SBC-Based Object and Text Recognition Wearable System using Convolutional Neural Network with Deep Learning Algorithm

Melchiezedhieck J. Bongao, Arvin F. Almadin, Christian L. Falla, Juan Carlo F. Greganda, Steven Valentino E. Arellano, Phillip Amir M. Esguerra

Abstract*: *This Raspberry Single-Board Computer-Based Object and Text Real-time Recognition Wearable Device using Convolutional Neural Network through TensorFlow Deep Learning, Python and C++ programming languages, and SQLite database application, which detect stationary objects, road signs and Philippine (PHP) money bills, and recognized texts through camera and translate it to audible outputs such as English and Filipino languages. Moreover, the system has a battery notification status using an Arduino microcontroller unit. It also has a switch for object detection mode, text recognition mode, and battery status report mode. This could fulfill the incapability of visually impaired in identifying of objects and the lack of reading ability as well as reducing the assistance that visually impaired needs. Descriptive quantitative research, Waterfall System Development Life Cycle and Evolutionary Prototyping Models were used as the methodologies of this study. Visually impaired persons and the Persons with Disability Affairs Office of the City Government of Biñan, Laguna, Philippines served as the main respondents of the survey conducted. Obtained results stipulated that the object detection, text recognition, and its attributes were accurate and reliable, which gives a significant distinction from the current system to detect objects and recognize printed texts for the visually impaired people.

Keywords*: *Visually Impaired, Real-time Object and Text Recognition, Convolutional Neural Network, Deep Learning.

Melchiezedhieck J. Bongao*, Computer Engineering Department, College of Engineering, University of Perpetual Help System Laguna, City of Biñan, Laguna Philippines. Email: zedbongao@gmail.com

Arvin F. Almadin, Computer Engineering Department, College of Engineering, University of Perpetual Help System Laguna, City of Biñan, Laguna, 4024 Philippines. Email: almadin1914@gmail.com

Christian L. Falla, Computer Engineering Department, College of Engineering, University of Perpetual Help System Laguna, City of Biñan, Laguna, 4024 Philippines. Email: ChristianLFalla@gmail.com

Juan Carlo F. Greganda, Computer Engineering Department, College of Engineering, University of Perpetual Help System Laguna, City of Biñan, Laguna, 4024 Philippines. Email: gregandæ@gmail.com

Steven Valentino E. Arellano, Computer Engineering Department, College of Engineering and Graduate School, University of Perpetual Help System Laguna, City of Biñan, Laguna, 4024 Philippines. Email: arellanostevenvalentino@gmail.com

Phillip Amir M. Esguerra, Electronics Engineering Department, College of Engineering and Graduate School, University of Perpetual Help System Laguna, City of Biñan, Laguna, 4024 Philippines. Email: esguerraphillip@gmail.com

I. INTRODUCTION

Safety of persons with disability (PWD) is being prioritized in the society. In the Philippines, there are preventions and awareness for the increasing numbers of blind people most especially those with cataract and glaucoma, which were the most common cause of blindness [1]. There are approximately 1.3 billion people living with visual impairment globally [2]. In addition, having a loss of certain extent of eyesight is called a low vision [3], while having a 3 out of 60 visual acuities is considered as blind [2], and misalignment of eye or a failure of both eyes is called strabismus or crossed eyed [4]. Similarly, incapability of VI in terms of recognizing and determining objects near them causes to misidentify objects and have incapability of reading, Likewise, difficulties in using invented technologies are experienced by VI together with the problems encountered from the accuracy and reliability of the innovative devices, which were invented to provide the VI experience the social and public amenities, and specifically in the more effective way of reading [5]. Besides, some assistive devices invented for VI encountered voice signal transmission technical problems [6],[7].

Nowadays, the latest and newly discovered hardware and software technologies provide better and easy way of developing functional devices. With this, TensorFlow with an open-source library for Deep Learning as a branch of Artificial Intelligence (AI), provides fast numerical computations [8]. TensorFlow is a powerful library that developed in Python and C++ programming language and provide with a large variety of operating system (OS). In connection thereto, Raspberry Pi (RPi) Single Board Computer (SBC) with Raspbian OS, which is a Debian Linux-based OS that includes Python programming tools [9]. Moreover, using a database management will ease the use for sorting and collecting data stored. SQLite is an open-source database with embedded database application [10]. Additionally, Convolutional Neural Networks (CNN) and Deep Learning have become an essential tool for extensive range of applications such as image classification, speech recognition or natural language processing as one of the machine learning techniques, and these techniques have achieved extremely high predictive accuracy, in many cases CNN can withstand with human performance [11].

