Automations for ABLE Alliance: Report

Mobile & Ubiquitous Computing

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I. ABSTRACT

Individuals with mobility impairments have witnessed substantial advancements in the field of motorized wheelchairs, affording them newfound independence. No longer reliant on assistance for mobility, they can now navigate autonomously. However, this independence, while liberating, ushers in new challenges. With users now moving independently and without supervision, scenarios may arise where the wheelchair becomes immobilized. Given that such incidents can also involve the user's phone being inaccessible, there arises a pressing need for a sophisticated system capable of promptly detecting and alerting emergency contacts in such precarious situations. Our study introduces a modular, multisensory, seamlessly integrated, and assistive device designed specifically for the mobility-impaired audience— a wheelchair crash detection and service system. The presented system essentially is a planet of two overarching parts: system implementation and user-interface. The system implementation section comprises of four subsidiaries, each equipped with defining sensors, control elements, buzzers, displays, speakers, and transducers. A notable feature of the system implementation is the focus on sensor-based context awareness, motivated by integrating various peripherals to achieve sensor fusion, which otherwise cannot be derived from a single sensor. The user-interface section is further divided into two categories. The primary category involves server provisioning/dispatch, SMTP communication, and audible speech, while the secondary category features visual notification outpost directly on the wheelchair. The iterative phases of the R&D have been executed under the agile methodology and the results have been reported on the experiments. This study contributes to ongoing institutional research at Georgia Institute of Technology and is housed under the Mobile and Ubiquitous Computing (MUC) group, affiliated with Georgia Tech ABLE Alliance, and extends to all caregivers who prioritize wheelchair safety for their patients.

II. INTRODUCTION

A. *Setting the Stage*

In this section, it is important to address the organization which will be the primary recipient of the implemented technology: the ABLE Alliance at Georgia Tech. To plead the case, we will first provide some context about the organization. The ABLE Alliance (at Georgia Tech), is dedicated to fostering a more inclusive and supportive environment for individuals of all abilities and disabilities within the Georgia Tech community. In terms of relating the outline of this project to the ABLE Alliance, the suggested project is set focused on enhancing the HRQoL (Health-Related Quality of Life) for its president, Trey Quinn, who faces the challenges posed by cerebral palsy. Trey's unwavering determination and ambition to succeed makes him an inspiring figure within the organization, but there are some aspects of his daily life that require assistance due to his condition. This project aims/attempts to best of ability to create a transformative environment through the implementation of advanced sensor technology that will not only improve Trey's day-to-day experiences but also serve as a somewhat beacon of inspiration for the entire ABLE Alliance community. So in simple terms, we intend to integrate smart automation systems into Trey's immediate environment, leveraging cutting-edge sensor technologies with respect to the manual task that we try to automate to have a more responsive access to safety in case of emergency that would otherwise consume precious time/effort (respective to Trey's condition). The advanced sensors and its propositional use details can be more thoroughly explained in the "System Design" section. However, the motivating factor of this project resonates in a much bigger grand scheme of things. While its importance is undeniable, only 10% of individuals requiring assistance, as reported in [8], currently have access to this technology. As we design for the benefit of our immediate neighbors, it's crucial to recognize the broader global need for these innovative solutions. As such, we actively engaged in informative talks, particularly from the Diversity and Inclusion chapter in Atlanta. Notably, an event hosted by the Mayor's Office of Equity, Diversity and Inclusion emphasized the imperative to "prioritize people and progress with a sense of urgency [11]." This resonated deeply with our mission, reinforcing the urgency and importance of our endeavor. The motivation is often rooted in empathy and a commitment to creating an inclusive society where individuals with mobility impairments are not only accommodated but actively supported with technology that understands and responds to their unique needs. Emphasizing the shared commitment to the project's cause, we were pleasantly surprised by the community's involvement. A celebrative instance was the generous $50 million donation from Arthur Blank to enhance accessibility at the Atlanta United training facility, specifically in support of the Cerebral Palsy, Deaf, and Power Soccer National Teams [12]. This significant contribution highlights the collective dedication towards promoting accessibility as a shared societal goal. Fortunately, we have come to a new paradigm where accessibility transcends mere empathy, evolving into a dynamic and inclusive journey supported by a multitude of global cooperation efforts [7].

B. Research Question

All in all, this is the research question that we address in this project:

> How can we effectively integrate efficient and reliable sensor-based, low-power smart technology into wheelchair systems to enhance the safety and overall quality of life for individuals with mobility impairments?

Generally, the research schema followed this generic pattern: data preparation, feature engineering, model selection, model testing, model repository, model serving, and model explanation. These are the basic infinity stones which are concealed under the hood; the wheelchair is operated as usual and in the case of an emergency, there is an affirmative action.

