EXPLORATORY STUDY ON EMOTION RECOGNITION AND ASSISTIVE COMMUNICATION FOR NON-VERBAL AND IMMOBILE CEREBRAL PALSY PATIENTS CASE STUDY : MUKISA FOUNDATION KAMPALA

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UGANDA CHRISTIAN UNIVERSITY
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Declaration

We hereby declare that this project report is original and our own work, it has not been presented anywhere else for any academic award or qualification. All external sources and references materials are properly cited at academic integrity levels.

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Dedication

This work is dedicated to all children living with Cerebral Palsy, whose strength, resilience, and unique ways of communicating continue to inspire the development of compassionate and meaningful innovations in care. Your lives are a powerful reminder of the importance of creating systems that listen, respond, and support you with dignity and understanding.

A very special dedication goes to Aloyo Praise, a brave child living with Cerebral Palsy, whose courage and spirit have been a profound source of inspiration throughout this project. This work stands as a small contribution toward improving the care and attention that children like you truly deserve.

Acknowledgment

We would like to express our sincere gratitude to everyone who contributed to the successful completion of this project.
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We are deeply thankful to our supervisors and lecturers for their guidance, constructive feedback, and continuous encouragement throughout the research process. Their expertise and support greatly enriched the quality of this work.
Special thanks go to the children living with Cerebral Palsy who, through their strength and resilience, inspired this project. In particular, we extend our sincere appreciation to Aloyo Praise, whose courage and lived experience gave this work a deeper purpose and meaning.
Finally, we are grateful to our families and friends for their unwavering support, patience, and encouragement during the course of this project.
Their belief in us made this achievement possible.

Abstract

This report presents the design, simulation, and evaluation of an affordable, sensor-driven assistive system intended to support the care of non-verbal, immobile children with Cerebral Palsy (CP) in Uganda. The system integrates low-cost heart rate, sound, and motion sensors with an Arduino microcontroller to monitor physiological and environmental signals and provide timely alerts to caregivers. The study also examines existing caregiver practices and challenges to inform system design.

Both a simulated model and a physical prototype were developed and assessed for feasibility, usability, and potential impact in institutional care settings. Ethical considerations were incorporated throughout the study, alongside a defined project timeline, budget, and expected outcomes. The implementation and evaluation were conducted at Mukisa Foundation in Kampala, providing practical insights into the system's effectiveness in real-world caregiving environments.

TABLE OF CONTENTS.

LIST OF FIGURES

LIST OF TABLES

Chapter 1:Introduction

1.1 Background

Cerebral Palsy (CP) is a group of permanent neurological disorders that affect movement, posture, and muscle coordination. These disorders arise from nonprogressive disturbances that occur in the developing fetal or infant brain, typically before, during, or shortly after birth. Although the brain injury responsible for cerebral palsy does not worsen over time, the physical and functional limitations associated with the condition often persist throughout an individual's life. The effects of CP vary widely depending on the severity and location of the brain injury, but common challenges include impaired motor control, abnormal muscle tone, difficulties with balance and coordination, and in many cases, limitations in speech and communication abilities.

Children with severe forms of cerebral palsy may experience significant mobility restrictions and may be unable to walk, sit independently, or control voluntary body movements. In addition, some children may also experience cognitive impairments, seizures, and sensory difficulties that further complicate their ability to interact with their environment. Among the most vulnerable group are children who are classified as non-verbal and immobile, meaning they are unable to communicate through speech and may also lack the motor control required to use gestures or other forms of physical expression. For these individuals, everyday activities such as expressing hunger, discomfort, emotional distress, or pain become extremely difficult, if not impossible, without external assistance.

According to the World Health Organization (WHO, 2021), approximately 17 million people worldwide live with cerebral palsy. The prevalence of the condition is particularly high in low- and middle-income countries where factors such as limited access to quality prenatal care, perinatal complications, infections, and inadequate neonatal healthcare services increase the risk of brain injury during early development. In many of these regions, healthcare systems may lack specialized resources for early diagnosis, rehabilitation, and long-term support for individuals living with CP. As a result, families and caregivers often face significant challenges in managing the complex needs of affected children. In Uganda, cerebral palsy remains one of the most common childhood physical disabilities. Despite growing awareness of disability rights and inclusive healthcare practices, individuals with CP continue to experience numerous barriers related to healthcare access, rehabilitation services, and assistive technology availability. Many families caring for children with CP depend heavily on caregivers, rehabilitation centers, and community-based support organizations to provide basic care and therapy. However, limited resources and insufficient technological support often make it difficult for caregivers to adequately monitor and respond to the needs of children with severe CP, especially those who cannot communicate verbally.

One of the most significant challenges faced by caregivers of non-verbal and immobile CP patients is the difficulty of understanding the child's emotional state or physical needs. Unlike individuals who can communicate through speech or intentional gestures, these children rely entirely on indirect signals to express discomfort or distress. Caregivers must interpret subtle cues such as facial expressions, body stiffness, changes in breathing patterns, unusual vocal sounds, or shifts in posture.

As a result, caregivers may unintentionally misinterpret or overlook important signals that indicate a child's needs. Situations such as hunger, pain, discomfort from prolonged positioning, emotional anxiety, or the need for medical attention may go unnoticed for extended periods. These delays can have serious consequences for the health and well-being of the child. For example, delayed feeding may lead to nutritional issues, while delayed diaper changes can increase the risk of infections or skin complications. Similarly, emotional distress that remains unrecognized may cause prolonged discomfort and negatively affect the psychological well-being of the child.

In recent years, technological advancements have created new opportunities for developing assistive systems that support individuals with disabilities. Various emotion recognition technologies have been developed using artificial intelligence, computer vision, and speech analysis to interpret human emotions based on facial expressions, vocal tone, or body language. Examples of such technologies include systems developed by institutions such as Massachusetts Institute of Technology, including projects like EmoReact (2022), as well as applications such as Seeing AI developed by Microsoft. These tools demonstrate the potential of technology to assist individuals by recognizing emotional cues and providing feedback through digital systems.

However, despite the promising capabilities of these technologies, most existing emotion-recognition tools are primarily designed for neurotypical individuals who can express emotions through standard facial expressions, speech patterns, or predictable body movements. Such systems typically rely on clear facial recognition, voice analysis, or intentional user interaction to interpret emotional states. Unfortunately, these requirements limit their applicability for children with severe cerebral palsy. Furthermore, many advanced assistive technologies are expensive and require sophisticated hardware or stable internet connectivity, making them difficult to implement in resource-constrained environments. In countries like Uganda, healthcare institutions and caregiving centers often lack the financial resources necessary to acquire and maintain such technologies. Given these challenges, there is a growing need for affordable and context-appropriate assistive technologies that are specifically designed to support the needs of individuals with severe cerebral palsy. Instead of relying solely on facial recognition or speechbased interaction, alternative approaches can focus on monitoring physiological and environmental signals that may reflect emotional or physical changes. For instance, variations in heart rate may indicate stress or discomfort, while unusual vocal sounds or sudden motion patterns may suggest distress or agitation. By integrating these signals through simple sensor technologies, it may be possible to create a monitoring system capable of detecting emotional changes and alerting caregivers when attention is required. Developing such a system could significantly improve the quality of care provided to non-verbal and immobile CP patients. By supporting caregivers with real-time information about potential emotional or physical changes, assistive technologies can reduce the likelihood of misinterpretation and enable faster responses to the needs of vulnerable patients. In addition, low-cost sensor-based solutions could be implemented more easily in rehabilitation centers and caregiving environments within developing countries, thereby improving accessibility and sustainability.Therefore, this study focuses on exploring the feasibility of using simple physiological and environmental sensors to detect emotional states and caregiving needs in children with severe cerebral palsy. By examining signals such as heart rate, sound, and motion, the research seeks to contribute toward the development of practical, affordable assistive technologies that can support caregivers and enhance the well-being of non-verbal CP patients.

1.2 Problem Statement

Children living with severe Cerebral Palsy (CP) face significant physical, cognitive, and communication challenges that greatly affect their ability to interact with others and express their basic needs. Cerebral palsy is a neurological condition caused by damage to the developing brain, often occurring before, during, or shortly after birth. This condition primarily affects muscle control, posture, and movement, but in severe cases it can also affect speech, emotional expression, and the ability to communicate. Among the most vulnerable group are children with severe Celebral Palsy who are both non-verbal and immobile, and this meaning they cannot speak, gesture effectively, or move independently to express discomfort or emotional distress. As a result, their ability to communicate fundamental needs such as hunger, pain, fear, fatigue, or emotional discomfort becomes extremely limited for caregivers and health professionals, understanding the needs of these children is often difficult and uncertain. Since the children cannot communicate verbally, caregivers must depend on indirect and often unreliable cues such as changes in breathing patterns, body stiffness, unusual sounds, facial expressions, or subtle movements. However, these cues are frequently inconsistent or absent because neuromuscular impairments limit the child's ability to produce clear or predictable signals. In many cases, caregivers are forced to rely on guesswork, observation, and personal experience to interpret the emotional state of the child.