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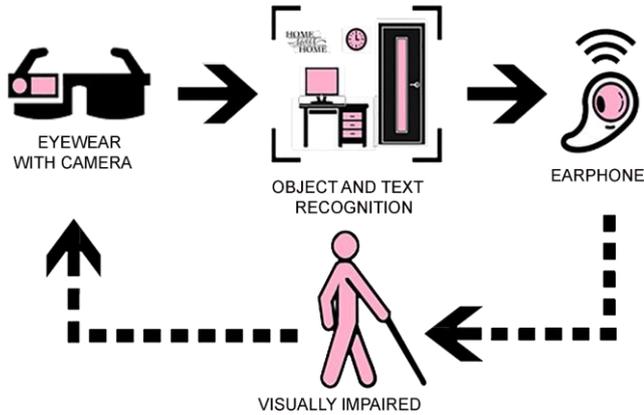

Fig. 1. The Conceptual Model of the Study

Fig. 1 shows the conceptual model of this study that represented the communication process between the device and the user. The focus of the developed system was to detect and translate stationary objects, road signs, money bills and texts within the scope and range of the camera used and with the objects that were incorporated to the DNN trained model. This study does not include the possible encounter with moving objects that cannot be recognized by the system and only recognized the limited number of objects to be translated into audible outputs in English and Filipino languages based on the number of trained images. Additionally, it does not cover any prevention of hazardous events that can be experienced by the user but rather limits on preventing misidentification of objects.

The system only recognizes English language for text recognition and with a maximum and minimum size and style; and a maximum range of the texts and translated into an audible output. It has also a battery notification status using an Arduino microcontroller unit. It also has a switch for object detection mode, text recognition mode, and battery status report mode. The disruptions from Bluetooth voice signal transmission for the audible output, the power disturbances, and fast moving and dark-colored objects were considered as the delimitations. In terms of the distance, an object must be in 1.5-meter range from the eyewear, and approximately 6 to 8 inches distance of the printed texts from the camera. The developed system has no graphical user interface (GUI) and can be used in an open and closed areas by one visually impaired person only.

The purpose, goal, and objective of this study was to provide a wearable technology, which utilize the latest multi-functional assistive device for recognizing objects properly and to fill in the lack of reading ability of the visually impaired. Specifically, to determine the rate of accuracy of the algorithm used in object detection and text recognition; and the rate of reliability in terms of translating the detected objects and texts into audible outputs. Furthermore, the developed system can improve the social communication for visually impaired. Implementation of technology pertaining to the proper distinguishing of objects and a reading assistance can be one of the application solutions for helping the visually impaired people.

II. METHODOLOGY

Descriptive quantitative method was used for research design to illustrates existing conditions so that these could be manipulated later as an outcome of the research. Quantitative research would be used since it inspects the connection among variables about testing objective systems [12].
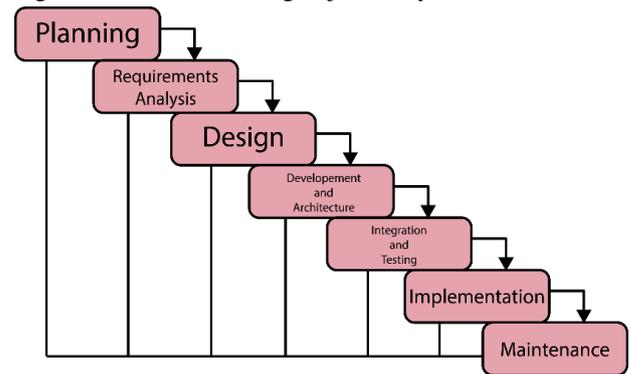

Fig. 2. Waterfall Systems Development Life Cycle (SDLC) Model

Fig. 2 shows the Waterfall Systems Development Life Cycle (SDLC) is a model that shows the process involved in developing the system, from the requirement gathering to the final engineer product [13]. It was used to identify the hardware and software modules through prototyping model, which was under the analysis phase of SDLC that was used in the developed system.

Observations and system testing were conducted to examine the behavior and movements of the visually impaired people when using the current system using Speeded-Up Robust Feature (SURF), and the developed system, respectively. In addition, consultation from university instructors, visually impaired, and professionals in the field of visually impaired, special education (SPED), assistive device, and Statistics were also conducted to acquire information for the better development of the system.

Furthermore, percentage, composite mean and t-test were used as statistical treatments. The developed system has been assessed and tested to totally blind, crossed-eye, and low-vision people, together with professionals in visually impaired, and Special Education (SPED) teachers of Biñan Elementary School to determine its performance among the other type of wearable device.

A. Machine Learning

The developed system used a deep learning algorithm using TensorFlow as the main library for datasets. TensorFlow trains a convolutional neural network (CNN) image classifier using datasets and training models that grants the speed and accuracy of the recognition.

