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CANE MOUNTED KNEE-ABOVE OBSTACLE DETECTION AND WARNING SYSTEM FOR THE VISUALLY IMPAIRED

M Balakrishnan, Kolin Paul*, Ankush Garg, Rohan Paul, Dheeraj Mehra, Vaibhav Singh
Department of Computer Science and Engineering[1]

P.V.M. Rao, Debraj Chatterjee
Department of Mechanical Engineering[1]

[1]Indian Institute of Technology, Delhi
Hauz Khas, New Delhi -110 016, India

ABSTRACT

There are numerous constraints that visually challenged people face in independent mobility and navigation. They primarily use the white cane as a mobility aid allowing them to detect close by obstacles on the ground. The detection of objects above knee height is almost impossible and is a major hindrance for them.

In this work, we have reported the design and implementation of a detachable unit which acts to augment the functionality of the existing white cane, to allow knee-above obstacle detection. This unit consists of an ultrasonic ranger and a vibrator controlled by an eight bit microcontroller to offer an increased detection range of three meters. The distance information is conveyed to the user through non-interfering multi-frequency vibratory stimuli, the frequency of vibration indicating the proximity of obstacles. This unit is also capable of detecting fast moving obstacles.

Considerable effort has gone into the electromechanical design of this unit conveying the vibrations effectively and ensuring that it is easily attachable on the existing white cane without sighted assistance. A crucial design optimization goal was cost – the unit has been developed as a" low cost" device which is affordable by the poor in developing countries.

1 INTRODUCTION

Among the many challenges faced by the visually challenged persons are the constraints of independent mobility and navigation which stem from hazards in an unfamiliar environment. The white cane is the most popular navigation aid used by the visually challenged. It enables them to effectively scan the area in front and detect obstacles on the ground such as uneven surfaces, holes, steps, walls etc. Its low cost, portability and ease of operation make it an extremely popular navigation aid. However, the cane has two major shortcomings:

- In a practical setting, it can only be used to detect obstacles up to knee-level. Hence, potentially hazardous obstacles like protruding window panes, raised platforms and horizontal bars go undetected.

- The detection range of the cane is restricted to about 0.5m from the user. Certain obstacles (e.g. a moving vehicle) cannot be detected till they are dangerously close to the person.

There have been efforts to augment the white cane. An obstacle detection system, the K-Sonar [1] provides distance information through 'tone-complex' sounds which act as sound signatures to detect obstacles. But sonic output produced by the device masks other important auditory cues necessary for safety and orientation, e.g., sound emanating from an approaching vehicle. The augmented cane by Elchinger [2] also has the same drawback.

*Author of correspondence, Phone: (91) (11) 2659-6033 Fax: (91) (11) 2658-1060 Email: kolin@cse.iitd.ernet.in

Another mobility aid, the Ultracane [3] uses ultrasound based echo-location for obstacle detection. Distance information is conveyed to the user through two vibrating buttons (5x7 mm). For correct operation, it is imperative to place the thumb across the top of the handle to cover both the vibrating buttons at the same time. The ranging unit is attached to a carbon graphite cane shaft which makes the device expensive. The unit cannot be mounted on the commonly used white cane.

Other existing navigation systems use laser technology. An example is the Laser Cane by Nurion [4][5]. The cane uses laser to determine the distance to the object in its path. It has three channels that cover the head, forward and ground areas. The device outputs a vibration to the index finger of the hand holding the cane. However one disadvantage is that the laser could be harmful to people in close proximity to the user.

Despite recommendations by mobility experts, the visually impaired cane users show considerable variations in the grips used to hold the cane (Figure 1). The same user might use the inclined grip while moving in an open space and a straighter conservative grip in a crowded area. For correct operation, the K-Sonar, the Ultracane and the Laser Cane must be used with the inclined gripping style. This involves relearning, which is difficult and inconvenient since the visually challenged are accustomed to using the cane in a particular manner with a personalized grip. Another limitation is that the available systems can only detect the presence or absence of an obstacle and cannot determine whether they are approaching the user or not.

(A) (B) (C)

FIGURE 1: DIFFERENT GRIPS FOR HOLDING THE CANE (a) INCLINED-DOWNWARD, (b) INCLINED-SIDEWAYS AND (c) CONSERVATIVE- STRAIGHTER

Mobility aids available in the international market are expensive. For instance, the K-Sonar is priced at 1069 USD, the Laser Cane at 2,500 USD and the Ultracane costs 770 USD. Out of the 150 million visually impaired people worldwide, 75% reside in the less developed countries of Africa and Asia where the annual per capita income is below 635 USD [6].

This work presents a cane-mounted detachable unit that increases the detection range of the white cane and detects obstacles above knee-level. The system was developed in close collaboration with potential users at the National Association for the Blind, New Delhi. The device employs ultrasound-based ranging and provides distance information through a vibratory stimulus. The system also warns the user incase of a fast approaching obstacle within detection range. The device has been carefully designed to ensure maximum transfer of vibrations and easy usability for various users. The projected cost of the device is under 50 USD.

