Application of Omnidirectional Haptic Feedback on Collision Warning System Using Open Source Computer Vision for Visually Impaired

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Abstract - The goal of this study was to investigate how to develop and test a haptic based collision warning device supported by machine learning for object detection. This study evaluated the performance of a developed model by conducting manual tests to measure its accuracy, precision, and recall. The testing involved thirty (30) photos for each of the thirteen (13) classes incorporated in the model. Additionally, the study examined the variation in detection under two different thresholds: five (5) and seven (7). This research study evaluated the hardware aspect of a device using two methods. Firstly, an evaluation form was administered to eight (8) participants, covering five parameters: Functionality, Reliability, Efficiency, and Maintainability. Secondly, the study conducted real-time testing of the vibration motors at various distances of the object from the device to assess its performance. This research study found that the accuracy, precision, and recall of a trained model are significantly affected by the quality and quantity of images used for training. Specifically, the testing revealed that the device's ability to detect various objects is reliant on the threshold set on the device. These findings underscore the importance of using high-quality images during training to improve the performance of object detection models.

The developed model can effectively perform object detection tasks with high accuracy, precision, and recall. Choosing an appropriate threshold is crucial for collision warning systems that incorporate machine learning, as a higher threshold may decrease detection rates. Haptic-based collision warning systems can alert users to upcoming obstacles by utilizing various vibration patterns based on the object's distance, offering valuable insights for the development of haptic feedback collision warning systems.

Keywords: machine learning, collision warning system, visually impaired, tensorflow lite, open source computer vision, python programming, arduino uno, raspberry pi, frames per second

I. INTRODUCTION

Each person requires vision because they rely on their eyes to see and understand the world around them. Globally, at least 2.2 billion people have a near or distance vision impairment according to World Health Organization (2022). In contrast to blindness, visual impairment usually means that the person has some residual sight, also referred to as low vision (Schelin et al., 2021). People with visual impairments traditionally rely on low-cost methods like a white cane or guide dogs, but these methods have limitations. These individuals are often dependent on others to perform daily tasks and require assistance to improve their quality of life.

Pachodiwale (2021), presented a research entitled Viva: A Virtual Assistant for the Visually Impaired which is a Android-based navigation system that provides haptic and voice navigation assistance by detecting obstacles in the user's surroundings and calculating the potential risk.

However, this method causes some individuals to lose focus while listening to the audio-based signals. In response to this issue, the researchers developed a haptic-based system that uses haptic feedback to provide collision warnings for the visually impaired. This system aims to improve the user experience by reducing the cognitive workload and avoiding the negative health effects caused by ambient noise. Moreover, study will use an Open Source Computer vision library and TensorFlow lite for machine learning model creation, training, and deployment.

1.1 STATEMENT OF THE PROBLEM

The general problem of the study is how to develop a haptic-based collision warning system using Open Source Computer Vision for the visually impaired. Moreover, this research intends to answer the following questions:

1. How to develop real-time multiple object tracking using Open Source Computer Vision?
2. How to design a haptic-based collision warning system?
3. How to conduct a software system test design for haptic-based collision warning system that covers:
   3.1. accuracy;
   3.2. precision;
   3.3. and recall?
4. How to evaluate a hardware system evaluation for haptic-based collision warning system that covers:
   4.1. functionality;
   4.2. reliability;
   4.3. efficiency;
   4.4. and maintainability?

II. RESEARCH METHODOLOGY

This chapter presents the methods and techniques that will be utilized in the study, which included the development of the system and its evaluation. This chapter also covers the population and sample of the study, the research instruments that will be used, the data collection procedure, and the data processing and statistical treatment that will be used for the conduct of the study.

2.1 METHODS AND TECHNIQUES OF THE STUDY

The researchers will use two different methodology models to develop and establish each of the outcomes. For the software system, the researchers will utilize Agile Software Development for this study. Agile Software Development is a simple strategy that was presented to get beyond the drawbacks of established development approaches, cut costs and overhead, and provide flexibility to accommodate requirement changes at any point. This is accomplished by controlling the tasks and coordinating their completion using a particular set of values and principles. (Al-Saqqa et al., 2020). In comparison to the traditional methods, Agile is more efficient for small and medium projects and is short-term for designing certain functionalities, which is why the researchers chose this methodology in this study.

