Journal of Innovative Technology Convergence
Vol. 6, No. 3 September 2024, pp. 51-66
https://doi.org/10.69478/JITC2024v6n3a06

A Modified Cane for the Blind using Computer Vision

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Abstract: This study aimed to develop "A Modified Cane for the Blind using Computer Vision" that can detect possible objects and obstacles from the surroundings. A collection of a large image dataset to develop a model has been divided into three (3) datasets with the ratio of 70% for training, 20% for validation, and 10% for testing. The model was used for a mobile application to detect objects from the surroundings. A series of designs for a mobile application and a modified cane were created until the final prototype was made. The ultrasonic sensors, micro-controllers, and other electronic components were connected and tested for effectiveness and accuracy. The final prototype of a modified cane and the mobile application were combined to create a system called "a modified cane for the blind using computer vision." The effectiveness of the system was evaluated by five (5) IT experts and five (5) blind persons in terms of functional suitability, reliability, performance efficiency, usability, security, compatibility, maintainability, portability, and the overall result with a mean of 4.46. The results of the evaluation show that the overall mean was "Excellent." This implies that the system is effective and meets ISO 25010 standards in terms of software quality.

Keywords: Computer vision, Ultrasonic sensor, Object detection, Modified cane

1. Introduction

Computer vision has gone through significant advancements over the last few years. These advancements have not only made a great impact in the field of computer science but also in other fields such as medicine, space exploration, security or surveillance systems, and visual impairment [1].

According to the Department of Health (DOH), an estimated 2.2 billion people around the world suffer from vision impairment [2]. Yet the first World Health Report on Vision, recently published by the World Health Organization (WHO), reveals that half of them, or about 1.1 billion, do not receive the care they need for conditions like near and farsightedness, glaucoma, and cataracts [3].

Based on the 2018 Philippine National Blindness Survey and Eye Disease Study conducted by the Philippine Eye Research Institute of the National Institute for Health, vision impairment and blindness

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Received [June 14, 2024]; Revised [July 31, 2024]; Accepted [August 15, 2024]

Published by InnoCon Publishing
ISSN 2704-4440

rank among the major concerns in the country with a current prevalence rate of 1.98%. This represents 1.11 million Filipinos with cataracts, 400,000 with uncorrected error of refraction, almost 300,000 with glaucoma, and 200,000 with maculopathy. Additionally, there are over 4 million Filipinos living with undiagnosed eye problems that need to be addressed [2].

In connection with the problem concerning blind people, the government has not yet provided any solutions to the growing number in the country. So, in response to the Department of Health and the World Health Organization's desire to help blind individuals, this study aims to develop "a modified cane for the blind using computer vision" that would enable the user to visualize their surroundings through their smartphone camera, identify possible objects from the surroundings, and alert them ahead of whatever obstacle is detected.

2. Literature Review

2.1 Computer Vision

Computer vision is extracting data from digital images and understanding the data from images using an algorithm [4]. The first step in solving a computer vision problem is to grasp the idea of how human vision functions. Via the iris, the human eyes gather light, which is then projected onto the retina. From there, neurons in the nerve cell carry the signal to the brain. In computer vision, the camera records images in the same way that the human eye does and then converts them into computer-readable pixels.

The pixels from the images can be used as a pattern that will determine the kind of output that will be identified. It is important to determine the concept of images and how they work to extract into a meaningful value that will be processed by the computer and the data of a captured image to train a neural network. This prime step enabled the researcher to understand the concept of brain function applicable in computer vision applications.

An Artificial Neural Network (ANN) is a machine learning algorithm approach inspired by how the human brain works and is an attempt to mimic it [5]. Artificial neural networks are the collection of artificial neurons. The perceptron's are layers with connections between layers. The simple ANNs are called feedforward networks, with an input layer followed by a series of hidden layers and finally an output layer. feedforward refers to the fact that the neurons of a layer are only connected to the following layer and that the connections are one-directional.