The paper is organized as follows. Section 2 presents an overview of the electro-mechanical design of the system. Section 3 discusses the electrical and mechanical subsystems in detail. The next section is devoted to experimentation and feedback from potential users from the National Association for the Blind, Delhi. Section 5 includes the discussion and section 7 concludes the paper.

2 DESIGN OVERVIEW

We developed a detachable unit that can be mounted on the top fold of the white cane. The device employs directional ultrasound based ranging to detect obstacles in front or above knee height within a range of 3m. The user obtains distance information through vibratory stimuli which supplement the auditory cues emanating from the environment and those produced by tapping the cane. The device vibrates in distinct patterns that vary with changing obstacle distance. The vibration frequency increasing incrementally according to changing obstacle distances. The ranging algorithm has been optimized which allows detection of fast approaching obstacles within 3m. In this situation the user is warned by a buzzer tone.

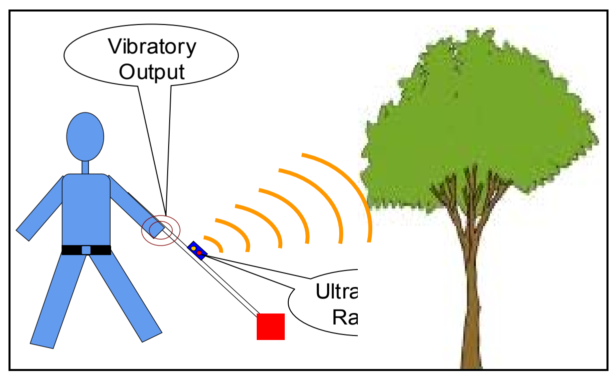


FIGURE 2: ULTRASOUND BASED RANGING COMBINED WITH VIBRATORY OUTPUT

The system has been designed as an independent detachable unit so that the existing white cane does not have to be re-modeled. An attachment mechanism has been developed so that the user can attach the device on the cane without sighted assistance. The unit can also be used as a general purpose distance estimation device.
The module runs on a standard Li-ion rechargeable battery. For charging the user connects an AC or USB adapter (similar to charging a cell phone). This eliminates the inconvenience of opening the battery pack to replace batteries.

The mechanical design of this product was challenging in many ways as several requirements, both user and functional, have to be met. Detachability, light weight, flexibility to be used by people having different holding styles and different gripping styles, reliability, ergonomic considerations, optimum structure-signal interaction and cost were some of the major issues addressed in arriving at the proposed design.

3 DETAILED DESIGN DESCRIPTION

In this section we discuss the implementation of the mobility aid in greater detail. We discuss the electrical subsystem in the following sub-section while the next sub-section dwells on the mechanical design of the device.

3.1 Electrical Subsystem

Figure 3 shows the top level block diagram. An ultrasonic ranger, SRF04 [7] is used for obstacle detection and vibrations are produced using a small DC motor. The unit runs on rechargeable Li-ion battery for which a charging circuit has

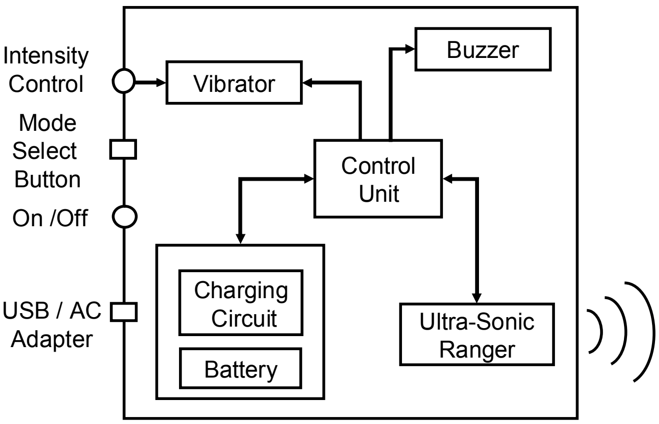


FIGURE 3: TOP LEVEL BLOCK DIAGRAM

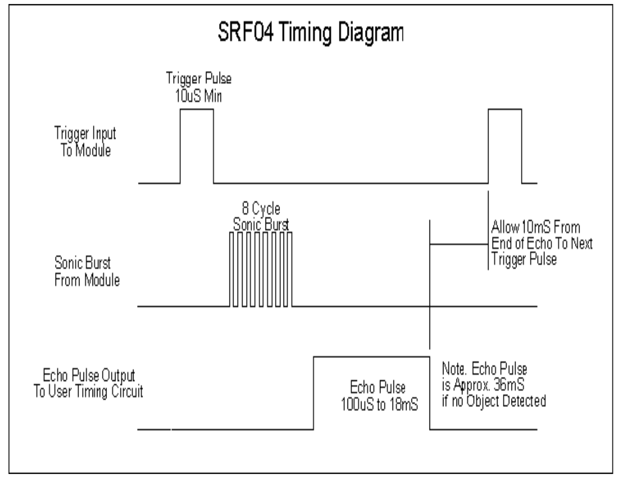
been developed. The control unit consists of an 8051 micro-controller [8]. The system states are conveyed to the user through short duration tones produced through a buzzer. The following paragraphs discuss the modules in detail.

