in aligning our design with user expectations and system capabilities, thereby facilitating more efficient functionality design and problem-solving throughout the project.

Learning Outcomes: My involvement in the ideation phase of the BabyGuardian project provided several key learning outcomes. First, I learned the importance of aligning project goals with team capabilities and market opportunities. By focusing on a niche market, we leveraged existing trends while ensuring our project remained manageable. The data acquisition challenge underscored the need for thorough initial assessment of project requirements and potential hurdles. Moving forward, incorporating more robust planning and risk assessment strategies at the outset would significantly enhance project execution. Furthermore, the experience highlighted the importance of adaptability and resourcefulness in overcoming unforeseen challenges. Creating the Expected, Sensed, and Desired framework was particularly enlightening, as it underscored the value of systematic design thinking in addressing complex problems. This approach, as supported by literature on sensing-based interaction design, bridges the gap between analytical and inspirational design methodologies, ensuring a holistic and user-centered development process [14].

4.2 Methodology

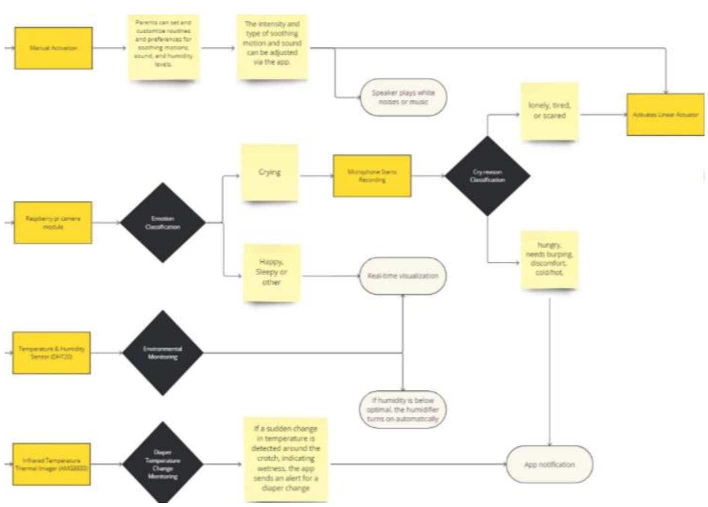

Figure 6: Part of the User Experience Flowchart version no.3 as guidance for implementing the smart features and operation logics for BabyGuardian

Devise the User Experience: I was responsible for to devise the user interaction and experience flow. The user experience with BabyGuardian begins with the initial setup, where parents connect the bassinet to the companion app via QR code and WIFI. Once the baby is placed in the bassinet, monitoring automatically starts using the Raspberry Pi camera module and various sensors.

A live stream of the baby will appear on the companion app for parents, images of the baby will be taken at regular intervals and fed to our computer vision model trained to classify the baby's facial expressions into four distinct emotional states: happy, sad, sleepy, and surprised. If the baby cries, the microphone records the sound, and AI models classify the cry reasons from seven categories, triggering appropriate responses such as activating the linear actuator for soothing motions or adjusting the humidifier.

Real-time environmental data visualizations and alerts are sent to both the Android app and Watch App, enabling parents to customize and control settings, ensuring their baby’s comfort and safety with ease. Parents can tap the Ask Gemini button to send the data along with any query to Google’s LLM API and get parenting advise from AI.

Challenges and Solutions: A significant challenge we faced was the lack of firsthand experience with parenting and understanding how parents typically interact with smart bassinets. This gap made it difficult to design a product that would be genuinely helpful and convenient for parents. To overcome this, I asked a team member to conduct thorough research on existing smart bassinet competitors, analyzing their features and identifying areas for improvement and innovation. Additionally, I consulted our supervisor, Ruiji, who provided valuable insights into essential smart features, such as diaper change alerts and cry reason classification. This combination of market research and expert advice helped us refine our design to better meet the needs of our target users.

Learning Outcomes: Firstly, I learned the importance of user-centered design and the need to thoroughly understand the user’s perspective to create effective solutions. The process of researching competitors and seeking expert advice highlighted the value of iterative improvement and innovation on existing products. Additionally, developing the user experience flowchart reinforced my skills in systematic design thinking and the ability to visualize complex interactions clearly. One area that could be improved in future projects is the initial phase of user research. Engaging directly with potential users, such as parents, through surveys or interviews could provide more nuanced insights and further enhance the relevance and usability of the final product. Overall, this experience underscored the importance of empathy, research, and continuous feedback in designing user-friendly IoT applications.

4.3 Component Procurement and Budgeting

Responsibilities and Design Choices: I was responsible for ordering all components, including sensors, actuators, motor drivers, and cables for prototyping and experimentation. I compiled four order lists for the technician "Bonot" to submit to the finance department, clearly stating the reasons for each component. I meticulously compared technical specifications from datasheets against our requirements and evaluated prices and delivery times across retailers like Alibaba, Amazon, and RS Components.

