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Design of Smart Cane with integrated camera module for visually impaired people

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Abstract— **In the world, millions of visually impaired or blind people are living. They are always dependent on other people or trained pets to move through an unknown environment. A typical walking stick cannot meet the safety monitoring and guidance requirement of blind people. This paper focuses on designing and developing a smart cane capable of sensing and signaling the environmental features around visually impaired people. The proposed smart cane has two ultrasonic sensors for measuring the distance between the smart cane to the stationary and hanging objects found to be an obstacle. Alert signal is provided by the actuator when the obstacle is falling inside a threshold level of 2 meters. The design integrates a camera module ESP-32 to capture the moving object/people's image in addition to the obstacle detection. The camera module gets enable signal from the PIR sensor to capture the image of the moving object/person and save processor time. It also provides information about the situation around the blind person and their relatives in case of an emergency. It provides the implementation cost and power requirement of the smart cane to develop a camera-enabled stick.**

Keywords: ESP32 camera, Smart Cane, Blind people, Power calculation, Distance measurement

I. INTRODUCTION

World Health Organization (WHO) report of blindness and visual impairment 2020 states that one billion people are visually impaired, totally blind, and vision loss for people over 50 years old [1]. The increase in the rate of visually impaired problems keeps increasing day by day due to various reasons like a reflective problem, cataract, etc. Those people highly depend on other people or their trained pet animals to ensure their safety while moving through an unknown environment. A visually impaired person commonly uses a walking stick when they do not have any people to help them. The basic walking stick is a mechanical design that can be foldable and ensure safety but restricted to their strength to handle it. A smart cane is an electronically equipped stick powered by a battery and indicates the challenges before the victim using microcontroller-based sensing and control. It focuses on detecting the obstacles ahead, spotting the person stored in the database, and connecting the victim to their close relations using GSM tracking. It helps the visually impaired person for moving inside the house or through unknown terrain. It leads to a smart cane design capable of assisting the visually impaired with a cost-effective design that makes their life easy and comfortable. The paper proposes an intelligent solution to blind people for making their daily lives convenient and connected to their close relations to take care of them from remote locations.

Many researchers worked on the design and development of smart cane with various facilities and advancements. Smart Stick for the Blind is a favorable solution to travel in an unknown location towards a destination. This system uses an IR sensor, an ultrasonic sensor, and a water sensor to detect various obstacles. However, these systems notify the external environment through an actuation signal if any one of the sensors gets triggered. Recorded audio messages are used with Bluetooth-connected speakers to indicate the distance of the person's obstacles [2]. Ultrasonic sensors are used in many designs to calculate the barrier's location and indicate the static blocks around the person using a group of sensors like ultrasonic sensors and infrared sensors [3]. The IR sensor detects the staircases, and the ultrasonic sensors measure the distance of the puddles and indicate using speech warning messages and vibration motor. 18F46K80 microcontroller, vibration motor, and ISD1932 flash memory detect obstacles in the range of 4 meters within 39 ms as processing time. It gives a suitable message that helps the user move twice the normal speed, ensuring his/her safety. The smart stick design gives the fast response, low cost, low power consumption, lightweight, and folding ability.

In recent years, many pieces of research focus on image data for various safety applications. It is employed in [4] that proposes biometric instruments of blind peoples to sense and detect obstacles. They are provided with spectacles to wear on, embedded with ultrasonic distance measurement scale equipment and a camera with a headphone. The device uses the target finding using ultrasonic sound. The camera in the device stores the face image and helps identify the person and recall from the memory whenever the person reappears before him.

Pothole detection [5] for the visually impaired uses a camera that captures the image at 15 frames per second, and based on the concept of image processing, the pothole is detected. The problem with this system is the use of a camera makes it expensive, and also, a lot of images captured per second increase overhead and storage requirement. The warning sound signal has a frequency correlated with the pixel orientation [6].

Global Positioning System (GPS) integration is also getting focus on smart stick design for few applications. It's also noteworthy that a GPS receiver can provide the subject's current location and nearby landmarks. The feedback information indicates the user with a vibration signal or as a sound signal [7]. Consequently, training is necessary to help the user understand the signals and react to them in real-time, having its own time and cost [8]. There is also a proposed solution that helps blind to avoid obstacles around them without holding any sticks or other heavy things. There is a system that is a spectacle module associated with a sonar sensor, the vibrator, which detects the barrier and alerts. The camera calculates the surface's smoothness during daylight and dark using RGB data and sends images to the smartphone via Bluetooth controlled through a microcontroller [9]. The design is a very small, wearable, lightweight, low-cost spectacle for the blind and feasible for their assistance. There is a system designed as a wireless system using Wi-fi communication to the ultrasonic sensor to be comfortable to be carried by the user. The system helps visually impaired people to move around in indoor or outdoor scenarios [10].