Ultra-sound Ranging: A dual-transducer ultrasonic ranger (SRF04) with a range of 0.03 - 3m is used for obstacle detection. Once triggered by the micro-controller (through a 10usec TTL level pulse) the ranger produces an 8-cycle sonic burst at 40 KHz frequency (see Figure 4(a)). Immediately, the echo pulse output line is raised high which is lowered upon reception of the reflected waves. The echo pulse output is typically between 100usec-18msec and 36msec in case of timeout. A blanking interval of 100usec is needed to avoid noise from the initial ping. A gap of 10msec is required between end of echo and the next trigger pulse.

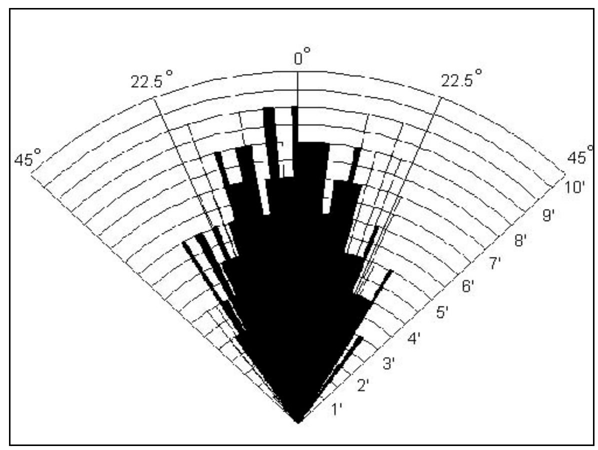
The microcontroller computes the obstacle distance by measuring the width of the echo pulse. Depending upon this computed distance, an appropriate vibratory pattern is selected. The system operates in two modes which are selectable through the mode select button on the device.

- Short Range Mode (< 1m): Useful while navigating within a room
- Long Range Mode (< 3m): Used outdoors e.g. roads, parks etc.

Figure 4(b) shows the detection cone of the ranger projected on a two dimensional plane. The angular width of the detection cone is typically 45^0. The sensor can detect a 3cm thick object at a distance of 2m. As the distance increase the detection zone boundary becomes uneven.



(A)



(B)

FIGURE 4: ULTRA-SOUND RANGER SRF04: (A) TIMING DIAGRAM, (B) DETECTION CONE

Vibratory Feedback: Vibrations are produced using an asymmetric DC motor (5.5 x 6.4 x 15.6 mm). These small motors are typically used in mobile phones. The entire detection range is divided into four sub-ranges for the Long Range Mode and three for the Short Range Mode (Table 1, Figure 5). Each sub-range is associated with a unique, easily discernable, vibratory pattern (Figure 6). Vibratory patterns are produced by manipulating the duration while the vibrator is running and the interval between successive vibration pulses. Thus, by recognizing the vibratory pattern the user can infer the obstacle distance. e.g., If the unit is vibrating in pattern 3 in the long range mode, the user can infer that the obstacle distance is 1-2 m.

The typical current requirement of the vibrator motor is 40mA. Since the micro-controller can only provide a maximum current of 650uA, a PNP transistor with proper biasing is used to drive the motor (Figure 7). The transistor current gain can be changed by varying the base resistance R (0-1K) through a potentiometer knob. This allows users to adjust the intensity of vibrations according to their skin sensitivity.

TABLE 1: DIVISION OF DETECTION RANGE INTO SUB-RANGES AND ASSOCIATED VIBRATORY PATTERNS

Detection Zone	Vibratory Pattern	Obstacle distance (cm)	
		Long Range Mode	Short Range Mode
I	1	3–50	3-30
II	2	50–100	30-60
III	3	100-200	60-100
IV	4	200-300	-

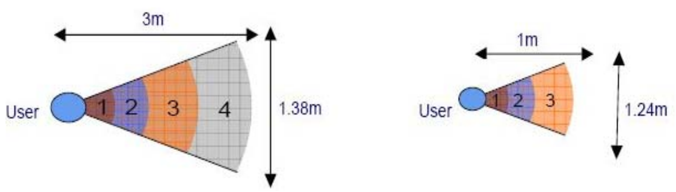


FIGURE 5: TOP VIEW SHOWING THE HORIZONTAL AND ANGULAR COVERAGE OF THE DETECTION ZONE (COLORED) FOR LONG RANGE MODE (LEFT) AND SHORT RANGE MODE (RIGHT)