Challenges and Solutions: A significant challenge was balancing cost and delivery time. Chinese manufacturers offered lower prices but longer shipping times of around three weeks, while Amazon provided faster delivery within a week but at significantly higher costs, often three to five times more expensive. I had to carefully weigh these trade-offs while keeping the overall budget under £400.

Learning Outcomes: This experience taught me the importance of thorough research and careful consideration of component specifications to ensure they meet project requirements. Additionally, I gained valuable insights into supply chain management, learning to balance cost, delivery times, and overall project timelines. Negotiating these trade-offs effectively was crucial in optimizing resource allocation while adhering to budgetary constraints. Moving forward, I will apply these lessons in future projects, emphasizing meticulous planning and strategic decision-making during the procurement process.

4.4 Hardware Design and Implementation

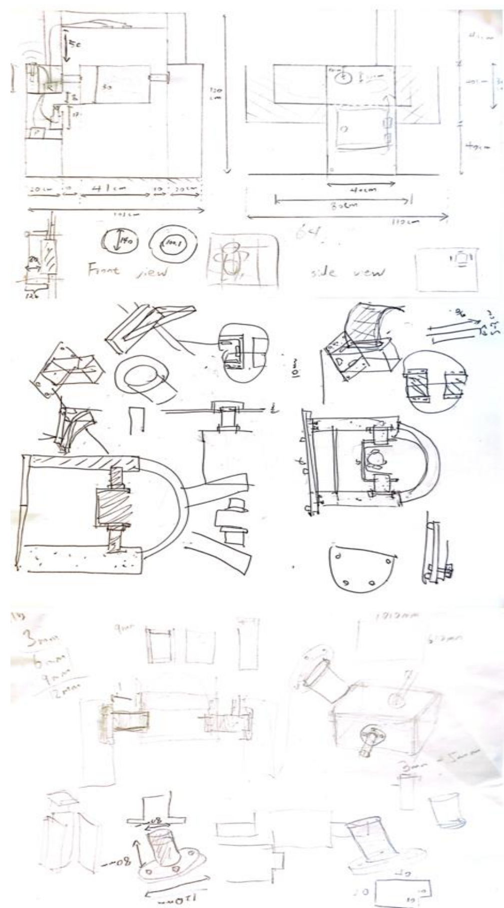

Figure 7: Structural Design for the BabyGuardian Smart bassinet outer case, inner bassinet and the two 3D printed shafts with 10mm bearings to hold them together.

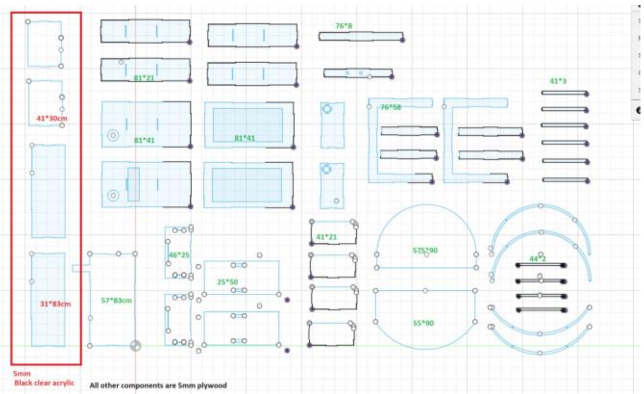

Figure 8: The 2D designs for laser-cutting.

Responsibilities and Design Choices: My responsibilities included creating a detailed 3D model of the smart baby bassinet in Fusion360, ensuring accurate dimensions and integrating holders for actuators, sensors, and cable routing holes. I chose to power the entire bassinet using a 12V portable power bank and animated the 3D model to demonstrate the bassinet's mechanics, which was utilized in our pitch slides. Additionally, I generated the 2D DXF shapes for laser cutting all the plywood components to their precise specifications. I designed and created most of the pitch slides, excluding the software portion for the final presentation. Meticulously calculating the weight capacity and stress tolerance of the 6mm plywood bassinet structure, I ensured it could withstand a load of 10kg while optimizing material usage.

Challenges and Solutions: One significant challenge was addressing the workshop manager Danny's concerns regarding structural safety and material usage. He was particularly cautious about both the bassinet's stability and minimizing plywood sheet consumption due to limited stock. To overcome this, I made concerted efforts to reduce plywood usage while maintaining structural robustness through careful design iterations. Another difficulty arose from the varying voltage requirements of different components, with some operating at 5V and others at 12V. To accommodate this, we incorporated a PiRelay and an L298N Motor Driver, allowing us to manage the voltage supply effectively. However, we encountered an issue where a temperature sensor was damaged due to an incorrect voltage supply, highlighting the importance of diligent voltage management.

Learning Outcomes: Creating a comprehensive 3D model and meticulously calculating load capacities were crucial in ensuring the bassinet's structural integrity and functionality. Additionally, I gained valuable insights into material selection and optimization, balancing cost, availability, and performance requirements. The voltage supply challenge underscored the need for meticulous component integration and voltage management, a lesson that will be invaluable in future hardware projects. Overall, this experience highlighted the significance of iterative design, problem-solving, and diligent execution in successful hardware implementation.

