A Novel design of Integrated Proximity Sensors for the White Cane

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This paper documents a low cost solution for integrating proximity sensors onto the white cane for the blind. It promotes the sensors as a peripheral device that uses digital signal processing and ultrasonics to compute distance measurements using time-delay calculations of ultrasonic signals. The design increases the coverage of the cane and overcomes the common bad habits in techniques of its use. The integrated cane will allow detection of high-level objects and give a greater reaction time for changes in the level of the user's path, such as dips. Initial calculations for the timing of signals, and the coverage of sensors for the cane are explored, and descriptions of signal filtering and audio feedback methods used are discussed.

1 Introduction

The available devices in the Australian market for the vision-impaired tend to be expensive and cumbersome or cause discomfort when in use. Also, there are no devices that provide sensing for dips in the path. A large majority of vision-impaired people use the white cane as a principle walking aid. Due to their simplicity and low cost, the white cane has become the most widely used instrument for the blind in the world [6]. With a side-to-side swinging action the cane can "feel" objects directly in the path of the user. However, this feedback is limited as such, and the cane is inefficient in detecting dips in the path and unable to detect high level objects [7].

After consultation with the Association for the Blind of Western Australia (ABWA), it was established that a genuine interest for a cost effective sensor attachment device for the white cane, which can overcome the coverage limitations of the white cane exists. The following requirements for the integrated cane device were drawn up:

- Ability to detect objects in the user's path, as well as overhanging objects and dips, at a range of approximately 3-5ft
- Tolerance for individual user techniques, such as wrist rolling, arm movement and dropped arm
- Relatively low cost
- Add-on device for the regular white cane
- Light weight
- Feedback in the form of audio signals or vibration in the handle

The sensor's ability to detect dips more efficiently in the path is useful when negotiating streets, with their curbs, potholes and water drains. The available devices with similar specifications include headsets, neck straps and hand-held designs. White cane users have not taken a liking to these designs as they tend to be a burden - the neck straps and headsets are said to be uncomfortable and too inconspicuous. Overall, a large population of white cane users dislike using additional devices to assist them, with the exception of the cane, as they prefer to be as independent as possible. An add-on device to the cane was therefore much preferred to a separate accessory in the design of the sensor. These requirements have been integrated into the solution presented in this paper using a digital signal processor based design to extend the coverage and range of the white cane and also to overcome the problems in techniques used for the cane.

2 Background

2.1 White Cane

A white cane is a mobility aid device that enables the visually impaired to feel their environment and locate obstruction in their path. The white cane is often made of fibreglass, carbon fibre or metal and is long and thin. The user holds the cane on a preferred hand and uses a side-to-side tapping motion on the desired path of travel. Detection is based on the cane coming into obstructive contact with an object. Dips in the ground can be detected if the user is able to notice the cane needing to be lowered to achieved a tap on the ground. Hence the ability of a user to detect a dip is based on the user's sensitivity to ground levels, and it is viable to assume that the larger the drop in the ground level, the easier it will be for users' to detect the change. With sensors attached, sensitivity to ground levels will no longer rest in the ability of the user but will be augmented by the proximity sensors.

In general the length of the cane is measured from the ground to the sternum of the user. Hence the cane is generally related to the height of its user. Using the correct techniques, a sensing range of about 3 to 5 feet is possible. However, this does not ensure safety from overhead, fast moving or changing objects, and obstacles that are not within the sweeping path. The cane varies in size and a strong metal or moulded plastic end is generally used to ensure durability and to make a distinct sound when the cane is tapped against objects. An easy to grip handle as well a wrist strap are included for ease of usage, and most white canes can be folded away when not in use. In convention, the tapping end of the cane will be referred to as the 'tip' and the handle end of the cane will be referred to as the 'end'.