The consequences of this communication barrier can be significant. When caregivers fail to accurately interpret the emotional or physical state of a nonverbal Celebral Palsy patient, the child may remain in distress. Situations such as prolonged hunger, delayed diaper changes, unmanaged pain, or emotional anxiety may occur because caregivers are not immediately aware of the child's condition. Over time, repeated delays in responding to these needs can negatively affect the child's overall health, emotional well-being, and quality of life. In addition, caregivers themselves experience increased stress and emotional burden due to the constant uncertainty about whether they are correctly interpreting the child's needs.

This challenge is particularly evident in resource-limited healthcare environments such as those found in many parts of Uganda. Specialized assistive technologies that support communication for individuals with disabilities are often expensive and therefore inaccessible to many families and care institutions. Rehabilitation centers and non-governmental organizations working with children with disabilities frequently operate with limited resources and rely heavily on manual observation and caregiver intuition. One example is Mukisa Foundation, an organization that supports children with cerebral palsy and other disabilities. Reports from caregivers and staff in such institutions indicate that non-verbal CP patients often fail to communicate urgent needs effectively. This can lead to preventable situations such as delayed feeding, prolonged discomfort, missed medical attention, or unmanaged emotional distress. These challenges highlight the urgent need for supportive technologies that can help caregivers better understand the condition of the children under their care.

Despite the global advancement in assistive technologies, most existing communication devices are not suitable for children with severe cerebral palsy. Many of these technologies rely on the user's ability to perform deliberate actions such as pressing buttons, controlling eye movement interfaces, or speaking into voice-recognition systems. Unfortunately, children with severe CP often lack the motor control required to operate such systems. Furthermore, many commercial assistive devices are designed for use in high-resource settings and are sold at prices that are unaffordable for institutions and families in developing countries. The lack of locally developed and affordable solutions means that many caregivers continue to rely on traditional observation methods, which are often unreliable and time-consuming.

Another important challenge is the absence of real-time monitoring systems that can help detect changes in a child's emotional or physiological state. Emotional distress in children with CP may manifest through subtle physiological signals such as increased heart rate, irregular breathing, or sudden environmental reactions such as unusual vocal sounds or movement patterns. However, without technological assistance, it is extremely difficult for caregivers to monitor these signals continuously, especially when they are responsible for caring for multiple children at the same time. As a result, important warning signs of discomfort, pain, or emotional stress may go unnoticed until the situation becomes severe.

Given these challenges, there is a growing need to explore innovative, lowcost technological approaches that can assist caregivers in monitoring and interpreting emotional signals from non-verbal CP patients. Advances in sensor technology and simple machine learning systems provide opportunities to develop tools that can detect patterns in physiological and environmental signals. For example, wearable sensors can measure heart rate, while microphones and motion sensors can capture sound patterns and movement activity in the child's environment. When combined, these signals may provide valuable indicators of changes in emotional state, such as stress, discomfort, or calmness. Therefore, the absence of affordable, automated emotion-recognition support tools remains a major gap in the care of non-verbal children with severe cerebral palsy.

1.3 Purpose of the Study

The purpose of this study was to explore, design, and simulate a low-cost assistive system capable of detecting emotional states and caregiving needs among non-verbal and immobile children living with severe Cerebral Palsy (CP) through the use of physiological and environmental sensor inputs. The study aimed to address the persistent communication gap that exists between such patients and their caregivers by investigating how measurable signals such as heart rate, vocal sounds, and physical motion could be captured, analyzed, and interpreted to provide meaningful indications of emotional states or caregiving needs. By examining these signals, the research sought to determine whether a simple technology-based system could assist caregivers in recognizing distress, discomfort, or other emotional changes in real time and enable more responsive caregiving.

The study therefore focused on exploring the potential of physiological and environmental signals as indicators of emotional and caregiving needs. Physiological signals, particularly heart rate patterns, were considered important indicators because changes in heart rate can often reflect variations in emotional states such as stress, excitement, discomfort, or calmness. Similarly, environmental signals such as vocal sounds and motion were examined as additional cues that may reflect the child's condition. For example, unusual vocalizations, sudden movements, or changes in activity levels may indicate distress or discomfort even when the child is unable to communicate verbally. By combining these signals, the study sought to evaluate whether a more reliable and objective method of recognizing emotional states could be developed.

Another key purpose of the study was to design a conceptual assistive system that integrates these signals into a simple monitoring framework capable of generating alerts for caregivers. The system was intended to demonstrate how sensor data could be collected and processed to identify patterns associated with specific emotional states or caregiving needs. Rather than relying solely on human observation, the system aimed to provide automated notifications that could help caregivers recognize potential issues more quickly. Such alerts could inform caregivers when a child might be experiencing discomfort, distress, or other emotional changes that require attention.

The study also aimed to emphasize the importance of affordability and accessibility in the development of assistive technologies. Many existing assistive devices designed to support individuals with communication difficulties are expensive and therefore inaccessible to families and care institutions in lowresource settings. In countries such as Uganda, rehabilitation centers and organizations that support children with disabilities often operate with limited financial resources and may not have access to advanced medical technologies. As a result, the research sought to demonstrate the feasibility of developing a system that relies on simple and relatively inexpensive sensors while still providing meaningful support for caregivers.

In addition to designing the conceptual framework, the study also aimed to simulate the proposed system in order to evaluate its potential effectiveness. Simulation allowed the researcher to test how sensor inputs might be processed and how the system could respond to different signal patterns that represent emotional states. Through simulation, the study examined how combinations of physiological and environmental signals could trigger specific alerts, such as notifications indicating possible distress, discomfort, or calm states. This process helped to demonstrate the practicality of integrating sensor-based monitoring into caregiving environments.

The study also aimed to provide insights that could guide future research and development in assistive technologies for individuals with severe neurological conditions. By demonstrating how simple physiological and environmental signals could be integrated into a monitoring system, the research hoped to encourage further exploration of affordable technological solutions that can be implemented in real caregiving environments. Such innovations may ultimately contribute to improved healthcare support for vulnerable populations who currently lack adequate communication tools.

1.4 Objectives

1.4.1 General objective

The objective of this study was to develop and simulate a low-cost, Arduinobased assistive emotion-detection and caregiving-support system for non-verbal and immobile patients living with severe Cerebral Palsy (CP) using physiological and environmental sensor inputs. The study was designed to investigate how simple and affordable technological components could be used to support caregivers in identifying emotional changes and caregiving needs among patients who are unable to communicate verbally or through physical gestures. Because many individuals with severe CP experience significant neuromuscular impairments that limit their ability to express discomfort, hunger, pain, or emotional distress, the research sought to explore technological methods that could help bridge the communication gap between patients and caregivers. Specifically, the study aimed to design a system that integrates multiple sensor inputs, including heart rate, sound, and motion detection, in order to monitor signals that may indicate changes in emotional or physical states. Heart rate data was considered an important physiological indicator because variations in heart rate can reflect stress, discomfort, or excitement. In addition, environmental signals such as vocal sounds and motion patterns were examined as potential cues that might suggest distress or activity changes in patients who cannot communicate their needs directly. By combining these inputs, the system was intended to detect patterns associated with emotional states and trigger alerts that could assist caregivers in responding more quickly to the needs of the patient.

The system was developed using an Arduino microcontroller platform due to its affordability, accessibility, and suitability for prototyping sensor-based applications. Through simulation and conceptual system design, the study evaluated how sensor signals could be processed and interpreted to support caregiving decisions. The objective was therefore not only to demonstrate the technical feasibility of the proposed system but also to highlight the potential of low-cost assistive technologies in improving caregiving support for vulnerable populations, particularly in resource-limited settings such as Uganda.

