Wearable System for Mobility Improvement of Visually Impaired People

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Abstract

Degradation of the visual system can lead to dramatic reduction of the mobility by limiting the person to his sense of touch and hearing. This paper presents the development of an obstacle detection system for visually impaired people. The user is alerted of closed obstacles in range while traveling in their environment. The system, we proposed, detects obstacle that surrounds the user by using multi-sonar system and sending appropriate vibro-tactile feedback. The system aims at increasing the mobility of visually impaired people by offering new sensing abilities.

1 Introduction

The work we present in this paper is based on the use of new technologies to improve visually impair people mobility. Our research focuses on obstacle detection in order to reduce navigation difficulties for visually impaired people.

Moving through an unknown environment becomes a real challenge when we can’t rely on our own eyes [i]. Since dynamic obstacles usually produce noise while moving, blind people develop their sense of hearing to localize them [ii]. However they are reduced to their sense of touch when the matter is to determine where an inanimate object exactly is. The common way for navigating of visionless person is using a white cane or walking cane. The walking cane is a simple and purely mechanical device dedicated to detect static obstacles on the ground, uneven surfaces, holes and steps via simple tactile-force feedback. This device is light, portable, but range limited to its own size and it is not usable for dynamic obstacles detection neither than obstacles not located on the floor.

Another option that provides the best travel aid for the blind is the guide dogs. Based on the symbiosis between the disabled owner and his dog, the training and the relationship to the animal are the keys to success. The dog is able to detect and analyze complex situations: cross walks, stairs, potential danger, know paths and more. Most of the information is passed through tactile feedback by the handle fixed on the animal. The user is able to feel the attitude of his dog, analyze the situation and also give him appropriate orders. But guide dogs are still far from being affordable, around the price of a nice car, and their average working time is limited, around 7 years [iii].

The system we have designed consists in sensing the surrounding environment via sonar sensors and sending vibro-tactile feedback to the user of the position of the closest obstacles in range. The idea is to extend the senses of the user through a cyborgian interface. This means that the user should use it, after a training period, without any conscious effort, as an extension of its own body functions. Since there’s reluctance from the visually impaired community toward new technologies, we design our system as a complement of the traditional white cane. It will focus on detecting obstacle at shoulder high and on letting the user perfectly hand free.

This paper describes the architecture and discusses the potential benefits of the system we have designed. One of the main contributions is the use of multi sonar based architecture of our system to give spatial information about the obstacles in the surrounding. The rest of the article is organized as follows: next section overviews related works concerning blind people navigation aids. We analyze the advances done by new technologies in the area of handicap reduction for visually impaired. We present our contribution in details: the principle of the application and the design of the system architecture. Then we present the test methodology and their analysis. The paper concludes with general discussion and our plans for future work.

2 Related Work

A deal of research has been performed to improve autonomy of visually impaired people and specially their ability to explore the environment. Wearable systems have been developed based on new technologies: laser, sonar or stereo camera vision for environment sensing and using audio or tactile stimuli for user feedback [iv].

Some early examples about those systems can be illustrated by the C-5 Laser Cane [v] based on optical triangulation to detect obstacles up to a range of 3.5 m ahead. It requires environment scanning and provides information on one nearest obstacle at a time by means of acoustic feedback. The laser system measures the distance to the obstacle and a sound tone proportional to this distance is played. This system developed in the 70’s is the precursor of a large series of devices trying to remove the cane of the blind user. More recent development using stereoscopic cameras coupled with a laser pointer and audio system have been developed at the University of Verona [vi]. One of the main interests here consists in the translation of the 3D visual information into relevant stereoscopic audio stimuli. The sound generated on ear phones simulates a distant noise source according to the position of the obstacle. This system has been designed to be implemented on wearable device, like a pair of sun glasses equipped with two micro cameras and a PDA. Using audio signals may perturb the user’s hearing, which is the main sense that let visually impaired people to perceive the dynamic distant environment. As a Camera vision based system, it can recover more information than only distance to the obstacle. With appropriate algorithm they can also compute information about the nature and specificities of the environment. The problem with vision algorithms is their need of huge computation power and their sensitivities to light exposition.