III. LITERATURE OUTLOOK

Based on published literature, there are many ongoing efforts to go from stage "wheelchair" to stage "smart wheelchair" [6]. Most commercially sold wheelchairs do not have pre-built safety countermeasures put in place in case of many situations: uneven terrain, potholes, curb banks, and etc [4] [5] [2]. Currently, the market standard for such emergency cases is some sort of wearable system such as a pendant, to detect a fall. Although, we declared this innovation to be complementary to our design. [10] proposed a method by using an ultrasonic sensor to judge any close curb markers and immediately stop the wheelchair itself. This light-weight implementation can be an easy installation, however, such an approach can be sometimes unreliable due to false positives, of which we had to be mindful about.

[9] also conducted research on the reliability of triggers that set off the subsequent workflow and its response time. They use weight-sensitive pads as the input mechanism. As soon as the fall monitor signals have crossed a certain threshold, the caregiver is notified.

[1] was very vibrant in finding a specific use-case, where a Android patient was custom tailored an Android application which was co-linked with her Android smartwatch to continuously gather heart rate metrics. The metrics were then processed for any sudden abrupts/anomalies using a random forest machine learning model which then outputted the results in another Android caregiver's phone. Having such an open minded ecosystem, would definitely make things much easier to work with. In our specific use-case, the patient is an Apple user. One key takeaway from this study though, is a comprehensive ecosystem with a proper segway for data flow.

[3] In this research, a study on human fall types and detection have been noted. They use vision-based systems equipped with the latest machine learning, localization, and mapping techniques to gauge an unintentional fall. They seem to be on the cusp of utilizing the brightest talents, and vast accessibility to resources to accomplish their goal. This is a total overachievement; however, we do not have such privileges and man power. We also needed a budget-friendly product, however, localization is the key takeaway here.

[13] artfully illustrates the use of a sound recognition framework for detecting abrupt crashes by analyzing sequential sound occurrences from the speaker as input. We were mind-blown by this ingenious approach of repurposing the speaker, traditionally an output device, for real-time data collection. This dynamic was coupled with machine learning techniques, specifically Convolutional Neural Networks (CNNs), renowned for their efficacy in image and audio processing. Essentially, their system showcases an analysis of mel-frequency cepstral coefficients (MFCCs) from audio signals to discern potential crash sounds. The authors derived this from analogous inspiration of sound recognition patterns keen on identifying distinct fire alarm sounds. The auditory input/output is the main takeaway for our system here.

[15] showcases the intricate communication infrastructure embedded within automobiles: a "LAN" (Local Area Network) specifically tailored for automotive systems known as the Controller Area Network (CAN). It is a widely used communication mechanism in automotive systems that facilitates real-time communication between various control units. The computer architecture of this hardware includes a high speed bus chaining from the CAN to the Electronic Control Unit (ECU) constantly transmitting signals through a pipelined processor to produce deterministic and predictable behavior, which is crucial for safety-critical applications [16]. While this phenomenon primarily pertains to the operating modularity of a vehicle, the underlying concept can be adapted for the local server system of a wheelchair. This adaptation serves to orchestrate efficient server dispatch in response to emergency situations.

Similarly, [17] creatively depicts the dynamics inherent in terrestrial cellular networks. The cellular reach of numerous mobile network providers extends only to the virtual boundaries defined by the reach of their strategically positioned towers which cater to specific geographic regions. While some cruise ships offer onboard cellular services through satellite communication called roaming activation, these services are separate from traditional terrestrial cellular networks [18]. These examples can be intuitively adapted directly for the wheelchair's server system, although the acquisition of permissions for testing with national emergency service server lines remains tentative, given the prototype nature.

Ultimately, we draw inspiration from these studies and technological phenomena as valuable references and benchmarks that inform and guide our project's development.

IV. SYSTEM DESIGN

This section delves into the comprehensive architecture of our product—an innovative wheelchair crash detection and service system. The system implementation segment encompasses four specialized subsidiaries, each integrated with key features such as sensors, control elements, buzzers, displays, speakers, or transducers.

All these subsidiaries are powered by an ESP32 S3, fortified with 2.4 GHz Wi-Fi, Bluetooth Low Energy (LE), 512KB SRAM, 4MB flash memory, and three UART controllers [19]. The selection of the ESP32 S3 microcontroller was driven by its suitability for memory-intensive projects, interconnectivity, and efficient power management, making it an optimal choice for our cutting-edge wheelchair system.

Each subsystem within the setup can respond to distinct levels of emergency scenarios and are complementary to each other.

A. Gold Care System

The core of the system incorporates the MPU6050 (6-axis gyroscope/accelerometer), capacitive sensor, and an ESP32 S3. Leveraging the MPU6050, the system continuously receives real-time input to detect potential falls and promptly communicates with the local Python server for effective dispatching of emergency communication. It is affixed to the right side of the wheelchair.