Every edge of a neural network has a corresponding weight, which determines the amount of influence by the source neurons over the destination of the other neurons. The weights are adjusted during the training phase of a network. The network has initial weights, commonly set to random digits or taken from another pre-trained model on a different problem. This is known as transfer learning. This is the type of problem where the networks are given an input, such as an image, and are tasked with determining what the image represents. One way to classify input is through supervised learning, where the dataset has user-predefined input and output pairs that the network learns from. The known output is often referred to as ground truth. To be able to evaluate the performance of a model, this dataset is split into three: one for training, one for validation, and one for testing. This is because one wants to test the model on data that is unseen by the model.

2.2 Ultrasonic Sensor

The ultrasonic sensor is an electronic device used to measure distances [6]. Ultrasonic sensors are used as proximity sensors. This sensor can be found in parking technology, and anti-collision safety systems, or obstacle detection systems. Ultrasonic sensors are less susceptible to interference from smoke, gases, and other airborne particles [7].

The transmitter of the ultrasonic sensor triggers a signal and propagates the signal back to the receiver. The sound frequencies of this sensor cannot be heard because this is above 20 kHz and the object that can be detected, including solids, liquids, and powders. This sensor can reliably detect a solid, transparent, or glossy object [8].

3. Methodology

The evolutionary prototyping model [9] was used in a software development life cycle (SDLC) as a guide to build the system. It is a software development method where the developer or development team first constructs a prototype. After receiving initial feedback from the customer, subsequent prototypes are produced, each with additional functionality or improvements, until the final product emerges.

3.1 System Architecture

Figure 1 shows the system architecture.

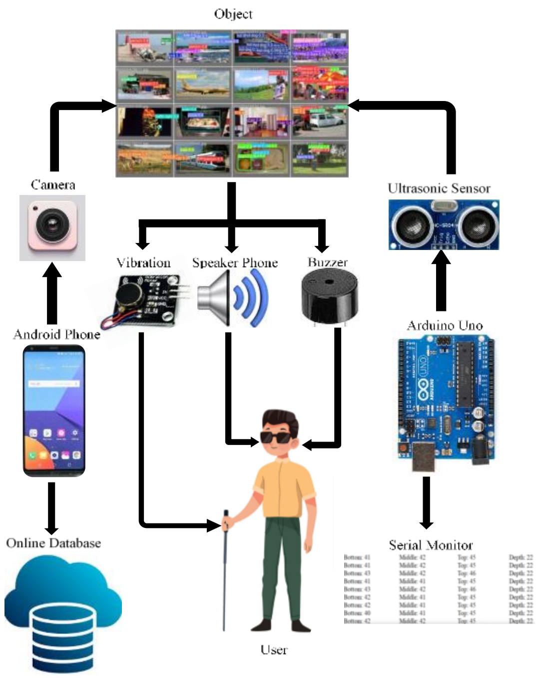

Figure 1. System Architecture

The process starts at the top image, which is the object. An object is anything like a plant, animal, human, or any physical structure that can be seen and touched by a human. At the right, the ultrasonic sensor emits a sound pulse that propagates at the speed of sound through air until the sound pulse encounters an object. The sound pulse bounces off the object and is returned in reverse to the sensor where this echo is received. The vibration motors, buzzer speaker, then turn on to alert the user with any possible obstacle. The mobile phone camera captures the video live stream to be processed by the machine learning algorithm that will detect possible objects identified by putting a bounding box of a detected object. The text-to-speech conversion is used as a tool to convert the labeled object inside the bounding box during operation and produce an audio output through the speaker of the phone. The location of the user is sent to the cloud database by recording the motion of the user, which will then be used for tracking their location through Google Maps. A serial monitor is used to display the output of a sensor value and the distance value in centimeters.

3.2 Design Specification

Figure 2 shows the schematic diagram of the modified cane design specification.