One other recent project, CyARM [vii], is also based on wearable low cost devices but using slightly different approach. It uses ultrasonic transducers to detect the distance to the nearest obstacle. This information is passed to the user through variation of tension of the fixation wire attached to the belt. Higher tension means the proximity of the obstacle. The CyARM application offers an interesting solution. By using sonar sensing and tactile feedback it creates a new portable interface for navigation. However it is still not hand free and needs the user to constantly move the device to sense the environment.

Nowadays, some new commercial devices appear on the market, like the UltraCane [viii] which uses a build-in sonar system and sends back vibrations through the handle according to the presence of obstacles. The ultra cane enhanced the traditional white cane by giving information about the obstacles before direct contact. But it doesn’t provide any new functionality to the traditional cane and the localization is still done by movement of the cane and it doesn’t detect objects at head height.

Many researches are going on the use of vibrating system to enhance navigation, especially when visual feedback is reduced, absent or already overloaded. Vibrating devices have been used in several applications to enhance navigation ability. Most of those applications aim at giving spatial orientation information to the user through vibrating feedback. One example of this application is the research done on vibrating belts for navigation way point enhancement [ix]. The device consists in a belt containing 8 vibrators which vibrates according to the position of the target given by GPS coordinates. The system has been tested on board of a helicopter and a boat to detect its influences on the trajectory taken by pilot by using direct GPS coordinate and/or tactile feedback. Prototype of tactile display onto the user body have been tested on aircraft crew members by the Naval Aerospace Medical Research Laboratory for enhancing spatial orientation and situation awareness in military applications[x].

Knowing the interest of the user community is one part, but vibrotactile rendering of spatial information leads to some questions of ergonomic and cognitive perception. Research from the TNO Human Factors Organization lead by Jan B.F. van Erp on vibrotactile interfaces provide useful guidelines for future application development [xi].This paper presents guidelines on tactile information coding, their usability, threshold and pitfalls in terms of subjective magnitude, frequency, location and temporal patterns.

Since the early sixties, researches have been conducted on the sensitivity of the human body to vibro-tactile stimulation in term of amplitude, frequency and spatial cues [xii][xiii]. Based on those studies, the main idea is that subjective magnitude [xiv] and frequency allows up to 9 discernable levels to code the information [xv]. The temporal sensitivity of the skin is very high with a detection threshold down to 10 ms [xvi]. Spatial accuracy of the human skin is variable according to the area considered while the finger end can discern stimuli separated by only a couple of millimeters while that can raise up to 3 centimeters[xvii]. It leads us to build a vibro tactile device which modulates the magnitude and frequency of the vibration input onto a large surface of the user body.

Although many pitfalls still have to be taken in account in the design process. Pattern recognition, for example, can suffer from spatial masking. This phenomenon occurs when close stimuli overlap in time. The apparent location of a stimulus can be induced by the presence of two distinct stimuli around this location [xviii]. Temporal effects occurs when two stimuli appears closely in time on the same location. The sensation provoked by the second stimuli can be drastically modified if the times step between then is less than a few hundred milliseconds [xix]. Modulating the frequency of the stimuli can be done to reduce the influence of such masking. Continuous excitation of the skin by vibration leads in overwhelming the skin sensors and attenuate the perception of the phenomena [xx].A solution consist in using burst stimuli of 200ms on for 800ms off as during the experience done at the university of Oxford [xxi]. However it shows that even under those conditions, spatiotemporal masking is still a major limitation in pattern recognition. To prevent such a pitfall, only one type of information will be passed to the user through the vibro-tactile device and the evolution of the stimuli will be continuous in space. In order to achieve this continuity, spatial information about the actuators has to be taken in account.