The rationale behind utilizing the MPU6050 lies in its capability to discern changes in acceleration due to gravity when the wheelchair experiences a fall: change in y-acceleration from upright posture vs fallen postures. However, during our initial prototype testing, we identified a design challenge. Wheelchairs navigate various terrains, leading to tilting that affects the accelerometer/gyroscope readings differently. To address this, we refined our code to account for wheelchair movement. By setting a threshold based on typical wheelchair speeds (exceeding 4.5 mph or approximately 2 m/s), we pinned that as a base case to reliably determine if the wheelchair was in motion.

Ensuring accuracy in fall detection prompted the implementation of a backup mechanism. We introduced a capacitive sensor, allowing users to inform the system that no assistance is required by merely giving it a Midas touch. The system displays a red LED to signify a detected fall and a green LED for normal motion or when the capacitive sensor registers a denial. This dual-check system ensures user input validation.

1) ***Server Provisioning:*** Tailored to our Gold Care System hardware, we coded a full fledged python-flask server to manage communication seamlessly. The HTTP client-server duo takes charge of flagging a legitimate fall and transmitting a corresponding status code to the local Python server. Although we initially explored bypassing firewall restrictions to utilize eduroam for connectivity, we encountered a swift shutdown from the IT department that led us to adopt a mobile hotspot as a temporary solution. The local python server is able to catch any status signals within the geofence proximity from the secure connection.

The local Python server is very versatile and can execute the affirmative action pipeline efficiently. It initially grabs the caregivers attention by sending out a desktop notification. Simultaneously, it dispatches the crashed patient's electronic health record directly to the caregiver's email inbox using SMTP protocols. Beyond demographics, the server proficiently relays the patient's precise location coordinates (latitude and longitude), a method endorsed by co-author Jong Yoon Kim, who draws from his experience in the Republic of Korea Air Force. Mr. Kim advocates for this approach, deeming it more effective than traditional street addresses, which can sometimes lead to confusion.

Ahead of the game, we also proactively incorporated request counter logic into our client-server code to prevent consecutive emails from being sent out and flagged as spam by the email filtering tool.

Subsequently, our private database repository, Crash Policy, comes into play for patients handled by the caregiver. Functioning as a secure logbook, this repository houses all health records and sensitive data, accessible only to authorized caregivers and patients. The database repository is also automatically synchronized to avoid any delays in addressing the emergency at hand.

B. Silver Care System

Tilting is still a challenge that we needed to address. A tilt which is not caught by the MPU6050 may still be a severe threat to the patient, so hence our Silver Care System. This system is affixed on top of the head rest. As the chair moves or stands upright, the tilt buzzer points skyward, indicating an upright posture with no fall detected. However, in the event of a wheelchair fall or a dangerous tilt angle beyond the comprehension of the Gold Care System hardware, the tilt ball aligns parallel to the ground, triggering the buzzer for assistance.

Simultaneously, an LCD display provides instructions for those coming to help. A minor challenge in mounting the tilt ball switch was false buzzing due to minor fluctuations when the tilt ball wasn't stiffly mounted on the breadboard or encountered bumps on the road. To address this, we implemented a debounce technique to filter out brief signals, such that the buzzer only activates when the tilt state persists for a defined duration.

The sound emitted from the buzzer helps people know the wheelchair needs to be uprighted, and the patient needs help.

C. Bronze Care System

In addition to the aforementioned systems, we recognized that an additional safety service mechanism would be an important complement to the overall architecture. For added robustness, we introduced a magnetic contact switch that would activate on a strong impact. A threatening impact need not always cause the wheelchair to fall or tilt. For example, a hard collision with curb banks, havoc on the road, speedbumps, bicycles, or even other individuals may still impose a risk to the well-being of a sensitive patient.

Affixed on top of the wheelchair, we strategically positioned a magnetic contact unit composed of two magnetic parts. On a strong impact, these magnetic parts would split off and disengage the electrical circuit, indicating to the system that the wheelchair has received a substantial force and the user might be in danger.

D. User Interface

Tailored to the Bronze Care System implementation, a notable feature of user interface is the is a 'on-the-spot' pulse diagnosis sensor silked into the hand rest section of the wheelchair which immediately collects the vitals and prints it on an 4.3-inch e-Paper UART module along with their name, date of birth, blood type, medical condition, and emergency contact information. This is such that first-responders arriving to help will be able to quickly diagnose the user instead of starting from scratch.

Significantly, we opted for the e-paper display based on its distinctive features: electronic ink technology, low power consumption, and reflective display properties [20]. Even in the absence of power, the display persists in case the wires disconnect due to collision, owing to its use of ink rather than electric displays. Additionally, the pulse sensor includes an infrared LED and a photodiode that emits light into the fingertip tissue, and the pulse is measured as per pulsatile changes in blood volume [21]. This extracted data is a very important vital sign that adds outstanding value to the health monitoring aspect for the user.