2.1.1 Technique of Use

There are many techniques used for the cane, but almost all of them are derived from a single technique that is approved and taught by the ABWA. Although this technique is taught as the standard method of usage, many users, particularly the elderly tend to develop their own preferences or adopt habits that may either increase or decrease the efficiency of the cane. The cane should be at least one and half to two-steps from tip to ground in length holding it slightly above the waist close to the body. The handle of the cane should be centred in front of the user and held with the palm of the hand under it, and the index finger pointing down the length of it. Gripping of the cane should be light and the side-to-side tapping motion should be fluid, as this will enable the user to get a better feel of the environment over a strong rigid hold of the cane. The tip of the cane is swung back and forth from one side of the body to the other side using the wrist motion to move it. The wrist should be the pivot point of the cane, and there should be no arm movement, as this will change the distance and angle of the swing and range of the cane will then vary as it is swung from side-to-side. The swinging arc should be roughly the shoulder width as swinging too widely is dangerous to passer-bys and it will also reduce the effectiveness of the cane. The other hand should be kept free as it can be used to protect the user from obstacles in front and on both sides.

Generally, it is advisable for the user to tap the cane each time a step is taken. When stepping with the right foot then the cane should be tapped in line with the left shoulder. This will ensure the user have adequate information about the environment of his or her next step.

This technique is very flexible and can be changed to suit individual preferences and situations. For instance when travelling in crowded places the cane should be kept close to the body to avoid tripping other people. Slowing down the walking pace should also be taken in more hazardous environment, as there is less time to react to information supplied by the cane. Also when climbing up stairs, it is a good idea to hold the cane in a straight up and down position, letting the tip to tap the steps in front. This will provide distance between the current step and the next step, as well as the height required to take the next step.

2.1.2 Bad habits

Though the white cane technique is very versatile and flexible, many users tend to develop bad habits such as rolling their wrist, while swinging the cane [6]. This can cause many serious problems such as wrist strain and inefficient use of the cane. Rolling the cane can be especially bad, because during the tapping action any roll will mean that the cane is not held on properly and that a wild swing will result. The effects of this bad habit are that angles of the swing arc will constantly vary and so will the distance between pick-up distance and the user. Hence coverage of the cane will not be efficient. This is an important factor to consider in the development of this project as the arc swing angles, distances and cane direction will directly affect the sensors' coverage.

The proposed design is aimed at limitations of the white cane. It includes sensors to continually monitor for high level objects and increase efficiency in the detection of dips. With the increased coverage generated by the sensors, the reaction time will be increased from one step to three steps. This will improve the user's ability to detect drop-offs in ground levels.

3 The Design Concept

The proposed design centres around the use of a micro controller to calculate distance measurements of ultrasonic signals sent and received by two sets of transducers fixed onto the white cane. One set will be dedicated to sensing low-level objects and the other for high-level objects. The programming flexibility of a micro controller is also an advantage as it allows for software development, which will define the sensor range and calculations.

The process of detection begins with a stream of pulses generated by the micro controller at selected time intervals. These pulses are transmitted along the path of the cane by low cost ultrasonic transducers for the distance measurements. Ultrasonics is an ideal method for this type of application, as it is of low frequency and undetectable to human ear [5]. In terms of ground level sensing, the receiver will pick-up the reflected signals from the path, and the micro controller will calculate the distance measurements according to the following relation,

$$D = \frac{1}{2} \times C \times [T2 - T1] \qquad (1)$$

Where:

D is the distance of object in (m)
C is the speed of sound in the travelling medium (air) in (m/s)
T1 is the time of wave transmission in (s)
T2 is the time of wave is reception in (s)

A micro controller compares the time-delay between the transmitted signal and the received signal. If the signal is calculated as having been received in a shorter time than expected, then there is an object in the path. If signal is calculated as having been received in a longer time than expected, then there is a dip in the ground.

For head level sensing, the micro controller monitors for any reflected signals. If one comes back, then there is an object at head level. Residual signals from distant objects will be eliminated with the use of software-based timer cut-offs, and signals outside a specified time allowance will be disregarded and not used in any distance calculations. For a person with a height of 1.7m, the cane would be approximately 1.2m long. The swing arc is approximately 50°, as is the angle of the cane to a horizontal. It is from these assumptions that we base the rest of our calculations. Further measurements can later be studied to find a trend between the height of users and cane angles and measurements. These calculations can then be applied to them, so that people of various heights can use the cane.

