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iCap: A Low-Cost Cap for Visually Impaired

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Abstract: The boom in science and technology has significantly contributed towards the welfare, comfort and ease of movement of mankind, more so for the specially-abled sections of society. Though smart canes are considered to be the cutting-edge technology in terms of improving the lifestyle of visually impaired persons, there are still a few core issues which need to be keenly addressed such as detection of hanging objects, providing hands-free environment, prevention of accidental damage to surroundings, etc. Obstacles like hanging tree branches, open windows, hanging objects or boards on the roads, are few of the hurdles which still pose a problem for the blind. Smart canes do not provide a solution to such problems, although detection of potholes and obstacles lying on the ground have successfully been achieved. Furthermore, with a huge section of the visually impaired being uneducated and financially weak, most smart devices available in the market remain unaffordable and unusable. In this paper, we propose a solution for such obstacles in the form of the "iCap". The iCap is a light weight and low-cost embedded system; an intelligent cap capable of detecting potholes, obstacles lying on the ground as well as hanging obstacles using a pair of ultrasonic sensors (HC-SR04). It enables the wearer (the visually impaired person) to navigate independently without the fear of being hit by random obstacles. Additionally, experiments were carried out to find the actual area within which an object would be detected by the iCap, and also the thresholds of size and shape of objects beyond which the objects would remain undetected.
Keywords: Intelligent Cap, Smart cane, Visually Impaired, Arduino UNO, Ultrasonic Sensor (SH-SR04).

I. INTRODUCTION

The lives of visually impaired people are relatively cumbersome than those with normal vision because of the difficulty they face in moving around. They are afraid to move and walk around due to the constant fear of being hit by moving objects, of colliding with the obstacles lying on the roads, of falling into pits and holes on roads. Other inevitable obstacles a visually impaired person might encounter on regular intervals are low lying objects and hanging tree branches, open windows, hanging objects, sign boards installed on the roads especially near the footpaths or on the roadsides at a particular height from the ground. These are the major types of obstacles a visually impaired person comes across very frequently.

The introduction of smart canes [1], a walking stick with sensors, especially ultrasonic sensor, has successfully made a significant improvement in assisting the movement of visually impaired persons. However, smart canes give more emphasis to obstacles up to the knee-level since such obstacles are more frequently encountered. It does not solve the problem of facing an obstacle above the knees or above a particular height (say, 3-4 feet) from the ground. Likewise, there other devices, some can be carried and some can be worn, which help the visually impaired persons to move around without being hit by obstacles. However, it is observed that most such devices are extremely costly or sophisticated making it unaffordable and unusable to the uneducated and financially weak sections of society. According to the report by National Programme for Control of Blindness & Visual Impairment, Govt. of India, blindness was more prevalent in the rural population as compared to urban population (2.14% vs 1.80%). Likewise, it was also observed to be higher among illiterates (3.23%) compared to literate population. In a bid to enable the visually impaired belonging to both rural and urban sections of the society, in this work, we propose the design of an intelligent cap, the iCap. The iCap would enable the wearer, a visually impaired person, to be warned of potholes and overhanging objects as well as low lying obstacles, with warning messages or sounds. Our proposed device is simple, cheap and light weight, making it both pocket and user friendly.

II. RELATED WORKS

Science and technology always try to make human life easier. People with complete blindness or low vision face many difficulties during their navigation. Blindness, partial or complete, may be by birth or can occur due to many reasons such as disease, injury or other conditions that limit vision. Globally, an estimated 253 million people live with vision impairment, out of which 36 million are blind, and 217 million have moderate to severe vision impairment [2]. The burden of visual impairment in India is estimated at 62 million. A visually impaired person faces many challenges, environmental, social, technological, the biggest challenge being navigation.