Implementation and testing of a vibrotactile vest for the torso have been developed at the University of Pohang in Korea [xxii]. Some interesting tests have been realized on how to render various shapes in space in correlation to the static position of the vibrators. The results show that users feel the presence of moving 3D object in the vibration space and are able to mentally reconstruct spatial information and orientation of those objects. The movement is an important vector of information for those types of interfaces since it allows mental reconstruction according to our self position perception [xxiii]. Speaking about motion, a vibrating device has been tested for the purpose of reducing spatial disorientation among astronauts during weightlessness [xxiv]. The device gives the position of a “virtual” gravity by rendering a constant direction in space representing the bottom direction. The major interest in this paper consists in using the user movement as the variable of the system.

The mistrust of the visually impaired community against the new technologies is a major limitation of the large distribution of those systems. They often prefer rely on basic system like the cane. It is important for a usable electronic travel aid to let the user hand free in order to allow the use of traditional navigation tools. By letting the user hand free, the whole system has to be embedded in the clothes. Wearable constraint implies that all the system and computing power has to be implemented into small electronic system powered by battery. The system has to be low electrical consumer in order to be usable for several hours in a row. Even if camera based system offers more possibility in term of quantity of information, the computation power requested to treat this amount of data is too high for a proper miniaturization. Small sized, low power consumer in energy and computation, sonar based system seems to fit perfectly our needs for the application. By using vibro-tactile feedback we will not obstruct the hearing of the user while soliciting an unused sense. The next part will describe the system we developed based on those two relevant technologies: sonar sensors and vibrators.

3 Working principle

This section presents how our system works and which patterns have been developed to inform the user of its own localization. Obstacle detection is one of the main problems to solve to ensure safe navigation for blind users. We use the multi sensor architecture of our system to develop new obstacle avoidance abilities.

First we determine from which direction the obstacles are coming from. Localization on the horizontal plane is done by appropriate combination of vibration according to the feedback of the sensors. The sonar modules returns the distance of the nearest obstacle in range. The figure 1 shows the sensing abilities given by our system and the exact shape of the field of view of the sonar sensor.

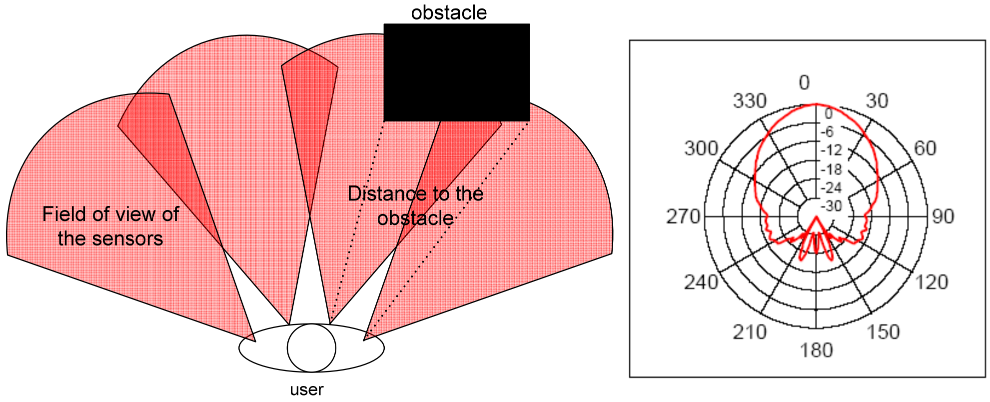

figure1: sensing map

According to the position of the sensors and actuators, the vibrotactile feedback is calculated as shown in figure 2. The sonar modules have been placed to cover a large area in front of the user. The overlapping of the sensors field of view allows finer sensing of the environment. The positioning of the actuators has been arbitrary chosen to be close to the spatial sensitivity of the skin. By using a high linear density of the actuators, we insure a spatial continuity of the vibrotactile feedback.

