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SMART BLIND STICK WITH VISION BASED OBSTACLE DETECTION AND ASSISTIVE NAVIGATION

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ABSTRACT

Visually challenged people face many challenges in day-to-day life for performing simple activities as simple as navigating through an unfamiliar space. This project proposes a smart stick to overcome some of the limitations by integrating Arduino, ESP32CAM, Ultrasonic sensors, GSM, GPS, audio module providing assistive feedback through speakers and vibrating motors. This project uses MATLAB to train the objects captured via the camera to provide smart obstacle detection, classifies walkable path, recognize traffic light signals and gives audio guidance to them. The central processing used here is an Arduino microcontroller board. In case of emergencies the user's location is detected by the GPS and is sent to the contacts via GSM. It also uses low power for computational purposes; therefore, the project is proposed to use a rechargeable Li-ion battery. The proposed project combines computer vision, sensor-based obstacle detection to provide assistance to vision impaired people with assistive feedback for their improved mobility, safety. Thus, providing freedom of movement.

Keywords—ESP32, Global system for Mobile communication (GSM), Global positioning system (GPS), MATLAB, Ultrasonic sensor.

1. INTRODUCTION

Vision is one of the most important senses of our body, we perceive and experience world through it. Without proper vision, we struggle to even walk, read, learn and fail to appreciate the beauty of the world. The World Health Organisation estimates that at least 2.2 billion people have vision impairment and that global blindness is set to triple by 2050. The leading causes of vision impairment are due to refractive errors and cataracts. In this there are about 40-45 million people who are completely blind. This type of vision impairment poses a huge global financial burden, with the annual global cost of productivity to be about US$ 411 billion.

Most of the people in this category wants to navigate the world without any assistance and need freedom in moving around. This leads to people having many challenges in their modern life, which includes the risk of accidents in unfamiliar environments, need for emergency communication and real-time assistance. They generally use white cane, which helps them to move to different and unfamiliar places.

In our technologically evolving world, the integration of hardware and IoT is becoming increasingly common. So, integrating a cane with IoT must be easy and should be cost efficient with high reliability. Our paper focusses on developing a smart stick for completely blind people to provide assistance by detecting obstacles, buildings, manholes and providing them with walkable paths, most importantly helps in traffic light detection. It integrates vision processing and provides emergency outreach in unprecedented events. Our project also utilizes machine learning for vision processing that includes object detection and path detection. There are many in-built features in MATLAB that provides various image processing capabilities and also path detecting features with the help of image segmentation, edge detection, etc…

Note that the people using our smart blind stick need to have proper hearing senses to be able to fully experience the functions of it. Although the vibration feedback can be used in the case of hearing impairment to detect the oncoming obstacles. This paper proposes the stick for laying a groundwork for proper utilisation and integration of IoT, machine learning techniques in building an assistive technology for vision impaired peoples with cost-effective hardware and efficient software algorithms.

2. PROPOSED SYSTEM

The proposed system is a smart blind stick for obstacle detection and for assisting in navigation developed with the key features of the existing system explained in the above literature surveys. The system's main purpose is to detect the oncoming obstacles and provide a walkable path by identifying the objects. The objects or obstacles are detected by the ESP32-CAM that acts as a virtual eye for the disabled individual. The objects captured by the CAM are processed by the MATLAB for identifying. The obstacles or any objects in particular are pre-trained in the model by using pre-existing open-source datasets and the objects identified are announced through the speaker. The ultrasonic sensor fitted with the stick is for the obstacle detection within a specified range that may affect the path of the person when moving in a particular direction.

When the obstacles are detected by the ultrasonic sensor, the vibration feedback is given to alert the user to avoid the obstacle in the oncoming direction. It is fitted with GSM and GPS that tracks the location of the user and sends the live location to the number registered to it via GSM. An SMS is sent to the registered number with the coordinates of the user obtained from the GPS. A power control module is fitted with the whole system for regulating the power supplied to the system. Along with this an audio module that has a microphone and a speaker is also fitted that can record a voice to the memory and can be played back to the other person in emergency cases with a press of a button, also a separate button is provided for recording the voice. This whole system is controlled by Arduino that uses AT-MEGA microcontroller that acts as a central processing for the whole system. The different hardware and software components used for the proposed system are explained in detail below:

A. HARDWARE:

1)Arduino: Arduino is an open-source electronics platform that provides an easy-to-use hardware and software. Arduino also simplifies the process of working with microcontrollers by simplifying the process of coding and combining it in to a single IDE. Our system's main central processing is a custom-built Arduino, based on the UNO. It is a basic type of the Arduino microcontroller that uses ATmega328P. The microcontroller is custom built to support the various peripherals that are needed in our system. Extra pins are added to the same for an extensive use of all the components mentioned above

2)ESP32-CAM: The ESP32-CAM has the ESP32-S surface-mount printed circuit board module developed by Ai-Thinker. It has an OV2640 camera sensor with a video resolution of 640X480 pixels which makes it ideal for use in video projects. It is chosen in our project as it is a basic camera with comparatively low cost and can be integrated with our Arduino microcontroller. It has inbuilt Wi-Fi, Bluetooth, and microSD card storage. The power consumption here is very low, however, it needs an external programmer for flashing the program to its memory as it lacks USB-to-serial converter.