1.4.2 Specific objectives

a) 1. To collect and analyze sound and heart rate data to determine emotional patterns in non-verbal CP patients. The process involved examining variations in vocal sounds and fluctuations in heart rate to determine possible correlations between physiological responses and emotional states. Through systematic observation and analysis, the research identified behavioral and physiological indicators that could help infer emotions such as calmness, distress, discomfort, or happiness in patients who are unable to communicate verbally.

b) 2. To design and simulate the device using Arduino and sensors in TinkerCAD. The project designed and successfully simulated a prototype assistive device using the Arduino platform together with multiple sensors within the TinkerCAD simulation environment. The design process involved selecting appropriate sensors, configuring circuit connections, and programming the Arduino microcontroller to receive and process sensor inputs. Through iterative testing and simulation, the system architecture was refined to ensure that the device could effectively monitor physiological and environmental signals relevant to patient care while maintaining reliability and functional accuracy within the simulated environment.

c) 3. To develop and integrate sensor logic and classification rules that classify emotional states, for example, calm, neutral, and happy. The study developed and integrated logical rules and classification mechanisms within the device's programming framework to interpret sensor data and categorize the emotional state of the patient. By establishing threshold values and conditional decisionmaking rules based on sound intensity and heart rate patterns, the system was able to automatically classify emotional states such as calm, distressed, or happy.

d) 4. To implement a real-time notification system for caregivers for the feeding and diaper intervals. The device implemented a real-time notification and alert system designed to assist caregivers in monitoring essential caregiving activities such as feeding schedules and diaper-changing intervals. The system was programmed to generate timely reminders and alerts based on predefined time intervals and sensor inputs.

e) 5. To evaluate the device's accuracy and caregiver usability. The project evaluated the performance, accuracy, and usability of the developed device by assessing how effectively it interpreted sensor data and generated appropriate emotional classifications and caregiver notifications. The evaluation involved testing the system under different simulated scenarios to measure the reliability of the classification logic and the responsiveness of the notification system.

1.5 Research Questions

RQ1. How did caregivers identify emotional or physical needs in non-verbal CP patients?

RQ2. What were the main challenges caregivers encountered while tracking feeding times, diaper changes and distress signals?

RQ3. Could heart rate, sound, and motion signals be used to reliably estimate emotional changes in CP patients?

RQ4. What system design and alert thresholds were suitable for institutional adoption?

RQ5. How acceptable was a sensor-based assistive system to caregivers and institutional managers?

1.6 Justification and Significance

The significance of this study lay in its effort to explore a technological solution that could support caregivers in recognizing emotional and physical changes among non-verbal CP patients. By proposing a sensor-based assistive system capable of detecting signals such as heart rate variations, unusual sounds, and motion patterns, the study sought to provide an additional layer of support for caregiving practices. The integration of these signals into a monitoring system could allow caregivers to receive timely alerts whenever a patient might be experiencing distress or when routine caregiving actions may be required. Such a system could help reduce avoidable delays in responding to patient needs and improve the overall quality of care provided in caregiving environments.

Another important contribution of the study was its potential to reduce the cognitive burden placed on caregivers. Caring for children with severe cerebral palsy often requires constant attention and continuous monitoring, which can be physically and emotionally demanding. By providing automated alerts and objective monitoring of physiological and environmental signals, the proposed system could assist caregivers in making more informed decisions and reduce the uncertainty associated with interpreting ambiguous behavioral cues. In addition, the system could generate objective records or logs of caregiving activities and detected events, which may be useful for institutional monitoring, evaluation, and quality assurance processes.

The study was also significant because it focused on the development of a lowcost technological approach that could be implemented in resourceconstrained environments. In many parts of Uganda and other regions in East Africa, healthcare institutions and rehabilitation centers operate with limited financial resources and may not have access to expensive assistive technologies. By emphasizing affordability and accessibility through the use of simple sensor components and microcontrollerbased systems, the research highlighted the potential for locally adaptable solutions that can improve caregiving practices without requiring costly infrastructure.

1.7. Scope

1.7.1 Geographical scope

The study was conducted at Mukisa Foundation, a well-known rehabilitation and support center located in Kampala, Uganda. The foundation is widely recognized for its commitment to improving the lives of children living with various disabilities, particularly those affected by Cerebral Palsy (CP).

Mukisa Foundation serves children exhibiting different forms and levels of cerebral palsy, ranging from mild motor impairments to severe cases that involve both mobility and communication limitations. Among the children receiving care at the center are those classified as non-verbal and immobile. These children rely almost entirely on caregivers and medical staff for assistance with everyday activities such as feeding, hygiene, positioning, and emotional support. As a result, the caregiving environment within the foundation presents a unique opportunity to study the challenges associated with interpreting the needs and emotional states of children who cannot communicate directly.

The foundation operates as both a rehabilitation facility and a supportive learning environment where caregivers, therapists, and healthcare professionals work together to improve the physical and emotional well-being of children with disabilities.Because of its specialized focus on children with cerebral palsy and its experience working with severe non-verbal cases, Mukisa Foundation provided an appropriate and relevant setting for this study. The institution gave us insight on the caregiving practices in order to better understand the daily challenges caregivers face when attempting to identify emotional distress or physical needs among non-verbal CP patients.

1.7.2 Content scope

The scope of the study was limited to exploring the concept and feasibility of this sensor-based assistive system rather than developing a fully deployed medical device. As such, the research concentrated on prototype development, system simulation, and conceptual evaluation of how such a system could function within a caregiving environment. The study did not attempt to replace professional medical judgment or provide clinical diagnosis of patient conditions. Instead, the proposed system was intended to serve as a supportive tool that could assist caregivers in recognizing potential emotional or physical changes more quickly.

Furthermore, the study did not include advanced predictive analytics or complex artificial intelligence techniques for emotion classification. Instead, the study prioritized a rule-based alert system based on predefined sensor thresholds that could indicate potential distress or caregiving needs.

By clearly defining boundaries, the study ensured that its objectives remained focused on practical caregiving support rather than broader medical or technological applications. The scope was therefore limited to non-verbal and immobile CP patients, the use of heart rate, sound, and motion signals for emotion recognition, and the simulation of a low-cost prototype system capable of supporting routine caregiving activities. This focused approach allowed the research to address a specific and practical challenge while laying the groundwork for potential future studies that could expand the system with more advanced technologies or clinical applications.

1.7.3 Time scope

The study was carried out between October 2025 and December 2025 and involved several key research activities. During this period, We conducted a comprehensive literature review to understand existing studies related to Cerebral Palsy, emotion recognition technologies, and assistive caregiving systems. Field visits were also undertaken to Mukisa Foundation in Kampala, Uganda, where observations and discussions with caregivers helped provide practical insights into the daily challenges faced when caring for non-verbal and immobile Celebral Palsy patients.

1.8 Definitions of Key Terms

Emotion recognition The process of identifying and interpreting a person’s emotional or affective state such as distress, calmness, or happiness by analyzing measurable physiological, behavioral, or environmental signals, including heart rate, facial expressions, sound patterns, or body movements.

Non-verbal CP patient A person living with Cerebral Palsy who is unable to effectively use spoken language as a means of communication, and therefore relies on alternative methods such as gestures, assistive devices, or physiological cues to express needs, feelings, and responses.

PPG Photoplethysmography, A non-invasive optical sensing technique used to measure changes in blood volume within the microvascular tissue. It is commonly applied in monitoring heart rate and other cardiovascular parameters by detecting variations in light absorption through the skin.

Assistive technology A broad range of devices, systems, or equipment designed to enhance, maintain, or improve the functional capabilities and independence of individuals with disabilities, enabling them to perform tasks that might otherwise be difficult or impossible.

2. Chapter 2: Literature Review and Theoretical Framework

2.1 Theoretical and Conceptual Framework

This study was grounded in the principles of Affective Computing theory and Human–Computer Interaction (HCI), which together provided a strong foundation for understanding how technology could interpret and respond to human emotions in a meaningful way. Affective Computing focused on the ability of systems to detect, interpret, and simulate human emotions using measurable signals such as physiological responses and behavioral cues. In the context of this study, it supported the idea that indicators like heart rate, sound patterns, and body movement could be analyzed to infer the emotional states of non-verbal and immobile Cerebral Palsy patients. Complementing this, Human–Computer Interaction emphasized the design of systems that were intuitive, user-friendly, and responsive to the needs of end users in this case, caregivers. It ensured that the outputs generated by the system were not only accurate but also delivered in a clear, timely, and actionable manner that supported caregiving tasks.

Conceptual Model (variables):

- Inputs: Heart rate, sound level/patterns, motion (PIR).
- Processing: Signal filtering, thresholding, simple heuristics / rule-based inference.
- Outputs: Visual/audible alerts, SMS (optional), logs.

Outcomes: Reduced missed care events, improved caregiver response time, improved patient comfort.