Electronic Travel Aids (ETAs) helps to navigate a person by collecting information about the environment and exhibits in a form that allows a blind to understand the environment. It proposes a computer vision-based pothole detection and uneven surface detection approach that helps blind people meet their needs. The system uses laser projected patterns and records the patterns as a monocular video. Upon analyzing the patterns, the features are extracted and predict the path. Over 90% accuracy in detecting potholes is possible with the proposed system that assists blind people in real-time navigation [11].

A sonification process builds the map of the surrounding by the disparity image and converts it to a stereo musical sound. It has information about the features of the environment in front of the user. The sound indication through stereo headphones conveys the blind people about person or object around [12]. There is a sensor fusion-based obstacle avoiding system that utilizes a camera for acquiring the depth information of the surroundings. An ultrasonic rangefinder measure the distance of the obstacle from the stick [13]. Akshi devices employed with Radio frequency identification detection (RFID) reader can detect pedestrian crossing. Obstacles are detected using RFID, ultrasonic sensors, and raspberry-pi fast processing board and available through the AKSHI tracker app. The app allows the guardian to log in and access a blind person's location through GSM and GPS module. If the device meets an emergency, it communicates to the guardian. It avoids the wrong trigger using a press button interfaced with the mobile app [14]. The Guide Cane uses the same mobile robotics technology as the Nav-Belt. It is a wheeled device pushed ahead of the user via an attached cane. When the Guide Cane detects an obstacle, it steers around it. The user immediately feels this steering action and can easily follow the Guide Cane's new path without any conscious effort [15]. A proposed system for converting the images into sound patterns and provides auditory image representations within human hearing systems [16].

The proposed research work considers the advantages of previous developments with sensors and actuators to develop a smart stick capable of delivering alerts and providing surrounding information through vibrators and message signals. It also concerned the processing complexity and affordable cost. It is a simple design with an integrated camera covering the entire foreground information and identify the obstacle's existence and distance from the cane. Two ultrasonic sensors are in place for ensuring the presence of an obstacle and calculate the distance. Ultrasonic sensor one is placed at the bottom to sense the steps or stone in the pathway. Ultrasonic sensor two detects the hanging obstacles like wires or tree branches and indicates it to the user. An integrated camera module gets the image of the person standing in front and compares the face with the database to indicate the user. A PIR sensor triggers the camera module to snap when it detects a moving object/person's image, reducing the microcontroller's processing time.

The work presents the proposed methodology in section 2, which includes the cost and power source match the requirement. Section 3 covers the hardware design description, and section 4 discusses the sensor data analysis and result discussion, followed by the conclusion and future scope.

II. PROPOSED METHODOLOGY

The paper's prime objective is to design and develop a smart stick that will give confidence and safety to move around the world with their interest. The design satisfies the user to feel good contemplating appearance, and it should not be an extra burden for the people. It also assures the detection of obstacles, which may either be static obstacles or moving obstacles. The objects below knee level and hanging object ahead of the chest level have been addressed here for the completeness of different obstacles. It informs the presence of obstacles to the user by exiting an alarm signal using vibrators. The design uses a dedicated camera module with a PIR sensor to recognize the moving objects or persons before the cane. Whenever the PIR sensor identifies a moving object will be taken as a photo and compared with the database. The facial images pop out to the user with a recorded message. Figure 1 covers the block diagram of the work.

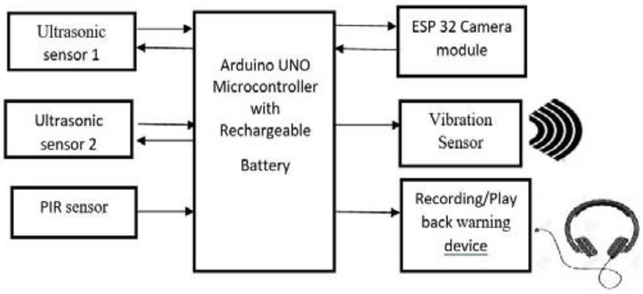

Fig. 1. Block diagram of proposed smart cane features

The figure shows the connectivity of various sensors and actuators to a central microcontroller unit powered by a rechargeable battery module. Figure 2 describes the layout of the design as the prototype of the smart cane. In the market, the ordinary cane is available with 90-120cm, which can be remodeled to be an effective smart stick with smart assistance. It also ensures the project component's dimensional details and their positioning over the cane. Each component has been tied to the cane with spacing and is connected to guide the blind/eyesight-affected individuals.

