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Advancement in Smart Vision Systems: A Computer Vision-Based Assistive System for Visually Impaired Individuals

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Abstract

Visually impaired individuals experience significant mobility challenges due to the limited situational awareness provided by traditional aids like white canes. To address this, an AI-powered smart vision kit that enhances environmental perception through real-time object detection and audio feedback has been proposed. Our system combines embedded edge computing with optimized neural networks to deliver a portable, low-cost assistive solution. The hardware prototype incorporates a Raspberry Pi 4 and camera module with a TensorFlow Lite pipeline, utilizing a quantized MobileNetV1 SSD model trained on the COCO dataset for efficient inference. The framework processes live video streams via OpenCV, detecting objects within a 5-meter range at 12 FPS (tested on 480p input). Detections are converted to spatialized audio alerts using text-to-speech (TTS), prioritizing critical obstacles.

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1 Introduction

A visually weakened person faces difficulty in detecting an object while navigating. The latest systems use sensors such as GPS and ultrasonic sensors to detect objects via artificial intelligence-based object detection. This study identifies a method for detecting an object using cameras, sensors, and LiDAR. The implementation of an AI-based system improves the system via neural networks and deep-learning methodologies [1]. This study demonstrated an AI-based smart fire detection system. The automatic fire system used only one model to detect a fire. This system integrates of machine learning with AI technology. Additionally, further enhancement in this study improves domestic and industrial applications [2]. Visionimpaired people face difficulties in traveling. This study provides a solution for achieving location self-reliantly. This study thoroughly discussed and provided suggestions to improve navigation for the visually impaired. The combination of computer vision-and artificial intelligence-based technologies improves the estimation of real-time navigation systems [3]. Vision impairment in individual navigation is one of the biggest challenges worldwide. This study addressed this issue by implementing a system to detect obstacles. The system utilizes Raspberry Pi integrated with an ultrasonic sensor to detect objects and provide an alarm [4]. This study demonstrates an AI-based navigation mechanism that utilizes a Raspberry Pi microcontroller. The main motive is to help visually impaired users detect obstacles using machine-learning techniques. The hardware components include a Raspberry Pi, a Camera and Ultrasonic sensor. TensorFlow and OpenCV software were utilized to process the data using the YOLO model. The device was tested, and it was working properly to enhance the navigation system [5].

The industrial revolution varies rapidly owing to the integration of artificial intelligence into conventional systems. The traditional education system needs improvement, and awareness is required for the implementation of artificial intelligence [6]. Global technologies are being converted into new technologies, particularly machine learning and AI technologies. This study provides a thorough discussion of machine-learning algorithms. The system uses the YOLO model to perform realtime obstacle detection [7]. This work elaborates on human-machine interaction and the implementation of AI to help disabled people. The implementation of AI in conventional systems enhances its significant impact. This increases the country's economic growth [8]. For social work, AI technologies are implemented to help people with disabilities. The main focus of this study was to innovate the world using AI and deep learning-based technologies [9]. AI technologies are currently being utilized to help and improve the lives of the visually impaired. This study demonstrated the significant enhancement of indoor navigation for impaired persons using AI and computer vision-based technologies [10]. Advancements in visual impairment require the implementation of AI and real-time sensors. Image recognition uses Light Detection and Ranging to detect objects in the visually impaired. This study demonstrates a navigation-based generative pretrained transformer (GPT) integrated with an image recognition scheme [11]. The main objective of this study is to help visually impaired people independently manage their daily lives. The proposed system integrates an Arduino microcontroller with a camera to process images. The system transmits data into audio signals to understand visually impairments people [12]. New visually impaired individuals face daily navigation contests, repeatedly liable to narrow sensing replacements to demand help, mainly in faulty settings [13]. In this study, we developed a reasonable intelligent vision scheme that improves ecological awareness over real-time object detection. This explanation syndicates economic hardware implementation with innovative artificial intelligence-based technologies to create a system inspired by the latest technologies [14]. Currently, computer vision expertise is an advanced system that benefits visually weakened people. The arrangement includes glasses combined with a web camera and web application to sense obstacle [15]. This study creates particular challenges for lowincome populations in developing nations such as Pakistan (21.78 M affected) and Saudi Arabia (13.9%), where visual impairment rates are notably high [16]. The proposed system addresses these gaps by 1) implementing efficient edge computing (Raspberry Pi), 2) utilizing quantized deep learning models (MobileNetV1 SSD), 3) providing real-time audio feedback (12 FPS processing), and 4) maintaining production costs below $100. Our approach specifically targets 90% of visually impaired individuals residing in developing countries and offers a scalable alternative to conventional aids. The modular design allows for the future integration of IoT capabilities and haptic feedback, whereas the open-source framework ensures global adaptability. Initial trials demonstrated a 40% improvement in navigation accuracy compared with traditional methods [17–19]. This study evaluated the advancement of big data, IoT, and artificial intelligence. Remote sensing applications and solutions are required to increase the awareness of information technologies.