Several systems have been proposed and designed to aid the visually impaired. Some systems like the smart canes [3] can be carried while there are a number of devices which are wearable. The oldest and most common device used by the visually impaired is the white cane. A white cane is a device used by the visually impaired which primarily allows its user to scan his surroundings for obstacles or orientation marks, but is also helpful for onlookers in identifying the user as blind or visually impaired and taking appropriate care. However, the white cane cannot detect overhanging objects like tree branches, sign boards, open glass windows, etc. Also, at times using a white cane may result in unfortunate incidents such as scratching a parked vehicle with the cane, hurting a passerby, etc. A Smart Cane [4] solves the challenges and empowers the visually impaired through independent and safe mobility. Mutiara et al. [5], carried out an experimental study to enhance the efficiency of normal canes used by blinds and finally the results led them to install the ultrasonic sensor on the cane to detect obstacles, holes and other hindrances. Saaid et al. [6], carried out a study on the orientation of sensors embedded in the cane, and came to the conclusion that a 90-degree angle gives the best test results when positioned at the upper portion of cane. Another similar device is the weWalk [7] which is equipped with built-in speakers, smartphone integration and sensors that send vibrations to warn users of obstacles up ahead. The weWalk cane consists of an electronic handle with a regular ‘analog’ white cane that is inserted into the bottom. Chandana et al. [8] designed a smart white cane for blind-deaf-dumb communication with GEO location indication. Their system uses a Raspberry Pi microcontroller.

However smart canes need to be carried which may not be convenient in all situations. Today there are numerous wearable devices to assist the visually impaired such as Maptic, Sunu Band, Aira AR Smart glasses, Buzz clip, etc. Koka. et al. [9], proposed a solution to eliminate the cane by mounting the sensors on the body of a blind person. They designed a simple and wearable belt with five sensors to detect the obstacles, stairs and avoid any inconvenience while walking. Bhunje et al. [10] have worked on the aspect of object identification using the camera attached to the pair of sunglasses, with three main functional components: scene capture, data processing, and audio output. Their prototype reads printed text on hand-held objects to assist the visually impaired persons. Robert et al. [11] made an ALVU (Array of Lidars and Vibrotactile Units), a contactless, hands-free wearable device to detect low and high hanging objects and their physical boundaries in immediate environment to provide safe navigation. A sensor belt worn around the front of user’s waist to find the distance between the user and obstacles and a haptic strap worn around the user’s upper abdomen to provide haptic feedbacks, are its two parts. Peiris et al. [12] proposed the EyeVista, which is a wearable navigational device to facilitate visually impaired sprint athletes. The proposed system uses Raspberry Pi single board computer to process the real-time image captured by Raspberry Pi camera module to navigate the athletes within the assigned track and to avoid collisions.

Another wearable device, a simple substitute to the smart cane, is the smart cap which carries out the functionalities of a smart cane but is wearable. Chugh [13] designed a Smart Cap, which narrates the description of the scene to the wearer. The system uses state of the art deep learning techniques from Microsoft Cognitive Services for image classification and tagging and is powered by the voice assistant 'Alexa' through Amazon Echo. Another cost-effective Smart Cap [14] was proposed which provides narratives about the surrounding environment. The smart cap solution proposed by Nishajith et al. [15] captures the scene around the user with a NoIR camera, objects are detected and the earphones give voice output describing the objects. Machine learning models are used to identify and classify the objects and a Text to Speech Synthesiser (TTS) software called eSpeak is used to convert details of the detected object (in text format) to speech output. However, it is noticed that most of these wearable devices are highly sophisticated, expensive, not easily available, or too complicated to handle or operate, especially for the uneducated people of rural India. Shukla et al. [16], proposed a smart cap, which is a system having a simple architecture that transforms the visual information captured using a camera to voice information using Raspberry Pi. A Text-to-speech Synthesizer (TTS) software is used for converting the details of the detected object (in text format) to speech output. Chakraborty et al. [17] proposed model which consisted of a Sender Module and a Receiver Module. The Sender Module comprised of an Arduino Uno board, an HC-05 Bluetooth module, power source, wires and 4 ultrasonic HC-SR04 sensors fitted in four directions perpendicular to one another in a cap/hat.