The Prototype Model will be implemented by the researchers for the hardware system of this study. A prototype is built to understand the whole scope of study as well as its benefits to the user. This prototype was fit based on the currently known requirements. By using this model, the researchers can have fast feedback from the respondents from Calumpit. Bulacan (Kute, 2014).

The researchers aim to utilize quantitative research to treat the data that will be gathered from the participants. Through the investigation of numerical patterns, a variety of methodologies, techniques, and presumptions are utilized in quantitative research to explore psychological, social, and economic phenomena. A variety of numerical data is collected (Coghlan & Brydon-Miller, 2014).

Quantitative research uses scientific inquiry to address questions about the sample population using data that are observed or measured (Allen, 2017). This quantitative research will develop a more efficient collision warning system for the visually impaired which will have improved responsiveness and adapting to its surrounding environment by applying omnidirectional haptics for efficiency in obstacle location and estimation. The researchers need to evaluate if this technology will be a beneficial contribution and has the capability to be deployed to the public.

2.2 PROJECT AND DESIGN DEVELOPMENT

2.2.1 Software Design and Development

The researchers will only utilize the first four (4) phases of Agile software development since this development focuses on the system software. The process does not include the deployment and review phases, and it will proceed to the integration of hardware development.

Requirements: The first phase in Agile development in which the researchers will break the requirements of the project into small pieces as per the request of the end users. With the help of each user's stories, the researchers will have an insight about primary features required by the end-users.

Design: The second stage will revolve around the designing of the device needed to be accomplished during this software development. Including the illustrations for each software, training of data and determining what programming language should be used in order to construct and build the software.

Development: After gathering the users' background, the researchers will establish relationships amongst the users' backgrounds and determine whether some users can be grouped together. And then, the researchers will prioritize the development of the requirement as per the level of importance.

Testing: The researchers will execute the testing process using regression testing. This Agile test phase will provide the researchers a regular reflection on how the device will become more effective. Moreover, Agile testing ensures that the final device meets the required expectations by providing frequent feedback.

2.2.2 Hardware Design and Development

For hardware development, a prototype or initial version of the device is built and tested to determine its functionality, reliability, efficiency and maintainability.

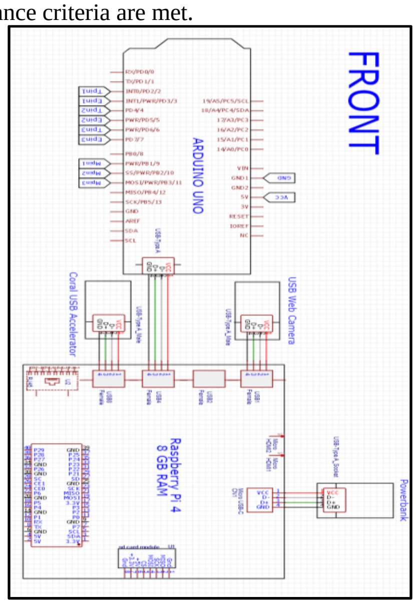
Prototype Construction: The creation of a functional prototype is an important phase in the development of a system or technology. Its main goal is to evaluate and improve the hardware's design, reliability, and performance prior to development. This phase typically comprises several stages, such as conceptualizing the design, planning the construction process, selecting the appropriate materials, and physically building the prototype.