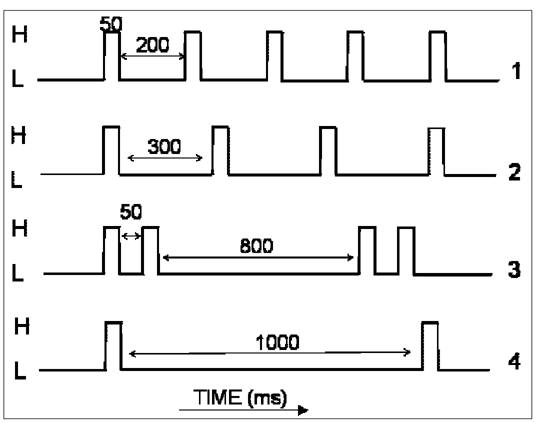


FIGURE 6: PICTORIAL REPRESENTATION OF VIBRATORY PATTERNS. (H INDICATES THAT THE MOTOR IS ACTIVE WHEREAS L SIGNIFIES NON-VIBRATING INTERVALS)

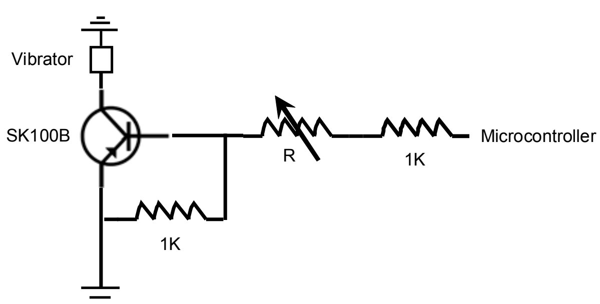


FIGURE 7: VIBRATOR INTERFACE WITH THE MICRO-CONTROLLER

Charging Circuit Subsystem: The device is powered by a rechargeable Li-ion battery (900 mAh, 3.0- 4.2V output). We have used the MAX8606 [9] battery charge-management IC to produce the predefined sequence of current and voltage profiles necessary for charging the battery. The variable voltage produced by MAX8606 is stabilized using TPS61032 [10] voltage regulator providing a constant 5V system supply (Figures 8, 9).

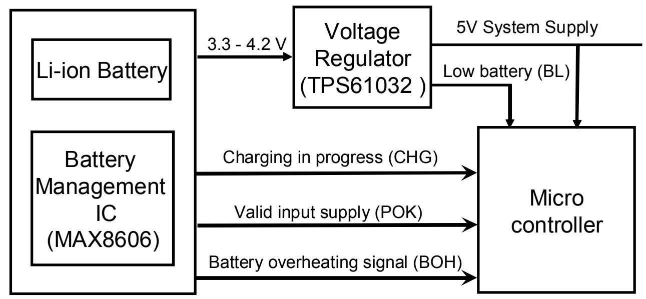


FIGURE 8: MAX8606 INTERFACE WITH THE MICRO-CONTROLLER

The MAX8606 chip provides the following status bits to indicate battery status:

- POK: Presence of a valid power source for charging (4V-5.8V, exceeding the battery voltage by 250mV)
- CHG: Proper charging of the battery
- BOH: Battery over-heating conditions

Voltage regulator TPS61032 generates the low battery signal (BL) once the battery voltage falls below 3.5V. To enhance battery life, pull-ups are created using a low-dropout linear regulator, MAX8880, supplying an ultra-low current (3.5uA). Battery conditions are indicated to the user through short beep sequences using a buzzer embedded in the circuit.

Figure 10 shows the system state diagram and the associated beep patterns. The normal functioning state indicates continues ranging and production of correlated vibratory patterns. To indicate low battery power, beep3 is sounded every 2 min while normal functioning is retained. The device must be turned off to prevent deep discharge of the Li-ion battery.