III. PROPOSED SOLUTION

From the evolution of normal and traditional canes to smart canes, several problems were mitigated. The major problem solved was the low-lying obstacles, just few feet above the ground. But the over hanging objects, above 3 feet-4 feet, still posed a problem to the visually impaired. A number of wearable devices have been proposed and are also available in the market. However, it is observed that they are either too expensive, too sophisticated or complex in operation.

In this work, we propose a solution wherein the obstacles from top (head) to the upper-middle portion of the body (chest) are detected along with potholes and other on-surface obstacles. The proposed iCap, is a device which can detect the obstacles above a certain height from the ground, depending on the height of the person wearing it, in addition to detecting obstacles on the ground or in front of the person.

It has been designed to give out warning messages in the form of short recorded messages and beeps, to its user so that the user can take necessary action to prevent getting hit by the obstacle. The user is warned about the presence of an obstacle within the range of 2cm to 70cm, so that the user can either change the direction or bend down a little to avoid getting hit by that obstacle.

Fig. 1 The prototype of iCap

The iCap has been designed keeping in mind three important aspects, simplicity, affordability and comfort of the wearer of the iCap. A pair of ultrasonic sensors (SH-SR04), an Arduino UNO microcontroller, a thin speaker (0.5W, 80 Ohm) for audio output, an active buzzer, few batteries and a couple of LEDs are some of the components used to design the circuit as shown in Table I. These are then installed on a normal wearable cap to enhance the comfort level of the person wearing it. Since the Arduino UNO supports 16-bit PCM, 8KHz MP3 audio file, a free and open-source digital audio editor software "Audacity" [18] has been used to get the same configuration of an original recorded voice which reads the warning message "Stop- Stop- Ruk Jao- Ruk Jao" for hanging obstacles. Then with the help of an audio encoder, the audio signal is encoded and represented in minimum number of bits while retaining the quality of speech. This is then fed to the Arduino via a program, to play when hanging obstacles are detected. On detection of potholes and ground obstacles the wearer will be warned by buzzer sounds of two different frequencies.

TABLE 1
MATERIALS USED for iCAP

Materials	Quantity
Arduino UNO R3	01
Ultrasonic Sensor (SH-SR04)	02
Speaker (0.5W, 80 Ohm)	01
Fabric cap	01
Switch (15mm * 21mm)	01
LEDs (5mm) (White, Green, Red)	03
Active Buzzer	01
9 volt battery	01
Push Buttons	03

A. Ultrasonic sensor (HC-SR04)

An ultrasonic sensor is a device with a transmitter, receiver and a control circuit. The transmitter emits the ultrasonic waves, inaudible to humans, above 20KHz, into the environment to detect an obstacle. The reflected waves from an obstacle are received by the receiver to confirm the presence of an obstacle within the pre-fixed range. This ultrasonic sensor, also known as ultrasonic ranging module, supports a measuring range of 2cm to 400cm with the resolution of 3mm [19].

Generally, the "Trig" pin acts as transmitter and "Echo" pin as receiver. The sensor sends out an 8-cycle burst of ultrasound at 40KHz and raises its echo only after a short 10uS pulse is supplied to trigger input to start ranging. So, the time interval or time of flight (TOF) between transmitting a trigger signal and receiving back an echo signal, can be used to calculate the distance between an obstacle and ultrasonic sensor using the formula:

Distance(d)=(timeofflight/2)*speedofsound (1)

Speed of sound = 343m/s or 1/ 29.1 cm/uS
Therefore,
Distance, d (in cm) = (Time of flight / 2) * (1/29.1).