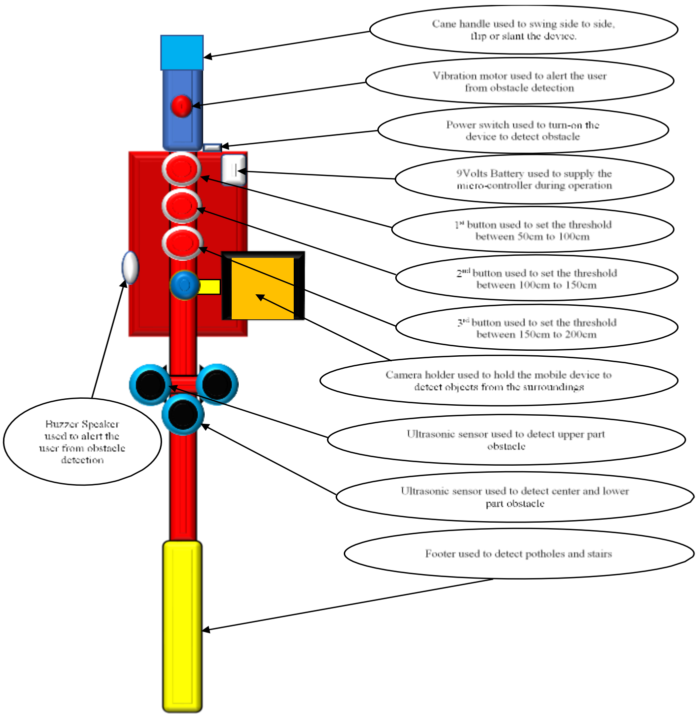

Figure 2. Design Specification

On the upper part of the modified cane is the handle, where the user can swing side to side, tilt, or slant the device according to their liking. The vibration motor and the buzzer sound are used to alert the user once an obstacle is detected. The user can feel the vibration from the handle during operation. The default threshold of the ultrasonic sensor is between 2 and 50 cm upon turning on the power switch. The first button indicates the threshold value between 50 and 100 cm once the button is pressed by the user. The second button indicates the threshold value between 100 and 150 cm, and the third button indicates the threshold value between 150 and 200 cm. The camera holder used to handle a mobile device that has an application to detect objects from the surroundings that provides audio sound to the user once the object is identified. Ultrasonic sensors from the upper part are used to detect obstacles above the body waistline of the user, and the sensor of the lower part detects obstacles at the center. The footer of the cane detects potholes and stairs.

3.3 Testing and Evaluation

To test the accuracy of the system that can detect objects in the surroundings, the F- measure was used. It was tested using 82 classes of different sample images. The precision (*P*), recall (*R*), and F1 score were used in this study.

Precision (*P*) is a model evaluation and performance metric that corresponds to the fraction of values that actually belong to a positive class out of all the values that are predicted to belong to that class. Precision is also known as the positive predictive value (PPV).

The formula of precision is depicted in equation 1.

$$P = \frac{Number\ of\ True\ Positive\ (TP)}{Number\ of\ True\ Positive (TP) + Number\ of\ False\ Positive\ (FP)} \tag{1}$$

Recall (*R*) is a model evaluation and performance metric that corresponds to the fraction of values predicted to be a positive class out of all the values that truly belong to the positive class (including false negatives). The formula for recall is depicted in equation 2.

$$R = \frac{Number\ of\ True\ Positive\ (TP)}{Number\ of\ True\ Positive\ (TP) + Number\ of\ False\ Negative (FN)} \tag{2}$$

The F1 score combines both precision and recall and symmetrically represents them via a harmonic mean. The F1 score integrates precision and recall into a single metric to gain a better understanding of model performance. The formula for the F1 score is depicted in equation 3.

$$F1\ score = 2 \times \frac{(Precision \times Recall)}{Precision + Recall} \tag{3}$$

3.4 Data Gathering Instrument

A standard ISO 20510 questionnaire was adopted and prepared by the researcher and distributed to the five (5) IT experts and five (5) blind persons for the system's evaluation. To interpret the scores, the five-point Likert scale was used, as indicated in Table 1 [10].