Affixed to the right side of the wheelchair, the user interface also incorporates a speaking system customized for individuals that have a speech disability. A speech-impaired user, like Trey due to cerebral palsy condition, can utilize this portion of the system as an assistive communication method designed to better express themselves in shocking situations, when it may be challenging to get the words out verbally. It comprises three buttons and a DFPlayer module designed to play MP3 audio stored in the SD card. The ESP32 S3 sends control commands to the DFPlayer module using serial communication (TX & RX), which is hooked to an internal audio amplifier and can directly drive small speakers [22]. Each button corresponds to one of the three predefined sentences: "Please help me, I'm Stuck", "Born 2000 blood type O-", "Call emergency services!". These speeches serve various situations as needed. [1]

E. Mechanical Solutions

This section conveys a focus on physical components and enhancements. We 3D-printed a 2.7-inch cubical box with one partition. The larger partition is approximately 1.5-inch width, exactly enough to tuck two portable mini-batteries. The other half of the partition is 0.5-inch width, precisely crafted to hold the hook of another external mini-battery. The batteries will charge the four ESP32 S3s. To house the entire hardware, we initially requested the Georgia Tech Stamps Health Care Services office for a spare wheelchair, however, they were limited in quantity at the time. Hence, we decided to make our own using wood-working. The wooden wheelchair has two bulky white blocks for the seat and back rest area. Two thinner wood blocks were positioned to imitate the hand rest. Finally, we improvised three mini book rack wheels to put the entire frame in motion.

[1] *All flowcharts are provided in Appendix A for the audience to understand the overall architecture in each system.*

V. CHALLENGES / FUTURE

Mobile and ubiquitous computing aims to seamlessly integrate technology into daily life, while having the users be unaware of their interaction. Our project epitomizes this concept, aiming to assist users without requiring their active involvement once set up.

The primary challenge lies in building a cohesive ecosystem where our sensors seamlessly interact with the wheelchair and user's devices, forming a harmonious whole. Achieving this initial integration was pivotal and complex.

We face the challenge of designing sensors that augment the user experience without causing inconvenience while riding in the wheelchairs. Essentially, the system should not be obtrusive to the audience using it. We presently have multiple ESP microcontrollers positioned strategically in different areas with wiring everywhere. However, it is important to recognize that this is just the nature of any prototype. Although it is not aesthetically pleasing, we prioritized the functionality of the machine and delivered it magnificently.

For future work, we aim to make the wires more discreet by implementing a proper PCB design. We would also like to take into account for interconnecting the multiple ESP32 S3s using a WIFIClient library and solar powering them. Again, this will decrease a lot of overhead to the physical connections.

Furthermore, the current system necessitates the user to manually press a button for speech output. Looking ahead, we envision an enhancement similar to [14], where the system can autonomously generate speech based on different scenarios by leveraging machine learning from the cloud to respond dynamically to other people's interactions.

Ultimately, beyond the challenges hammered during the system design section, the task of ensuring our sensors accurately detect emergencies while minimizing false positives presented another important nuance. Our goal is to create a system that not only enhances safety and service, but also respects the users' peace of mind. Despite having a smaller workforce (in comparison to other teams), we were determined to cross out the objectives as per the timeline and *we delivered just that and then some.*

VI. RESULTS / CONCLUSION

We ran several rigorous experiments to exercise our machine and check the adherence to Human Computer Interaction (HCI) principles as well as prompt timing in emergency situations.

First, we commence with the Gold Care System response with respect to time (depicted in Figure 5). The accelerometer/gyroscope and local server combo exhibited remarkable speed, triggering an initial desktop notification in under 3 seconds. Everything else that follows is relatively faster compared to response times tested with a competing technology in [23], which rings an initial mobile notification during an emergency at an exhausting 9 seconds versus our machine emailing at 4.5 seconds only. We also assessed fall accuracy by recording the accelerometer/gyroscope error percentages during simulated falls on both left and right sides, as shown in Figure 6. On average, the sensor's error percentages were similar on each side, with a slight reduction naturally observed for the right side. Next, the Silver Care System's audible sound testing, depicted in Figure 7, has been recorded to be around 2.5 seconds, immediately after detection of a tilt. This efficiency was by far a very impressive number, compared to a demanding 30-second wait before sound is emitted from the Apple Watch series 7 after a hard fall has been detected [24]. Subsequently, we observed the pulse collection and diagnosis from the Bronze Care System (depicted in Figure 8) had a remarkable 2.3-second overall statistic following the magnetic contact trigger, averaging at 3.5 seconds. This was fairly on par, considering the finger remains on the hand-rest during the entire time of operating the wheelchair. Lastly, the speech times for each sentence remained consistently under 4.5 seconds, charted in Figure 9. This deliberate choice is to ensure concise and informative communication.

All of the charts are provided in Appendix B.

