

Design & Development Of Mapping Tool For The Blind Or Partially Sighted

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ABSTRACT People who have visual impairment face many problems doing their simple daily activities without needing the help of other people or specially trained dogs. This study intends to design and develop an optimal solution. The solution will be based on artificial intelligence technologies such as computer vision, intelligent text to voice conversion, detecting objects and/or obstacles, and conveying the information verbally. This will offer modern assistance techniques such as smart glasses and canes, helping the needy navigate indoor and outdoor. The solution will also provide a book reading capability. In this study, a system offering indoor and outdoor object detection, obstacle detection and real-time text recognition and conversion to audio will provide users with information to help them overcome navigation and detection problems. A comprehensive test will be carried out to check the ability of the system to achieve its designated task effectively, environmental test conditions, including tool performance under normal daylight, high or bright light, and total darkness. The text to voice ability was tested, in which case the system detected video subtitles and text from images equally well. The results indicate that the system performs equally well in all cases.

I. INTRODUCTION

Eyesight is a valuable sensing instrument for humans; it allows humans to investigate their environment. According to the World Health Organization (URL-1), about 285 million visually impaired people worldwide (39 million being blind and 246 million having a low vision). Vision's problems in most cases are due to an injury, a disease, age-related degradation. Persons with this handicap face many difficulties while trying to execute their essential day to day needs (navigation, reading books, etc.). For these reasons, many assistive devices are commercially available; the most popular are cane guides and dogs. However, these classical tools do not provide all the information required, such as speed and distance, which are necessary for the perception and the control of locomotion during navigation; also, they can't help with reading books or road signs etc.

Moreover, many methods and systems have been proposed to assist visually impaired people in navigating activities such as the sidewalk (F. Ahmed et al., 2018), recognize and reading text from objects (Norharyati et al. 2019), etc. Still, most of the proposed methods are not efficient. Another wearable, more efficient and comfortable detection tool was smart glasses'. This tool offers the user a clear vision while maintaining a performance similar to a computer. Several companies have worked to develop their version of the smart glasses' including Google, in 2013 with a tool called "Google Glass" followed by Eyesynth (URL-2), eSight (URL-3), NuEyes Pro (URL-4), AngleEye (URL-5), and orCam (URL-6). These innovations have in common an embedded system connected to wi-Fi or Bluetooth to establish wireless communications. These smart glasses have some limitations; the majority offer text reading but not object detection (eSight, Eyesynth, NuEyes Pro) and also, all of them do not support the low light mode. The proposed project will offer the

possibility of recognizing and identifying objects using the raspberry pi infrared module camera, followed by a classification process in real-time, and then using the text to speech learning transition to generate voice feedback. Object detection is achieved in all lighting conditions (dark, low, and bright light).

The system will also have the possibility of measuring object distance and providing the user with a suitable warning; the object can be closer or very close, identifying an obstacle as a person or object. The system will also allow reading books or text in real-time and converting it into audio. The system also offers the possibility to convert any generated text into one of the three proposed languages (Turkish, English and French).

II. PREVIOUS STUDIES

Many studies and research were carried out to improve visually impaired persons' quality of life. The author in (Barontini F et al., 2020) interviewed several blind people to formulate an idea about the features and functionalities that an ideal navigation tool should have; the main concept of this system were based on Haptic information Tactile simulation. In this case, the user wears a hand device with a motor to help a blind person while moving around; for example, if he moves right, the device will pinch him on his right hand, etc. In (Mauro Avila et al., 2015) the author developed a navigation system it provides a visually impaired person with the ability to define addresses or rooms. Also, the author in (Tanveer et al. 2015) aims to assist them in navigating and tracking their location if they are lost using GPS; the system proposes two languages for voice assistance (Bengali and English). In (Real et al., 2019) the author presented techniques to help future developers interested in working and helping blind people; the author discussed the advantages and disadvantages of each proposed method. So the author of this scientific paper has chosen: indoor positioning, computation offloading, distributed sensing, etc. the author has taken different approaches that have been proposed in the past in order to explain the strengths and the limits of each method presented. Some important key features for an ideal walking assistant have been extracted from (M. M. Islam et al., 2019) after a detailed review made. It includes a low cost, lightweight and straightforward design with reliable interior and exterior coverage. Another study (D. Dakopoulos et al. 2010) was made based on comments from several blind user groups to extract 14 operational characteristics to describe a good walking assistant.