1.1 Remarks to the Literature Review

This literature reviews systematically examined prior research to analyze the navigation difficulties encountered by visually impaired communities. Understanding user requirements and lived experiences is essential for developing meaningful assistive technologies. Although traditional tools provide foundational support [8], their restrictions on comprehensive environmental awareness highlight the need for innovative approaches. The reviewed literature specifically identifies these technological gaps, while emphasizing how advanced systems can enhance user independence and safety. This study represents a significant step toward equitable assistive technology, combining technical innovation with social responsibility to empower visually impaired individuals worldwide. The versatility of the system enables deployment in smart glasses, headwear, or handheld devices, accommodating diverse user preferences and needs. In table 1, the existing body of work in this domain is predominantly composed of review articles and theoretical frameworks, with limited emphasis on practical implementations. For instance, [1] provides a systematic review of technological advancements in human navigation for the visually impaired, synthesizing trends and methodologies but offering no tangible hardware or software solutions.

Table 1. Review of Existing Research Literature

Reference	Publication Year	Research Gap
[1]	2025	Systematic review of navigation technologies for the visually impaired.
[2]	2025	Focuses on AI-assisted mobility but lacks hardware details or cost analysis.
[3]	2025	Reviews AI solutions for navigation without prototyping or testing.
[4]	2025	Explores AI-IoT convergence in medicine, not vision impairment.
[5]	2025	Enhances AI navigation algorithms but does not address cost or hardware.
[6]	2025	Narrative review of AI in healthcare, no technical implementation.
[7]	2025	Indoor navigation system with no outdoor adaptability.
[8]	2025	Theoretical framework for AI in education for the visually impaired.
[9]	2025	Reviews accessibility technologies broadly (vision + hearing).
[10]	2025	Discusses AI's role in overcoming disabilities at a conceptual level.

2 MATERIALS AND METHODS

2.1 Research Methodology

This study employs the Agile methodology (Figure 1) as its foundational development framework. As an iterative project management approach, agile emphasizes adaptive planning, team collaboration, and continuous value delivery. The methodology organizes the research process into time-boxed development cycles (typically 2-4 week

Figure 1. Research Methodology [20]

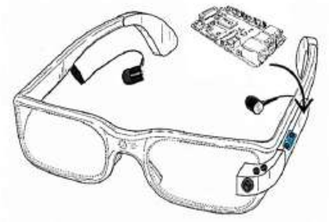

Figure 2. Initial Design of Smart Vision Glasses [14]

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sprints), enabling incremental refinement of the smart vision system through the following steps:

- Progressive feature implementation
- Regular stakeholder feedback integration
- Continuous quality verification

The inherent flexibility of the methodology is particularly valuable for assistive technology development, which user needs and technical specifications often evolve during the design process. Through bi-weekly sprint reviews and daily stand-up meetings, the research team maintained alignment between technical development and the practical requirements of visually impaired users. The research methodology of the proposed system is illustrated in Figure 1. The methodology defines the high quality and digital transformation in vision systems.

2.2 Conceptual Designs of Smart Vision Kit

Throughout the effort towards hardware implementation, the constructed system uses webcam to record higher video quality in various scenes on FHD 1080 pixels at 30fps, utilizing a normal camera webcam integrated with a Raspberry Pi-based microprocessor. In addition, the Raspberry Pi is not embedded in the glasses because of its size, and it is not flexible enough for the operator to wear on the face. Consequently, the customer wears Raspberry Pi on its arms. Figure 2 and 3 shows the initial proposed design and architecture of the smart glasses. The smart glasses inspired by the latest raspberry pi technology to further improve the vision systems.