Table-I: Data Set Sizes

Data Set	No. of Classes	Size
General Objects	90	9,000 images
Road Signs	5	500 images
Philippine Currency (PhP) Bills	6	600 images

Table 1 shows the data set sizes, which specified the 100 different kinds of images (or stored data) for each object used in training using TensorFlow image classifier. Moreover, this served as the guide in determining the sufficient data set sizes to acquire the desired accuracy for object detection and text recognition.
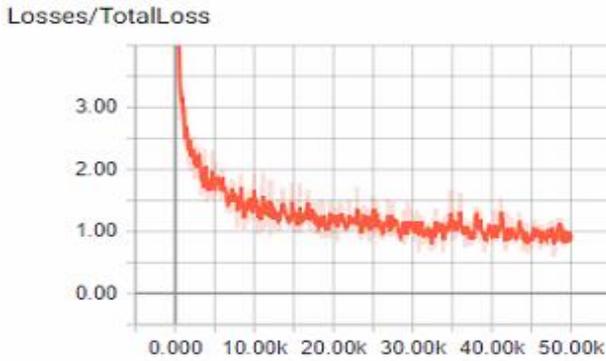
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Fig. 3. Tensorboard Training Graph

Fig. 3 shows the training progress of the CNN datasets through the Tensorboard training graph, which trained the images over time in the term of steps and losses. Loss functions are very important in the TensorFlow deep learning to measure the distance or difference between a predicted output and the ground truth label of the trained models effectively. Additionally, the loss function results are the accuracy rate for CNN and the loss needs to be constant to achieve the best possible accuracy of the training.

B. System Requirements and Specifications

The requirements and specifications of the developed system which was required to be used to make the developed system work were the following:

Table-II: System Requirements

System Requirements	Characteristic Properties
Operating System Used:	Raspbian 9 (Stretch)
Programming Language(s):	Python 3.0-3.7
Database Language(s):	SQLite 3.0.0 – 3.26.0
Integrated Development Environment:	Arduino IDE Jupyter IDE
Input Data/Device(s):	Object and Text Image Wearable Device
Output Data/Device(s):	Elliot Bluetooth Earphone
LED:	Adafruit LED Sequins
No. of LEDs Used:	3
Sensor / Camera:	Raspberry Pi Camera V2
Single-Board Computer:	Raspberry Pi 3 Model B+
Switch(es):	SPST (Single-Pole, Single-Throw) Push Button 1P10P Rotary Switch
Power Source(s):	Power Bank 5V, 24000mAh

Table-III: System Specifications

System Specifications	Characteristic Properties
Detection Interval:	Real Time Basis
Camera Resolution	8MP (Megapixels)
Frames per second:	0.7fps-1.6fps
Angle of Detection:	90°
Types of Detection:	Object Text Philippine Currency Road Signs
Text Recognition Language:	English
Audible Output Languages:	English and Filipino
Power Source:	5V/2.5A DC Power Input
Operating Voltage:	3.3V DC
Bluetooth Range:	5-6 meters
Bluetooth Version:	4.2
Exterior Features:	Acrylic type
Connectors:	Flex Cable