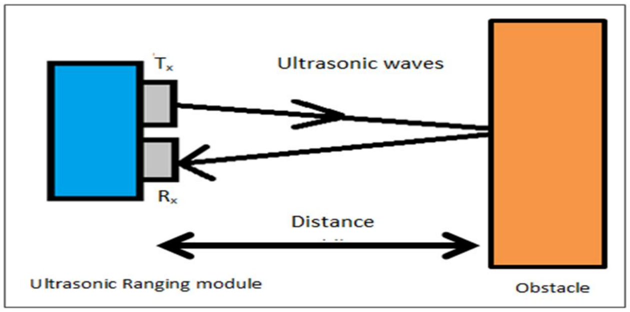

Fig. 2 Working Principle of Ultrasonic Sensor

B. Circuit Diagram of iCap

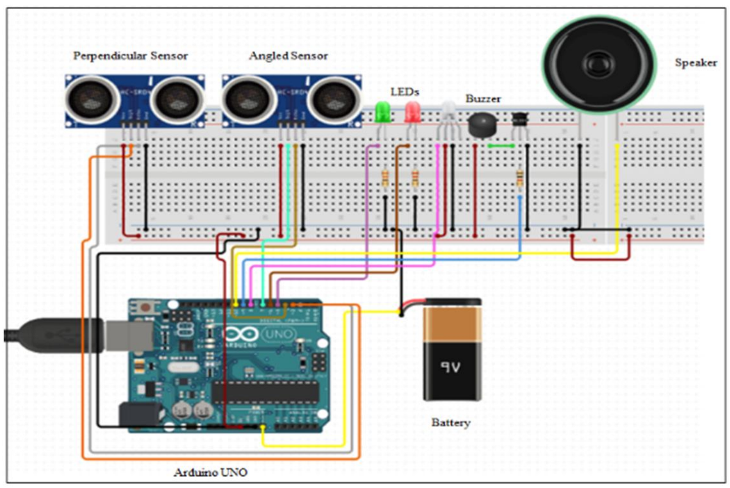

Fig. 3 Circuit Diagram of iCap

C. Mathematical Analysis of the area of coverage of Ultrasonic Sensors

In our work, an attempt has been made to find out the area under which the prototype or iCap, is able to detect an obstacle. Furthermore, it is also attempted to find out the relationship between area coverage and obstacle distance from the ultrasonic sensor which is discussed below. The beam angle of an ultrasonic sensor is equal to 15 degrees and its maximum range (d) is 400cm [20]. Since, the ultrasonic range swaps away the area in a conical way, it forms an isosceles triangle with the base as beam width as shown in Fig. 4

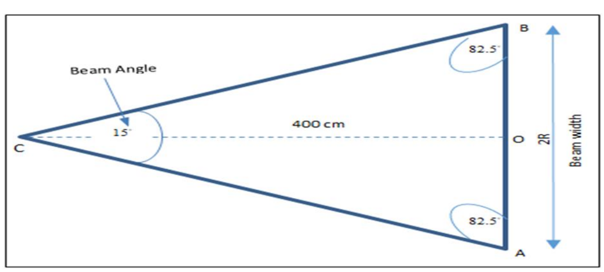

Fig. 4 Ultrasonic beam from sensor

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In isosceles triangle ABC,
<ACB = 15 o , (beam angle)
Therefore,
<CBA = <CAB = 82.5 o . (Isosceles triangle)
Now in right angled Triangle AOC,
<AOC = 90 o, <OAC = 82.5 o , <ACO = 7.5 o (CO is angle bisector)
Let's assume the length of AO = R,
So, the radius of the circle which forms the base of cone which encompasses the area of coverage of the ultrasonic waves w.r.t the distance of obstacle from the sensor is given by the equation:
Radius(R)=d / tan(82.5) (2)
CO = d = 400cm,
Therefore,
R = 400 / tan (82.5)
= 52.66 cm
Total coverage area at the base of the ultrasonic beam is given by the equation
Total Coverage Area = pi *R *R (3)
Therefore, maximum area covered by the ultrasonic sensor is given as: Areamax = 8707.45 cm2 or 0.87 m2

It is thus observed that the area coverage with ultrasonic sensor is directly proportional to the distance of the obstacle from it, with the constraint of maximum distance of 400cm.

Since R is proportional to d (from eqn 2), Amax is also proportional to d, i.e., distance between an obstacle and a person wearing the iCap.