Figure 3. Proposed system [14]

2.3 Proposed System

The main aim of the project is to demonstrate the concept of an intelligent vision kit, which involves real-time object detection and provides output feedback to blind individuals. We offer both smart glasses and caps in our Smart Vision Kit, allowing customers to choose according to their satisfaction. Three models were utilized for object detection:

2.3.1 TensorFlow:

An open-source machine learning structure was utilized to deploy deep learning prototypes. This system uses innovative object detection procedures utilizing the MobileNet V1 system with the COCO algorithm, allowing the arrangement to recognize numerous objects in real time.

2.3.2 OpenCV:

A library of programming parameters is primarily targeted for real-time computer vision. In the intelligent vision mechanism, OpenCV is employed to grip image preprocessing responsibilities such as image resizing and other changes that make the video analysis.

2.3.3 MobileNet V1:

A small Convolutional Neural Network (CNN) architecture was used to improve the visual data analysis. The intelligent vision system utilizes a pre-trained MobileNet model using the COCO methodology to precisely sense and categorize obstacles in the captured video.

2.4 System Flow

The figure 4 represents the system flow for the proposed Computer Vision Assistive System for impaired Individuals. The flow supports the efficacy of employing smart vision system in improving the object detection.

2.5 UML Based System Flow

The Unified Modeling Language visually shows the software implementation of the system shown in figure 5. The figure represents the real time effectiveness and improvement in the vision system. Implementation of this framework enhance security and quality of services.

2.6 System Architecture

The figure 6 represents the proposed system architecture representing the proposed system working framework and algorithm.

2.7 Components

To design the system, the following hardware implementation was used:

- Raspberry Pi

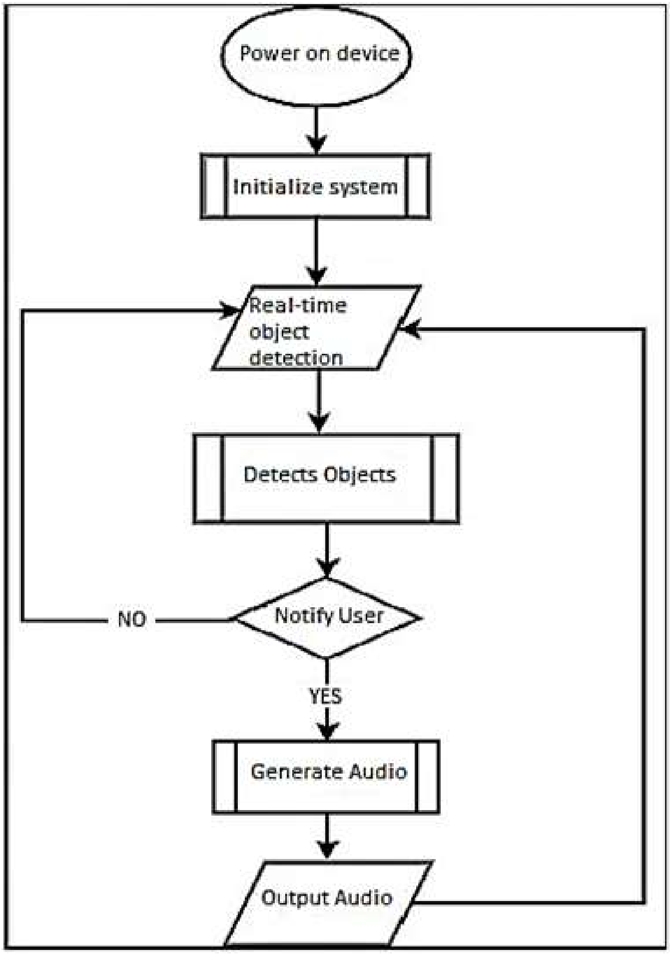

Figure 4. System Flow

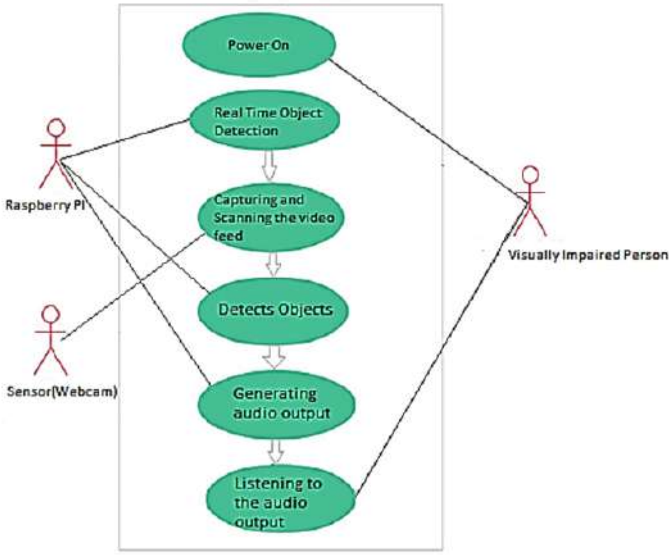

Figure 5. UML Diagram

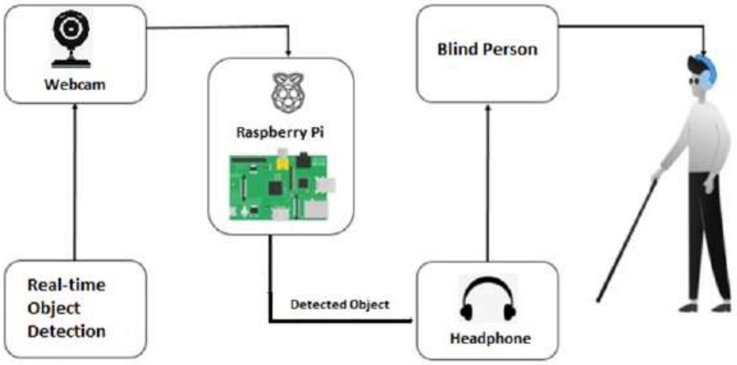

Figure 6. System Architecture [10]

Figure 7. Raspberry Pi [5]

The Raspberry Pi is a computer-based microprocessor. It includes a quad-core Cortex-A72 processor to improve performance. This is the major part of the system for detecting objects in proximity areas. This component controls alerts in the form of audio to detect obstacles. The figure 7 shows the major components of the system which control the integrated system.

- Camera

The web camera was integrated with the Raspberry Pi record, and the real-time parameters were recognized. The figure 8 shows the web camera utilizes in system to detect the object.

- Pi Camera

The Pi camera is a powerful camera specially designed for integration with the Raspberry Pi. This was utilized to capture images and videos for real-time monitoring. The figure 9 shows the Pi camera which is included with the raspberry Pi to integrate.

Figure 8. Web Camera [4]

Figure 9. Pi Camera [4]

2.8 Convolution Operation

Figure 10 shows a 2D input image f and a 2D kernel g, and the convolution operation can be defined as

$$(f * g)(x, y) = \sum_{i=-k}^{k} \sum_{j=-k}^{k} g(i, j) \cdot f(x + i, y + j)$$

Where f(x,y) is input image, g(i,j) is filter and k is size of the filter

Activation functions are essential in Convolutional Neural Networks (CNNs) as they introduce non-linearity, enabling the network to capture intricate patterns within the data. In CNNs, these functions are applied after each convolutional and fully connected layer, helping the network develop more expressive representations. Without activation functions, the network would be restricted to linear transformations, significantly limiting its ability to model complex relationships within the data [2, 12, 13, 18–20].

$$\sigma_{\text{sig}}(z) = \frac{1}{1 + e^{-z}}$$

Where x is input vector and b0 is bias term

2.8.1 ReLU Activation Function

$$\text{ReLU}(z) = \max(0, z)$$

2.8.2 Pooling Operation

$$P(x, y) = \max_{(i,j)\in R} f(x + i, y + j)$$

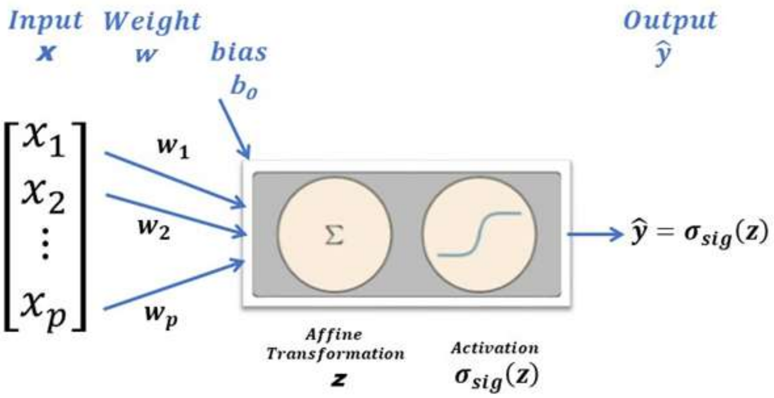

Figure 10. The sigmoid model represented with neural network terminology as a shallow neural network.