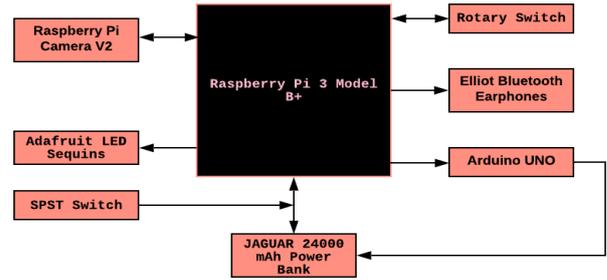### C. System Design and Development

Fig. 4. System Block Diagram

Fig. 4 shows the system block diagram, which was the Raspberry Pi 3 SBC Model B+ representing as the central processing unit of the system wherein, it has a switch for power on and off. The camera module was connected to the Raspberry Pi SBC and mounted in the eyewear together with Adafruit Light-Emitting Diode Sequins. All of these were powered by 5V DC 24,000 mAh Power bank which served as the power supply of the system. The Bluetooth Low Energy (BLE) earphones were rechargeable and have its own power supply, which automatically paired and connected to the system upon using it.
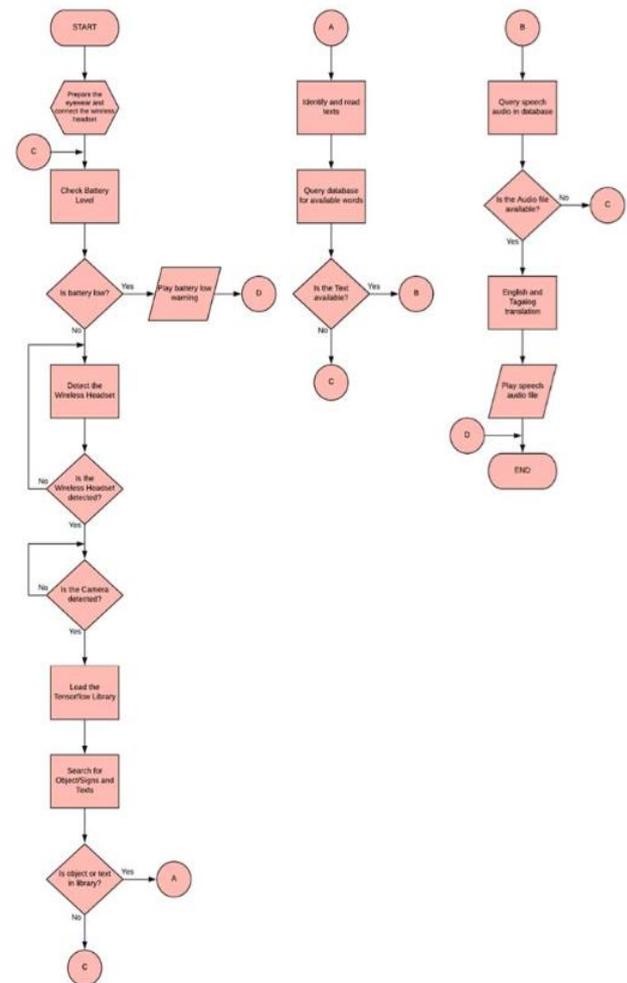

Fig. 5. System Flowchart Diagram

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Fig. 5 shows the system flow starts from the preparation of the eyewear, followed by the detection of wireless earphones, camera, and checking of the battery level was also included. The system will play an audio warning if the battery level is low, and it will not be used for object and text recognition process. Otherwise, the battery is fully recharged again. Afterwards, it will load the TensorFlow Library to make the system ready to detect objects, road signs, and texts. After the detection, it will search for available texts stored in the TensorFlow Library. It will also search for matched audio speech file that will be played through the wireless earphones if the stored texts are match. If the detected objects, road signs, or texts are not available in the TensorFlow Library, the system will loop again to search for objects, road signs and texts.

Fig. 6. System Schematic Diagram

Fig. 6 shows the schematic diagram, which was the Raspberry Pi 3 SBC Model B+ representing as the main board for the connections of the other modules. The power bank was connected through Raspberry Pi Switch going to the Micro USB of the SBC. The Pi Camera module was extended by Pi Camera HDMI (High-Definition Multimedia Interface) Cable then it was connected to the Camera CSI (Camera Serial Interface). The pin-2, was the supply voltage, and pin-9 was the ground connected to a circuit of Adafruit Light-Emitting Diodes Sequins with on and off switch. The Elliot earphones were connected via Bluetooth with low-energy (BLE) connection.

Fig. 7. Python 3 I

Fig. 7 shows the Python 3 IDLE user variables which includes the debug, speed and volume, it will change the

output debug settings on or off, the speech speed that ranges (0.5 – 2.0) and the audio volume of the output. It also showed the thread controls for the background processing of the system.

D. System Architecture

System Architecture refers to the detailed, technical, operational, and economical aspects of structural and hardware architectures of the developed system.
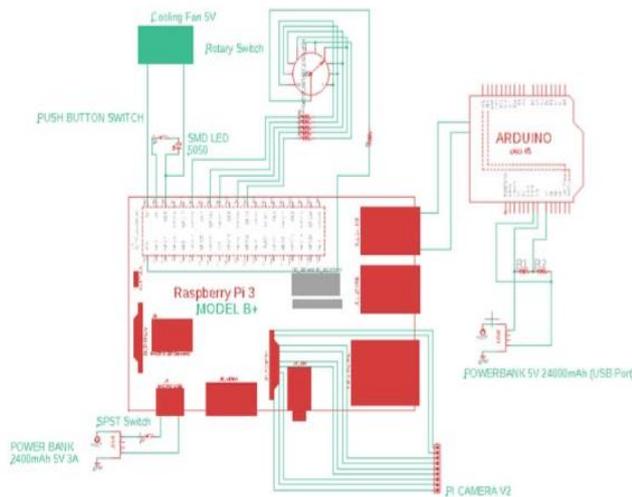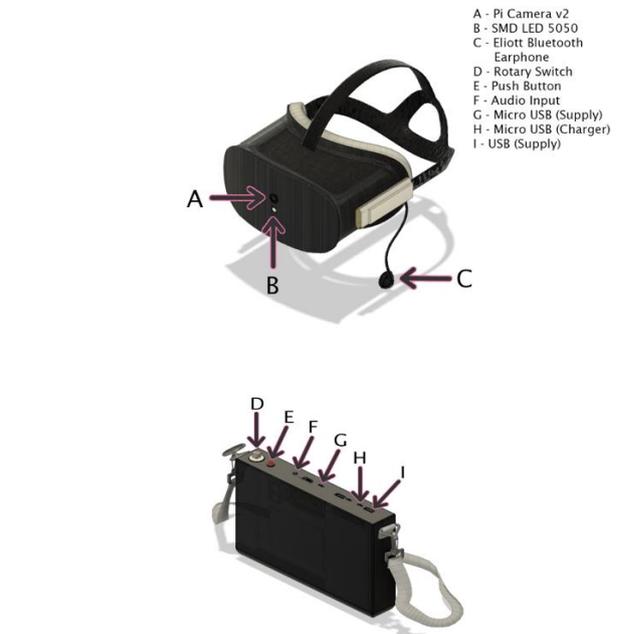