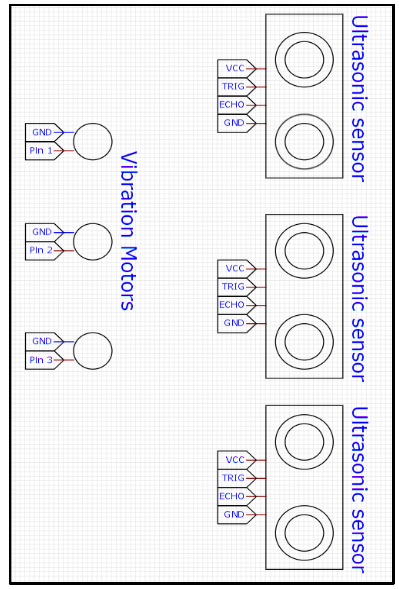
Design: The success of a device or technology heavily relies on its design during the evaluation phase. The design should satisfy the set evaluation criteria and should be both efficient and aesthetically pleasing. At this phase, designers should communicate with stakeholders and users to gather feedback on the device's design and adjust it accordingly. Iterative refinement is necessary to ensure that the design meets the required specifications and can meet the users' needs. A device that fulfills the evaluation criteria and has a well-designed appearance is more likely to meet the needs of its users.

Coding: Coding is a critical aspect of the evaluation phase as it ensures that the system or technology functions correctly. The code should be optimized for efficiency, maintainability, and ease of comprehension. Software developers may perform rigorous testing during this phase to detect and resolve any glitches or problems within the code. Collaboration with designers is also necessary to ensure that the code adheres to the device's design and user experience. The effectiveness of coding is paramount in producing a successful system or technology that meets evaluation standards and fulfills user needs.

Testing: Testing is a critical element of the evaluation phase as it confirms that the system or technology satisfies the defined criteria. The testing process involves analyzing the device's efficiency, user-friendliness, and functionality to recognize any errors or flaws that necessitate rectification. The researchers will use different approaches, including user acceptance testing and regression testing to assess the device's performance. This process is necessary in ensuring that the system satisfies the requirements of its target users and is of high quality. To obtain end-user input, the researchers will conduct a trial on the finished device in Calumpit, Bulacan. The system will be assessed by the visually-impaired people from the evaluation form they will answer after testing the device. The researchers will compile the data from the users' evaluation.

Maintenance: is a vital aspect of the evaluation phase and requires continuous support and upkeep of the system or technology. The researchers' effort is necessary to detect any issues or defects in the system. To improve performance and address any identified issues, updates or patches may be developed during this phase. Proper maintenance is critical in ensuring that the hardware device remains usable and relevant to its users, which can prolong its lifespan. Additionally, the system's success is highly dependent on proper maintenance, as it ensures that it continues to satisfy the needs of its users. After the testing, the researchers will re-evaluate the system based on the end-user's feedback. Also, the researchers will determine if the acceptance criteria are met.





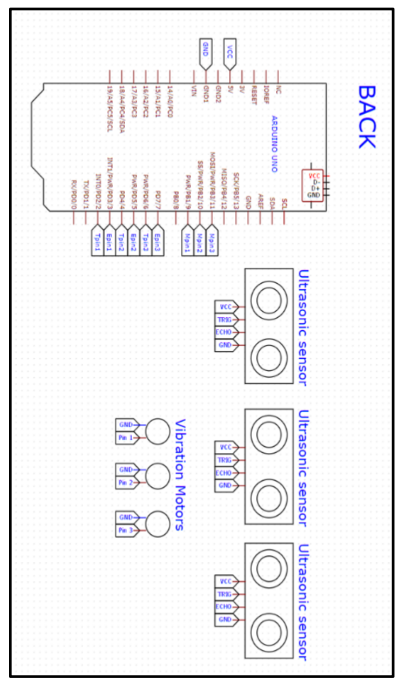


Figure 1 Schematic Diagram for Application of Omnidirectional Haptic Feedback on Collision Warning System Using Open Source Computer Vision for Visually Impaired