Table 1. Five-Point Likert Scale

Range	Descriptive Rating
4.21 – 5.00	Excellent
3.61 – 4.20	Very Good
2.61 – 3.60	Good
1.81 – 2.60	Fair
1.00 – 1.80	Poor

3.5 Data Analysis Procedure and Statistical Treatment

The weighted mean was used as the statistical formula to determine the result of the evaluation. The result was tabulated using the Statistical Package for the Social Sciences (SPSS) software.

4. Results and Discussion

4.1 Mobile Application Tested on 82 Classes of Sample Images

The accuracy of the system was tested using the precision, recall, and F1 scores. Table 2 denotes the 82 classes of sample images used to test the accuracy of the model using a mobile application.

Table 2. 82 Classes of Sample Images Tested on Mobile Application

No.	Test Images	Detection Percentages	Precision/Recall
1	Airplane	56.59	True positive
2	Apple	65.96	True positive
3	Backpack	45.92	True positive
4	Banana	85.89	True positive
5	Baseball Bat	58.75	True positive
6	Baseball Glove	87.89	True positive
7	Bear	87.25	True positive
8	Bed	65.09	True positive
9	Bench	62.55	True positive
10	Bicycle	89.04	True positive
11	Bird	89.74	True positive
12	Boat	83.89	True positive
13	Book	56.80	True positive
14	Bottle	65.01	True positive
15	Bowl	75.34	True positive
16	Broccoli	82.69	True positive
17	Bus	73.69	True positive
18	Cake	76.01	True positive
19	Car	93.44	True positive
20	Carrot	52.07	True positive
21	Cat	76.76	True positive
22	Cell Phone	79.56	True positive

23	Chair	78.87	True positive
24	Clock	74.26	True positive
25	Couch	64.30	True positive
26	Cow	88.08	True positive
27	Cross Walk		False negative
28	Cup	74.89	True positive
29	Dining Table	60.62	True positive
30	Dog	80.17	True positive
31	Donut	93.28	True positive
32	Elephant	90.78	True positive
33	Fire Hydrant	92.61	True positive
34	Fork	74.89	True positive
35	Frisbee	53.24	True positive
36	Giraffe	94.55	True positive
37	Hair Drier		False positive
38	Handbag	60.40	True positive
39	Horse	93.00	True positive
40	Hot dog	56.24	True positive
41	Keyboard	64.53	True positive
42	Kite	85.65	True positive
43	Knife	88.09	True positive
44	Laptop	60.94	True positive
45	Microwave	54.01	True positive
46	Motorcycle	77.00	True positive
47	Mouse	71.75	True positive
48	Orange	69.33	True positive
49	Oven	82.19	True positive
50	Parking Meter	64.56	True positive
51	Person	91.25	True positive
52	Pizza	79.88	True positive
53	Potted Plant	73.09	True positive

54	Refrigerator	62.89	True positive
55	Remote	85.80	True positive
56	Sandwich	68.56	True positive
57	Scissors	83.88	True positive
58	Sheep	90.80	True positive
59	Sink	82.09	True positive
60	Skateboard	69.15	True positive
61	Skis	85.88	True positive
62	Snowboard	62.50	True positive
63	Speed Limit	67.58	True positive
64	Spoon	82.48	True positive
65	Sports Ball	61.78	True positive
66	Stop Sign	92.14	True positive
67	Suitcase	66.94	True positive
68	Surfboard	66.40	True positive
69	Teddy Bear	76.64	True positive
70	Tennis Racket	71.95	True positive
71	Tie	85.35	True positive
72	Toaster		False positive
73	Toilet	83.13	True positive
74	Toothbrush	54.16	True positive
75	Traffic Light	81.16	True positive
76	Train	70.41	True positive
77	Truck	65.27	True positive
78	TV	58.30	True positive
79	Umbrella	80.51	True positive
80	Vase	94.21	True positive
81	Wine Glass	89.73	True positive
82	Zebra	91.13	True positive