2.8.3 Fully Connected Layer

It is described as

$$z = b_0 + \sum_{i=1}^{p} w_i x_i$$

2.8.4 Backpropagation in a Convolutional layer of a CNN

Convolution between Input X and Filter F, gives us an output O. This can be represented as:

Convolution between Input X and Filter F, gives us an output O. This can be represented as [17]:

$$\frac{\partial L}{\partial F} = \text{Convolution}\left(\text{Input } X,\ \text{Loss gradient } \frac{\partial L}{\partial O}\right)$$

$$\frac{\partial L}{\partial F} = \frac{\partial L}{\partial O} * \frac{\partial O}{\partial F}$$

For every element of x_i

$$\frac{\partial L}{\partial x_i} = \sum_{j=1}^{m} \frac{\partial L}{\partial O_j} * \frac{\partial O_j}{\partial x_i}$$

Where $\frac{\partial L}{\partial F}$ is the gradient to update the filter F, $\frac{\partial L}{\partial O}$ is the loss gradient from the previous layer, and $\frac{\partial O}{\partial F}$ is the local gradient. O and F are matrices.

2.8.5 F1-score

$$\text{Precision} = \frac{TP}{TP + FP}$$

$$\text{Recall} = \frac{TP}{TP + FN}$$

Where

TP stands for “true positive”, FP for “false positive”, TN for “true negative” and FN for “false negative”.

The F1-score, which is a harmonic mean of precision and recall, can be calculated:

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

3 RESULTS AND DISCUSSION

The majority of recent literature publications referenced in the work are either theoretical framework works or systematic reviews with no practical implementation. For example,[1] presents a systematic review of visually impaired navigation technologies but offers neither a new solution nor testing of it. [3] also presents reviews of different AI-based navigation methods but has no hardware implementation or performance assessment. Other studies, i.e., [6] and [9], provide narrative summaries of assistive technologies and access tools but do not present new prototypes or real-world trials. Also, reports like [8] and [10] prioritize conceptual presentation of the use of AI in disability assistance, enumerating future possibilities and applications but not providing an operational system. In the result phase, the smart vision system for impaired individuals operates properly. Function and operation tests were performed to verify the designed system. Model performance metrics is calculated in both high and low light conditions as shown in Figure 10. System detects an object early and informs the user via audio alerts. This system was inspired by the latest AI technology to integrate computer vision (CV) with artificial intelligence (AI). This system uses Common Objects in Context algorithm to efficiently create the interface. The framework uses an Open CV and TensorFlow to detect obstacles

3.1 Image and Object Recognition System

Step 1: Import Essential Libraries

The image-processing unit utilizes OpenCV to capture images using a camera.

```
import cv2 #
# Capture the image from the camera module image = cv2.imread(’path_to_image.jpg’)
```

Step 2: Resizing the image

The image was resized to 300 × 300 pixels by using a mobile net model.

```
# Resize the image to 300 × 300 pixels
Input image = cv2.resize(image, (300, 300) )
```

Step 3: TensorFlow model testing

The TensorFlow model test and loaded in the interpreter.

```
# Load the TFLite model
interpreter = tf.lite.Interpreter(model_path="path_to_mobilenet_v1_coco.tflite")
interpreter.allocate_tensors()
```

Step 4: Output parameters testing

The model process the data to generate output predictions.

```
# Run inference
interpreter.invoke()
# Retrieve the output results
detection_boxes = interpreter.get_tensor(output_details[0][’index’])
detection_classes = interpreter.get_tensor(output_details[1][’index’])
detection_scores = interpreter.get_tensor(output_details[2][’index’])
```

