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Electronic Device for Blind Mobility Aid

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Abstract: This study presents an auditory guidance system for the blind. We design a simple but useful wearable system composed of two types of sensor subsystems. One is stereoscopic sonar system which functions as an environment sensing and the other is the floor obstacle detection. Wide beam ultrasound sensors are used to detect obstacles in environment sensing function, so a broader range is covered. The second subsystem uses a narrow beam ultrasound sensor to detect obstacles at floor level. This type of sensor is required for sensing a limited surface in the path of the user for detecting holes and small obstacles. These two functions increases the mobility of blind people by offering extends of its own body functions. Experimental results are provided to show the effectiveness of the proposed apparatus.

Key words: Blind mobility, ultrasound, echolocation, electronic travel aid, DSP

INTRODUCTION

Visual data contains a large amount of information such a shape, color, roughness and motion of objects. That is, the visual system receives much more environmental information than any sensory system. So the blind people must be equipped with a visual substitution system which can augment their scope of social and economic activity and level up their welfare. If a person has adequate information about his travel path, he will be more comfortable, while navigating unfamiliar spaces. This study is based on the use of new technologies to improve blind people mobility. Our study focuses on obstacle detection in order to reduce navigation difficulties for blind people, so increasing safe and independent travel. In the course of our study, we found that blind people expressed a desire to know the exact location of objects in front of them, wishes to avoid the most dangerous events like holes and small obstacles raise on the path and to prevent danger on left and right sides. They prefer navigating outdoor with the cane as primary mobility aids and rely on an Electronic Travel Aid (ETA) as a secondary mobility aids. The cane provides for blind people a greater degree of psychological confidence. The blind utilizes the cane to recognize the condition of ground such as a depression, cavity and the stairs, with his hand's tactile sensations intuitively. The user utilizes the cane to protect him against a danger, because the natural attitude when approaching an obstacle is to interpose the cane between. But the most significant problem with the cane is that it only provides a limited preview, the user needs fast reaction times. There is also a risk of tripping other pedestrians or inadvertent contact with objects. An electronic travel aid eliminates all these drawbacks, because it is a must sophisticated system which gathered more environmental information and transform it into either tactile or auditory stimuli. Towards that end, the system we have designed consists in sensing the surroundings via sonar sensors. Suitable analysis of the acquired data provides visual information and the user can get the information through audio output.

PREVIOUS WORK

The blind pedestrian is constantly in fear of collision and injury. Nor the cane neither the dog can solve this problem. The foremost disadvantage of the cane is its failure to detect obstacle outside of its reach. However the blind often prefer rely on this basic navigation tool in conjunction with an electronic travel aid. The other solution, when the blind accept it, is guidedogs which is a best travel aid, but can not provide so much information and is an expensive to maintain. Hence during the last several decades, researchers have been developing some models of blind mobility aids, designed to help users detect obstacles in their way. The best known are Sonicguide[1], Russell Pathsounder[2], Mowat sensor[3],

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Nottingham Obstacle Detector[4] and Laser cane [4]. Furthermore, these devices must be used in a scanning function. Once an obstacle is detected, a mental effort of the user is required to estimate the relevant dimensions of the object and to plan a path around it. This procedure is time-consuming and straining. Other developments propose some solutions to extract richer information on the blind's environment and to allow him walking with minimum collisions. These systems convert the signals of the stereo ultrasonic to binaural sound[5,6] or into tactile stimuli[7]. Another development using stereoscopic cameras coupled with a laser pointer and audio system have been designed at the University of Verona[8]. As for the stereo ultrasonic signals, this system achieves a transformation of the visual information 3D into stereoscopic audio stimuli. But the problem with the algorithms of image processing is the necessity of a huge computation power, as well as their sensitivity to the external lights. A promising new ultrasound device, the Ultracane[9], acts as a standard cane while providing information about head and chest level obstacle in the environment. But the localization is still done by movement of the cane, so it doesn't provide any new functionality to the traditional cane. One of the most interesting aid systems is the Guidecane[10]. Like the widely used cane, the user holds the Guidecane in front of himself/herself while walking. The Guidecane rolls on two wheels that support its weight. The information gathered on the environment by the ultrasonic sensors are not transmitted to the user nor into audible sound neither into tactile stimuli, but are processed by software that determines the path to follow. A servomotor operating under this software steer the two wheels on the prescribed path around the detected obstacle. If the user wants to turn on the left or on the right he manipulates a mini joystick located at the handle. It possesses the advantage that it requires a very few h of practice. Nevertheless the mechanical components (joystick, wheels, motor) risk to fall in breakdown, what embarrasses the user. It is possible to propose a system less sophisticated, portable, light and easy to use, but especially of an affordable price for the users. Our contribution is the propositon of a system helping the blind to travel outdoor that detects obstacle protruding into the path above the user's waist and those at ground level like holes and small objects. Information gathered by our system on the environment in front of the blind, is processed then quantified audible signal on the direction and distance of obstacle is transmitted to the user via headphones. This system possesses the characteristic to be insensitive to external ultrasonic sources.