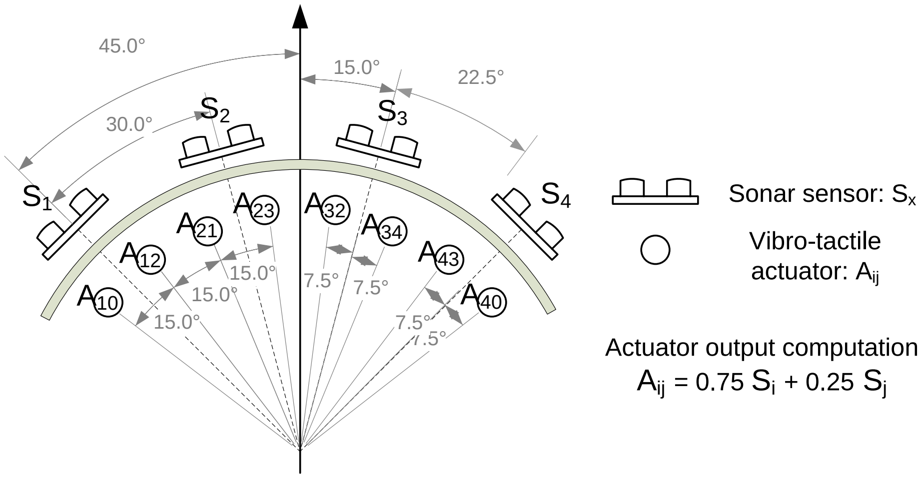

Figure2: Ideal mounting of the system and feedback computation

The information to render onto the vibrator is coded as a 200 ms burst of vibration with variable intensity every second. This technique has been used to not overwhelm the user skin and avoid attenuation of his sensitivity to the stimuli resulting form adaptation. In order to normalize the rendered vibration according to the variable skin sensitivity of the user, we are using for each vibrator a sensitivity curve issued from individual calibration. This curve is a hermit spline which is used to adjust the user feedback according to the state of the system. The curve is set using three control points corresponding respectively to the detection threshold, an average excitation and the maximum intensity as presented in the figure 3 below. The goal is to insure coherent feedback and normalize the response of the actuators.

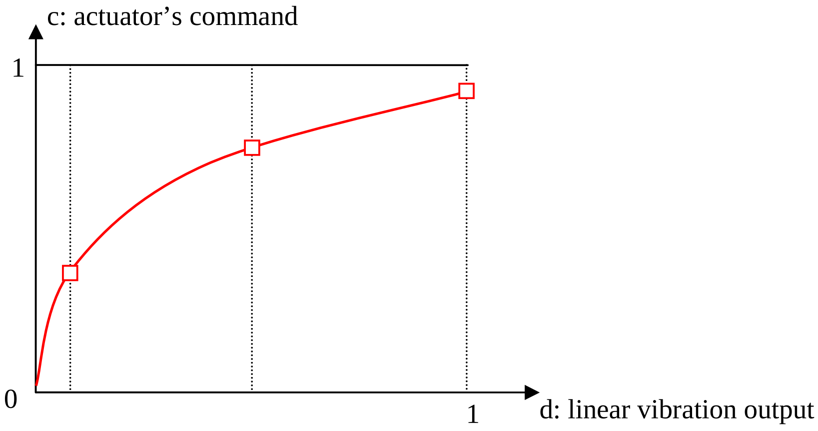

Figure3: Calibration curve

Moving obstacles can also be localized using the same principles taking in account the user own displacement. The user will feel the dynamic changes into the vibro-tactile feedback. By this means, he will be able to estimate the position and the speed of the moving object.

Then the user of our system should be able to position himself/herself according to the environment and estimate moving object trajectories. The different methods presented for obstacle localization have been implemented as follow.

4 System Architecture

4.1 General structure

Now we present the system architecture where its components are attached to a jacket. This wear cloth provides a natural way of carrying that facilitate its use (see figure 4). The components we integrate are: 4 sonar sensors, a microcontroller, 8 vibrators and a pc for the calibration needs.