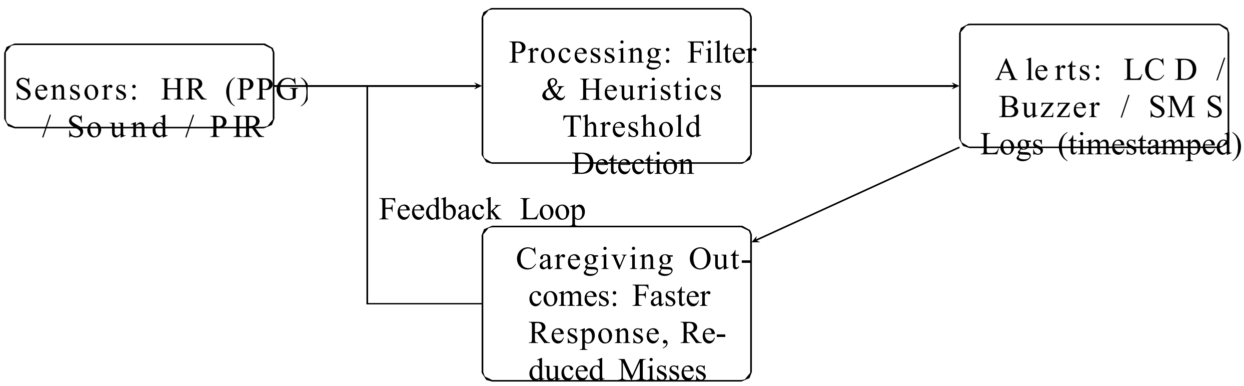

Figure 1: Conceptual framework: signal flow from sensors to outcomes.

3. Chapter 3: Methodology

3.1 Study Design

This study employed a mixed-methods exploratory research design, integrating both qualitative and quantitative techniques to obtain a comprehensive understanding of the caregiving environment, emotional communication challenges, and the feasibility of using sensor-based technology to support non-verbal and immobile children with Cerebral Palsy (CP). The choice of a mixed-methods approach was considered appropriate because it allowed the study to capture both numerical data and indepth experiential insights, thereby providing a more holistic view of the problem. While quantitative methods facilitated the measurement and analysis of physiological signals such as heart rate, sound, and motion, qualitative methods enabled the exploration of caregiver experiences, perceptions, and challenges encountered in daily caregiving activities.The study design consisted of theese three major components:

3.1.1 Qualitative Component

The qualitative component was designed to explore and richly describe the subjective experiences, perceptions, and challenges faced by caregivers of non-verbal and immobile children with Cerebral Palsy (CP). Given that caregiving in such contexts required continuous emotional attunement, contextual decision-making, and the application of tacit knowledge developed through experience, qualitative methods were considered essential for capturing nuanced aspects of care that quantitative approaches could not adequately address. This component provided deep insights into how caregivers interpreted patient behaviors, responded to emotional cues, and navigated the complexities of daily caregiving routines in resource-constrained environments.

To achieve these objectives, multiple qualitative data collection methods were employed, including in-depth interviews, non-participant observation, and field notes. These methods allowed for data triangulation, thereby enhancing the credibility and richness of the findings.

a) **In-depth Interviews:** Semi-structured interviews were conducted with a diverse group of participants, including primary caregivers, physiotherapists, occupational therapists, and institutional staff members directly involved in the daily care of CP patients. The use of semistructured interview guides ensured consistency across interviews while also allowing flexibility for participants to elaborate on their experiences. The interviews explored how caregivers identified and interpreted distress signals in non-verbal patients, including changes in facial expressions, body movements, and vocalizations.

b) **Non-Participant Observation:** Observational sessions were also conducted in natural caregiving settings, including during feeding times, therapy sessions, resting periods, and routine hygiene activities. We adopted a non-participant role to minimize interference with normal caregiving practices while systematically documenting interactions and events as they occurred. The purpose of these observations was to record spontaneous caregiving decisions, response times to patient needs, and the types of emotional or behavioral cues exhibited by the patients. Particular attention was given to moments of uncertainty or delay, where caregivers had to interpret ambiguous signals without verbal communication.

c) **Field Notes:** Detailed field notes were recorded throughout the data collection process to document contextual and descriptive information that could not be fully captured through interviews or structured observation alone. These notes included descriptions of caregiver–patient interactions, tone of voice, emotional expressions, routine disruptions, and subtle patient body movements that might indicate discomfort or distress. We also documented reflections, emerging patterns, and notable incidents observed during fieldwork. Institutional dynamics, such as staff coordination, workload distribution, and caregiving protocols, were also recorded to provide a broader understanding of the caregiving environment.

3.1.2 Quantitative Component

The quantitative component focused on the collection and analysis of objective physiological and behavioural data obtained through sensor simulations and prototype testing. This component was intended to provide measurable evidence regarding the feasibility, accuracy, and responsiveness of the proposed assistive system. By relying on numerical data rather than subjective interpretation, the quantitative approach enabled the study to evaluate system performance in a structured and empirical manner. It also complemented the qualitative findings by validating whether the identified caregiving challenges could be addressed through sensor-based monitoring and automated alert mechanisms.

To achieve these objectives, the study employed two main strategies: simulated sensor logging and prototype data logging. Prior to the deployment of the physical prototype, simulations were developed using platforms such as Tinkercad and other equivalent tools to model the expected behavior of the system under different conditions. These simulations were used to generate synthetic datasets representing heart rate variations, sound intensity patterns, and motion-triggered events. The simulation process allowed us to test different threshold values and decision rules without the risks or constraints associated with real-world implementation.

This numerical evidence will demonstrate whether the system provides reliable alerts, improves response time, or reduces missed care activities.

3.1.3 Integration of Qualitative and Quantitative Findings

At the interpretation stage, qualitative experiences such as caregiver narratives describing distress cues, emotional signals, and routine caregiving challenges were systematically compared with quantitative sensor patterns obtained from simulations and prototype data logging. This stage played a critical role in bridging the gap between subjective human experiences and objective numerical data. By aligning caregiver observations with measurable physiological and environmental indicators, the study was able to validate whether the sensor-based system accurately reflected real-world caregiving situations.

This approach enabled the identification of patterns that might not have been evident through a single method alone. Qualitative insights helped to contextualize the numerical data, explaining why certain patterns occurred, while quantitative findings offered objective evidence to support or refine caregiver interpretations. In this way, the two data sources complemented each other, leading to a more comprehensive understanding of patient needs and system performance.

This integration enriched the final conclusions of the study by ensuring that the findings were grounded in both lived experiences and empirical evidence. It also strengthened the validity and reliability of the results through triangulation. Ultimately, the combined analysis ensured that the recommendations developed from the study were not only technologically sound but also practically relevant to real caregiving environments.

Target Population

The target population for this study consisted of individuals who interacted closely, consistently, and professionally with non-verbal and immobile patients diagnosed with Cerebral Palsy in Kampala, Uganda. This group primarily included caregivers, healthcare professionals, and support staff who were directly involved in the dayto-day care, monitoring, and support of such patients within both home-based and institutional care settings.

- **Primary caregivers:** These are the frontline workers responsible for the daily care of the children, including feeding, repositioning, bathing, monitoring comfort levels, and responding to signs of pain or distress. They interact with the children for the longest duration each day and possess extensive practical knowledge of subtle patient cues.
- **Physiotherapists:** These professionals work on muscle tone management, range-of-motion exercises, and posture alignment. They are often the first to detect discomfort related to muscle contractures, stiffness, or pain during movement.
- **Occupational Therapists:** These specialists focus on sensory processing, comfort, seating, and assistive device integration. They provide insights into how physiological signals like sudden muscle tension or changes in breathing may reflect distress or discomfort.
- **Nurse Supervisors or Nursing Assistants:** These staff members oversee health monitoring, medication routines, vital signs, and emergency responses. Their medical knowledge helps interpret whether physiological changes (such as heart rate spikes) indicate emotional distress, pain, or medical complications.
- **Support Staff familiar with CP care:** Some institutions include specialneeds aides, therapy assistants, or volunteers trained in daily support tasks. Their consistency and observational familiarity also provide relevant perspectives.

3.2 Data Collection Methods

This study employed four complementary data collection methods: semistructured interviews, non-intrusive observations, prototype trials, and document review. These methods were carefully selected to capture both subjective experiences and objective insights from caregivers working with non-verbal and immobile patients with Cerebral Palsy.

3.2.1 Semi-Structured Interviews

Semi-structured interviews were conducted with a range of caregivers and healthcare professionals, including caregivers, physiotherapists, occupational therapists, nurse supervisors, and other staff members who worked closely with non-verbal and immobile children with Cerebral Palsy. These participants were selected because of their direct involvement in daily caregiving routines, their experience in observing non-verbal cues, and their ability to provide informed perspectives on both patient needs and the potential use of assistive technologies.