For this work, the displacement of ultrasonic waves is considered to be 70 cm instead of 400 cm because it is desired that the wearer should be able to detect the obstacle at a distance of minimum two steps, which is approximately 70cm for a person of height more than 5 feet.

So,
AO = R, CO = 70cm
Therefore,
R = 70 / tan (82.5) = 9.21 cm (from eqn 2)
Total area (Areamax) = π * R * R (from eqn. 3)
= 266.34 cm2 or 0.0266 m2
Hence the iCap can detect the obstacles within the area of 266.34 cm2 or 0.0266 m2 given a constraint that an obstacle is at a minimum distance of 70cm from the sensor.

D. Working of iCap

Two ultrasonic sensors are placed in front of the cap, one parallel to the ground i.e., the perpendicular sensor, for detecting hanging obstacles and other, angled sensor, for detecting potholes and on-surface obstacles at an angle of (90 –α), w.r.t the perpendicular sensor, where α depends on the height(H) of the visually impaired person. Since the value of α depends on the height (H) of wearer, they have been categorized into three Height Groups according to their heights given in Table 2.

Table 2
Height Groups Of Visually Impaired

Group Name	Height (H) (in cm)	Distance (d) (in cm)
Height Group A	>152.4	70
Height Group B	106.68-152.4	40-70
Height Group C	<106.68	40

Group categorization of visually impaired has been done according to their heights in order to find the angle α and distance (d) for respective height groups. Hence the iCap would be useable for visually impaired persons of all heights. The parameters such as height(H), distance(d), angle(α), are to be changed in the code of Arduino in order to use the iCap for all height groups without making any changes in the hardware of iCap.

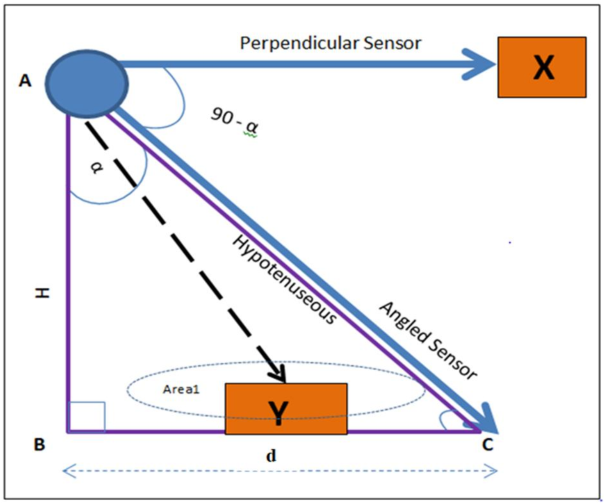

Fig. 5(a) Ultrasonic Angle Analysis of Angled sensor for on-surface obstacle detection

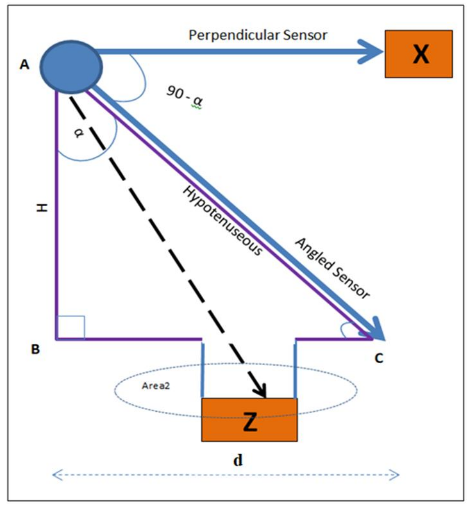

Fig. 5(a) Ultrasonic Angle Analysis of Angled sensor for Pothole detection

In Triangle ABC of Fig. 5(a) and Fig. 5(b),

α = tan-1(d/H) (4)

Where "H" is the height of the person wearing the cap.