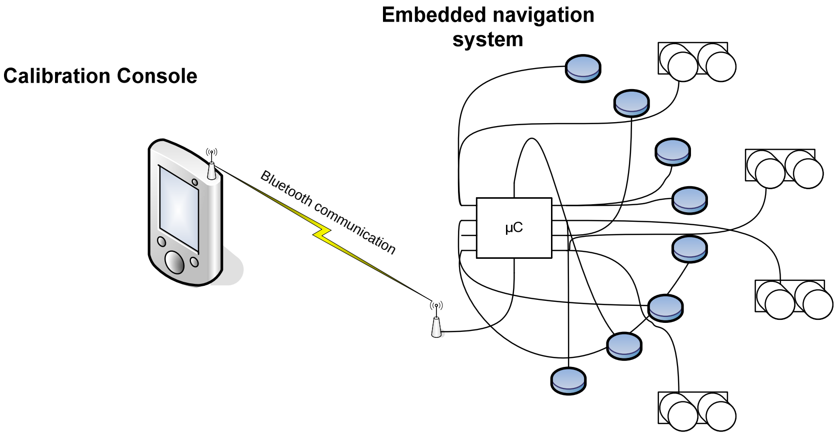

Figure4: Schema of the system architecture

4.2 Sensor

The sonar system is based on four ultrasonic transducers mounted together. The sensors are fixed at shoulders high to increase the field of sensing and side determination. Each sensor is equipped with two transducers. One emits an ultrasonic wave while the other measures the echo. By differentiation of the input and output signals, a microcontroller pic16F87 computes the distance to the nearest obstacle. Then this information is transmitted as a PWM signal to the receiver.

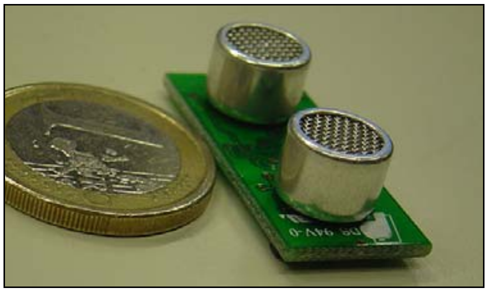

Figure5: sonar sensor

We are using sonar modules designed for robotics and remote controlled unit applications. Those devices are accurate enough for our application around 1% of error. The range is limited from 3cm till 3m in a field of view around 60°, which perfectly fit our needs. The electrical consumption is really low (a few mW) allowing them to run for coupled of days on standard battery supply. The packaging of the transducers is light and small enough (14x32x8mm) to be fixed on a jacket without any inconvenience.

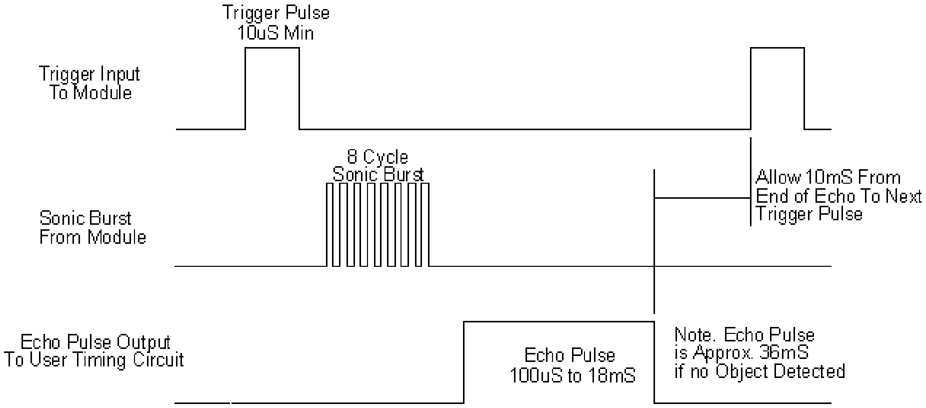

Figure 6: sonar module timing diagram

The diagram above explains the procedure we followed to be able to initiate the sonar sensor and interpret its emitted echo pulse signal. Indeed, once the sonar trigger has been fired, it sends eight cycles of sonic burst to the environment. Then, when the echo pulse of the sonic burst comes back to the sonar, the counter's start value is noted down. The counter is stopped when the echo pulse stops. This distance can then be calculated using the timer's value.