For the detection of objects, a lot of researchers tried to help avoid obstacles were made (Ali Ali et al., 2017); including the use of drones in this field was set as an option (C. Yi et al., 2013). The author in (Rahmat Tullah et al., 2020) proposes a blind walking aid that uses ultrasonic sensors to measure the distances between detected objects and the visually impaired person and produces a sound from its buzzer if the distance between them is less than 100cm as a warning. This aid also offers the possibility of detecting if there is a pool of water in front of the user. The smartphone's sensors were used in (M. Ehatisham-ul-Haq et al., 2017) to detect the user's activities such as walking, standing, sitting, running etc. The real-time identification was based on the user's physical activity recognition. The work presented in (Shifa Shaikh et al., 2020) is a machine learning solution whose main aim is to extract features using YOLO framework trades with object detection. The system also provides text to speech option to describe to the user's the surrounding environment. Another good example is (Shankar Sivan et al., 2016) an assistive device that includes several modules such as object detection, text recognition, and door detection and also have a security system to help detect intruders.

Based on the potential of computer vision services, a prototype was made in (Hasventhran Baskaran et al., 2019) to generate a narrative that describes the real world by formulating complete sentences such as "It's a group person reading", "It's a bird sitting on a tree" etc. then those sentences are converted into real-time speech. The last example uses raspberry pi as a processor control for face detection and tracking (P. Velraj Kumar et al., 2020) using image processing.

Several research studies have taken place in object detection (Bai, S et al., 2018 – S. Pehlivan et al. 2019), each offering different solutions for obstacle detection (R. Radhika et al., 2016 – Sami UR Rahman et al., 2018).

However, the main challenge for the visually impaired problem of identifying text and converting the recognized text to voice, including reading books, is still valid. The research carried out in (Roy Shilkrot et al., 2015) provides a portable reading device that provides an efficient system with acceptable accuracy using computer vision technology to scan printed text. The system presented (P. Sabin Prasanna et al., 2018) allows visually impaired persons to read a book in real-time by converting the detected text into audio.

Blind people or those who have serious vision problems are daily experiencing many challenges,

including moving within the enclosed environment or navigating their way in the outside world and/or reading.

Nowadays, many tools are available on the market to help these people, but so far, available solutions are either not suitable or they only solve one real problem meaning the person will have to rely on several tools to solve several problems. Hence, the main objective of this work is to present the visually impaired with one device that provides the solution to a number of the major challenges that they face. The device is a real-time assistance system with high accuracy. It offers the option of navigation both within confined space and outside open space, including navigation within crowded areas, reading, and translation of the text into three languages (English, French and Turkish).

III. PROBLEM STATEMENT

A. Proposed system

The proposed system will use two branches of artificial intelligence, namely deep learning and computer vision, to achieve object and text detection and identification, plus other options to be discussed in this section. The project is divided into two main parts:

- **Object Detection:** It will provide the user with vital information regarding objects with his environment, including object and obstacle detection, and allow the user to avoid them in real-time by delivering detected object details as speech form.

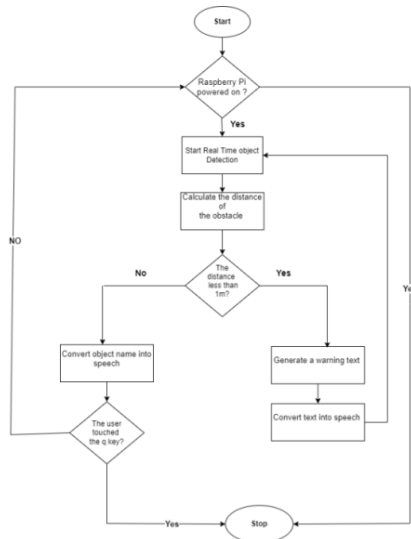


FIGURE 1. Object Detection Flowchart.