2.2.3 Integration of Software and Hardware

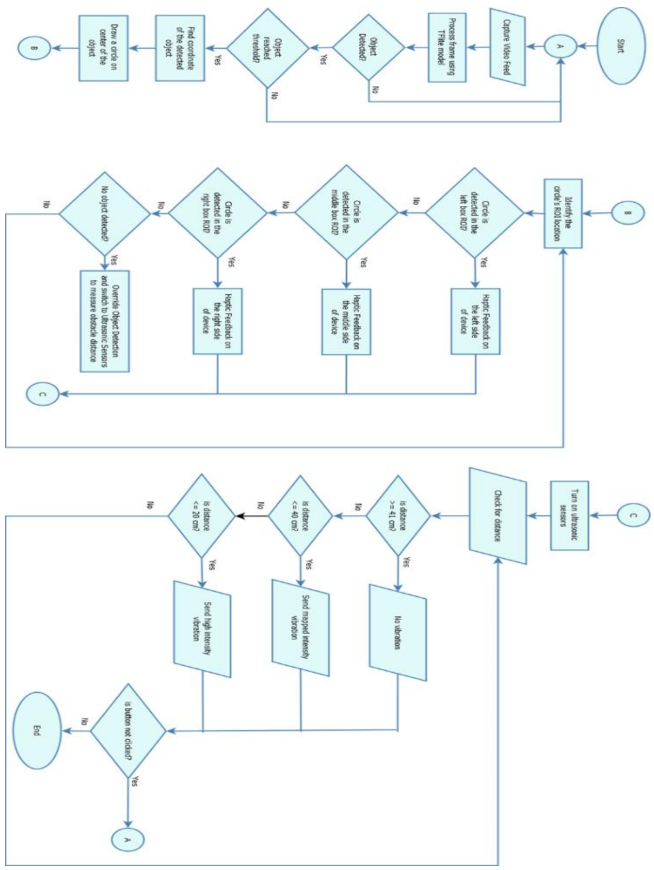


Figure 2 Flowchart of Application of Omnidirectional Haptic Feedback on Collision Warning System Using Open Source Computer Vision for Visually Impaired

The system was designed to provide a collision warning system that is specifically designed to assist visually impaired individuals in navigating their surroundings safely and independently. It will utilize a camera to capture video feed of the surroundings and analyze it in real-time to detect any obstacles that may be in the user's path. Once an obstacle or hazard is detected within a certain proximity, the system will activate a set of vibration motors that are strategically positioned on the user's body. These vibration motors will provide tactile feedback to the user, alerting them to the presence of the obstacle and allowing them to take the necessary evasive action to avoid a collision. This system is designed to be highly effective and reliable, providing the user with an accurate and timely warning of potential obstacles in their path.

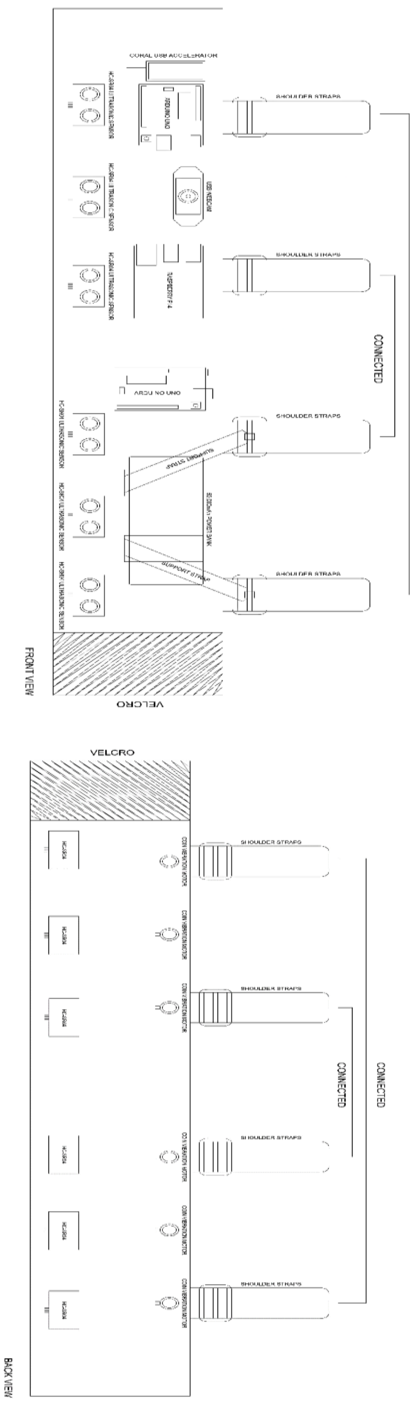


Figure 3 Prototype of Application of Omnidirectional Haptic Feedback on Collision Warning System Using Open Source Computer Vision for Visually Impaired

After completing the schematic diagram, the researchers gathered all the necessary materials and components for both systems and assembled them to create the prototype, which is depicted in Figure 4.