3)Ultrasonic Sensor: The sensor used here is HC-SR04 that has a range of 2cm to 400cm (approx. 4m) and has an accuracy of 3mm. The working of ultrasonic sensor is by transmitting the high frequency waves at above 40KHZ and when the reflected waves from an obstacle is received, the distance is calculated by the known speed and frequency. The respective waves are known to be trigger and echo signals.

4)GPS: Global Positioning System (GPS) is a satellite-based system that uses satellites and ground stations to measure and calculate the position on Earth. The GPS receiver module gives output in standard (National Marine Electronics Association) NMEA string format and provides output serially on Tx pin with a default 9600 Baud rate. Our stick constantly uses this location and sends them to the user via GSM module for live location tracking when an object is detected within the set range.

5)GSM**:**Global System for Mobile communication (GSM) is an architecture used for mobile communication. This GSM/GPRS module is used to establish communication between our stick and a mentioned user. It requires a SIM (Subscriber Identity Module) card like mobile phones to activate communication with the network. This continuously transmits the location received from the GPS to the number(s) registered when an object is detected in the set range of the ultrasonic sensor.

6)Audio module and vibration sensor: The audio module used here is YS41F**.** It has both audio recording and playback capabilities with separate buttons being used for these two functions along with an inbuilt microphone. An audio can be pre-recorded by the user or any other person for any emergency purposes in the future. The same can be played to any other person nearby by pressing the playback button. This module is powered by three lithium-ion batteries. The vibration sensor used here is a coin type micro vibration motor that vibrates when the ultrasonic sensor detects an object. It is connected to the arduino itself.

7)Power module and Battery: For providing powers to multiple components including Arduino this power module is used. It is a DC-DC converter that converts 12V to 3.3V, 5V and 12V. The battery used here is a rechargeable 12V acid battery. It can be recharged by an adapter that converts standard household voltage to 12V. However, these types of batteries are heavy and are considerably large, making the stick heavy.

B. SOFTWARE:

1)Arduino IDE: It is an official software for programming Arduino microcontrollers, that is mainly used for writing, compiling and uploading the code in almost all Arduino modules/boards. This is used to program all the embedded components mentioned above and is compiled, uploaded to the arduino. This is also used to program the ESP32-CAM via the arduino for capturing the obstacles.

2)MATLAB: MATLAB stands for Matrix Laboratory. It is a high-performance language that is used for technical computing. Image recognition with MATLAB can be achieved using various techniques and tools provided by MATLAB's Image Processing Toolbox and Deep Learning Toolbox. It provides a user-friendly environment for image processing and deep learning tasks, making it easy to implement image recognition. The different datasets available are used to train different obstacles and objects that can come into the person's path to be able to identify them. However, the code is made to run on the MATLAB software itself rather than converting it into TinyML to be able to run them in the arduino itself as it requires an advanced version of arduino that can lead to increase in the cost of the system proposed here and can be easily integrated when converting this into a product.

<Other software if told and the name of datasets.>

IV. METHODOLOGY

The system is designed with user-friendliness in mind and reliability, efficiency in terms of power is also taken into account. The hardware is chosen such that they use low power and is very low weight. Many numbers of objects in the image recognition datasets are trained to the device, to detect a variable number of objects. This leads to detection of most common objects that may come into the path of user. The different types of hardware selected for the specific purpose are mentioned above.

1)Hardware assembly: The system's main visual interfaces such as ultrasonic and ESP32-CAM are placed at the front. The ultrasonic is placed at the centre of the stick and camera is placed above it. The CAM is placed at a correct location after many testing to place it in the correct position for clear object recognition. Other components are placed nearby to the Arduino for less wiring and fast transmission of signals. The vibration sensor and the audio module is placed as near as possible to the person's hand to be able to give a strong sense of vibration to them and for clear hearing.

2)Traffic light detection using ESP32 camera and MATLAB: The ESP32 camera module is responsible for capturing real-time images of traffic lights at pedestrian crossings. The captured images are transmitted to a MATLAB based image processing systems, where they are analysed to determine the traffic signals status.

- The machine learning algorithm used for image recognition is trained on a dataset of traffic light images under lighting conditions, angles and environmental factor.
- The image processing system applies colour detection, feature extraction and classification technique to identify whether the signal is red, yellow or green.