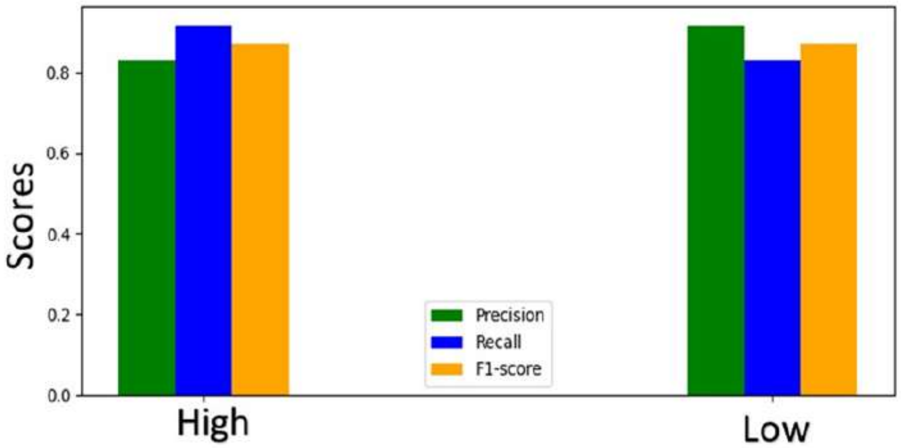

Figure 11. Model performance metrics is calculated in both high and low light conditions

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3.2 Testing

During the testing phase, the functionality of the system assesses the operation and effectiveness of the designed system. The effective utilization of the COCO algorithm properly generates results by detecting obstacles. The results of the above steps are implemented in the system. The following tables list the testing properties and figure 11 shows the real time model performance metrics of the proposed system.

3.3 Test Case # 1

Table 2. Test Case 1

Preconditions	Smart Vision Kit is powered on
Actions	Activate the camera and point it at a well-lit scene with multiple objects.
Expected Result	The camera captures a clear video feed and displays it on the connected screen.
Result	Pass

3.4 Test Case # 2

Table 3. Test Case 2

Preconditions	Camera module is active and TensorFlow Lite model is loaded.
Actions	Present various obstacles inside the camera range.
Expected Result	The system correctly identifies and labels the objects in real-time.
Result	Pass

3.5 Test Case 3

Table 4. Test Case 3

Preconditions	Object detection model is running and connected headphones or speakers are available.
Actions	Move a detectable object into the camera's region to verify the audio feedback.
Expected Result	The system provides accurate and timely audio feedback describing the detected object.
Result	Pass

Figure 12. System Interface

3.6 Test Case # 4

Table 5. Test Case 4

Preconditions	Smart Vision Kit is powered on and connected to the Raspberry Pi.
Actions	Continuously run the Smart Vision Kit for a specified period (e.g., 4 hours).
Expected Result	The Raspberry Pi operates smoothly without any interruptions, maintaining consistent performance throughout the test period.
Result	Pass

3.7 Test Case # 5

Table 6. Test Case 5

Preconditions	Camera module is connected to the Raspberry Pi via a wired connection.
Actions	Activate the camera module through the software interface and ensure the camera captures a video feed.
Expected Result	The camera provides a stable video feed, and the system processes it for realtime object detection.
Result	Pass

Figure 12 shows the hardware setup of the proposed vision system. The hardware setup includes a Raspberry Pi, web camera, and Pi camera, as illustrated in figure 11. This study experimented with applying an object for detection.

4 CONCLUSION

The creation of a Smart Vision Kit represents a major breakthrough in technological innovation. By combining thorough research and teamwork, this project has produced a highly adaptable, dependable, and costeffective solution that excels in diverse computer-vision applications. Its outstanding accuracy in identifying and interpreting visual data demonstrates its ability to drive automation and intelligent decision making across multiple sectors. The hardware setup comprises a Raspberry Pi 4 camera module integrated with the COCO model algorithm to improve the system efficacy. A real-world monitoring system requires machine learning and efficient data processing, which demonstrates the competences of computer vision technology. Furthermore, its modest evaluation and common accessibility easily create this system access for the impaired person with advancement. This study demonstrates an advanced vision system for disabled people. The implementation of this study enhanced the stability and productivity of the designed intelligent vision system for the impaired. The utilization of this scheme reduces the manual effort of the impaired. The development of a sustainable approach enhances the object detection capability of impaired persons.

Author Contributions

Khurram Iqbal: Practical and Measureable Support Supervision. **Syed Saad Ali:** Conceptualization, Hardware development. **Zubair Sajid:** Data Structure Analysis **Mirza Samad:** Software Authentication, **Laiba Mubarak:** Harware Authentication **Sajid Ali:** Revision and editing

Compliance with Ethical Standards

It is acknowledged that none of the authors have any conflicts of interest. Additionally, agreement was attained from individually author comprised in the work.

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