To calculate the accuracy in precision (equation 1), the number of true positives is 79 divided by 79 of true positives plus 2 false positives, which results in a total of 97.53% accuracy. To calculate recall, equation 2 was applied except that false negative was used, where false negatives are the ground truth objects that should have been detected by the model but were not.

$$Precision = \frac{\text{No. of True Positive}}{\text{No.of True Positive+No.of False Positive}}$$

$$= \frac{79}{79+2} \quad = \frac{79}{81} \quad = 97.53\ \%$$

$$Recall = \frac{\text{No. of True Positive}}{\text{No.of True Positive+No.of False Negative}}$$

$$= \frac{79}{79+1} \quad = \frac{79}{80} \quad = 98.75\ \%$$

To calculate the F1 score, equation 3 is used to determine the precision and recall are now combined to get the results.

$$F1 = 2\ \times \frac{(\text{Precision} \times \text{Recall})}{\text{Precision+Recall}}$$

$$F1 = 2\ \times \frac{(97.53 \times 98.75)}{97.53 + 98.75} = 2\ \times \frac{(9631.0875)}{196.28} = 2\ \times\ 49.0681\ = 98.14\ \%$$

The result of the calculation was 98.14%, which is the F1 score, which means that the model has the highest accuracy using the mobile application.

4.2 Summary Evaluation of five (5) IT Experts and five (5) Blind Persons using ISO 25010 Standard Criteria

The following are the discussions on the interpretation results by the five (5) IT experts and five (5) blind persons based on the ISO 25010 Software Quality Standards to test its conformance to the international standards in terms of its functional suitability, reliability, performance efficiency, usability, security, compatibility, maintainability, and portability.

Table 3 shows the summary of evaluation results by the five (5) IT experts based on the ISO 25010 Standards in terms of functional suitability, which has an overall mean of 4.40, which is interpreted as "Excellent." The perception of the IT experts about the system based on ISO 25010 standards in terms of functional suitability showed that functional completeness, which covered the system's set of functions covering all the specified tasks and user objectives, was rated with a mean of 4.60; functional correctness, which was about the system providing the correct results with the needed degree of precision, was rated with a mean of 4.20; and functional appropriateness, wherein the system's function facilitates the accomplishments of specified tasks and objectives, was rated with a mean of 4.40. All three requirements were satisfied with a rating of M = 4.40, indicating that the system was interpreted as "Excellent." This implied that the system has remarkable functional completeness and correctness in the detection of objects from the surroundings and obstacles ahead. However, the system's functionality depends on the angle of the device, such as a camera. The camera should be oriented in such a way that it will be parallel to the object that is being detected, and it should have to be aligned with the object.

Table 3. Summary of Evaluation Results of the Five (5) IT Experts

ISO 25010 Criteria	Mean	Interpretation
Functional Suitability	4.40	Excellent
Reliability	4.70	Excellent
Performance Efficiency	4.53	Excellent
Usability	4.60	Excellent
Security	4.60	Excellent
Compatibility	4.20	Very Good
Maintainability	4.52	Excellent
Portability	4.60	Excellent
Grand Mean	4.52	Excellent

The perception of the IT expert's respondents about the system based on ISO 25010 standards in terms of performance efficiency has an overall mean of 4.53, which was interpreted as "Excellent." The time behavior had a mean of 4.80 and resource utilization had a mean of 4.60, indicating that the system was interpreted as "Excellent." The capacity of the system, which was about the maximum limits of a product or system parameter that meet the requirements, was rated with a mean of 4.20, which was interpreted as "Very Good." This means that the system has conformed to the performance efficiency standard set by the ISO. The results imply that the system could perform its required functions efficiently and meet the user's required standards. However, the system's performance efficiency depends on several factors, such as the orientation of handling the device; it should be parallel to the object so that the ultrasonic sensor is effective even for a small object that can be detected.