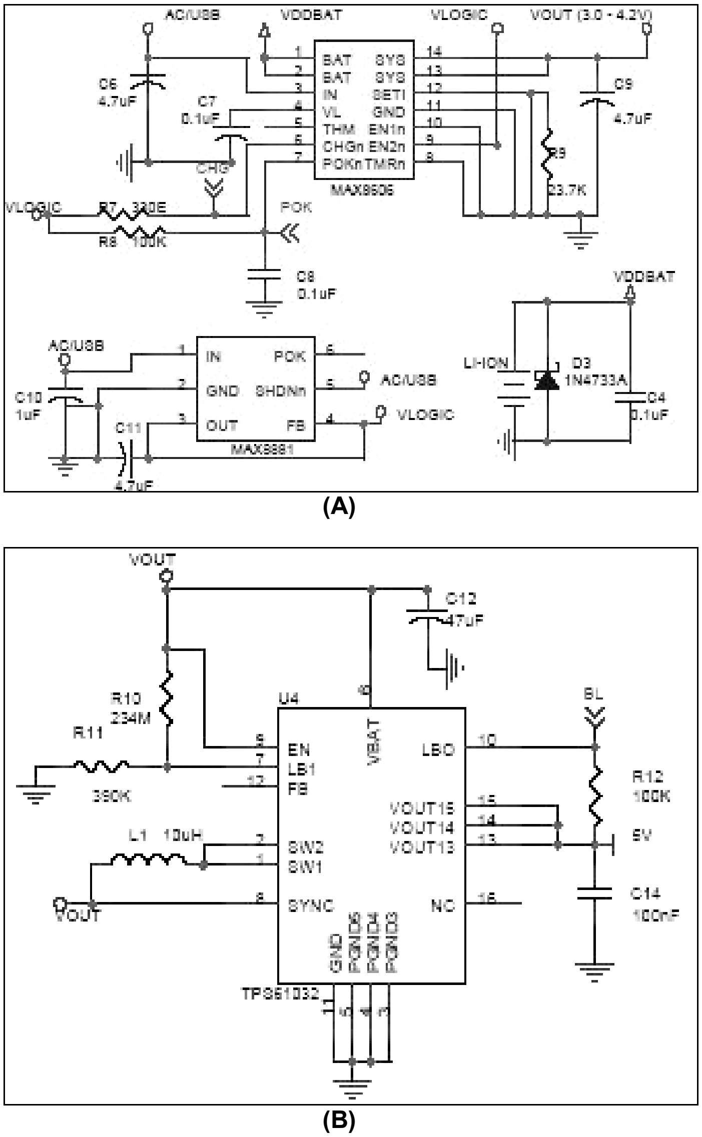


FIGURE 9: CHARGING SUB-SYSTEM CIRCUIT A) BATTERY CHARGE-MANAGEMENT IC (MAX8606) AND LOW-DROP OUT REGULATOR (MAX8880) B) VOLTAGE REGULATOR (TPS61032)

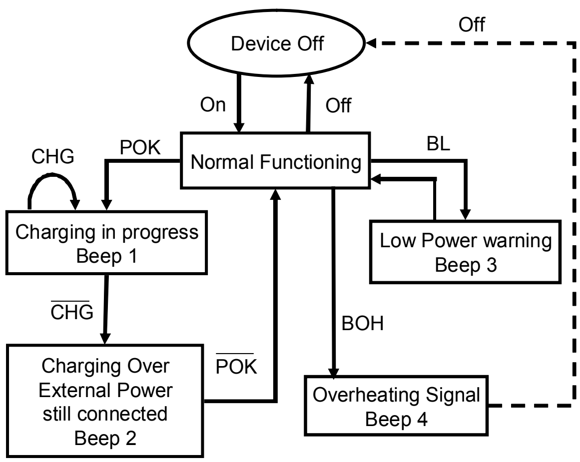


FIGURE 10: SYSTEM STATE DIAGRAM

For charging the user connects an AC or USB adaptor. The charging sequence is initiated once a valid power source is present and Beep1 is produced periodically to indicate charging. Once the battery is fully charged Beep 2 is produced (state: Charging Over). The transition to normal functioning state occurs once the charging power source is removed from the unit. In a rare case of battery overheating, both charging and ranging are immediately stopped and the user is warned through an emergency signal (Beep 4).

Control Unit: The control sub-system consists of an 8051 micro-controller AT89C55WD (clock rate: 1.84 MHz). The controller triggers the ultrasonic ranger for ranging, computes the obstacle distance and triggers the vibrator sub-system to output the desired pattern. It also monitors the battery status and gives indication to the user through buzzer tones. The ranging algorithm has been optimized so that the ultrasonic ranger can be triggered typically every 60ms (15 Hz). Hence the device shows high responsiveness to varying obstacle distance.

Apart from computing the distance, the instantaneous relative velocity of the nearest obstacle is also computed. Incase, this velocity is consistently above a predefined threshold then, the vibrations are ceased and the buzzer is sounded to warn the user. This gives the user some time for a reflex action instead of being hit unwarned. Within the detection range, an object moving at a maximum speed of 7 m/s can be detected. We are experimenting with this feature bearing in mind that the detection range of ultrasound rangers is increasing rapidly. We envision that increased range would allow early detection of fast approaching obstacles and give the user more time to move out of the way.

3.2 Mechanical Subsystem

This section deals with structural design and structure-signal interaction aspects of the product. Structural design details of the product are discussed first which is followed by study of vibration signal transfer and its interaction with the structure. The structural and geometric design of the product was arrived at by use of analytical and computations tools for product design, through laboratory experiments for structure-vibration signal interaction, and working closely with potential users of this product from the National Association for Blind, New Delhi which included mobility instructors. The structural design of this product was challenging in many ways as many conflicting user requirements and constraints have to be met without sacrificing intended function of structure-signal interaction. Some of the requirements to be met for the proposed product are listed below.