Fig. 8. Three-dimensional Structural Architecture of the System

Fig. 8 shows the structural architecture and components used in the wearable device, case, and it shows the actual prototype of the hardware of the developed system.
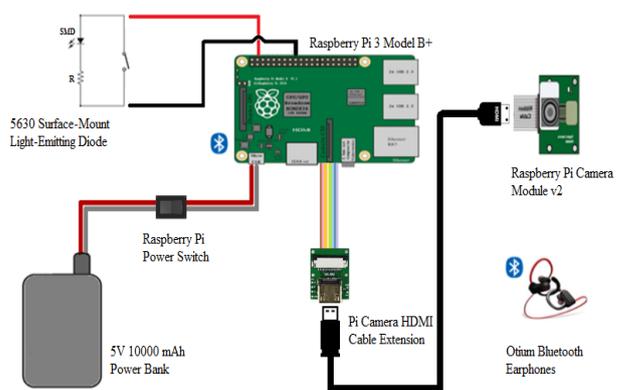

Fig. 9. Hardware Architecture of the System

Fig. 9 shows the hardware architecture or simply, the connections of electronics and electrical components that were used. It shows the electronic and electrical flow of the system and how it was used in the system development. It shows the schematic diagram, which was the Raspberry Pi 3 SBC Model B+ which represents the main board for the connections of the other modules, the power bank is connected through Raspberry Pi Switch going to the Micro USB of the SBC.

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The Pi Camera module is extended by Pi Camera Flex Cable then it was connected to the Camera CSI (Camera Serial Interface), and the pin-2, which was the supply voltage, and pin-9, which the ground was connected to a circuit of Adafruit Light-Emitting Diodes Sequins with SPST switch as on and off switch. The Elliot Bluetooth Earphones was connected via Bluetooth with low-energy (BLE) connection. A cooling fan was also attached to the RPi SBC to avoid the overheating of the main board.

Fig. 10. Actual System Prototype

Fig. 8 and Fig. 10 shows that the system was designed, fitted and compatible to wear for the visually impaired. The camera is set and placed in the eyewear with the vision of 90° from the point of view. The device also has its own source of power using a power bank; LED (light-emitting diode) serves as flash for night mode detection; and selection of buttons such as for the volume control and power button of the RPi SBC. Moreover, the main module has a customized case or a bag that is placed on the body of the user.
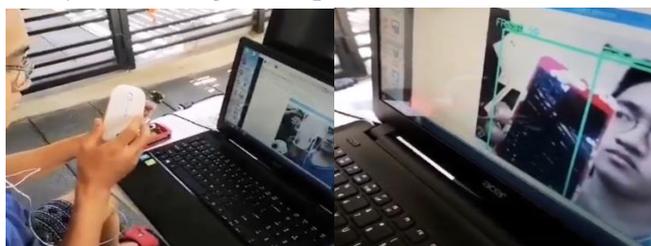
E. System Testing and Implementation

Fig. 11. Actual System Unit and Integration Testing

Fig. 11 shows the actual object detection by testing the frames per second (FPS) of the camera used. The unit testing was done to test the hardware and software modules separately to check its functionality. Integration testing was also executed where the combination of different hardware and software modules used to make sure that the integrated system was ready for system testing. System testing verified the compliance of the system as per the requirements.

Fig. 12. Actual System Testing by the Visually Impaired

Fig. 12 shows the actual testing by the visually impaired. Acceptance testing was performed by the beneficiary, and it was conducted to find if the requirements of specifications were met as per its objectives.