- **Text Reading:** The tool will detect and recognise textual contents within images and

or videos; it will convert the text to voice. This process will start by detecting and identifying the text and then transforming it into speech. The detected text is translated into three languages (Turkish, English and French). This means that the tool will allow the user to read and or listen and understand videos containing subtitles.

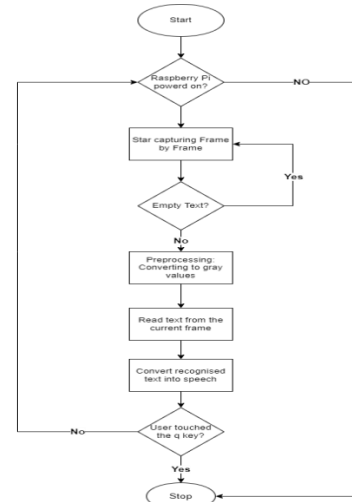


FIGURE 2. Text Detection Flowchart.

Figure 3 illustrates the architecture of the proposed system, which consists of the following modules:

- AI voice menu.
- Object detection.
- Text detection.
- Converting text to speech.
- Distance calculation and obstacle detection.

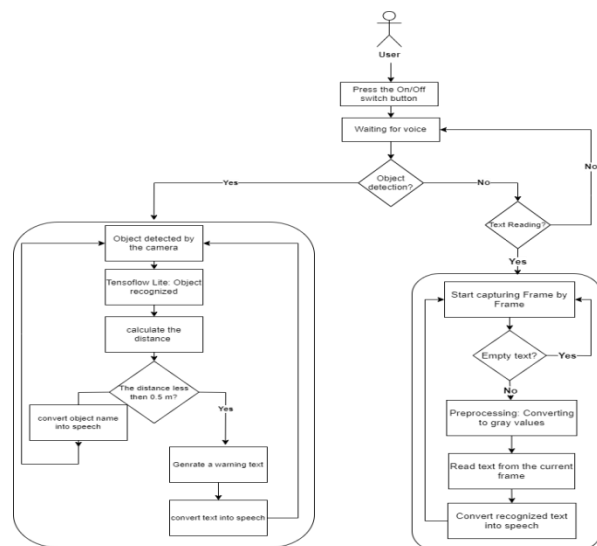


FIGURE 3. Tool workflow.

IV. IMPLEMENTATION

The proposed system consists of hardware and software components; the details of these components are described in this section.

A. HARDWARE

The hardware components and architecture consists of several devices and sensors integrated to achieve the goal of this work. It includes:

1. Raspberry Pi 4

Raspberry Pi is a small computer when connected to a screen, and the keyboard is used as a computer. Its small size and reasonable price make the Raspberry Pi ideal for performing vital tasks, including image and video processing and natural language processing. It also supports several programming languages, including Java, Python, and C++. IN this work, the Raspberry Pi (RPi) will act as the system's central processing unit.



FIGURE 4. Raspberry Pi 4.

2. Ultrasonic Distance sensor

In this work, several sensors are used to aid in the achievement of the proposed system task; this includes an ultrasonic sensor. The Ultrasonic sensor is to measure the distance from an object (obstacle) using sound waves. These waves are transmitted at a specific frequency; the sensor, in this case, waits for the detection of the reflected wave. The distance between the ultrasound sensor and the obstacle is obtained by calculating the time interval between transmission and reception. The ultrasonic sensor may not be able to accurately predict the distance if there are a number of objects at the same time some of the objects reflect the wave as good as other objects. However, due to cost and financial budget, the sensor is used to verify the tools ability to detect and deal with objects and obstacles.



FIGURE 5. Ultrasonic Distance Sensor.

3. Raspberry Pi camera

The following module camera has the possibility to take a high definition video. It also captures images that are passed to the RPi. After testing the tool under varied operation conditions, the image capture frequency is set to achieve optimal performance.



FIGURE 6. Raspberry Pi camera.

4. Sound Sensor

A sound sensor is a microphone sensor that detects the environmental sound and generates a digital output signal. The sensor is equipped with a potentiometer that allows sense clapping hands, including horn sound, sudden and loud voices or environmental noise. The optimal setting is achieved by testing the operation of the tool under extreme conditions. The reason for using a sound sensor is to provide the tools with the necessary ability to detect the ambient sound recognition and sound level recognition which will be used to estimate the source of the sounds as well as using the sound waves to identify the identity of the source.