4.3 Data treatment

Data treatment from the set of sensors is done on an embedded 8-bits microcontroller PIC18F6720 [xxv]. The microcontroller gathers the information from the ultrasonic transducers by measuring the width of the echo pulse signal. The pulse width is directly proportional to the distance of the nearest obstacle. By capturing the value of an internal counter 16 bits at rise and fall time of the echo pulse, the micro controller gets a 16 bit value of the distance.

Since the microcontroller has 8 bit architecture, for easier calculation we use a mask to recover the 8 most significant bits of the distance value. Once this value recovered, the output value to be rendered for each actuator is computed according to the different contributions of the sensors (see figure 2). The coefficient of 0.75 and 0.25 are really practical in our case, since the computation of the actuators values can be resolved using only bit shifting and addition. Finally we apply the calibration on each sensor value to compute the final output value of the actuator. This calibration curve takes into account the variation of skin sensitivity and normalizes the vibrotactile response. To compute the final value we test each control point of the calibration curve, store into the microcontroller memory. This curve is composed of 8 points which correspond to a rasterization of the hermite curve calculated on the calibration device.

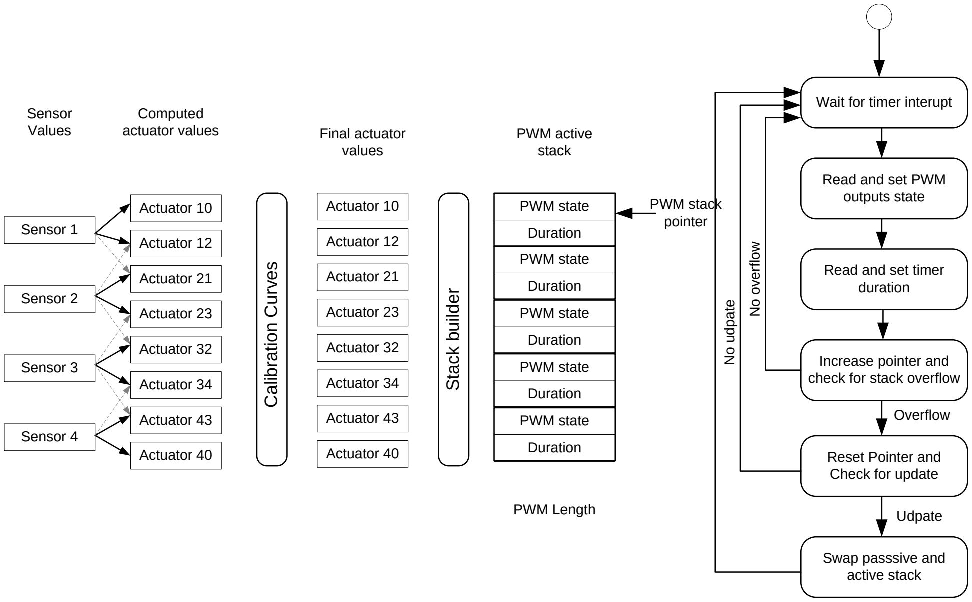

Figure7: embedded software architecture

When the new actuator values have been computed, the software orders them into a custom PWM stack which concatenates the value of the 8 outputs at each times step. The emulation of the PWM output is based on an internal backward counter which can be set and generates an interrupt on reset. The method used to emulate the different outputs out of a single timer is to compute the different time steps separating each change of the outputs as a whole entity. The software sets the counter to this time step and updates the desired outputs. When the time step is over, the pointer read down the new values on the stack and goes on.