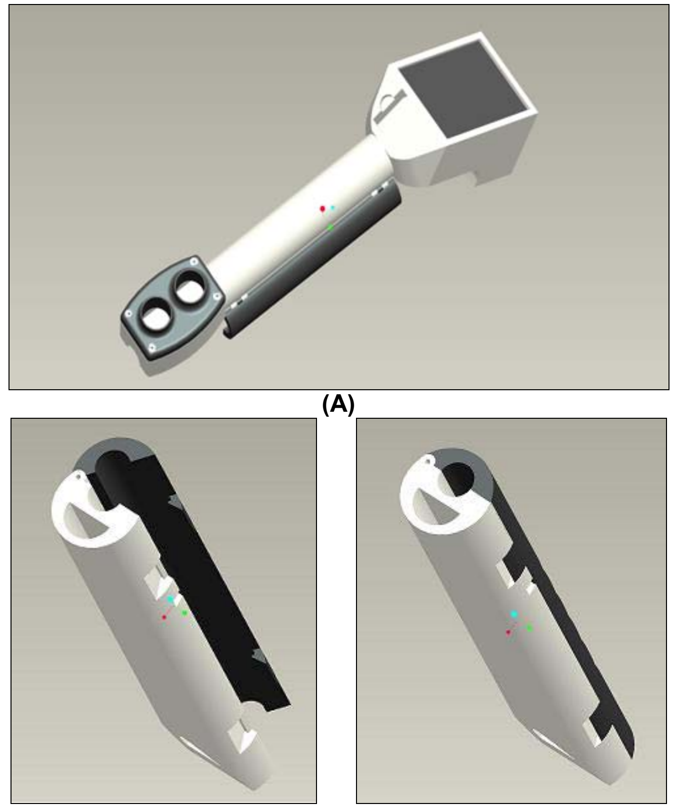
- The new navigation unit should work as a supplementary unit and not as replacement of white cane presently used for navigation.
- The unit should be light in weight without adding extra weight to the existing cane and at the same time without compromising in terms of strength, particularly impact strength.
- The product can be mounted and detached on the existing white cane easily, without any sighted assistance.

- The unit should be such that it has flexibility to be used by users having different styles of holding and different types of gripping.
- As the angle of inclination of the cane varies from user to user, the product should have flexibility to be used with a wide range of inclination angles.
- The user should be able to use existing white cane mounted with new navigational attachment without application of any additional force or torque.
- The navigational unit needs to be mounted on the white cane in such a manner that obstacle sensing unit always points out in the intended direction without any undesirable rotations leading to missing of signal.
- Whenever an obstacle is sensed, the feedback as a vibratory signal needs to be conveyed to user with an optimum intensity.
- Feedback signal in terms of vibrations should be local and its transmittivity to entire cane and other unintended portions of the navigation unit should be minimized.
- All the above requirements have to be met within an affordable cost target.

Following sub-sections discuss some salient features of the proposed product.

Detachability: As discussed earlier, white cane is traditionally used by visually impaired people for navigation. The product under consideration was designed as an additional attachment to the existing white cane and not as a replacement. One of the major requirements is that the user should be able to mount and detach the present navigation aid on white cane unit with ease. The mechanism designed is such that it could be used by visually impaired person without any sighted assistance and does not require any modification of the existing cane. The device is mounted on the upper portion of the cane. The user holds the gripping portion of the navigational device mounted on the cane, and not the cane itself. The mounting of new device on the upper portion of the cane also helps in maintaining the original length of the cane. As it was decided to use plastics as a structural material due to light weight consideration, a simple snap-fit mechanism was devised to attach the unit with white cane (Figure 11(b)). This mechanism utilizes the elastic property of polymeric materials for locking and unlocking.

Flexibility: Design flexibility in the proposed product was needed due to three reasons. The system should work and at the same time be convenient to use irrespective of holding style, gripping style and the angle of inclination at which the entire navigation system is held. Different holding and gripping style demands that a portion of the proposed unit at the top can be adjusted by providing a rotational degree of freedom. This is required in order to ensure that any part of the system does not collide with upper or lower wrist of the user. Similarly, flexibility in holding the navigation unit at different angles calls for a similar rotation freedom at the bottom portion of the unit where sonic sensors are mounted. Both these features can be easily incorporated using friction locking possible with polymeric materials.