3.1 Assumptions

The remainder of our calculations and measurements are based on the following assumptions [4]:

1) Temperature is 25 degrees Celsius.
2) All measurements relating to the cane are for a person of approximately 1.7m using a cane of length 1.2m

3.2 Sensing Range

A major problem that was to overcome with the proposed design is the bad techniques in use with the white cane. To combat these habits, this paper proposes using ultrasonic transducers with a wide pick-up angle. The prototype is being built using transducers with 30° angle of coverage (figure 1 and 2).

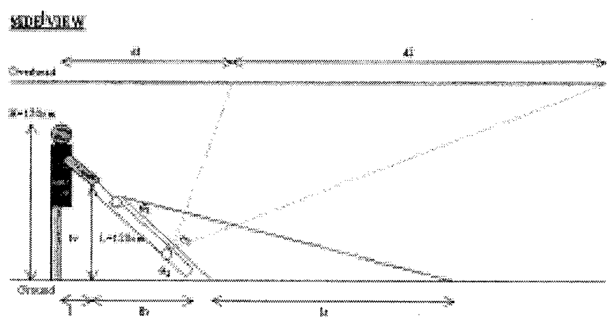

Figure 1: Vertical and horizontal coverage of the integrated cane

The low level sensing of objects is achieved by fitting transducers at the inner base of the cane's grip, pointing down the length such that the 30° coverage extend out in front of the cane. The 30° coverage means the cane's sensing range is extended 1.4m in front of the cane. In terms of lateral coverage, this means that the feedback swing arc of the cane is effectively increased from 50° to approximately 80°.

The vertical level sensing can be achieved by placing another set of sensors at the tip end of the cane. These transducers will point in the direction perpendicular to the cane. It is proposed that these sensors are placed 0.5m up from the tip so as to prevent it from being knocked against objects. This placement will also assist in balancing the overall weight of the sensor attachments. At head height (1.7m), this will give a detection range of object as close as 1.6m and as far as 3.6m.

With the extra coverage of the sensors, wrist rolling and other bad techniques will not affect the detection of objects in the path of the user. Extra lateral sensor coverage is generated from these bad habits, and objects outside of the path of the user will return a feedback, however, our proposed feedback output will be variable in pitch and tempo and is dependent on the distance of the object. After some use of the cane, users will familiarise themselves with the coverage, and feedback can be assessed differently by each individual user. A fuller description of the feedback is presented later.

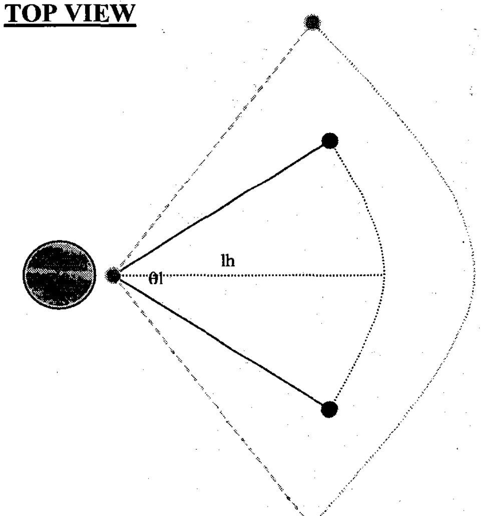

Figure 2: Lateral coverage of the integrated cane

3.3 Timing

Timing is a very important issue that has to be taken into consideration for the prototype development. Based on the general use of the white cane the sensor aid must accommodate different users and their habits to make it into a viable solution. The proposed solution of using ultrasonics and a micro controller to generate the output must be able to fit into the time constraints different users' walking speeds and methods of use. Our preliminary measurements are summarised in *Table 1.* It shows roughly the time division of each stage from sensing to feedback for the maximum range of the ground sensor (approx. 2.1m from tip of cane).