Each interview was designed to last between 20 to 40 minutes, with the exact duration depending on the participant's professional role, availability, and depth of experience. During the interviews, participants were asked openended questions to elicit detailed accounts of their observations, challenges, strategies for interpreting non-verbal communication, and perceptions of how technology could support their caregiving practices. The flexible structure of the interviews allowed participants to elaborate on specific incidents or experiences, providing rich qualitative data while still covering key research themes consistently across all respondents.

The data obtained from these interviews were carefully recorded and transcribed to ensure accuracy. This process provided nuanced insights into the day-to-day realities of caregiving for non-verbal and immobile children with CP, capturing both the practical challenges faced by staff and their professional judgments about patient needs. Additionally, the interviews helped to identify potential gaps in current caregiving practices and informed the design and evaluation of the prototype sensor-based system, ensuring that the technology addressed real-world caregiving requirements.

3.2.2 Non-Intrusive Observation

Observation was considered a fundamental tool for understanding the realworld dynamics of caregiving, particularly in situations where children with Cerebral Palsy expressed emotions or needs that could not be verbally articulated. In this study, non-intrusive observation was employed, therefore we refrained from interfering with or altering the normal routines of caregiving. We were positioned discreetly within caregiving environments, quietly monitoring interactions and documenting behaviours, caregiver responses, and routine practices.

The observations were conducted over multiple sessions to capture variations in behaviour across different times of day, types of caregiving activities such as feeding, repositioning, or diaper change, and individual caregivers' approaches. Detailed field notes were recorded to document not only observable behaviours but also contextual factors, such as the environment, equipment used, and caregiver strategies, which could influence patient responses.

What was observed?

We paid attention to:

- how caregivers interpret signs of discomfort, hunger, pain, or emotional distress,
- caregiver–patient interactions during feeding, repositioning, therapy, bathing, and resting,
- frequency and context of missed events, such as delayed feeding or diaper changes,
- behavioural cues exhibited by the children (e.g., facial tension, body movement, breathing patterns, vocalizations),
- external factors that influence routines (workload, time pressure, environmental noise).

3.2.3 Prototype Trials (Simulations and Pilot Testing)

This component focused on evaluating how the sensor-based system performed under realistic caregiving conditions. The assessment was designed to determine the system's functionality, reliability, and practicality when applied in environments similar to actual caregiving settings for non-verbal and immobile children with Cerebral Palsy.

Data were collected from both controlled simulations and short pilot deployments. During the controlled simulations, the prototype was tested in a structured environment to examine its technical performance, including sensor accuracy, responsiveness, signal stability, and overall system reliability. These simulations allowed for systematic testing under predefined conditions, enabling the researcher to identify potential technical issues and refine the system accordingly before exposing it to real-world use.

In addition to simulations, short pilot deployments were conducted to observe how the system functioned in more natural caregiving contexts. These deployments involved limited, time-bound trials where caregivers interacted with the prototype during routine activities. Feedback was gathered regarding ease of use, comfort, practicality, and usefulness in detecting physiological or behavioural indicators. The pilot phase provided valuable insights into user experience, system adaptability, and integration into daily caregiving routines.

The combination of controlled simulations and short pilot deployments ensured a comprehensive evaluation of both the technical performance and practical applicability of the sensor-based system.

a. Controlled Simulations

Before interacting with actual caregivers, the prototype underwent simulated testing using:

- Tinkercad circuits for electronic behaviour modelling,
- Python scripts for signal visualization (heart rate, sound intensity),
- artificial event triggers to test alarm conditions like high heart rate, sudden sound spikes, no motion detected.

These simulations:

- validated that the circuit was functioning as intended,
- helped determine appropriate threshold levels,
- identified potential false alarms,
- generated preliminary performance data.

b. Pilot Deployments

Upon successful simulation, the prototype was deployed under supervised conditions in the caregiving environment with ethical approval and informed consent. During the pilot:

- the system recorded heart rate variability, sound signals, and motion events,
- alerts were triggered based on predefined thresholds,
- caregivers responded naturally to the alerts,
- timestamps were logged for both alerts and caregiver responses.

Data that was collected from the prototype

- heart rate readings (beats per minute),
- sound intensity levels,
- PIR motion detection events,
- alert frequencies and types (distress alert, noise alert),
- caregiver response times,

Purpose of prototype data The prototype trials provided objective evidence on:

- how effectively the system detected distress,
- whether the system was user-friendly and relevant in real caregiving contexts,
- how technology influenced caregiver routines and decision-making.

Ethical safeguards

Pilot testing took place:

- with guardian/management consent,
- using non-invasive sensors,
- under supervision of clinical staff.

3.2.4 Document Review

Document review focused on institutional records and caregiver logs that provided historical and administrative data relevant to the study.

3.3 Prototype Design and Implementation

3.3.1 Hardware

The proposed assistive system was built using a selection of low-cost, easily available electronic components chosen for their reliability, compatibility with microcontrollerbased architectures, and suitability for real-time monitoring of physiological and environmental conditions. Each component played a specific role in capturing signals, processing inputs, generating alerts, or facilitating communication. The hardware components used in the project were detailed below.

A) Arduino Mega Microcontroller Board

The Arduino Mega served as the central processing unit of the system. It was responsible for receiving inputs from sensors, executing the programmed logic, controlling output devices, and managing timing and alert functionality.

Purpose in the project

- Reads heart rate data from the pulse sensor.
- Processes sound intensity signals to detect distress-related vocalizations.
- Monitors caregiver presence through the PIR motion sensor.
- Triggers alerts (buzzer, LCD messages, optional GSM SMS) when threshold conditions are met.
- Handles timing functions such as feeding reminders or inactivity alerts.

B) Pulse Sensor (GY-MAX30102 or Equivalent)

The **GY-MAX30102 pulse sensor** used photoplethysmography (PPG) to measure heart rate and pulse intensity by detecting changes in blood volume.

Purpose in the project

- Measures real-time heart rate of the child.
- Identifies sudden spikes or drops in heart rate, which may indicate:
  - pain,
  - discomfort,
  - emotional distress,
  - potential medical emergencies.
- Provides physiological data that supports interpretation of emotional state.

C) **Sound Sensor (Microphone Module)**

A **microphone-based sound sensor** detected variations in sound levels in the child's environment.

Purpose in the project

- Detects vocalizations such as crying, moaning, sharp gasps, or discomfort sounds.
- Monitors sudden spikes in sound intensity that may indicate distress.
- Works together with heart rate data to improve emotional inference accuracy.

D) **PIR Motion Sensor (Passive Infrared Sensor)**

The **PIR motion sensor** detected movement by sensing changes in infrared radiation.

Purpose in the project

- Monitors caregiver presence near the patient.
- Triggers inactivity alerts when no caregiver is detected within a defined time window.
- Helps identify neglected routines (e.g., feeding or diaper change delays).
- Complements heart rate and sound data to differentiate distress from normal activity.

E) **LCD 16x2 Display**

The **16x2 Liquid Crystal Display** provided a visual interface for caregivers.

Purpose in the project

- Displays key information such as:
  - current heart rate,
  - detected distress level,
  - type of alert (sound-based, HR-based, no-motion), – feeding reminders and timers.
- Provides instructions or system messages (e.g., “Caregiver Needed”, “High Heart Rate Detected”).

F) **Buzzer (Piezoelectric Alarm)**

The **buzzer** generated audible alerts that supplement the visual cues from the LCD.

Purpose in the project

- Provides immediate, attention-grabbing alerts during:
  - distress events,
  - high heart rate spikes, – prolonged inactivity detections,
  - missed routine reminders.
- Ensures caregivers are alerted even when not directly looking at the display.

G) **Pushbuttons**

Pushbuttons offered simple manual inputs to the system.

Purpose in the project

- Allow caregivers to:

– acknowledge alarms,

– reset timers (e.g., feeding timer),

– confirm completed tasks (e.g., diaper change done), – navigate LCD menu options.

• Provide a way to log caregiver responses manually.

H) **GSM Module (SIM800L)**

The **GSM module** allowed the system to send text message alerts (SMS) remotely.

Purpose in the project

- Sends distress alerts to caregivers or supervisors when they are away from the child.
- Provides remote monitoring capability for:
  - medical emergencies,
  - high-risk patients,
  - understaffed shifts.

• Ensures continuity of care beyond visual or audible local alerts.

I) **Additional Electrical Components**

These components ensured stability, reliability, and proper functioning of the circuit.