3)Obstacle detection using ultrasonic sensor: The ultrasonic sensor is used to detect obstacles in the path of the user, ensuring that they are aware of potential hazards while walking. The working mechanisms of the ultrasonic sensor includes:

- Emitting ultrasonic waves and measuring the time taken for the wave to bounce back from nearby objects and calculates the distance of the detected obstacle using the time delay.
- Then the processed data is sent to the Arduino UNO, which then provides an alert through the vibration sensor, if an obstacle is detected within a predefined range.

4)Central processing using Arduino UNO: The Arduino UNO microcontroller serves as the central processing unit for the smart stick, managing data from all sensors and modules. It executes the following tasks:

- Receiving real-time images from the ESP32 camera and forwarding then for the MATLAB processing.
- Analysing data from the ultrasonic sensor to detect obstacles and generate appropriate warnings.
- Controlling the push button switch for manual audio assistance and emergency alert activation.
- Managing power distribution to ensure efficient energy consumption.

5)Emergency alert system using GPS and GSM module: The GPS and GSM modules are integrated into the smart stick to enhance safety by providing real-time location tracking and emergency alerts. The functionality includes:

- The GPS module continuously track the user's location, ensuring that their position is available in case of an emergency.
- When an object is detected in front of the person, then the location (Latitude, Longitude) is sent to the registered number(s).

6)Audio playback and voice guidance system: The push-button switch and audio playback module provide real-time voice guidance to the user. The primary functions of this module include:

- Announcing traffic signal status (red, yellow, green, pedestrian signal).

- Alerting the user about obstacles detected in their path.

7)Machine learning model for traffic light detection: The machine learning algorithm used for traffic light detection is trained using MATLAB. The model development process involves the following: Collecting a large dataset of traffic light images taken under different weather conditions, lighting levels, and angles. Preprocessing the images using filtering techniques to enhance clarity. Extracting relevant features such as colour histograms, shape contours, and edge detection. Training a convolutional neural network (CNN) model to classify traffic signals accurately. Evaluating model performance using precision, recall, and accuracy metrics. Deploying the trained model on MATLAB for real-time image analysis.

BLOCK DIAGRAM:

3. INTEGRATION AND TESTING

The final stage of the methodology involves integrating all hardware and software components, followed by extensive testing. The testing procedure includes:

1)Unit testing: Each module, including the ESP32 camera, ultrasonic sensor, GPS-GSM, and audio playback system, is tested individually to ensure proper functionality.

2)Integration testing: All components are integrated and tested together to verify seamless communication between hardware and software.

3)Field testing: The smart stick is tested in real-world environments, like busy intersections and pedestrian crossings, to assess its performance under real-time conditions.

4)User feedback and improvements**:** Visually impaired individuals are invited to use the smart stick, and their feedback is collected to make necessary improvements.

<OUTPUT IMAGES>

4. CHALLENGES AND DRAWBACKS

During the smart stick’s development, several challenges were addressed to reduce the drawbacks of the proposed system. The main drawbacks are detection in low light conditions, real-time processing, accuracy of the obstacle detection and power issues. Low-light traffic light detection was improved using infrared filters and adaptive brightness adjustment. Real-time processing latency was minimized by optimizing the machine learning model and utilizing MATLAB’s parallel processing. Battery life was extended through power-saving modes and low-power components. These solutions enhance the efficiency, reliability, and overall performance of the proposed stick.

However, there exists GPS accuracy issues in urban areas which can be resolved by using Kalman filtering. For the prolonged use of the stick the battery’s size is not reduced leading to increased weight of the stick.

5. CONCLUSION AND FUTURE SCOPE

The smart stick enhances mobility, safety, and independence for visually impaired individuals by combining machine learning, real-time processing, and assistive technologies.

Its main components include an ESP32 camera, ultrasonic sensor, Arduino UNO, GPS-GSM module, and voice guidance for navigation. The MATLAB-based machine learning model ensures accurate traffic signal recognition, obstacle identification in different environments. The ultrasonic sensor enables obstacle detection, while the GPS-GSM module provides real-time location tracking and emergency alerts. Voice guidance enhances user experience, and the 12V rechargeable battery ensures uninterrupted operation. This innovation significantly improves navigation efficiency and acts as a prototype for future assistive technologies.

Future improvements to the smart stick may include enhanced functionality, efficiency, and user experience. Deep learning models, such as CNNs, could improve traffic signal detection, while LiDAR technology could offer more precise obstacle detection and mapping in any lighting conditions. IoT-based features like cloud integration and predictive analytics, would improve real-time monitoring and safety. Haptic feedback along with voice guidance and alerts can be more accessible in noisy environments.

Energy harvesting, such as piezoelectric or solar power, could reduce battery dependency leading to prolonged use of the stick. Multilingual voice guidance and integration with smart city infrastructure would further enhance accessibility in a greater level for seamless mobility. Guidance from healthcare experts and user feedback with continuous improvements can make the smart stick a more advanced and inclusive assistive device for visually impaired individuals.

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