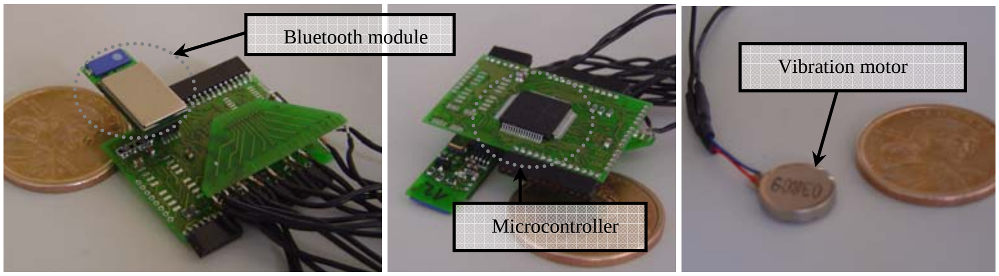

Figure8: embedded system

4.4 Actuator

The vibrators are miniaturized continuous current engines with an asymmetric rotor mass. The vibration is created by the rotation of the center of gravity of the mass around the axis of rotation.

The actuators used to render the tactile information are DC vibration motor issued from the mobile phone technology. For this application, we used the coin motor SAM-A300 which allow easy mounting on the user body. By sending PWM input to this simple brushless DC motor we can adapt its speed and by then the mechanical vibrating energy to transmit through the user skin. These motors are the size of a coin battery for watches which allow better integration into clothing. They are also produced in huge amounts so their price is really low.

4.5 Calibration console

The calibration of the actuators needs graphical interface and user inputs. This calibration device is designed for adjust the system to the visually impaired user by a third person. The actual interface allows us to select one of the actuators and modify dynamically its calibration curve. While the calibration system is connected we can disable the sonar and sends desired outputs on the actuators by triggering the slide bars. This interfaced has been implemented using the graphical engine Mvisio[xxvi]. This homemade library allows fast programming for 2D and 3D interface and can be run on different platforms.

Figure 9: calibration console

This part of the software has been implemented onto a handheld device for increase the mobility of the system. This device includes a Bluetooth connection which allows communication with the embedded microcontroller through a serial interface. Once the calibration curve edited the user can load it onto the microcontroller memory. This system has been used to increase the performance and the accuracy of the feedback for the tests presented in the next part.

5 Discussion and results

5.1 Test methodology

To evaluate the system we have develop a small test method. By blind folding the user eyes, we simulate the deficiency of the visual system. Then we disorient the user by several rotations around him. It avoids him to have memorized the path through the environment. Then we ask him to navigate through a corridor without using his hand to touch the walls. The user only relies on the system to know at which distance he is from the walls.

For evaluating the dynamic obstacle avoidance, we use other people walking toward the user and doors opening or closing. This simulation is designed to be close to the real condition of application. To avoid the user to detect the moving obstacle by hearing them, he has been equipped with hear plugs.

The evaluation is made by an outside person who is judge of the performance of the user by measure his time to pass through the corridor, his improvement due to training and if the user has encounter collision with the environment.

5.2 Results

These results have been obtained by passing the same tests on five different users. We measure on the graph shown in Figure 10 the time of each user on their attempts. The reference time on the first column represents the time to pass through the corridor in normal condition. The 3 others ones represent the successive performances of each user blindfolded and equipped with our system.