The perception of the IT expert's respondents about the system based on ISO 25010 standards in terms of compatibility has an overall mean of 4.20, which was interpreted as "Very Good." This is the standard criterion to which a product, system, or component can exchange information with other products or system components and/or perform its required functions while sharing the same hardware or software environment. When a system has this feature, it implies it can do dual or multiple courses of actions and functions at the same time. It also signifies that the user has the opportunity to perform several tasks that might be interrelated or correlated with other functions. The category on co-existence, in which the system can perform its required functions efficiently while sharing a common environment and resources with other products without detrimental impact on any other products, was rated with a mean of 4.00, which is interpreted as "Very Good." The category on interoperability, in which the system can exchange information and use the information that has been exchanged, has a mean rating of 4.40. The result implies that the high compatibility features of the system proved that it was able to perform well regardless of the availability of an Internet connection. Without such, the device can function, and the user can still use the device without any problems or interruptions.

The perception of the IT expert's respondents about the system based on ISO 25010 standards in terms of usability has an overall mean of 4.60, which was interpreted as "Excellent." The category on appropriateness recognizability of which the users recognize the appropriate need of the system was rated with a mean of 4.80. The category on learnability, in which the users can use the system with effectiveness, efficiency, freedom from risk, and satisfaction in a specified context of use to achieve specified goals of learning, was rated with a mean of 5.00, which is interpreted as "Excellent." The category on operability in which the system is easy to operate and control was rated with a mean of 5.00, which is interpreted as "Excellent." The category on user error protection, in which the system protects users against making errors, was rated with a mean of 4.40, which is interpreted as "Excellent." The category on user interface aesthetics, of which the user interface enables pleasing and satisfying interaction for the user, was rated with a mean of 4.20, which is interpreted as "Very Good." The category on accessibility in which the system is designed to be used by different types of users was rated with a mean of 4.20, which is interpreted as "Very Good." The result implies that the system has conformed to the usability requirements set by the ISO 25010 standards and that the system can be easily managed, learned, and operated because it was designed with a user-friendly interface. The modified cane was easy to handle, and the vibration motor was inside the handle. The modified cane was easily to operate, and control was greatly enhanced because of the ease of use, as the user only needs to turn on the switch button. These capacities had been fully satisfied by the system, as backed by the overall mean of 4.60, which implied a high usability of the system.

The perception of the IT expert's respondents about the system based on ISO 25010 standards in terms of reliability has an overall mean of 4.70, which was interpreted as "Excellent." The category on maturity in which the system is reliable under normal conditions was rated with a mean of 4.60, which is interpreted as "Excellent." The category on availability of which the system is available in times when it is required to be used was rated with a mean of 4.60, which is interpreted as "Excellent." The category on fault tolerance, in which the system operates as intended despite the presence of hardware, or software, or hardware faults, was rated with a mean of 4.60, which is interpreted as "Excellent." The category on recoverability in which, in the event of an interruption or a power failure, the system can recover the data directly affected and re-establish the desired state of the system was rated with a mean of 5.00, which is interpreted as "Excellent." The result means that the system complied with the reliability requirements set by the ISO 25010 standard, by which the modified cane will function even without using the mobile application and Internet connection, and the mobile application will function without the modified cane. This could prevent the user from panicking if something goes wrong. Either one of these systems will fail to operate, or the user can still use it.

The perception of the IT expert's respondents about the system based on ISO 25010 standards in terms of security has an overall mean of 4.60, which was interpreted as "Excellent." The category on confidentiality, in which the system ensures that data are accessible only to those authorized to have access, was rated with a mean of 4.20, which is interpreted as "Very Good." The category on integrity in which the system prevents unauthorized access to, or modification of, computer programs or data was rated with a mean of 4.60, which is interpreted as "Excellent." The category of non-repudiation in which the system records transactions and can be proven to have taken place so that the transactions cannot be repudiated later was rated with a mean of 4.60, which is interpreted as "Excellent." The category of accountability in which the transactions can be traced uniquely to the entity was rated with a mean of 4.60, which is interpreted as "Excellent." The category on authenticity in which the identity/function of the resource is the same as it was discussed was rated with a mean of 5.0, which is interpreted as "Excellent." This result means that the system complied with the security requirements set by the ISO 25010 standards in terms of providing security measures to protect the confidentiality and integrity of the data since only authorized persons could manipulate the system.