Figure 4 Final Prototype Output

III. RESULTS AND DISCUSSION

The researchers created a spreadsheet containing all the images they needed to test the accuracy, precision, and recall percentage of their custom Tensorflow Lite model. The researchers used a 0.5 threshold for the confidence level of their object detection and they collected 30 images per class of dataset. There are thirteen (13) classes in the dataset included in their model, these are; 1) stairs; 2) extinguisher; 3) chair; 4) signage; 5) door; 6) trashcan; 7) person; 8) shelves; 9) potted plant 10) motorcycle; 11) pillar; 12) post; and lastly, 13) car.

The researchers used two thresholds 0.5 and 0.7 in order to differentiate the advantages and disadvantages of those given parameters. The researchers initialize the testing with a 0.5 threshold to obtain the data of the system and the results show that it has a higher chance of multiple object detection however it leads to unwanted vibrations. They also test the device with 0.7 threshold to acquire the results of the system, the results shows that 0.7 threshold has a precise multiple object detection for safer navigation.

In comparison, the result from the 0.5 threshold has a higher percentage of object detection with 69% than the result from the 0.7 threshold with 54% object detected. In addition, the 0.5-threshold real-time testing result has a higher percentage of vibration intensity with 79% while the 0.7-threshold real-time testing result has 74% of vibration intensity.

Moreover, the back-side of the device had a passing rate of 87% for vibration, with a total of 26 counts, while the failed rate had 14% with 4 counts in real-time testing.

Based on the conducted study, the collision warning system was evaluated by visually impaired individuals who provided feedback through an evaluation form. The system's functionality received a high score with a general weighted average of 4.73 out of 5, while the reliability also received a high score with a general weighted average of 4.68, indicating strong agreement. The device's overall reliability achieved a general weighted average of 4.68, while efficiency received a general weighted average of 4.75, and all of its individual factors received a score of strongly agree, with the highest general weighted average of 4.88 and the lowest of 4.63. The results of the evaluation for maintainability were also presented, with the fourth parameter receiving a score of agree with a general weighted average of 4.38, while the remaining parameters received a score of strongly agree, with the highest weighted average of 4.88.

IV. CONCLUSION

Getting around safely without running into objects can be difficult for those people who have visual impairment. Those with good central vision but fading or lost peripheral vision are particularly vulnerable since they haven't been trained to be vigilant for incoming risks they cannot notice. This study was aimed to develop a collision warning system using omnidirectional haptic feedback supported by machine learning for object detection in the purpose of helping those people who have visual impairment as well as determining the effectiveness of using vibration as feedback for a collision warning system.

However, there are several limitations to this study. For example, the system's object detection can only distinguish a total of twelve (12) images or obstacles. The amount and types of images used to train that model, have a significant impact on its accuracy, precision, and recall, as shown in Table 4.2. Furthermore, the model cannot be trained to assist the user into navigating stairs, and the system cannot detect any additional obstacles that are not included in the model. The hardware portion of this study was proven to be functional, dependable, efficient, and maintainable based on the results, which reveal that participants were satisfied with their assessment scores interpretation, which was strongly agreed as shown in chapter 4 of this study. Moreover, the researchers concluded that using 0.5 threshold on the object detection model will make the device responsive through vibration rather than utilizing a 0.7 threshold. This makes the device effective and efficient in navigation for visually impaired since it will react to any detected obstacle.

All in all, the researchers were able to implement Omnidirectional Haptic Feedback on Collision Warning System Using Open Source Computer Vision for Visually Impaired. This study also demonstrated that haptic feedback is an excellent collision warning method.

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