Post-prototype development, we sought **feedback** from wheelchair users to compare our automated system with their existing manual setups. Participants, from the ABLE Alliance, engaged in various tasks, including calling emergency contacts, providing personal/blood type information, and seeking assistance, both manually and through our prototype. Subsequently, they evaluated the results based on accuracy, speed, comfort, customizability, and overall performance. In terms of accuracy, our system demonstrated commendable precision, although manual execution scored higher since there was absolutely no room for error. However, we expect the accuracy of manual tasks to drop in a real emergency situation where the wheelchair has fallen and the user is injured. For speed, the implemented system proved notably faster, with most tasks automated and the only manual action (verbally calling for help) requiring a simple button press. Participants also reported greater comfort with the prototype, given its effortless operation, making it particularly accessible for individuals with cerebral palsy. Customizability was indeed a plus from the implemented system; encompassing the toggling of various crash detection sensors and predefined custom speech was just something unattainable through manual means. Overall, users favored our system design over their current manual setups that they use today. Recognizing its intended use in emergencies, participants found the system to be reliable and reassuring [Fig.10].

Furthermore, we conducted a **NASA TLX** exam to quantify the user's perceived workload across various factors . Users reported minimal mental and physical demands, attributed to the system's automatic execution of tasks. For the temporal demand, which measures time pressure of a given task, the users said that the system was rushed but viewed this aspect positively since they rather prioritize the system to act fast in an emergency. Users reported minimal effort as they did not need to put much work into doing the task, except for the initial setup. Finally, the participants reported very low frustration as they felt that it was much better than manually completing each of the tasks one after another [Fig.11].

All of the analysis charts are provided in Appendix C.

VII. REFLECTION

As a team, we learned about several difficulties wheelchair users face as it may not always be outright obvious. We continue to learn as not everyone is affected by cerebral palsy in the same way either. Collaborating closely with someone who provided first-hand insight has definitely proved instrumental in engineering this assistive technology. At the end, our collective efforts culminated in the development of an exceptional prototype capable of proficiently analyzing wheelchair crash incidents and providing prompt service.While the allure of a GUI application was tempting, we opted with hindsight to acknowledge the potential burden, for the patient, to maintain yet another application, let alone in the midst of an emergency. Having *surpassed* the initial benchmarks, we offer tailored technology that personally understands the user and requires least maintenance cost. The rest unfolds with subsequent plans of future work as the team is ready to take on the next milestone.

VIII. ACKNOWLEDGMENTS

Acknowledging Robert "Trey" Quinn for his invaluable support. Gratitude to Dr. Thad Starner [Tech Lead on Google Glass] for allowing us to take on this enriching endeavor of a project. In memory of late grandmother Shakunthala Gattu.

IX. REFERENCES

1. Abdulla, Raed & Balakrishnan, Arun & Faiyaz, Jahin. (2022). Development of an IoT-Based System in Detecting Heart Attack and Continuous Monitoring of Heartbeat. 6. 37.

2. Mishra, Prashant & Mistry, Shruti & Kumari, Meera & Trivedi, Vardhan & Ghonge, Pandharinath. (2023). Gesture Controlled Wheelchair with IoT Based Fall Detection. International Journal for Research in Applied Science and Engineering Technology. 11. 2406-2411. 10.22214/ijraset.2023.50095.

3. Shanmoon, R. & Shukla, A. N., 2017. Approaches toward Future UIoT Based Person/Wheelchair Fall Detection. International Journal of Computer & Mathematical Science, 6(12), pp. 26-27.

4. Shaheen, D., E.Himabindu, Sreenivasulu, D. T. & Rangasamy, D. R., 2018. An OoT Based System to Detect a Person/Wheelchair Fall. International Journal of Engineering & Technology, 7(6), pp. 735- 739.

5. Posugade, V. G., Shedge, K. K. & Tikhe, C. S., 2012. Touch-Screen Based Wheelchair System. International Journal of Engineering Research and Application (IJERA), 2(2), pp. 1245-1248

6. Seneviratne, P., 2018. Hand-On Internet of Thing with Blynk. In: P. Bisht, ed. Build on the power of Blynk to configure smart devices and build exciting IoT projects. Birmingham: Packt Publishing, p. 246

7. Moon, Nathan W., Paul MA Baker, and Kenneth Goughnour. "Designing wearable technologies for users with disabilities: Accessibility, usability, and connectivity factors." Journal of Rehabilitation and Assistive Technologies Engineering 6 (2019): 2055668319862137

8. World Health Organization. World Report on Disability, 2023

9. Varghese, Lijo Jacob, Suma Chinnasamy, Sundar I, Jacob. (2021). Design and Implementation of a Machine Learning Assisted Smart Wheelchair in an IoT Environment. 10.21203/rs.3.rs-490123/v1.

10. M. Mazo et al., "Wheelchair for physically disabled people with voice, ultrasonic and infrared sensor control", Autonomous Robots, Volume 2, Issue 3, pp. 203-224, 1995

11. Office of Equity, Diversity and Inclusion. (n.d.). City of Atlanta. [Online]. Available: https://www.atlantaga.gov/government/mayor-s-office/executive-offices/office-of-equity-diversi y-and-inclusion. Accessed: December 1, 2023.