The perception of the IT expert's respondents about the system based on ISO 25010 standards in terms of maintainability has an overall mean of 4.52, which was interpreted as "Excellent." The category on modularity, in which the system is composed of discrete components such that a change to one component has minimal impact on other components, was rated with a mean of 4.80, which is interpreted as "Excellent." The category on reusability in which a part of a system can be used in more than one system or in building another system was rated with a mean of 4.60, which is interpreted as "Excellent." The category on analyzability in which the impact of the intended change to one or more parts of the system can be assessed, diagnosed for deficiencies or failures, or identified on which parts to be modified was rated with a mean of 4.40, which is interpreted as "Excellent." The category on modifiability in which the system can be effectively and efficiently modified without introducing defects or degrading existing quality was rated with a mean of 4.00, which is interpreted as "Very Good." The category on testability in which the test criteria can be established for the system and tests can be performed to determine whether those criteria have been met was rated with a mean of 4.80, which is interpreted as "Excellent." The result implies that the system can be easily maintained and updated. Changes in the system can be modified because the materials are available locally.

The perception of the IT expert's respondents about the system based on ISO 25010 standards in terms of portability has an overall mean of 5.00, which was interpreted as "Excellent." The category on adaptability, in which the system can effectively and efficiently be adapted for different or involving hardware, software, or other operational or usage environment, was rated with a mean of 5.00, which is interpreted as "Excellent." The category on installability in which the system can be successfully installed and/or uninstalled in a specified environment was rated with a mean of 5.00, which is interpreted as "Excellent." The category on replaceability in which the system can replace another specified software product for the same purpose in the same environment was rated with a mean of 5.00, which is interpreted as "Excellent." The result implies that the system can be deployed on any device because the model is portable.

The overall mean of the IT expert's evaluation based on the ISO 25010 criteria was "Excellent," with a mean of 4.52, which implies that the system has conformed to the international standard criteria for software development set by the ISO in terms of Functional Suitability, Reliability, Performance Efficiency, Usability, Security, Compatibility, Maintainability, Portability. These features of a system being practical and useful with the needed appropriateness made it standout with other systems.

The result means that the software conforms to the international standard set by ISO 25010 in terms of functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability, and portability. The modified cane for the blind using computer vision was developed with advanced software quality for all its users, particularly in the field of computer vision.

Table 4 shows the summary of evaluation results by the five (5) blind persons based on the ISO 25010 standards in terms of functional suitability with an overall mean of 4.20, which is interpreted as

"Very Good." The category on functional completeness, in which the system set of functions covers all the specified tasks and user's objectives, was rated with a mean of 4.20, which is interpreted as "Very Good." The category on functional correctness, in which the system provides the correct results with the needed degree of precision, was rated with a mean of 4.20, which is interpreted as "Very Good." The category on functional appropriateness, in which the system's functions facilitate the accomplishment of specified tasks and objectives, was rated with a mean of 4.20, which is interpreted as "Very Good." All three requirements were satisfied with a rating of M = 4.20, indicating that the system was interpreted as "Very Good." This implied that the system met the standard set by the ISO in terms of functional suitability.