Table 1: Timing for a sensor cycle

Stage	Description	Time (ms)
1	Micro controller initiate transceiver	0.50
2	Transistor switch for transceiver	0.10
3	10x40Khz sinusoidal pulse generated	0.25
4	Wait state after send	1.50
5	Transistor switch for receiver	0.10
6	Receiver port closed	12.14
7	Micro controller Calculation	3.00
8	Feedback Generated	7.00
	TOTAL TIME	**24.43**

The description of these stages are defined in further detail below:

Stage1: Micro controller initiate transceiver - this is the time it takes for the Micro controller to process the routine to initiate the transceiver sub routine.

Stage 2: Transistor switch for transceiver – the time taken for the transistor switch to activate the transceiver to send the pulses.

Stage 3: 10x40Khz sinusoidal pulse generated - the time taken to generate 10 sinusoidal pulses from the ultrasonic sensor. After Pulse is generated the transceiver stage is stopped.

Stage 4: Wait state after send - Once the 10 sinusoidal pulse is sent, the receiver will only activate after 1.5ms has pass to ensure that the sensor has a minimum sensor range of 0.5m.

Stage 5: Transistor switch for receiver - the time taken for the transistor switch to activate the receiver sensor.

Stage 6: Receiver port closed - to ensure a maximum range of 2.1m, the receiver sensor will be open for 12.14ms only. Any signal received after this time is discarded, as it is beyond the sensory range wanted.

Stage 7: Micro controller calculation - this is the time needed for the micro controller to activate the calculation sub routine and calculate the distance of object to apply the feedback.

Stage 8: Feedback generated - time taken to generate the audio feedback to the user.

As can be seen from the timing table (table 1) the total time from sensing to feedback should all take about 25 ms, taking into account that the speed of sound in air at 25°C is approximately 346 m/s. This represents the longest cycle time for the sensor since it is working at its maximum range. With this time constraint between each successive pulse, an average of about 40 sensor cycles can be achieved in 1 second [1].

The stages for the high-level sensor cycle are equivalent to the ones for the low-level sensors, however, the range of the maximum distance of the sensor pick-up is increase to 2.6m. Stage 6, the time the receiver port is held open must be increased to 15.03ms to allow for the extra distance of travel of the signal. This gives a cycle time for the high-level sensor as approximately 27.32ms, and 35 sensor cycles a second is achievable. The "on" states of the sensors will have to be distributed evenly between the two sets of transducers so that they will not interfere with one another. This means that each sensor will approximately get through 18 to 19 cycles per second. This will provide adequate sweeping coverage for most cane user techniques

3.4 Filtering Methods

The reflected signals picked-up by the receiver will be subjected to noise interference and attenuation. The signal will have to be amplified and the original signal recovered from the noise through a filtration technique. The amplified received signal will be a high frequency noise component superimposed on our original 40kHz signal. The signal can therefore be recovered by envelope detection using an AM demodulator.

3.5 Feedback

For prototype, the cane will emit an audio signal for feedback. A constant pitch is delivered depending on the vertical level of the object. This pitch will vary in tempo depending on the distance an object is to the cane, with a low tempo pitch meaning an object is detected at the outer range of the sensors, and a high tempo signalling an object close to the user. The cane can therefore be used as a radar-like instrument, and by sweeping it across the direction of an object the user can pinpoint the object and gauge its approximate size by listening to the pitch and tempo of the feedback audio and manoeuvre around the object.

4 Conclusions

The proposed design is aimed as a simple extension to the existing white cane that allows the user greater feedback. It serves to increase the coverage of the white cane and minimise the effects of bad techniques of its use. Its ability to detect dips and overhead obstructions is currently unavailable in the mobile aid market. Further more, the design fits well into the requirements reached in conjunction with ABWA. Some of these requirements are further discussed below.

4.1 Components

The major components, such as the micro controller and ultrasonic transducers required for the design can be obtained at low costs. They are also diminutive in dimension and lightweight, and attaching them onto a white cane is a realizable objective.

4.2 Software Development

Having the ability to reprogram the micro controller will allow further development in the cane's sensory potential. The program algorithm defines the sensitivity and range of sensors, so the software for the white cane can easily be redefined for the different techniques of the users.

5 References

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