(A)

(B)

FIGURE 11: PROTOTYPE OF THE DEVICE A) TOP VIEW B) SNAP-FIT ARRANGEMENT USED FOR LOCKING

Usability: By usability here means convenient to use without any hassles and without being used in a wrong manner. As the proposed unit should be light and should have sufficient strength, plastics are natural choice in this case for structural material. Polyamide has been chosen as structural material keeping its high strength to weight ratio and better wear resistance properties in mind. Further, the system is designed to keep the centre of gravity (COG) as close as possible to the grip. As the distance of the COG increases from the point of holding, an additional moment on the user's wrist is experienced. This is taken care by keeping the heavier components such as battery, circuits etc at the rear portion of the unit. Lighter sensing unit at the bottom and heavier battery holding unit at the top ensures that in an equilibrium position, sensors always point towards the obstacles ahead of the user. This also ensures that the negligible torsion is experienced by the user in using this unit. The gripping portion of the device has an elliptical cross-section with the minor axis dimension separating the fingers and the palm. This gives the user precise indication of the sensor direction and prevents any inadvertent rotation of the device.

Reliability: There are three parameters that decide the orientation of the sonic sensors is accurate and reliable. First is the location of the transducer on the cane (L), second is the angle at which cane is held by the user (θ) and third is the angle of the transducer with respect to the unit (Ø). Since the location of transducer is fixed on the cane and angle of holding the cane varies from user to user, it is required to adjust the angle of the transducer with cane (Figure 12). The following calculations show the correlation between Ø and Θ.

From Figure 12, one can derive:

$$\Theta + \text{Ø} = \mathrm{Cos}^{-1}((1/\sqrt{2} - \sqrt{2}*D) / (H_2 - H_1)) \qquad (1)$$

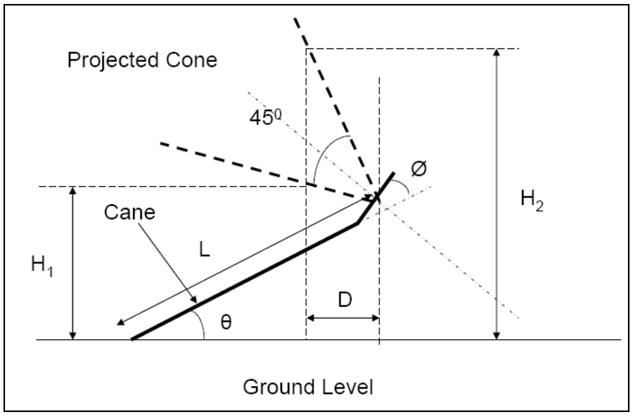


FIGURE 12: ORIENTATION DETAILS OF SONIC SENSOR

In present version of prototype, Ø has been kept as 10^0, assuming for an average Θ value of 55^0 (based on potential user's survey), but a provision has been made in the design to change Ø with changing Θ. The angle Ø can range from 0^0 to 30^0 with steps of 10^0 each. While holding the device with the inclined grip (Θ small), Ø is kept at 30^0. The user can decrease this angle once the conservative gripping style (Θ large) is adopted in a crowded area. This adjustability allows the correct orientation of the detection cone from the knee to the head level of the person.

Structure-Signal Interaction

To convey feedback about presence of obstacles to the user a small vibrator (DC motor with an asymmetric mass) is used to generate vibratory signals. As discussed earlier, the power source for this motor is through a rechargeable battery. Feedback signal in terms of vibrations should be local and its transmittivity to entire cane and other unintended portions of the navigation unit should be minimized. This aspect is also important to minimize the power consumption. This has been accomplished in the following four ways:

- Matching natural frequency of the system with operational frequency so that system always vibrates under resonant or close to resonant condition.
- Locating the vibrator at one of the antinodes of the system so that amplitude of vibrations is maximized.
- Locating the vibrator as close as possible to the handle where the unit is gripped.
- Minimizing the loss of vibrational energy from the unit to the cane.

In order to realize the above mentioned objectives, vibration analysis of the system has been carried out using computational tools and experimental studies using scanning laser Doppler vibrometer. Preliminary computational studies were carried out to find natural frequencies of the system using ANSYS software (Figure 13). Worst case conditions were chosen as boundary conditions in carrying out these experiments. Table 2 below gives results of this analysis.

TABLE 2: RESULTS OF MODAL ANALYSIS BY ANSYS

Mode No.	1	2	3	4	5	6
Natural Frequency (Hz)	4.72	5.77	22.16	23.32	26.13	27.14

Physical experiments were also carried out using scanning laser Doppler vibrometer, with complete navigation system mounted on cane. The results of the experiment yielded natural frequencies as shown in Table 3.

TABLE 3: RESULTS OF MODAL ANALYSIS BY LASER VIBROMETER

Mode No.	1	2	3	4	5	6
Natural Frequency (Hz)	6.14	7.75	18.86	20.62	21.80	23.79

Results presented above show that anti-node location is in between handle, from where user holds the unit. Based on above arguments, the location of vibrator is fixed at the anti-node position. To confine vibrations to the unit only, a material with low transmissibility between unit and the cane is used. Use of material with low loss coefficient is also in the pipeline to maximize vibrational energy reaching the user.