For a visually impaired person it will be beneficial if obstacle is detected at a distance 'd', two steps away from him/her, i.e., 70cm for Height Group A, 55cm for Height Group B, 40cm for Height Group C. So, this distance 'd', is kept constant for our design. Accordingly, the distance between the person and the obstacle is kept constant at 70cm considering the person belongs to Height group A, at 55cm considering the person belongs to Height group B and at 40cm considering the person belongs to Height group c.

In Fig.5a and Fig. 5b, we have,

X= A hanging obstacle

Y= An on-Surface obstacle

Z= A pothole

d= Distance between Visually impaired Person and Obstacle

AB= Height of a person wearing the cap = H

Area1= area of coverage under which the on-surface obstacles can be detected.

Area2= area of coverage under which the potholes can be detected.

Perpendicular Sensor = Sensor detecting the hanging obstacles

Angled sensor = Sensor detecting potholes and on-surface obstacles

In triangle ABC, Using Pythagoras Theorem,

AC = Hypotenuse = square root(d2 + H2) (5)

Hypotenuse helps in finding out the diameter of area of coverage for the angled sensor.

This whole setup in Fig. 5, helps a person to detect hanging objects as well as the on-surface obstacles, along with the detection of potholes and warns a person through a sound beforehand.

Perpendicular sensor keeps track of hanging obstacles along with the obstacles lying above the person's waist. Whereas, angled sensor keeps track of potholes and other obstacles lying on the surface. Both the sensors are customized to raise the sound alarm if any obstruction is detected within a distance of 'd' cm between the obstacle and any of the sensors for all the three age groups.

E. Pseudo code for the Arduino UNO

```
{
If distance <= d cm                  //for perpendicular sensor
Play (Tune1)                         //Hanging obstacles are detected
If distance < (Hypotenuse-2)        //for Angled Sensor
```

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Play (Tune2) //On-surface obstacles are detected
If distance > (Hypotenuse+2) //for Angled Sensor
Play (Tune3) //Potholes are detected
}

Safe Zones or Normal Surface where no obstacles or pothole is present is under the following conditions:
For Perpendicular Sensor: if distance> d cm
For Angled Sensor: if (Hypotenuse+2) ≥ distance ≤ (Hypotenuse +2).

When the distance is within the range of (Hypotenuse ± 2) for angled sensor or distance is greater than 'd' cm for perpendicular sensor, then the surface is considered normal or safe, and a person would be able to walk without any hesitation and no warning sound would be played by iCap. Hypotenuse ±2 is considered as normal height or depth of surface since an obstacle with 2cm height will neither be considered as on-surface obstacle nor a pothole with 2cm depth is considered as pothole.

IV. EXPERIMENTAL RESULTS

To verify that the sensors (both perpendicular and angled), successfully detected obstacles coming within its area of coverage, an experimental setup was designed with a paper cone of radius (R) and height (d) and was placed in a horizontal position in front of the perpendicular sensors, or in an inclined position in front of the angled sensor. The region within the paper cone represented the area of coverage of the ultrasonic sensor. Various types of objects were brought inside the cone to check whether they could be detected.

A. Size and category of obstacles

A huge set of reallife obstacle samples were taken and experimented to check if they could be detected and these obstacles were categorized them into 3 categories according to their shapes.

Category I: Rectangular sample obstacles
Category II: Cylindrical sample obstacles
Category III: Spherical sample obstacles