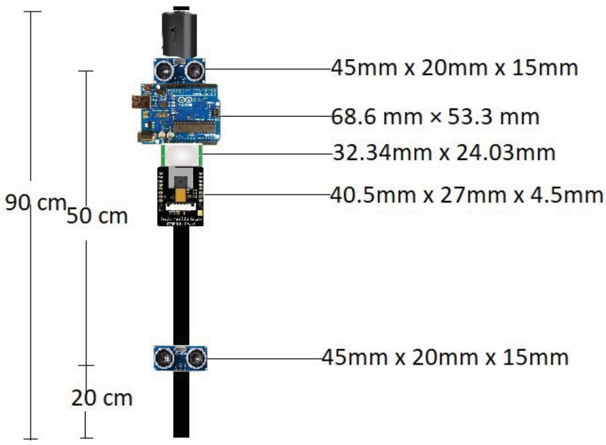

Fig. 2. The prototype of the smart cane

TABLE I. POWER CALCULATION AND PRICING OF COMPONENTS

Modules	Power requirement		Price (Rs.)
	Unit power (mW)	*Total power (mW)*	
HC-SR04 Ultrasonic sensor	75*2	150	300.00
Arduino UNO	1000	1000	500.00
PIR sensor	325	325	500.00
ESP 32 camera	1550	1550	1000.00
	Total	**3025**	**2300.00**
MAENT 18650 Li-Ion battery		**15000**	**600.00**

A rechargeable MAENT 18650 Li-Ion battery at 7.4V, 2000 mAH is providing power to the smart stick. It can power the cane for 4-5 hours backup for a single charge. Table 1 lists the component selection as per the power rating and its pricing.

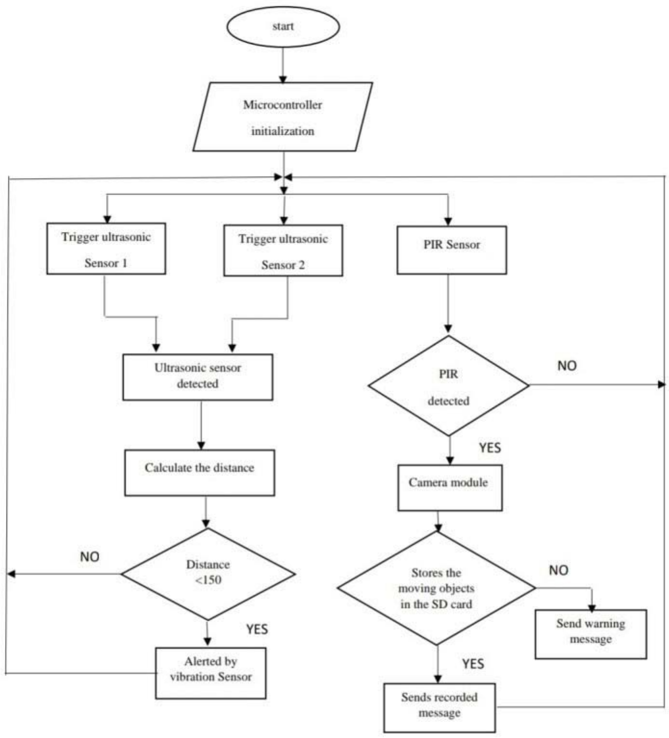

Fig. 3. Logic flow diagram for smart cane

The logical programming depends on the flow diagram shown in figure 3. Every microcontroller scan cycle will have three consistent operations, which include the trigger pulse generation for ultrasonic sensors 1 and 2 consecutively the PIR scan for detecting a moving object. For every 2 seconds, the trigger pulse enables the transmitter, which produces a pulse burst, and the receiver will absorb the echo signal reflected by the obstacle. It uses the time taken for travel for calculating the distance of the obstacle. Over a range of 400 cm detection zone, if the obstacle is within 150 cm, there will be an actuation vibrator to alert the person. PIR sensor-based camera module operation is another aspect of the smart cane. The camera module gets activated for every movement detection and takes a snap to compare the database recorded. It will indicate to the user about the environment through a prerecorded message.