III. RESULTS AND DISCUSSIONS

The current system used Speeded-Up Robust Feature (SURF), which is the speedup version of SIFT (Scare-Invariant Feature Transform) while the developed system uses a deep learning algorithm using TensorFlow as the main library.
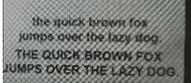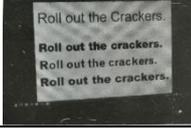
A. Object Detection Accuracy

Table-IV: The Rate of Accuracy in terms of Object Detection

Object Description	Captured Image	Accuracy Percentage	
		Current System	Developed System
No Parking		90%	100%
Pedestrian Crossing		90%	100%
No Smoking		90%	100%
Mean		90%	100%

Note. Retrieved from Text and Object Recognition Device for Visually Impaired based on Feature Extraction by De Guzman et al. Copyright 2019 by CAITE 2017: Computer Applications, Innovations, Technologies and Engineering, p. 40.

B. Text Recognition Accuracy

Table-V: The Rate of Accuracy in terms of Text Recognition

Text Titles	Captured Image	Accuracy Percentage	
		Current System	Developed System
Text1		99.4%	100%
Text2		99.43%	100%
Text3		97.51%	100%
Mean		98.78%	100%

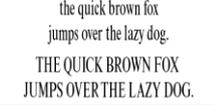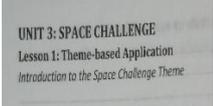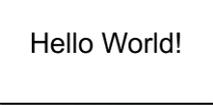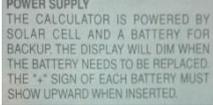*Note.* Retrieved from Text and Object Recognition Device for Visually Impaired based on Feature Extraction by De Guzman et al. Copyright 2019 by CAITE 2017: Computer Applications, Innovations, Technologies and Engineering, p. 40.

Table 4 and Table 5 show the objects and texts that were tested, ten (10) trials were made each object while text was based on the words that the system correctly recognized.

C. Rate of Reliability of the System Translation

Table-VI: The Rate of Reliability of the Developed System in Translation of Detected Objects, Road Signs, Money Bills and Recognized Texts into Audible Outputs

Objects	Captured Object Images	Reliability Percentage	Road Signs	Reliability Percentage	Money Bills	Reliability Percentage	Captured Recognized Text Images	Reliability Percentage
Bottle		100%		100%		60%	ROBOTICS DISCOVERY BUILDER EV3	100%
Clock		100%		70%		80%	the quick brown fox jumps over the lazy dog. THE QUICK BROWN FOX JUMPS OVER THE LAZY DOG.	100%
Backpack		100%		80%		90%	UNIT 3: SPACE CHALLENGE Lesson 1: Theme-based Application Introduction to the Space Challenge Theme	90%
Chair		70%		90%		100%	Hello World!	100%
Cellphone		80%		100%		!00%	POWER SUPPLY THE CALCULATOR IS POWERED BY SOLAR CELL AND A BATTERY FOR BACKUP THE DISPLAY WILL DIM WHEN THE BATTERY NEEDS TO BE REPLACED THE "+" SIGN OF EACH BATTERY MUST SHOW UPWARD WHEN INSERTED.	90%
						100%		
Mean		90%		88%		88.33%		96%

(Table 4 and Table 5, continued)

The current system has a 90% average accuracy while the developed system has 100% average accuracy in object detection. In terms of text recognition, the current system has a 94.39% average accuracy while the developed system has 100% average accuracy, respectively.

Furthermore, Table 4 and Table 5 also show that the developed system has greater accuracy in object and text recognition from the current system. The Speed-Up Robust Features (SURF) algorithm of the current system gave the respondents high accuracy rate in object detection with an identification time of approximately thirty (30) seconds while the deep learning algorithm provided an advance and higher accuracy and real time detection in objects because of the high-level training that the researchers used in developing the image classifier data. Therefore, the trained deep learning algorithm is more accurate in terms of object and text recognition than the SURF algorithm.

Table 6 shows the rate of reliability of the developed system wherein each table have five (5) samples each except for the table of the money bills which consists of six (6) samples that the developed system can detect and produce audible outputs. Ten (10) trials were made on each sample at the City of Biñan, Laguna, Philippines, and the results were computed in percentage. The objects obtained an average reliability percentage of 90%, road signs attained 88%, money bills have 88.33%, while the text tiles received 96%, respectively. The average percentage of the object and text recognition in total obtained a reliability rate of 90.58%, which concludes that the developed system is very reliable in terms of translation of detected objects and texts into audible outputs.

Reliability refers to consistency, for a system to be reliable the same test must be conducted under the same circumstances to produce the same results. Thus, the researchers conducted reliability test on the developed system which gave commendable results with the guidance and help of blind experts, making the developed system credible.