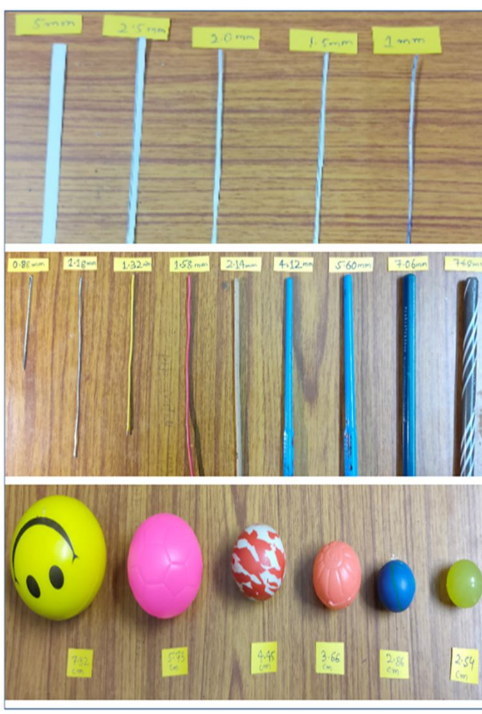

Fig. 6a Rectangular Sample Obstacles

Fig. 6b Cylindrical Sample Obstacles

Fig. 6c Spherical Sample Obstacles

Fig.6 Shape and Size of obstacles

These three categories of samples, given in Fig. 6, were taken with wide range of lengths and widths/ diameters in order to find the threshold size of obstacles below which the ultrasonic sensor fails to detect obstacles.

B. *Obstacle Detection Results*

All the three categories (Cylindrical, Rectangular and Spherical obstacles) of sample obstacles were brought within the region of coverage of sensors, i.e., within the paper cone and the results of detection are presented in Table 3 and Table 4.

Table 3
Cylindrical Obstacles With Different RADII

Obstacle Name	Diameter / Width (in mm)	Detected(✔) / Not Detected(✖)
Pen	7.68	✔
Pencil	7.06	✔
Painting Brush (big)	5.60	✔
Painting Brush (small)	4.12	✔
Incense stick	2.14	✔
Wire Coated	1.58	✔
Wire	1.32	✔
Steel Wire	1.18	✖
Needle	0.88	✖
Pen	7.68	✔

TABLE 4
Rectangular and Spherical Obstacles With Different RADII/ WIDTH

Obstacle size	Detected(✔) / Not Detected(✖)
> 30mm	✔
30mm – 1.3mm	✔
< 1.3mm	✖

From Table 3 and Table 4,
The threshold value of obstacle size is found to be 1.3mm below which the Ultrasonic sensor fails to detect. The obstacle can be of any shape but the width or diameter must be above 1.3mm.
Our proposed device, iCap, is able to detect any obstacle with the width more than 1.3mm.

V. CONCLUSION AND FUTURE WORK

This product cum assistant for the visually impaired was designed and developed in a bid to provide a low cost solution to one of the challenges they come across very frequently. The “iCap” would enable a visually impaired person to walk around without the fear of falling into potholes, colliding with ground line or hanging obstacles. This device has the potential to replace the traditional cane as well as the smart cane which is slightly irritating to carry around every time, with the added feature of detecting hanging objects. The iCap has been designed with minimum number of easily available low cost components, to make it light weight and budget friendly. It weighs approximately 250g and costs a meagre rupees 650. If manufactured in large quantities, the price can be further reduced.

Furthermore, we have carried out an analysis, both mathematical and experimental, to verify the area of coverage of the ultrasonic sensor used in the iCap. Extensive experiments were carried out to find the minimum size of an obstacle that can be detected by the ultrasonic sensor (SH-SR04) and this was found out to be 1.3mm in width/diameter.

In the current version of the iCap the value of distance (d) is set to 70cm for a person belonging to Height Group A, 55cm for a person belonging to Height Group B, 40cm for a person belonging to Height Group C. The values of distance (d) in the program are selected simply by using push buttons placed on the top of the iCap for all the three Height Groups without programming it.

As a future work, along with obstacle detection, the iCap can be modified and used for obstacle recognition, face recognition, pattern recognition by using technological domains such as machine learning, artificial intelligence, computer vision and deep learning. It can be used to detect zebra crossings on the roads so that a visually impaired person may cross the road without any mishap or accident.

Another future task may be to equip the iCap with sensors to detect the presence of water bodies near him/her and identify the type of surface he/she is walking on e.g., wet, dry, muddy, etc. This will be extremely helpful to the visually impaired, specially those living in rural areas having ponds, uncovered bore wells, wells, tanks, etc. Further variations in circuitry and addition of few other sensors like smoke sensor, IR flame detection sensor, color sensor, GPS sensor, etc., may be made to enhance the quality and efficiency of the iCap.