Table 4. Summary of Evaluation Results of the Five (5) Blind Persons

ISO 25010 Quality Characteristics	Mean	Interpretation
Functional Suitability	4.20	Very Good
Usability	4.60	Excellent
Grand Mean	4.40	Excellent

The perception of the blind persons about the system based on ISO 25010 standards in terms of usability has an overall mean of 4.60, which was interpreted as "Excellent." The category on appropriateness recognizability, in which the users recognize the appropriate need of the system, was rated with a mean of 4.60, which is interpreted as "Excellent." The category on learnability, in which the users can use the system with effectiveness, efficiency, freedom from risk, and satisfaction in a specified context of use to achieve specified goals of learning, was rated with a mean of 4.60, which is interpreted as "Excellent." The category on operability in which the system is easy to operate and control was rated with a mean of 4.60, which is interpreted as "Excellent." The category on user error protection, in which the system protects users against making errors, was rated with a mean of 4.60, which is interpreted as "Excellent." The category on user interface aesthetics, in which the user interface enables pleasing and satisfying interaction for the user, was rated with a mean of 4.60, which is interpreted as "Excellent." The category on accessibility in which the system is designed to be used by different types of users was rated with a mean of 4.60, which is interpreted as "Excellent." The result implied has conformed to the usability requirements set by the ISO since the system can be easily managed, learned, and operated because it was designed with a user-friendly interface. The modified cane was very easy to handle; the vibration motor was located inside the handle, and the phone camera was inside the case attached near the handle. The only thing a blind person can do with the device is to press the toggle switch button to turn on the device. These capacities had been fully satisfied by the system as backed by the M = 4.60 mean, which implied a high usability of the system.

The overall mean of the blind persons evaluation based on the ISO 25010 criteria was "Excellent," with a mean of 4.40. The result means that the software conforms to the international standard set by ISO 25010 in terms of functional suitability and usability. The modified cane for the blind using computer vision was developed with advanced software quality for all its users, particularly in the field of computer vision.

Table 5. Summary of Evaluation Results of the Five (5) IT Experts and Five (5) Blind Persons

ISO 25010 Quality Characteristics	IT Expert Mean	Blind Person Mean	Overall Mean	Interpretation
Functional Suitability	4.40	4.20	4.30	Excellent
Reliability	4.70		4.70	Excellent
Performance Efficiency	4.53		4.52	Excellent
Usability	4.60	4.60	4.60	Excellent
Security	4.60		4.60	Excellent
Compatibility	4.20		4.20	Very Good
Maintainability	4.52		4.52	Excellent
Portability	4.60		4.60	Excellent
Grand Mean	4.52	4.40	4.46	Excellent

Table 5 indicates the overall summary results of the evaluation by the IT experts and blind persons, where the system met the software quality criteria as to functional suitability, reliability, performance efficiency, usability, security, compatibility, maintainability, and portability, where the rating was 4.46, which is interpreted as "Excellent." This implies that the system is effective and has met the ISO 25010 Standards in terms of software quality. Based on the results of the evaluation, the study achieved its objectives.

5. Conclusion and Recommendations

Based on the findings of the study, the following conclusions were made:

1. The mobile application was very useful for the blind to detect and identify objects from the surroundings and provide an audio output for the labeled images and location in real-time.
2. The ultrasonic sensors were efficient and effective in detecting obstacles from the surroundings.
3. The modified cane for the blind using computer vision was user-friendly, lightweight, and effective.
4. The overall result of the system's evaluation based on the ISO 25010 criteria was excellent. The system met the software quality criteria as to Functional Suitability Reliability, Performance Efficiency, Usability, Security, Compatibility Maintainability, Portability, Accuracy and Acceptability. This implies that the system is effective and has met the ISO 25010 Standards in terms of software quality. Based on the results of the evaluation, the study achieved its objectives.

Based on the preceding findings and conclusions, the following series of actions are recommended:

1. The model used by the system has 82 classes only. So, future researchers may add more classes to detect more objects, such as food products and currency.
2. The system may be improved by putting more sensors, particularly at the top right, top center, and top left.
3. The system may be improved by adding a Wi-Fi module to Arduino to send data from sensors to the application, enabling it to speak the accurate measurement of an object and if the obstacle draws nearer to the user.

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