4.5 Hardware Testing

Sensor	Model	Use	Operating Current	Vcc Range
Infra Red Thermometer	MLX90614ESF-BAA MLX90614ESF-BCC MLX90614ESF-DCI	measure temperature without contact	2mA	3.3 – 6V
motion sensor	HC-SR501	parents presence detection	?	5-20V
Humidity and Temperature Module	DHT20	environmental monitoring	1mA	2.2 to 5.5V

FoV	Typical Effective Distance	Range	Resolution	Lib dependencies
About 100°	1cm	-40°C...85°C	0.02°C	adafruit/Adafruit MLX90614 Library@^2.1.5 adafruit/Adafruit BusIO@^1.15.0 SPI
35°	30cm			
5°	70cm			
110°	3-7m	/	/	arduino-libraries/Arduino_Sensorkit@^1.4.0
/	/	temperature range 10°C - 50°C; humidity 20-60%RH	0.01 °C and 0.024 %RH	

Figure 9: Testing the sensors for smart features after receiving the procurement order.

Responsibilities and Design Choices: My responsibilities included testing the procured sensors for the smart features and prototyping the bassinet structure using cardboard to validate the swing motion mechanism. Upon receiving the components, I conducted thorough testing of the sensors to ensure their functionality and integration with the system. Additionally, I constructed a cardboard prototype to assess the feasibility of the two-shaft and linear actuator design for the swing motion feature. This process allowed me to identify potential issues and optimize the design while minimizing material usage without compromising structural stability.

Challenges and Solutions: One challenge faced during hardware testing was the limited availability of certain components due to supply chain constraints. In such cases, I had to improvise by using alternative components or simulating their functionality through software emulation. This approach ensured that the testing process could continue uninterrupted while we awaited the delivery of the required components. Another difficulty arose when one of the sensors exhibited inconsistent behavior, which was eventually traced back to a faulty connection. Systematically checking each component and connection helped resolve the issue.

Learning Outcomes: The hardware testing phase reinforced the importance of thorough and methodical testing to identify and address potential issues early in the development process. It also highlighted the value of creative problem-solving and adaptability when faced with component availability challenges. Additionally, the cardboard prototyping experience demonstrated the benefits of iterative physical prototyping, allowing for hands-on evaluation and refinement of the design before committing to final materials and construction. Overall, this subsection underscored the significance of rigorous testing, troubleshooting skills, and the ability to adapt to changing circumstances in successful hardware development projects.

Figure 10: Prototyping the inner bassinet to test the two shafts and the linear actuator for the swing motion feature.

5 EVALUATION

We evaluated the performance of our facial expression and cry classification models using an unseen test set, ensuring their accuracy before integration. However, conducting a comprehensive evaluation of the complete BabyGuardian product was challenging due to time constraints and ethical considerations around testing with infants. While we adhered to stringent safety regulations and certifications, a thorough real-world evaluation involving actual use by parents and babies is crucial for validating the product's efficacy and identifying potential areas for improvement. Moving forward, we plan to collaborate with relevant institutions and experts to facilitate safe and ethical product testing with users, further refining BabyGuardian to provide the highest standards of safety and performance.

6 LIMITATIONS AND FUTURE WORK

The BabyGuardian smart bassinet is a good solution to promote safer sleep and reduce SIDS risk, but there are some limitations to address. Firstly, using computer vision and audio analysis for monitoring can be affected by things like lighting conditions or background noise. Exploring other or additional sensing technologies could make it more robust. Secondly, this project focused only on the bassinet itself, but integrating with other smart home devices and platforms could create a more seamless overall experience. Doing long-term studies with more users would also provide valuable insights to improve the product and validate its real-world effectiveness. Finally, as AI and IoT technologies keep advancing quickly, continuous research and development will be needed to incorporate the latest improvements and keep performance cutting-edge.

7 SELF-REFLECTIONS AND CONCLUSION

Through my different roles in this project, I learned a lot about user-centered design, strategic planning, managing the supply chain, and carefully implementing hardware. Aligning the project goals with market opportunities and what our team could do was crucial. Overcoming challenges like limited data and component constraints showed me the importance of being adaptable and resourceful. Developing tools like the Expected, Sensed, and Desired framework reinforced how valuable systematic design thinking is. Rigorous prototyping and testing underlined the significance of iterative refinement and troubleshooting skills. Overall, this experience gave me a deeper appreciation for multidisciplinary collaboration in tackling complex, human-centric problems like preventing SIDS.

The success of BabyGuardian has inspired me to keep exploring impactful applications of new technologies while prioritizing responsible development and meeting regulations. As I reflect on this project, I am motivated to continue finding innovative ways that emerging technologies can address global issues and improve lives. One major challenge I faced was gathering enough data to train the computer vision model for facial recognition due to ethical constraints around using infant images.

Final Prototype

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