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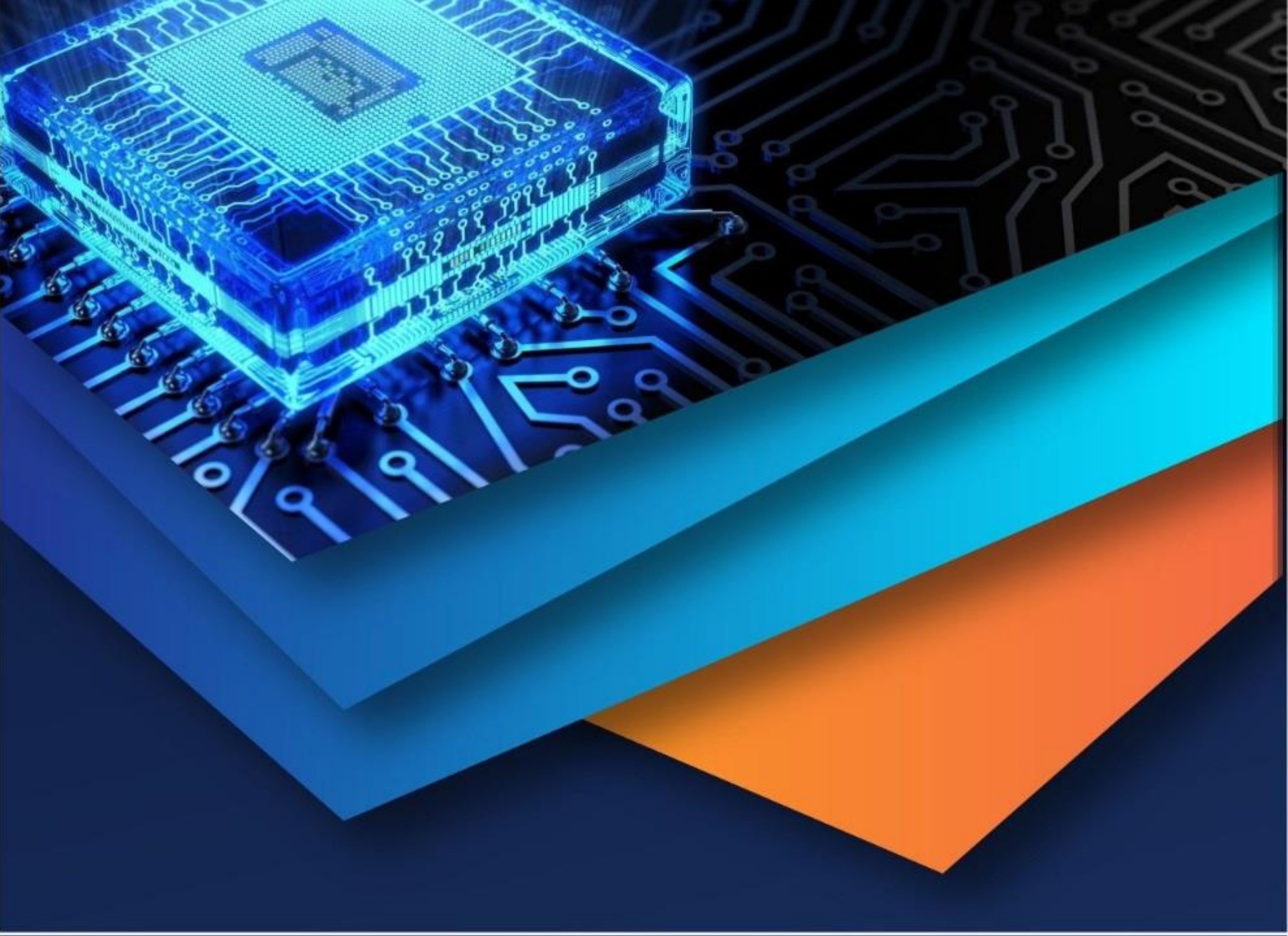

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