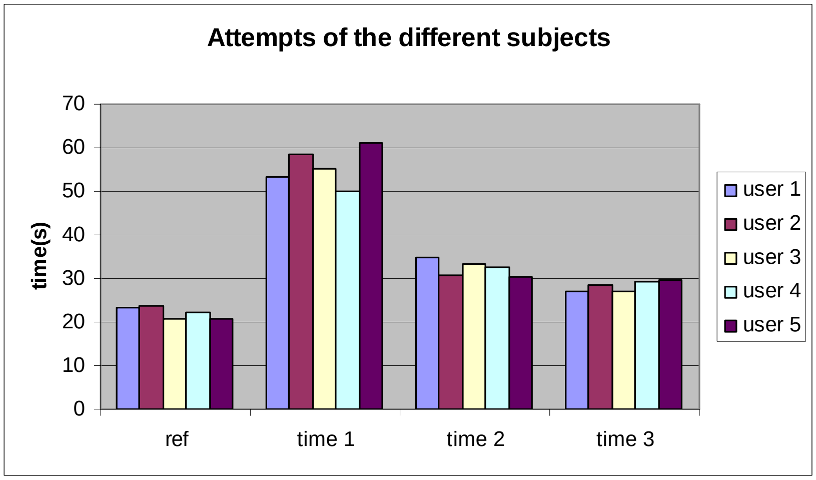

Figure10: results for the validation test

The results show that our system is quite intuitive since we can observe a reduction of 50% of the time to pass through the obstacles after a couple of minutes training with the system. The time to pass through the corridor is still a bit higher than with the full use of sight. This phenomenon can be explained by the limited confidence of the user in the system. The users sensed other people walking and avoiding them in the corridor. They had determined correctly on which side they have been passed by.

5.3 Discussion

The results of the experience are really encouraging. The equipped user is able to walk through the corridor in a reasonable time after a bit of training. The collisions are perfectly avoided and the user is able to distinguish an obstacle from its left and right and to localize himself in his environment. It provides reliable feedback about the surrounding environment by vibrotactile mapping. The combined motion of the user and a moving obstacle provide an accurate perception of its trajectory.

The users trained really fast with the system and managed to navigate indoor easily after several minutes. Those results demonstrate that our system is intuitive and easy to use. The oral informal feedback of the subjects who pass those attempts was that once the discovery time phase passed, the system was providing accurate information about the surrounding environment.

One aspect which reduces the performance of the system is the difference of the ultrasonic reflectance of the different materials that constitute our environment. This difference alters the reliability of the sonar sensor and can lead to some anomaly in the vibrotactile feedback.

Another disturbing phenomenon is coming from the occlusion of the sensor by the user hands. It becomes a really threshold for its usability at close range, because the natural attitude when approaching an obstacle is to interpose the hand between.

Except for those two minor artifacts, we were really pleased with the behavior of the system in those preliminary tests. The systems demonstrate itself, reliable, intuitive and accurate.

6 Conclusion

The system is still hardwired from the sensor to the actuators via the microcontroller. Each part of the system is also mounted on hard circuit board. It will be interesting to weave directly the wires inside the textile fiber and to use semi rigid support for the mounting of the electronic components inside the vest.

Another solution to improve the wearable aspect could be to design the system as a set of independent modules that can be fixed on the cloth and communicating via wireless connection. In order to accomplish a perfectly wearable system the miniaturization should be improved on the sensors and actuators. Those could never be, in a close future, perfectly wearable but could approximate the size of a standard button or clipper present on the most common vest.

The actual mapping is mainly based in the horizontal plane. It would be interesting in further development to map a 3D environment. One way would be to detect obstacles position and gives feedback to the user concerning their heights. This is a necessary step before removing totally the use of the white cane since actually our system won't be efficient for taking the stairs, for example.

The last aspect to be improved will be to change the nature of the sensor. This is due to the sensitivity of the ultrasonic sensor to the surface properties of the detected material. One interesting technology will be to use stereoscopic camera system and vision algorithm to gather depth information. As said in the state of the art, those methods aren't perfectly reliable for every kind of environment and can fail according to the surrounding lighting. But correlation of different technologies would be interesting to study.

In order to optimize properly our system, it will be important to test and adjust the system with a representative amount of visually impaired users. This is important to measure the benefit given by this system in addition to the traditional white cane.

However, with maximum power consumption below the Watt, our system can run for hours out of a single battery supply. By its multi-sensor architecture, it allows positioning by telling the user from which side an obstacle is coming. Each part is small enough to be fixed on the cloth which ensures the whole system is wearable. It also let the user hands free for other purposes. This device has permit to reach a step forward the integration of visually impaired people or a precious help when the vision is reduced by harsh environment. The current system still need little improvements before a perfect fit to the application but demonstrates perfectly its usability.

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