FIGURE 7. Voice Sensor.

B. SOFTWARE

A number of software tools are used to develop a working application with the proposed tool. The software tools used include Python is, a computer programming language, an interactive web tool known as a computational notebook, TensorFlow's lightweight solution for mobile and embedded devices, and (Open Source Computer Vision Library).

1. OpenCV

OpenCV (Open Source Computer Vision Library) is a cross-platform library that can help develop real-time computer vision applications. It mainly focuses

on image processing, video capture, and analysis, including face detection and object detection features.

It was built to provide a common infrastructure for computer vision applications and accelerate machine perception in commercial products. Being a BSD-licensed product, OpenCV makes it easy for businesses to utilise and modify the code (URL-7).

In this project, the OpenCV is used for object detection and text detection to grab images and then draw results on them.

2. Speech Recognition

Speech recognition is a ML process in which the sound is passed through some Deep Learning layers and captures features that can be used to train a model to classify and/or predict. It might also be used to identify and/or convert sound to text. Hence sometimes, it can also be called "speech to text". In this case, machine learning identifies words pronounced by a person and converts them into readable text (URL-8). The speech recognition systems process and interpret spoken words via algorithms and then convert them into text. It starts by analyzing the audio file; then, it is broken into segments and digitized into a computer-readable format. Finally, an appropriate algorithm matches it to the most suitable text representation.

3. Optical Character Recognition (OCR)

The technology is used for live stream text detection. The recognition part is the OCR, a technique used to distinguish printed or handwritten text characters inside digital images of physical documents, such as a scanned paper documents. The basic process of OCR involves examining the text of a document and translating the characters into a digital representation that can be used for data processing. OCR is sometimes also referred to as text recognition.

V. PROPOSED SYSTEM

The system software and related hardware for the proposed tool are discussed in this section. The software components used in this work are designed and developed using the RPi as the processing unit. The related hardware for each software component was designed and tuned using the necessary electronic components, including potentiometers, to achieve optimal hardware signals. Figure 8 presents a

block diagram of the proposed system. Once all the components were operational and tested separately, they were connected together with one component one after another to form the complete system. The integration process included several errors that needed, in some cases, modifications to related hardware and software. Once all the components were connected, a complete functionality test was carried out under all possible working conditions to verify the tool's ability to achieve its goal. From Figure 8, it can be that the system includes a Raspberry Pi, Raspberry Pi camera, Ultrasonic sensor, speaker, sound sensor, Three on/off switch units, and switch buttons. The system contains four major modules. These modules are presented in this section.

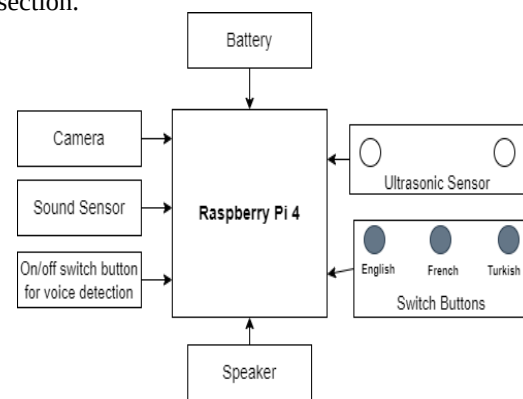


FIGURE 8. Block Diagram.

A. OBJECT DETECTION

The Single Shot Multibox Detector (SSD) is designed for object detection in real-time; it takes only one shot to detect multiple objects present in an image using a multi-box. SSD architecture (Mark Sandler, et al.) is a CNN framework that consists of two components feature extractor which is also called base network, followed by a set of auxiliary convolutional layers which enable features extraction at multiple scales and decrease the input size of each subsequent layer; and the second component is the bounding box predictor it's a group of small convolutional filters used to predict category scores and box offsets for a fixed set of default bounding boxes. SSD eliminates bounding box proposals like the ones used in the RCNN's, and it includes a progressively decreasing convolutional filter for predicting object categories and offsets bounding box locations. The SSD provides high accuracy and speed using lower image resolution for those reasons.