12. Georgia Tech News Center. (2023, October 10). Atlanta Primed to Become U.S. Soccer Capital Ahead of 2026 World Cup. Georgia Tech News Center. [Online]. Available: https://news.gatech.edu/news/2023/10/10/atlanta-primed-become-us-soccer-capital-ahead-2026-world-cup. Accessed: December 1, 2023.

13. Yan, Linyang & Ko, Sun-Woo. (2021). In-tunnel Accident Detection System based on the Learning of Accident Sound. The Open Transportation Journal. 15. 81-92. 10.2174/1874447802115010081.

14. Samaneh Madanian, Talen Chen, Olayinka Adeleye, John Michael Templeton, Christian Poellabauer, Dave Parry, Sandra L. Schneider, Speech emotion recognition using machine learning — A systematic review, Intelligent Systems with Applications, Volume 20, 2023.

15. Du, Yu-yang & Zhao, Hai-yan & Zhao, Jing & Li, Hui & Zhou, Huai-jun. (2016). Research on Security Issues Based on CAN LAN. 10.2991/ameii-16.2016.59.

16. Luo, Zhen & Jiang, Fen. (2014). Research on Electronic Automotive Combined Instrument Based on CAN Bus. Advanced Materials Research. 998-999. 731-734. 10.4028/www.scientific.net/AMR.998-999.731.

17. Zimbelman EG, Keefe RF, Strand EK, Kolden CA, Wempe AM. Hazards in Motion: Development of Mobile Geofences for Use in Logging Safety. Sensors (Basel). 2017 Apr 10;17(4):822. doi: 10.3390/s17040822. PMID: 28394303; PMCID: PMC5422183.

18. K. D. Ballal, R. Singh, L. Dittmann and S. Ruepp, "Experimental Evaluation of Roaming Performance of Cellular IoT Networks," 2022 Thirteenth International Conference on Ubiquitous and Future Networks (ICUFN), Barcelona, Spain, 2022, pp. 386-391, doi: 10.1109/ICUFN55119.2022.9829590.

19. L. M. Broell, C. Hanshans, and D. Kimmerle, 'IoT on an ESP32: Optimization Methods Regarding Battery Life and Write Speed to an SD-Card', Edge Computing - Technology, Management and Integration. IntechOpen, Aug. 02, 2023. doi: 10.5772/intechopen.110752.

20. Imran, Mohamed & Mohamed, Noor. (2013). E-Paper Displays:A Case Study.

21. Alshutbi, Eman & Bahbry, Doaa. (2021). Heart Rate Monitoring System Using Pulse Sensor and Arduino. 10.13140/RG.2.2.35406.18243.

22. Fuzzy Logic Based Perceptual Image Hashing Algorithm in Malaysian Banknotes Detection System for the Visually Impaired - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/DFPlayer-Mini-MP3-Player-and-5Ohm-speaker$_{f}ig4_{3}52188662[accessed13Dec,2023]$

23. Espinoza, Elizabeth & Carpio, Erich & Andrade-Arenas, Laberiano. (2021). Immediate Notification of Traffic Accidents through a Mobile Application. 10.20944/preprints202112.0490.v1.

24. Adedeji, Mariam. (2023). The Positive Impact of Apple Watch Fall Detection on Elderly Health and Mobility. 10.13140/RG.2.2.25749.70886.