Included items

- **Resistors** (for LEDs, sensors, and signal conditioning)
- **Breadboard or PCB** (circuit assembly)
- **Jumper wires** (signal connections)
- **LED indicators** (status signals for power, alerts, or system states)
- **5V/12V regulated power supply** (stable operation)

3.4 System Architecture design and functional flow

3.4.1 System Architecture Design

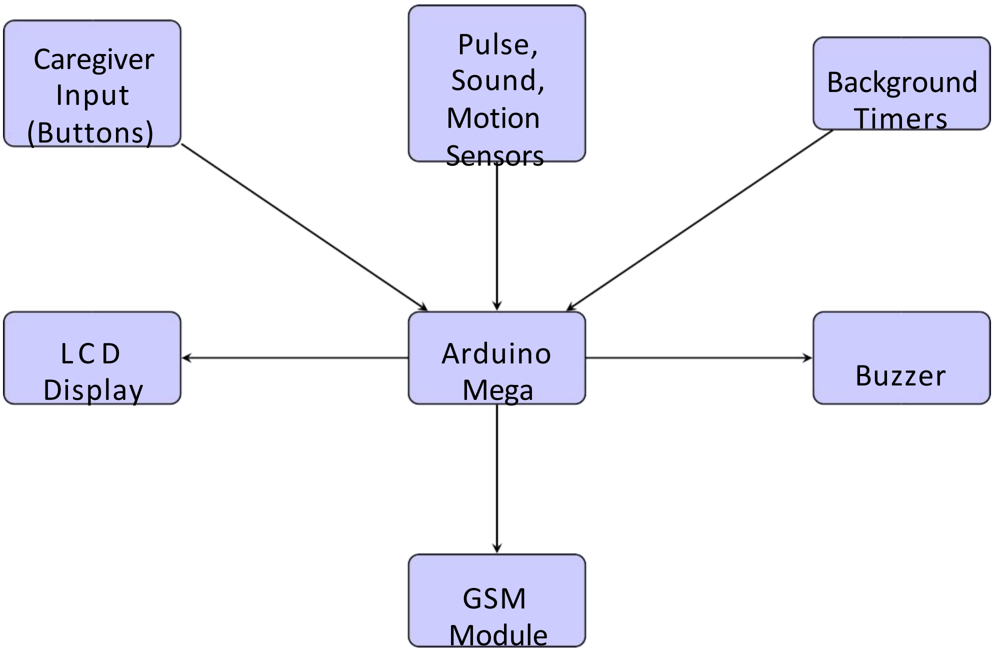

Figure 2: System Architecture Design showing sensors, Arduino Mega, peripherals, and caregiver interaction.

3.4.2 Fully-functional prototype

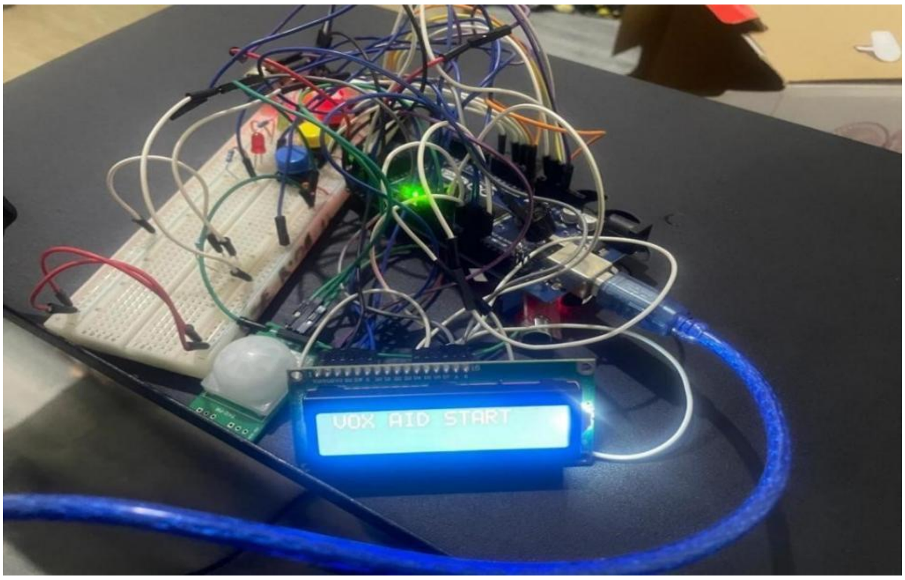

Figure 3: VOX-AID Prototype

3.4.3 Functional Flow Diagram

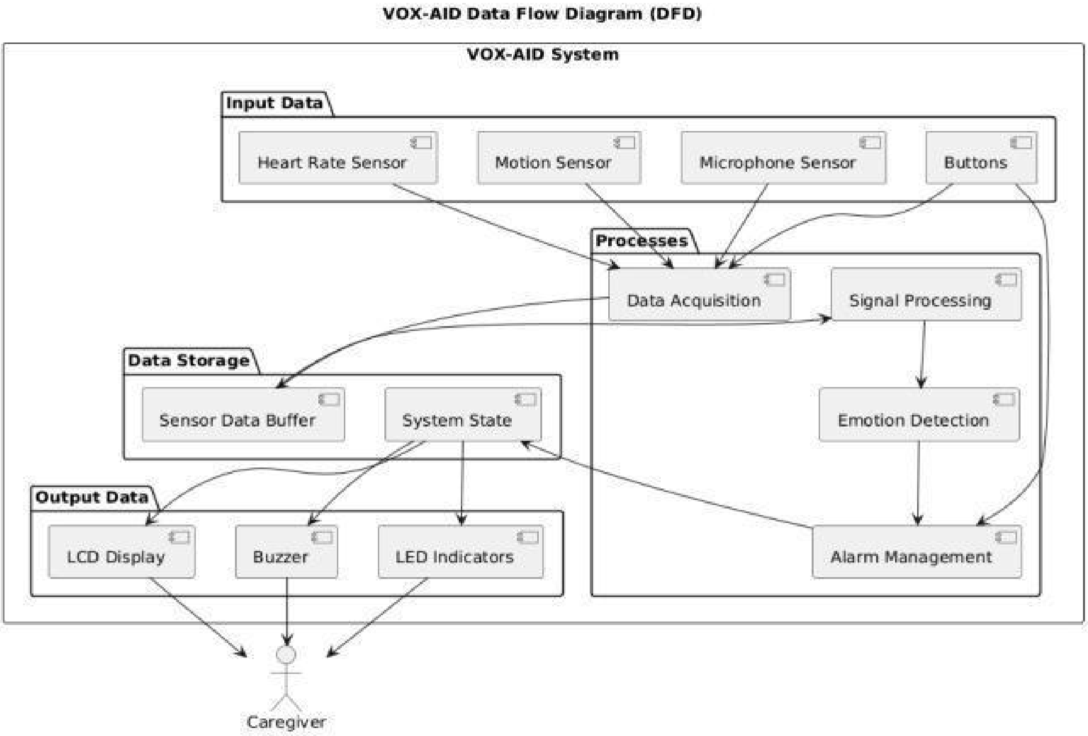

Figure 4: VOX-AID Flow Diagram

The functional operation of the system above follows these steps:

(a) **System Power-On:** When the caregiver powers on the device, the Arduino Mega automatically initiates a startup sequence designed to ensure that the system is functioning correctly. During this phase, the microcontroller performs a comprehensive self-check of all connected sensors and peripherals and this process helps to confirm that each component is properly connected and operating within expected parameters.

As the system initializes, the LCD screen displays a clear startup message indicating that the device is booting and preparing for operation. Once all checks are successfully completed, the display updates to show a readiness status, informing the caregiver that the device is fully functional and ready to begin monitoring. This process not only enhances reliability but also provides reassurance to the caregiver that the system is operating safely and effectively before use.

(b) **Continuous Reading of Heart Rate and Sound:** The pulse and sound sensors continuously monitor and capture the patient's physiological and vocal signals, such as heart rate patterns and variations in sound intensity. These sensors operate in real time, ensuring that even subtle changes in the patient's condition are detected without delay. The collected data is then immediately transmitted to the Arduino Mega, where it is processed and analyzed.

Within the microcontroller, the incoming signals are interpreted using predefined thresholds and algorithms to identify normal and abnormal patterns. This real-time data streaming and processing enable the system to respond quickly to potential signs of distress, ensuring timely alerts and improving the overall effectiveness of patient monitoring.

(c) **Threshold-Based Data Analysis:** Incoming sensor readings are continuously evaluated against predefined threshold values stored within the Arduino Mega to detect any unusual patterns or anomalies. These thresholds are carefully calibrated to represent normal and abnormal conditions based on expected patient behavior and physiological ranges.