A convolutional neural network (CNN) is a deep artificial neural network that can identify visual patterns from the input image with minimal pre-processing compared to other image classification algorithms. It produces highly accurate recognition results and can be retrained for new recognition tasks without building on pre-existing networks. The important unit inside CNN layers is a neuron. They are connected together in order that the output of neurons at a layer becomes the input of neurons at the next layer.



- **The convolutional layer** is the core building block of CNN. This layer performs a dot product between two matrices, where one is the set of learnable parameters otherwise known as kernel and the other matrix is the restricted portion of the receptive field.
- **Pooling layer:** Replaces the network's output at specific locations by deriving a summary statistic of the nearby outputs. This helps reduce the spatial size of the representation, which decreases the required amount of computation and weight. The pooling operation is processed on every slice of the representation individually. The network will use several pooling layers. However, the most popular one is the max pooling (figure 11) which reports the maximum output from the neighbourhood.



- There are many types of CNNs. One class of CNNs are depth-wise convolutional neural networks. The depth-wise is a type of convolution where a single convolutional filter is applied for each input channel. The depthwise convolutions Split the input and filter into channels, convolve each input with the respective filter, and stack the convolved outputs together (Figure 12). Compared to a standard constitutional neural network, the depth-wise performance using lesser multiplications implies deploying faster convolution neural network models without losing much accuracy.



FIGURE 13. The network architecture of MobileNetV2-SSDLite.

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(Mark Sandler et al.) it was trained on the MSCOCO dataset (URL-11) and then converted to run on Tensorflow Lite (URL-12).

Some of the COCO datasets features:

- 80 object categories, the "COCO classes" which includes "things" that can be easily labelled (chair, TV, Mobile, cars, cups ...etc.)
- 5 captions per image.
- Over 200 000 images of the total 330 000 images are labelled.
- 250 000 people with 17 different key points.

The pseudo code for the object detection algorithm is as follow:

Algorithm 1 : Object Detection

```

1: Initialise video stream
2: load label map
3: if label[0] is '???'
4:   remove label[0]
5: load the Tensorflow Lite model
6: while True
7:   Start timer to calculate frame rate
8:   Grab frame from video stream
9:   Acquire frame and resize to expected shape
10:  Retrieve detection results
11:  for all detections
12:    if confidence is above min threshold
13:      draw detection box
14:  Draw frame rate in corner of frame
15:  Display the results
16:  if 'q' button pressed
17:    break
18: end
19: distroyAllWindows()
20: stop video stream

```

B. TEXT RECOGNITION

Optical Character Recognition (OCR) is the technology used to distinguish printed or handwritten text characters inside digital images of physical documents in real-time.

The steps involved in the OCR are represented as follow:

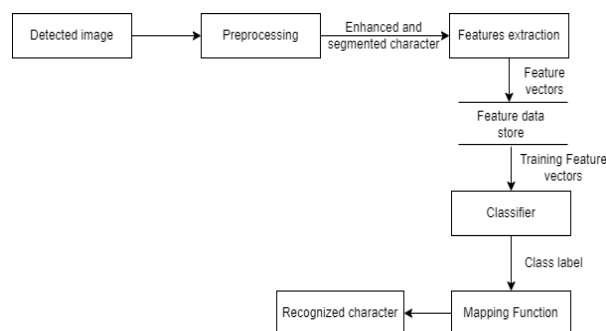


FIGURE 14. OCR architecture diagram.

Initially, the raspberry pi camera must be connected and recognized to capture frame by frame; once the current frame is detected, the pre-processing function is executed to convert to grey values and allow data detection, even those that are too bright. Then, if the detected frame doesn't show an empty text, the data is extracted, and a box defining it is drawn. The script will continue to be executed while waiting for the user to press the "Q" key and exit the process.