III. DESIGN SPECIFICATIONS

A. *The ultrasonic sensor*

It is an electronic device that measures a target's distance, which can reflect the transmitted signal. It emits an ultrasonic sound wave, receives the reflected sound, and converts it into an electric signal. The ultrasonic signal travels much faster than audible sound (i.e., 20KHz maximum range). Ultrasonic sensors have a transmitter that emits the sound by vibrating the piezoelectric crystals and a receiver that absorbs the reflected sound signal from the target. The sensor calculates the distance between the sensor and the obstacle using the time taken for the ultrasonic sound to be transmitted and received the reflected signal from the obstacle. The formula for calculating the distance based on ultrasonic sound is

$$D=1/2\ T * C \quad (1)$$

where, D - distance, T - time, and C - the speed of sound ~ 343 m/s

The ultrasonic sensor uses a 40 kHz transmission signal through the transmitter with a 2 cm diameter to generate beams of burst signals for every 2.46 seconds. It is an installation over the stick at a reasonable size in vertical mount. An upper sensor at the height of 70 cm detects wall mounted or hanging obstacles and a Lower sensor placed at the height of 20 cm detects the low-level obstacles like steps, stones, or chair before the cane.

B. Arduino Uno

It is a microcontroller kit with ATmega328P. Its features are 14 digital input/output pins with six PWM dual operation pins, six analog inputs with 10bit ADC, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header, and a reset button. It may be connected through an adaptor or directly to the computer/laptop via a USB cable, which serves a dual purpose of power supply and acting as a Serial port to interface the Arduino and the computer. A 9V-12V AC can also power it through a DC adapter to avoid power fluctuations. It is programmed in an integrated development environment (IDE) to debug the logic and program the microcontroller IC accordingly.

C. Esp32 camera module with PIR sensor:

The motion sensor detector with photo capture using an ESP32-CAM. It utilizes a passive infrared sensor (PIR) sensor, an electronic sensor that measures infrared light radiating from objects. PIR sensors work as motion detectors by absorbing the IR signals from objects. Initially, the ESP32-CAM is in deep sleep mode with external wakeup enabled to save power. When the motion is detected, the PIR motion sensor sends a signal to wakeup the ESP32 module to take video coverage. It can also take the photo and saves it on the microSD card. It goes back to deep sleep until a new signal from the PIR motion sensor is received. The controller sends a recorded audio message to the blind person by comparing it to the stored database images.

The smart stick fitted with camera module will get tilted as the person walks towards the destination. The camera image coverage as per datasheet information is up to 78° Field of view (FOV). Figure 4 describes the possible positions of the walking stick while the person is walking. So the stick make approximately an angle of 30° - 40° when the person walks like normal human and that ensures the coverage of 150° - 160° FOV. Even if it is tilted, the camera should capture all the objects around. This is useful, If the person drops the cane leads to the abrupt angle. It is considered for an sending an alert by passing message to the relatives about the situation.

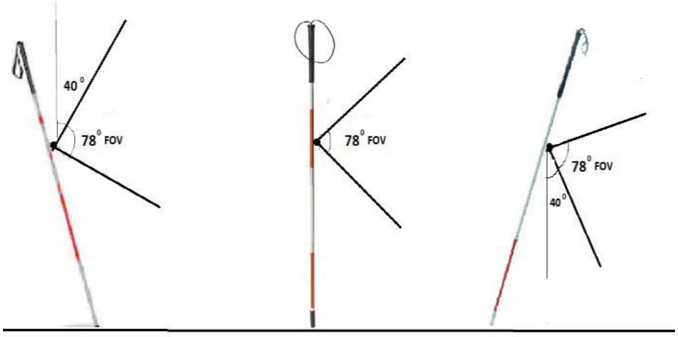

Fig. 4. Different positions of the stick during the walk

D. SW-420 vibration module

It works from 3.3V to 5V. The sensor uses a comparator that detects the vibration when it crosses a threshold point. It gives digital output corresponding to the vibration. The module has three peripherals available the module, two LEDs, one for the Power state and the other for the sensor's output.

IV. RESULTS AND DISCUSSION

The smart stick design utilizes both an ultrasonic sensor and an ESP32 Camera module with proper blending. It observes the tolerance in identifying an object or a person is possible by the combined usage of two modules. Table II summarizes the accuracy in distance measurement as per equation 1, the actual time taken by the sensor, and corresponding voltage. It describes the calculated value of distance concerning the theoretically proposed equation and the obstacle's obtained response in the various distance.