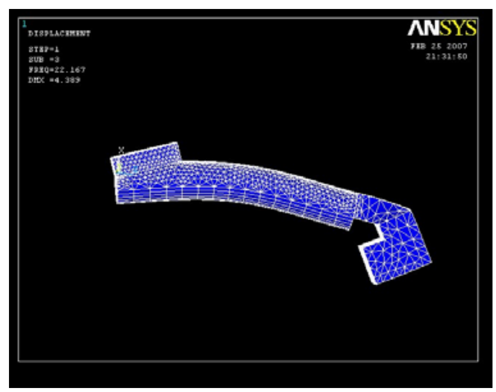


FIGURE 13: VIBRATION ANALYSIS USING ANSYS

4 EXPERIMENTATION AND USER VALIDATION

This section discusses the experimentation conducted at the National Association for the Blind, New Delhi. Ten adult visually impaired cane users were randomly selected for testing the applicability of the device in natural settings.

Detection of knee-above obstacles: An experiment was conducted in an unfamiliar environment possessing knee-above obstacles like a raised railing, side of a truck and the edge of a table. Volunteers did not have any prior knowledge about the identity or location of these obstacles. After initial familiarization with the vibratory patterns, users were instructed to walk till they detected the presence of an obstacle in their path. Two sets of observations were taken: first, with the system mounted on the cane and then only with the white cane. The starting position of the subject was changed before the second set of observations.

Figure 14(a) illustrates that the user was able to detect the raised side of a stationary truck from a distance of 2.5m. Without the unit, the obstacle could not be detected until the user collided with it. Figure 14(b) shows that the major portion of the cane went underneath the side of the truck and hence failed to warn the user.

Figure 15(a) shows a similar result where the user could detect a horizontal bar (7cm diameter, raised 1m from the ground) from a distance of about 2 m. Without the unit, the bar was detected only when the upper portion of the cane came in contact with it (figure 15(b)).

Negotiating common obstacles: Users were able to detect obstacles like walls, people and tables much before coming in contact with them. This information could be used to negotiate obstacles. Figure 16 shows a path finding experiment where the user is able to find a clear path without coming in contact with arbitrarily positioned observers.

(A)

(B)

FIGURE 14: DETECTION OF RAISED SIDE OF A TRUCK (A) WITH THE UNIT MOUNTED ON THE CANE THE USER DETECTS THE OBSTACLE 2.5M AWAY. (B) WITHOUT THE UNIT THE USER COLLIDES WITH THE OBSTACLE

(A)

(B)

FIGURE 15: DETECTION OF RAISED HORIZONTAL BAR. (A) WITH THE UNIT THE USER DETECTS A BAR 2M AWAY AND (B) COLLIDES WITH IT WITHOUT THE UNIT

Other Observations: Users demonstrated quick responsiveness to changing vibratory patterns and reported that distance perception through vibrations becomes innate without interfering with the normal flexible usage of the cane. Volunteers mentioned that the mounted unit cane was easier to lift and tap compared to the original cane, which can be viewed as a consequence of raising the centre of gravity of the system towards the palm of the user. The system could be used effectively by users with both the inclined and the straight grips (Figure 17).

FIGURE 16: PATH FINDING EXPERIMENT WITH AN EARLIER PROTOTYPE OF THE SYSTEM

Since an ultrasound beam is used for ranging, obstacles like a glass or a liquid surface can also be detected. A fully charged battery lasts about 15 hours of constant usage before recharging. According to a study by Blasch etal.[11], the average daily cane usage is 1.5 hrs. Hence the device can be used for 10 days before recharging.

FIGURE 17: USER WITH VARIOUS GRIPS TESTING THE PRESENT PROTOTYPE

5 DISCUSSION

Navigation for the visually impaired is often described as walking in a minefield where the person discovers obstacles only by unexpectedly coming in contact with them. The knee-above obstacle detection and warning system increases the detection range of the white cane and warns the user of knee above obstacles much before colliding with them. The system provides a much wider feel of the surroundings, improves safety and hence gives confidence to the user.

The device allows the user to hold the cane with a variety of personalized grips. The device does not attempt to remodel the cane, and comes as an attachment that can be mounted on the existing cane.

The system was developed in close association with potential users. Feedback was taken during the problem formulation, concept design and prototype evaluation stages which was critical for achieving our objectives.

The projected cost of the device is under 50 USD which should place it within affordable range for users in developing countries. The cost would decline substantially once these devices are mass produced.

6 CONCLUSION

A novel embedded system built with a simple microcontroller and an ultra-sonic ranger which provides vibratory output with a carefully tailored mechanical design has been prototyped for the visually challenged. Initial experiments with the target group demonstrate utility in real life scenarios. This potentially affordable system reduces dependence on sighted assistance thereby empowering the visually challenged.

7 ACKNOWLEDGEMNTS

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