The pseudo code for the real-time text recognition is as follow:

Algorithm 2 : Real time text detection

```

1: Initialise video stream
2: while True
3:   Capture frame by frame
4:   Extract any data (text, coordinates, score, etc.)
5:   if box's score is > 60
6:     Extract text
7:     if text is not null
8:       start coordinates and dimensions of the box
9:       draw the box
10:      sleep(1)
11:      Convert text to speech
12:      Display the results
13:      if 'q' button pressed
14:        break
15:    end
16:  distroyAllWindows()
17: stop video stream

```

C. TEXT TO SPEECH CONVERSION

To get audio feedback, whether for the object detection part, text recognition, or to generate warning messages for obstacle, Text to speech (TTS) synthesizer were used. TTS synthesis means converting written text into understandable natural speech. In this study, predefined libraries are used. The structure of TTS is given in Figure 15.

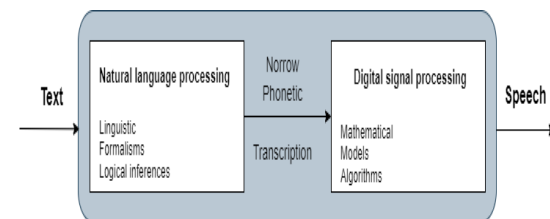


FIGURE 15. Theory of Text To Speech Synthesis.

Natural language processing (Elizabeth D, 2011) involves the reading and understanding of spoken or written language through the medium of a computer, like an automatic translation of a language into another, automatic answering of questions ...etc.

NLP uses machines to run deep learning algorithms to understand users' text communications and

intelligently respond to them based on the flow configurations.

Digital Signal Processors (DSP) take real-world signals like voice, audio, video, temperature, pressure, or position that has been digitized and then mathematically manipulates them.

A DSP contains these key components:

- **Program Memory:** Stores the programs the DSP will use to process data.
- **Data Memory:** Stores the information to be processed.
- **Compute Engine:** Performs the math processing, accessing the program from the Program Memory and the data from the Data Memory.
- **Input/Output:** Serves a range of functions to connect to the outside world.

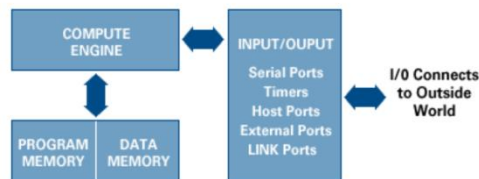


FIGURE 16. DSP architecture.

In this project, the espeak (Ramiz Kastrati et al.) engine is used for the conversion of text to speech. It's a compact open-source software text to speech synthesis, it uses a "formant synthesis" method which helps it supports several languages in a small size. The speech proposed by the espeak engine is clear and can be used at high speeds.

The espeak engine features:

- Includes different Voices whose characteristics can be altered.
- Can produce speech output as a WAV file.
- SSML (Speech Synthesis Markup Language) is supported (not complete), and also HTML.
- Compact size. The program and its data, including many languages, totals about a few Mbytes.
- Can translate text into phoneme codes, so it could be adapted as a front end for another speech synthesis engine.
- Potential for other languages. Several are included in varying stages of progress.
- Written in C.

D. OBSTACLE AND DISTANCE MEASUREMENT

In this study, an ultrasonic sensor is used to detect objects for the obstacle avoidance component. The distance between the device and the obstacle is calculated; if the distance is less than 2 meters, the system generates a warning message which will, in turn, be converted into audio.

The sensor uses ultrasonic sound to measure distance; it sends out an ultrasonic sound with a frequency of about 40 kHz. The sensor has two main parts: a transducer that creates an ultrasonic sound and another that listens for its echo. Sound travels at approximately 340 meters per second. To measure the distance so to measure the distance, the following formula is used:

$$\text{Distance} = \frac{(\text{Time} * \text{SpeedOfSound})}{2}$$

It is divided by 2 because sound has to travel back and forth.

The pseudo code for the obstacle detection is as follow:

Algorithm 3 : Obstacle detection

```

1: Set GPIO Pins
2: Set GPIO direction (IN / OUT)
3: Try:
4:   while True:
5:     calculate the distance
6:     if distance <= 2 meters
7:       Generate warning text
8:       Convert text into speech
9:       sleep(1)
10:      draw the box
11:      sleep(1)
12:    if 'q' button pressed
13:      break
14: end
15: GPIO cleanup

```

VI. Results and discussions

To determine the performance of the proposed system, it was tested under various scenarios (Variation in lighting, distance from the camera and number of objects in the frame) and this to identify the object in real-time, recognize text and detect an obstacle, then convert all the obtained results into speech.