APPENDIX A

Legend

Rectangle = Action : Circle = Sensors : Diamond = Decision

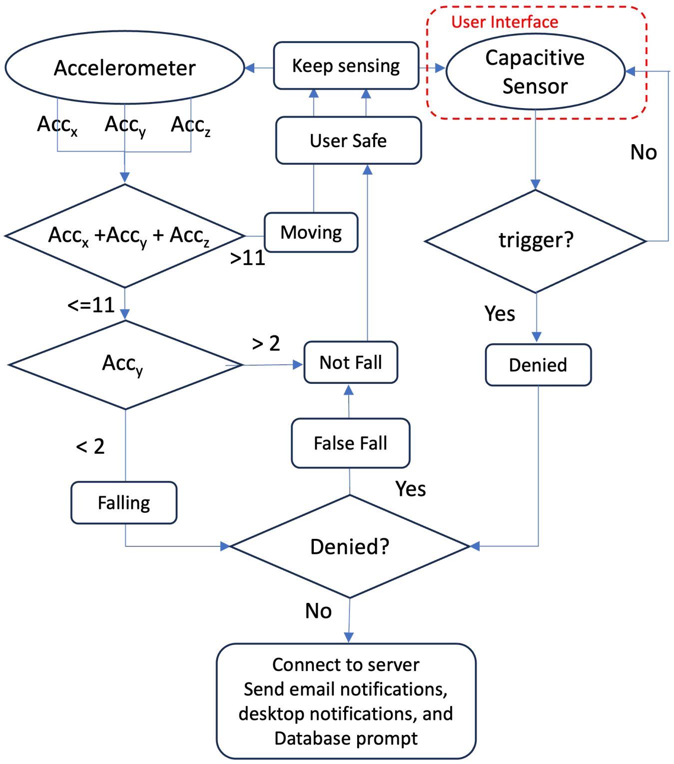

Fig. 1. Gold Care System Flowchart

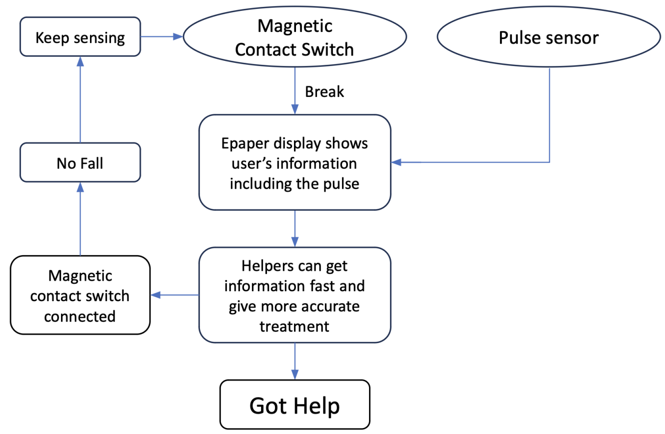

Fig. 3. Bronze Care System Flowchart

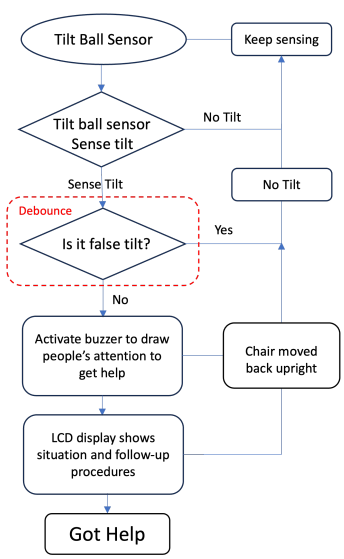

Fig. 2. Silver Care System Flowchart

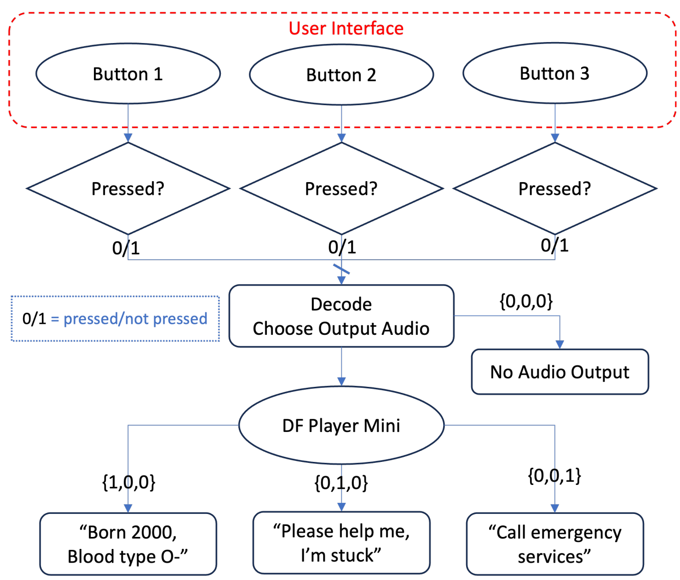

Fig. 4. User Interface Flowchart

APPENDIX B

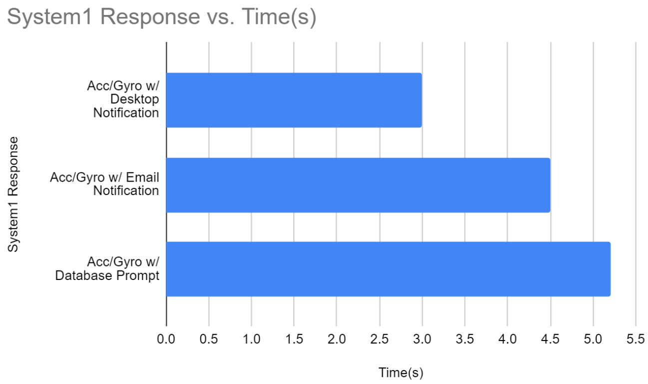

Fig. 5. Gold Care System Response Time

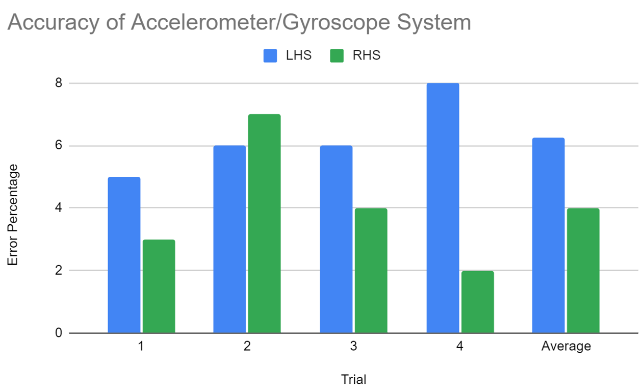