For instance, a heart rate that exceeds the set limit may indicate distress or discomfort, while unusually loud vocalizations could signal pain or agitation. Similarly, prolonged silence or the absence of expected sound patterns may suggest inactivity, unconsciousness, or a potential issue requiring attention. By systematically comparing real-time data with these thresholds, the system is able to quickly identify deviations and classify them as potential alerts, enabling prompt intervention by the caregiver.

(d) **Triggering Alerts for Abnormal Cues:** When the system detects abnormal patterns that exceed the predefined thresholds, it immediately triggers a series of alert mechanisms to notify the caregiver. The Arduino Mega activates visual alerts on the LCD screen, displaying clear messages that indicate the type of issue detected, such as elevated heart rate or unusual silence. At the same time,

an audible alarm is generated through a buzzer to ensure that the caregiver's attention is quickly drawn, even from a distance.

In addition to these local alerts, the system has initiated remote notifications using a GSM module. This allows SMS messages to be sent directly to the guardian's mobile phone, providing real-time updates even when they are not physically near their patient. By combining visual, auditory, and remote communication methods, the system ensures that critical situations are communicated promptly and effectively, enhancing patient safety and response time.

(e) **Logging Feeding and Diaper Events:** Caregivers interact with the system using push buttons to record essential care activities such as feeding and diaper changes. Each time a button is pressed, the event is automatically captured and timestamped by the Arduino Mega. This ensures that all care actions are accurately logged, enabling caregivers and supervisors to track routines over time and generate reliable reports for monitoring patient care consistency.

(f) **Background Timers for Care Routines:** The system has incorporated automated background timers that run continuously to support routine caregiving tasks. For example, a feeding timer is set to trigger every three hours, while a diaper change timer activates every one hour. These timers operate independently of manual input and help ensure that no critical care activity is overlooked. If a scheduled activity is not recorded within the expected timeframe, the system generates a reminder alert to prompt timely action.

(g) **Alert Display and GSM Notifications:** All generated alerts are clearly displayed on the LCD screen, providing caregivers with immediate and detailed information about pending or missed activities. In addition to on-device notifications, the system is utilizing a GSM module to send SMS reminders directly to caregivers or designated supervisors. This feature ensures continuous awareness, even when the caregiver is not physically near the device, thereby improving responsiveness and accountability as portrayed below;

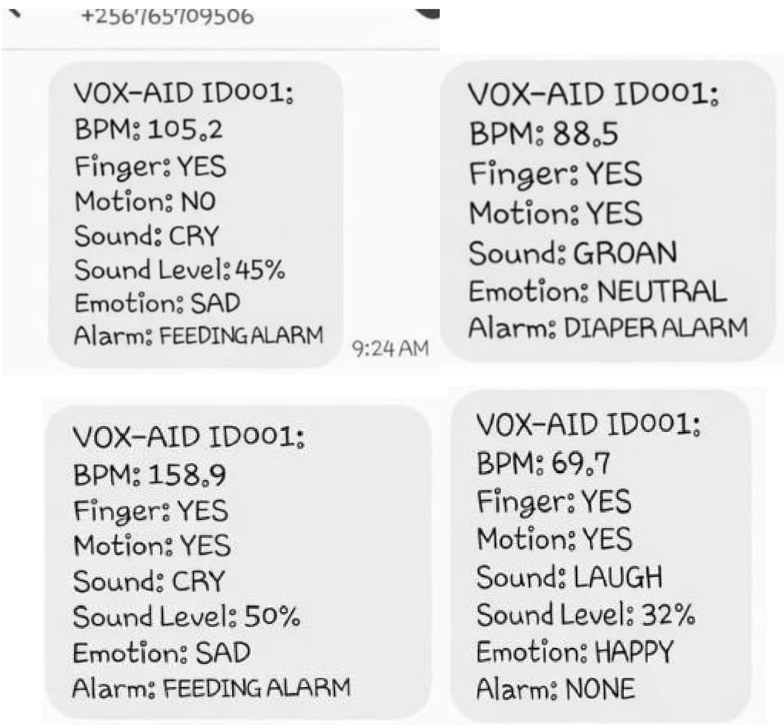

Figure 5: Samle GSM meassages sent to a caregiver

(h) **Motion Sensor for Caregiver Presence:** A Passive Infrared (PIR) motion sensor is integrated into the system to detect caregiver presence around

the patient. The sensor monitors movement within a defined range and logs activity patterns over time. If no motion is detected during critical care periods, such as scheduled feeding or diaper change intervals the system interprets this as a potential lapse in supervision and triggers additional alerts or reminders. This feature enhances patient safety by ensuring that the caregiver remains actively engaged, especially during essential care windows.

3.4.4 LCD Display Output of the Vox-Aid Prototype

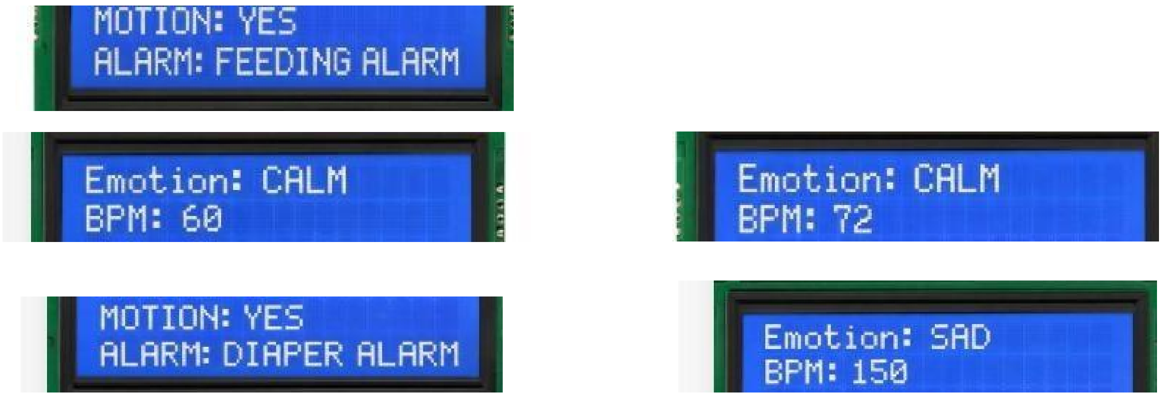

Figure 6: Sample LCD Display messages

4. Chapter 4: Ethical Considerations, Limitations and Expected Outcomes

4.1 Ethical Considerations

a) **Approvals:** Ethical approval for the study should be formally sought and obtained from the Uganda National Council for Science and Technology (UNCST), the Uganda National Association for Cerebral Palsy (UNAC.

b) We sought and obtained permission from Ugnada Christian University as the project needed approval for presentation as the final year project proposal, the Mukisa Foundation Ethics Committee, Guardians and Parents prior to the commencement of any data collection activities. This process involved the submission of a comprehensive research proposal detailing the study objectives, methodology, potential risks, and measures put in place to protect participants. Each of these bodies carefully reviewed the proposal to ensure that the study adhered to established ethical standards, particularly in relation to research involving vulnerable populations such as individuals with cerebral palsy. Approval was granted only after all ethical concerns were adequately addressed, and the research was deemed to uphold the principles of respect for persons, beneficence, and justice.

c) **Privacy:** The study was conducted with strict adherence to privacy and confidentiality principles to ensure that all participants were adequately protected. No personally identifying information was collected, recorded, or published at any stage of the research process.

d) **Non-invasiveness and safety:** The study exclusively utilized non-invasive sensors to monitor physiological and environmental conditions. This approach was intentionally selected to minimize any form of physical discomfort, risk, or harm to the patients, particularly given the vulnerability of individuals with cerebral palsy. The sensors used in the study did not penetrate the skin or interfere with normal bodily functions; instead, they operated externally by capturing signals such as heart rate, motion, and sound levels. Prior to deployment, all equipment was tested to ensure that it met safety standards and functioned reliably without posing any hazards. Additionally, all pilot trials and data collection sessions were conducted under the supervision of qualified clinical staff who were experienced in handling patients with special needs. Their presence ensured that any unforeseen issues could be promptly addressed and that the well-being of the patients remained the top priority throughout the study. Caregivers were also briefed on how the devices functioned, which helped reduce anxiety and foster trust in the research process.

e) **Right to withdraw:** The study also upheld the fundamental ethical principle of voluntary participation by ensuring that all participants retained the right to withdraw at any point without facing any negative consequences. Participants were assured that their decision to withdraw would not affect their access to care, services, or their relationship with any of the involved institutions. In the event that a participant chose to withdraw, all data associated with them was immediately excluded from further analysis and, where applicable, securely deleted to maintain their privacy. Our team made continuous efforts to create a respectful environment, allowing participants to express concerns freely and make decisions without any form of pressure or coercion.