D. The Significant Difference between the Current Object and Text Recognition and in using the Developed System

Table-VII: The Significant Difference between the Current Object and Text Recognition and in using the Developed System in terms of its Rate of Accuracy

Rate of Accuracy		t-Value	p-Value
Current	*Developed*		
94.39%	100%	2.5706	0.0368
Interpretation		Significant	

Note: Significant @0.05
Current - Rate of Accuracy of the Current Object and Text Recognition
Developed - Rate of Accuracy of the Developed Object and Text Recognition

Table 7 shows the significance difference of the current system and the developed system through t-Value and p-Value. The rate of the accuracy was compared and the results of the accuracy rate for the current system obtained 94.39% and the developed system acquired 100%.

Based on the t-Test, the t-Value has a value of 2.5706 whereas p-Value has 0.0368 at 0.05 significance, which concludes that the developed system is significant.

IV. CONCLUSION

The developed system had an increase rate of accuracy compared to the current system due to the real-time detection of the trained model, which successfully detected objects and texts that proves the increase beneficial factors for visually impaired. Furthermore, developed system had a high reliability in terms of object, road sign, and money bill detection as well as text recognition, which is suitable as a modern assistive device for visually impaired. In addition, in terms of reliability and accuracy the developed system is better than the current system. For additional enhancement of the developed system improvement of the Frames per Second (FPS) increase the accuracy of the detection.

Likewise, additional features of the system can enhance the translation objects and lessening the output time delay of the audio. Application of distance integration of detected object to add warnings and guidance of proximity of the objects. Additionally, widening and expanding the camera vision from 90° by using other camera modules compared to the developed system.

ACKNOWLEDGMENT

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AUTHORS PROFILE

Engr. Melchiezedhieck J. Bongao acquired his Bachelor of Science in Computer Engineering (BSCpE) last May 2019 at University of Perpetual Help System Laguna (UPHSL). He was currently a Software Engineer at Denso Techno Phil. Inc. at Makati City, Manila Philippines. During his college years, he is a Student Assistant for 2 years, once served as Secretary of Computer Engineering Department's MicroSociety. He is also an Iskolar ng Biñan (2014-2016). His undergraduate thesis was recognized as Second-Best Thesis in Computer Engineering Program and also awarded as Best in Research Poster Presentation in the 8th Engineering Research Forum of UPHSL.

Engr. Arvin F. Almadin attained his Bachelor of Science in Computer Engineering (BSCpE) degree last 2019 at University of Perpetual Help System Laguna (UPHSL). He is currently a System Evaluation Engineer at Toshiba Information Equipment Philippines located at 103 East Main Ave. Ext., Special Export Processing Zone, Laguna Technopark, Binan, Laguna, Philippines 4024. He was the treasurer of the Computer Engineering Department's MicroSociety and the CpE board member of the Engineering Student Council (2017-2019). Also, he was a member of the Institute of Computer Engineers of the Philippines Student Edition (ICpEP.SE) Region 4-A. He is also an Iskolar ng Biñan (2014-2017). His undergraduate thesis was recognized as Best in Research Poster Presentation in Computer Engineering program and the UPHSL's 8th Engineering Research Forum Outstanding Research Poster Presentation.

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Engr. Juan Carlo F. Greganda earned his Bachelor of Science in Computer Engineering (BSCpE) last May 2019 at University of Perpetual Help System Laguna (UPHSL). He is currently an Associate Software Engineer at Accenture, Inc. located at Accenture Uptown Mall, BGC TOWER 2, Taguig City, Metro Manila. He was a System Evaluation Engineer at Toshiba Information Equipment Philippines located at 103 East Main Ave. Ext., Special Export Processing Zone, Laguna Technopark, Binan, Laguna, Philippines 4024. During his college years, he served as PRO-External of the Computer Engineering Department's MicroSociety for four consecutive years. During the 8th Engineering Research Forum of UPHSL, his undergraduate thesis was recognized as Best in Research Poster Presentation and Second-Best Thesis in Computer Engineering Department.

Engr. Christian Lumasac Falla, acquired his Bachelor of Science in Computer Engineering (BSCpE) degree last 2019 at University of Perpetual Help System Laguna (UPHSL). He is currenty a Associate Software Engineering at Accenture - Global One Center located at Lot 5 Block 2 E-Commerce Road Eastwood, Bagumbayan, Quezon City, 1110 Metro Manila. During the college years he was a member of Institute of Computer Engineers of the Philippines Student Edition (ICpEP.SE) region 4-A. His undergraduate thesis was recognized as 2nd Best thesis in Computer Engineering Program and awarded as Best in Research Poster Presentation in the 8th Engineering Research Forum Outstanding Research Paper.