Fig. 6. LHS vs RHS Error Control

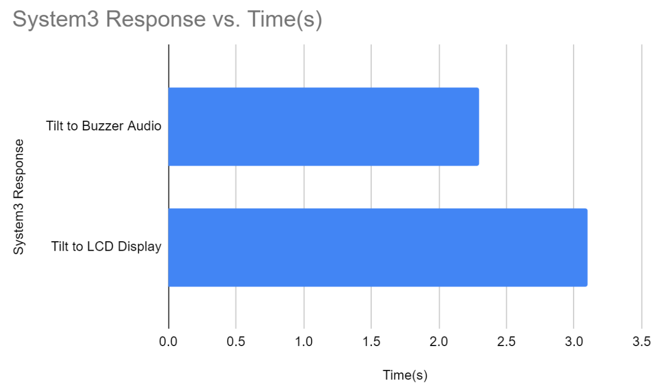

Fig. 7. Silver Care System Response Time

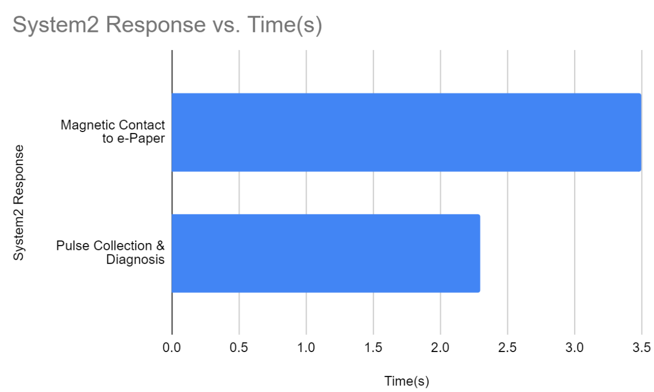

Fig. 8. Bronze Care System Response Time

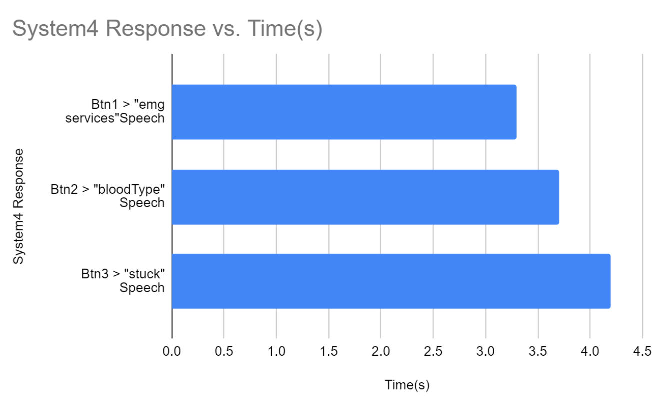

Fig. 9. Speaker Speech Response Time

APPENDIX C

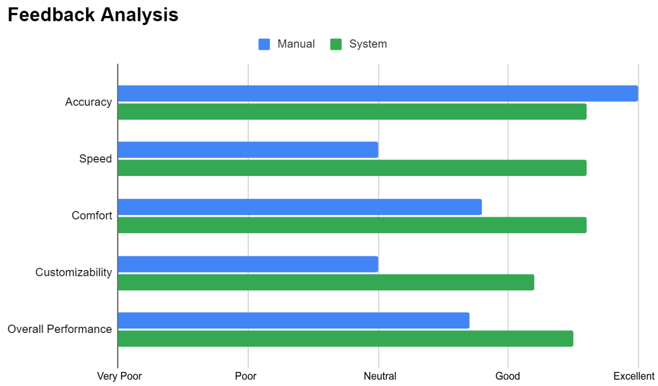

Fig. 10. Chart depicting feedback analysis from members of ABLE Alliance.

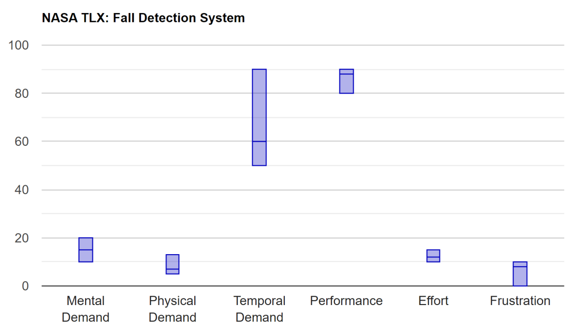

Fig. 11. NASA Task Load Index (TLX) scale on examiners.