TABLE II. DISTANCE MEASUREMENT BY THE ULTRASONIC SENSOR

Distance (cm)	Time(ms)		Voltage (V)
	Calculated data	*Sensor data*	
6	0.8	0.4	0.41
20	1.2	1.16	0.53
30	2	1.75	0.59
40	2.8	2.33	0.66
50	3.2	2.91	0.74
100	6	5.83	1.21
200	12.4	11.66	2.13
267	16	15.56	2.65
320	18.8	18.65	3.02
360	21.2	20.99	3.33
400	24	23.32	3.96

Figure 5 shows the relation between distance and time taken to get the echo signal. The graph is sensitive during the 50 cm span, and it settles in the remaining 350 cm. it indicated that the response is linearly changing as per equation 1. The output voltage indicating various distance is also listed in table II. The output voltage pin Echo produces a square pulse with variation in width depending on the obstacle's distance as in figure 6. The trigger signal periodically produces a sonic pulse burst, which is received back as echo signals as pulses.

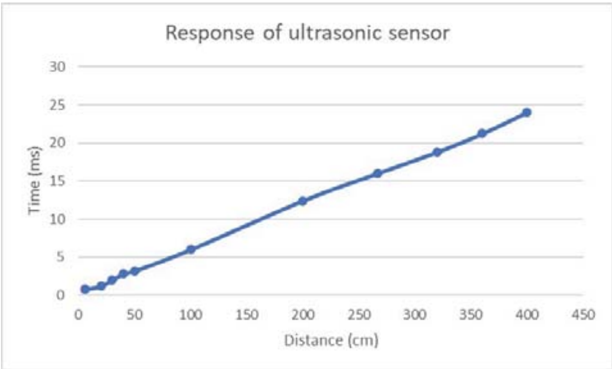

Fig. 5. The relation between distance and time of the ultrasonic sensor

Fig. 6. Captured DSO waveform for 200cm obstacle

The DSO captures the sensor's response with various distances, and it shows the time it takes to predict the distance of the obstacle. It indicates an obstacle well in advance to the user as the sensor covers an area of 4-to-5-meter distance effectively ahead of the smart stick. In addition to that, the camera module is also integrated into the stick. ESP32 camera is a cheap and readily available solution for face detecting applications. In this work, the camera module backs up to recognize and indicate the person ahead of the smart stick user. It will greatly serve the user when they are going for a walk or staying alone at home. The moving objects/person has been informed by the PIR sensor, which enables the camera to record the image. Once it captures a person's face, it will compare it with the already saved image database. If the person is already in the cloud database, it will give the person's name to the user. If the person is an intruder, to the home or in walkout place, their image gets saved in the database. It also informs the user that the person is not in the database and alerts them in advance. Figure 7 shows the image capture and recognition of various subjects. As the camera module coverage is 160, it can track the image in a slewed position too.

Fig. 7. Image capture of persons by ESP 32 with alert messages.

Figure 7 shows various messages about the person detected by the camera and their decision as a message to the user. Subject 1 and 2 are already recorded faces, so it says "Hello" for the individuals if they appear ahead of the camera. The third face is the one that is already saved, so it shows the number of appeared times mentioned with sample and ID name, so it may inform the user that the person is already known. If it finds the person who is not likely to be good, it can be categorized as intruders and informed to the user. In this way, there may be extended safety for the blind people keeping cloud data of the people who interacted with the user as a record.

V. Conclusion

The smart stick design discussed in this paper justifies the need for improving the safety measures to blind people while traveling in a known or unknown environment. It experiments ensures added safety using a camera module in the stick for recording images of the individual approaching the person with a less computational burden. It also senses the obstacles which are stationary or moving objects/person and alert appropriately for the user. The design evolves from the flaws in the existing system and adds more features to the smart stick to ensure the user's safety. It is possible to integrate smartness to the microcontroller enabled stick capable of imaging and object sensing. The prototype ensures the possibility of added safety in the existing cane in the market with slight remodification. Camera module can be embedded into the fabricated cane with ultrasonic sensors placed in vertical position ensures compact smart stick.

VI. FUTURE SCOPE

In future, camera positioning onto the stick should be optimized to have a fabricated smart stick with reduced error and a cost-effective solution for blind people. It will be challenging to implement the continuous monitoring of environment by the camera with Arduino Uno hence it requires PIR sensor to enable the module once a moving object is observed. In future continuous monitoring and communication may be included by improved processor speed and features. The work shall be extended with latest image processing packages like TensorFlow lite to integrate machine learning for incorporating direct processing large database of object detection and classification to user into the model.

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