A. Normal light object detection

The system was tested in a room with normal lighting; the test results are shown in Figure 17; the system detected the object with high accuracy. The system can also detect more than one object in the same frame and label the objects correctly.

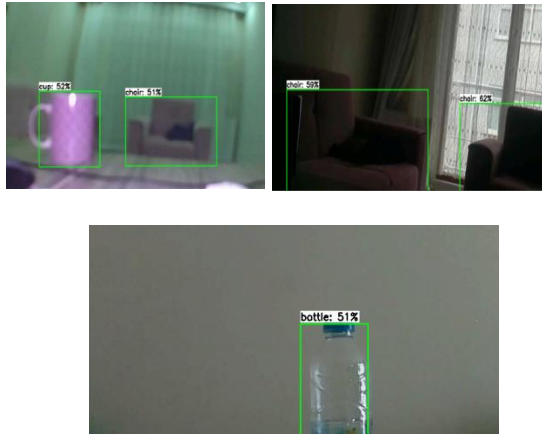


FIGURE 17. Objects detected in normal light.

B. Object detection within a dark and low light environment

The system test is carried out in a dark room, and as shown in Figure 18, the system can detect the various objects with acceptable accuracy, namely 78% for the mouse and 58% for the cup. An IR camera was used to carry out the detection in this test.

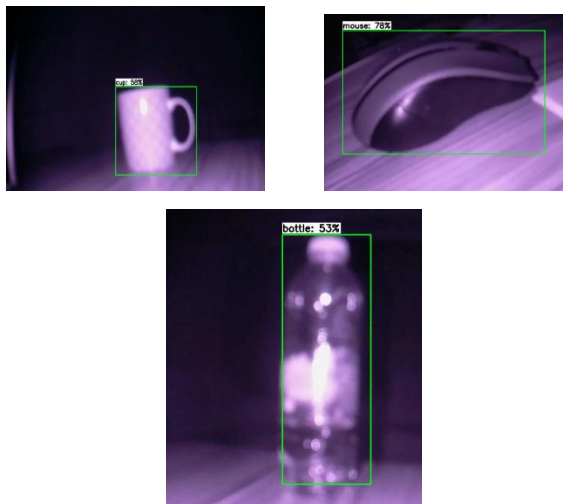


FIGURE 18. Objects detected in the dark.

The present camera had a problem, and it needed to have a magnifying lens attached to it to overcome the problem. Some of the problems and limitations faced during this test include Blair or unrecognized images; this was due to the object's colour and its relation to the surrounding colours, its distance from the camera etc. Figure 19 shows a typical example of an object that the tool failed to recognize. The object is a pink color armchair and with a white background.



FIGURE 19. Unrecognized object

C. Text Recognition

The system was tested for reading a scientific printed paper in real-time, as shown in Figure 20, the text was well recognized, and at the same time, it was converted into speech using the espeak engine.

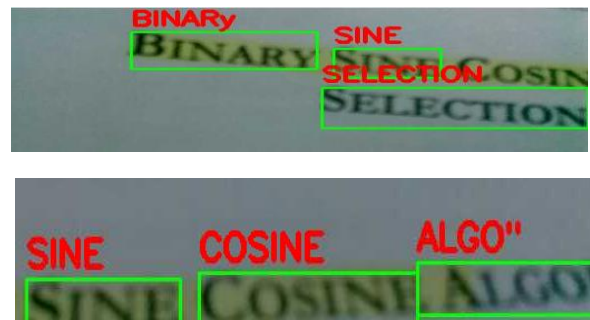


FIGURE 20. Text recognition.

VII. CONCLUSION

An aid tool has been created to help people with visual impairment surround the world and do their daily activities much easier. The system offering indoor and outdoor object detection, obstacle detection and real-time text recognition and conversion to audio and this in order to give the users the information to help them overcome navigation and detection problems. The solution provides also a book reading capability.

The system were tested to check it ability to achieve all the designated tasks, good results were detected after having subjected the hardware to several tests, namely under normal daylight, high or bright light, and total darkness for the object detection part. Also the text to voice ability was tested in the reading of images, video subtitles.

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