4.2 Limitations and Delimitations

a) Since the prototype study was conducted within a single institution, this inherently restricted the generalizability of the findings because the testing and pilot trials were confined to a specific care setting; the experiences, behaviors, and responses of both caregivers and patients may not have fully represented those in other institutions or community environments. Variations in staffing practices, patient demographics, resource availability, and organizational routines in different care centers could influence how the prototype performs in real-world scenarios. As a result, while the study provided valuable insights into the feasibility, safety, and initial effectiveness of the system, its outcomes may not be directly transferable to other clinical settings or populations. Broader testing across multiple institutions would therefore be necessary to validate the prototype's general applicability, ensure its adaptability to diverse caregiving contexts, and strengthen confidence in its potential for wider adoption.

b) Another notable limitation of the study was the relatively small sample size used for the pilot evaluation. Because only a limited number of caregivers and patients participated in the initial testing, the findings may not have fully captured the range of variability in user interactions, patient responses, or potential technical challenges that could arise in larger populations. A small sample increased the likelihood that the results may be influenced by individual specific factors or anomalies, rather than reflecting general trends or typical scenarios.

c) Prototype used rule-based inference rather than advanced ML in this stage.

d) An additional limitation of the prototype was the potential impact of environmental noise and sensor attachment challenges on the quality of the collected signals. Since the system relied on non-invasive sensors to monitor physiological and behavioral parameters, factors such as background sounds or patient movement could introduce interference or distortions in the data. Improper placement or displacement of sensors during use could further compromise signal accuracy, leading to incomplete or inconsistent measurements.

4.3 Outcomes of the Project

a) A comprehensive understanding of caregiver practices and care routine gaps: The generated detailed documentation of the daily routines, strategies, and decision making processes employed by caregivers in managing patients with cerebral palsy.

b) A fully developed simulated and physical prototype demonstrating realtime alerts: This prototype was capable of detecting and responding to variations in heart rate, motion, and ambient sound, providing immediate alerts to caregivers in real-time. The dual approach, simulation and physical testing, allowed iterative improvements, validation of sensor integration, and demonstration of the system's operational feasibility in a controlled environment before larger scale deployment.

c) Preliminary performance metrics from controlled tests: The study generated initial quantitative data on the prototype's functionality, including metrics such as detection accuracy, false alert rates, response time, and reliability under different simulated care scenarios.

d) Usability and acceptability findings from caregiver feedback: Insights were collected from caregivers regarding the practicality, ease of use, and perceived value of the prototype. This qualitative feedback will cover aspects such as interface clarity, alert relevance, comfort of sensor placement, and overall integration into daily care routines.

Below are the outcomes of the Vox-Aid prototype;

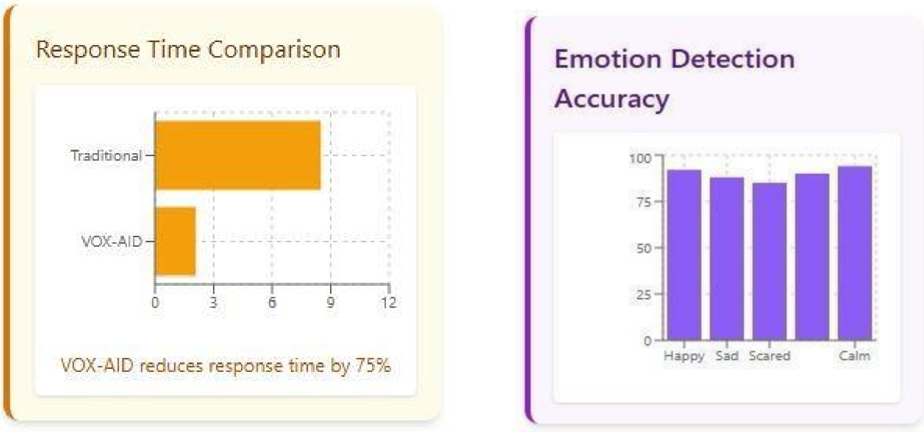

Figure 7: Response Time Comparision and Emotion Detection Accuracy

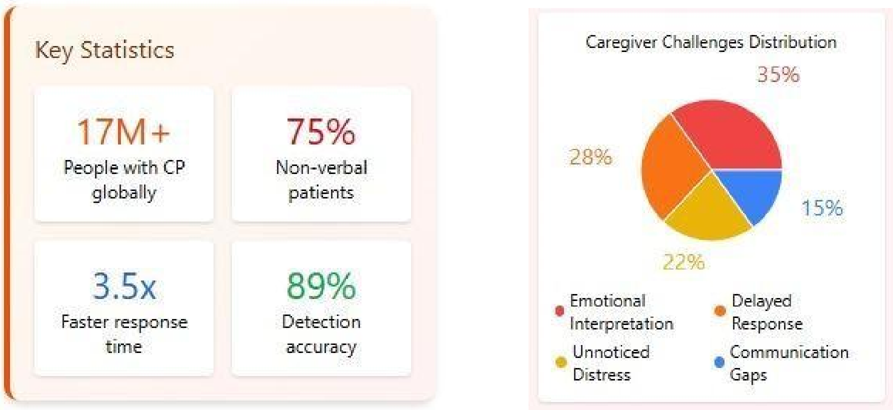

Figure 8:VOX-AID Key Statistics and Caregiver Challenge Distribution

5. Chapter 5: Project Management

5.1 Timeline

The project was planned over 9 months. The Gantt chart below gives a highlevel schedule.

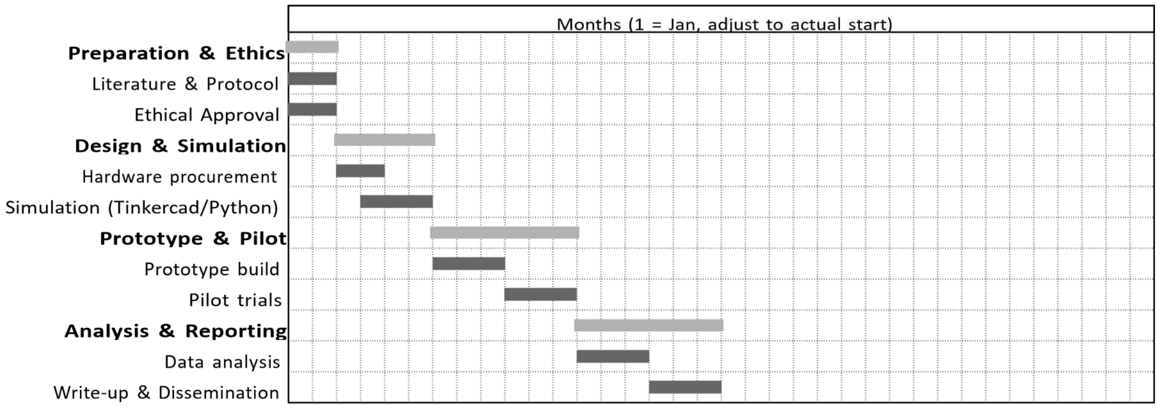

Figure 9: Project Timeline Gantt Chart

5.2. Budget

Table 5.1: Indicative budget (UGX / approximate USD in parentheses)

Item	Estimated cost (UGX)
Arduino Mega	100,000
Pulse sensor (GY-MAX30102)	25,000
Sound sensor (microphone module)	15,000
PIR motion sensor	20,000
LCD 16x2	25,000
GSM module (SIM800L) (optional)	80,000
Simcard	5,000
Buzzer, buttons, resistors, wires, breadboard	30,000
Data analysis software / misc	50,000
Contingency (10%)	50,000
Total (approx.)	**400,000**

Table 1: Indicative budget (UGX / approximate USD in parentheses)

A. Appendices

B. A.1 Component Table

Table A.1: System components and quantities

Name	Quantity	Component / Notes
Arduino Mega/Uno	1	Microcontroller
Pushbuttons	4	For logging events
LEDs (red, yellow, green, blue)	4	Status indicators
Microphone (sound sensor)	1	Module for vocalization detection
Pulse sensor (GY-MAX30102)	1	Heart rate sensor (PPG)
LCD 16x2	1	Display
Piezo / Buzzer	1	Audio alerts
Resistors (220Ω)	5	For LEDs
PIR motion sensor	1	Detects caregiver presence
Potentiometer (10k)	1	LCD contrast
GSM module	1	For SMS alerts
Simcard	1	For the gsm
Power supply (5V/12V)	1	Stable power

Table 2: System components and quantity table

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