Engr. Steven Valentino E. Arellano, CpE, MSME was born in the City of Manila, Philippines on June 21, 1992. He is a Freelance Digital Graphic Designer and Editor; Web Developer; Undergraduate Research/Thesis Adviser and Consultant for Computer, Electrical, and Electronics Engineering of University of Perpetual Help System Laguna (UPHSL); and Professional Member of Institute of Computer Engineers of the Philippines (Region IV-A), respectively. He was also a former college instructor and faculty member for Computer Engineering program of TRIMEX Colleges in the City of Biñan, Laguna, Philippines. He is a degree holder of Master of Science in Management Engineering (MSME) conferred last 2017 at UPHSL in City of Biñan, Laguna, Philippines. He also finished his Bachelor of Science in Computer Engineering (BS CpE) degree program last 2015 at the same university. He underwent the Six Sigma online training and obtained a White Belt Certification from the Council for Six Sigma Certification and Aveta Business Institute Online last September 2020.Throughout his college years in UPHSL, he served to the different positions such as Vice President for Internal Affairs, Treasurer, and Business Manager of MicroSociety (Computer Engineering Society) of UPHSL. He was also the Chief Layout Artist, Writer, and Editor of EngGenius (Engineering) Publication, and Digital Graphic Designer of Engineering Student Council and the College of Engineering. Prior to his dedication with digital graphic design, he was recognized as Best in Digital Graphic Design in the said university. The official logo of the National Collegiate Athletic Association (NCAA) South 16th Season was one of his graphic designs. He attended Canossa School in the City of Santa Rosa, Laguna, Philippines for his secondary studies from 2005 to 2009. During the 40th Commencement Exercises of UPHSL held in Philippine International Convention Center (PICC), Pasay City, Philippines, he was awarded a Plaque of Recognition for his Outstanding Graduate Thesis entitled "Child Detector Android Application through Smartphone Using Bluetooth Low Energy (BLE) Beacon Technology", which was published in the International Journal of Engineering and Advanced Technology (IJEAT), ISSN: 2249-8958, Volume 8, Issue 2, December 2018. He had also scholarly published research together with other co-authors and fellow engineers in the International Journal of Innovative Technology and Exploring Engineering (IJITEE), ISSN: 2278-3075, Volume 7, Issue 12, September 2018, entitled "Sign Language and Speech Translation Wearable Device for Special Education Schools in the Philippines". The said research was also cited as one of the book chapters for wearable and Android application devices in Volume 6, Chapter 2 of Recent Developments in Engineering Research, Print ISBN: 978-93-90431-77-9 and eBook ISBN: 978-93-90431-78-6 with revised title of "Investigating the Sign Language and Speech Translation Wearable Device for Special Education Schools in the Philippines", which was published by Book Publisher International last October 2020. His other academic papers about machine learning and artificial intelligence (AI) applications were electronically available in the International Journal of Recent Technology and Engineering (IJRTE), ISSN: 2277-3878, Volume 9, Issue 3, September 2020, entitled "SBC-Based Diabetic Retinopathy and Diabetic Macular Edema Classification System Using Deep Convolutional Neural Network", and "SBC-Based Cataract Detection System Using Deep Convolutional Neural Network with Transfer Learning Algorithm" electronically distributed in Volume 8, Issue 2, July 2019 of IJRTE, respectively. IJEAT, IJITEE and IJRTE are published by Blue Eyes Intelligence Engineering and Sciences Publication.

Engr. Phillip Amir M. Esguerra earned his Bachelor of Science in Electronics Engineering (BSECE) last 2015 at University of Perpetual Help System Laguna (UPHSL). He is currently earning his Master of Science in Management Engineering (MSME) degree at UPHSL. Currently he is working as a Software Development Engineer. He is also a freelance Web Developer. He also has done various projects including an entry in a hackathon that involves an Android based application that uses Bluetooth Low Energy for applications such as anti-theft, object tagging and search, and other related functions. During his college years, he served as President of Engineering Student Council (ESC), Perpetual Institute of Electronics and Communications Engineering Society (PIECES) and Engineering Mathematical Society. For his undergraduate thesis, he has done Application of Mimicking for the Control of Anthropomorphic Robotic Arm in Bomb Disposal Robot which consists of a telemetry suit worn in a human arm that can control a robotic arm. His other academic papers about machine learning and artificial intelligence (AI) applications were electronically available in the International Journal of Recent Technology and Engineering (IJRTE), ISSN: 2277-3878, Volume 8, Issue 2, July 2019 entitled "SBC-Based Cataract Detection System Using Deep Convolutional Neural Network with Transfer Learning Algorithm". IJRTE is published by Blue Eyes Intelligence Engineering and Sciences Publication.