DESIGN

Overview: Our system is composed of two subsystems, the first one (Sub1) utilizes two ultrasonic sensors for environment recognition and the second one (Sub2) is used for floor sensing with one ultrasonic sensor. These subsystems emitted a brief burst of ultrasound and then measure the time until an echo is detected. While the blind move around outdoor, the device communicates him some audible sounds on the existence of obstacles. It collects data on the environment using ultrasonic sensors and extracts information on the direction and the distance to the obstacle. This information is transformed into audible stimuli. The blind recognizes his environment through the audible sound generated by the system. Information generated by this system reduces the user's mental effort to plan his path. The concept of our system is represented by Fig. 1.

The three sensors attached to a belt worn by the blind at thorax level. Two sensors point horizontally and realize the function of sensing the environment in front of the user. This function consists in localizing the object and communicates then to the blind an audible frequency corresponding to the direction and distance of this object. This sensing function is sufficiently fast (period of scan = 30 ms), as the follow-up of dynamic objects evolving before the blind is possible.

Floor sensing: The third sensor points towards floor, the point of impact of its beam is fixed to one meter from the user. This sensor achieves the function of floor sensing to detect holes and small objects; it possesses a thin beam. This system allows the user to map an image of his nearest environment and help to walk comfortably. We opted for an audible system instead of a tactile system, because with the first, information on the obstacle can be quantified (pitch, intensity, transmission rate). Our system generates audible frequencies not vocal messages, because this last technique requires a special circuit,

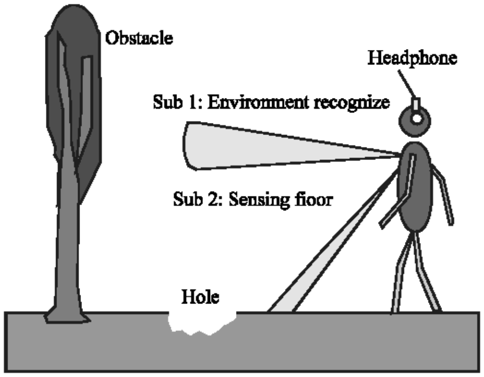

Fig. 1: Concept of blind mobility aid

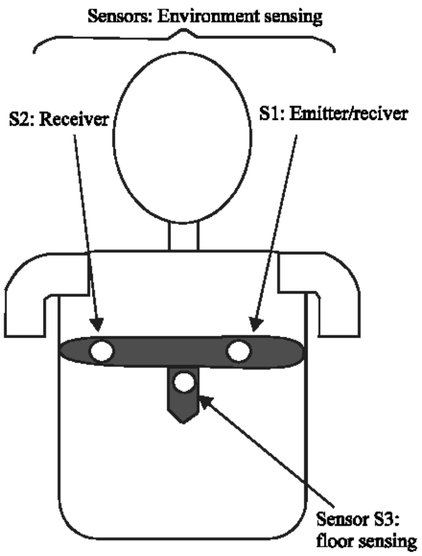

Fig. 2: Arrangement of sensors

whereas an audible frequency is produced by a simple timer. The other advantage of the audible frequencies on the vocal messages is the speed of interpretation, which leads to a fast reaction of the blind to an event. The ears are not completely covered by the earphones of this device, so that the blind can pick-up environmental auditory cues helping it in his mobility.

Visual information acquisition: Three ultrasonic transceivers are used to recognize the environment. The ultrasonic sensors are designed by Murata Manufacturing Co.Ltd and can be used both as transmitter and receiver. In our system, ultrasonic transceivers are arranged as follows:

- Two ultrasonic sensors S1 and S2 (MA40B8S/R) attached on a belt to the level of the blind's thorax and distant of 15cm (Fig. 2). One sensor acts as both emitter and receiver whereas the second is a receiver. This pair of sensor fulfills the function of sensing the environment. When an ultrasonic signal is emitted the two receivers capture the echoes of obstacle, only the first reflecting object within the beam is detected. The difference in time reception of echoes allows deciding on the direction of the obstacle, its distance is obtained using time of flight technique (TOF: Time of Flight). These two sensors have a fixed frequency of 40 Khz and a wide beam angle: 50 degrees.
- A third S3 sensor (MA80A1) attached on the same belt, slightly below the first two sensors. This sensor acts as both emitter and receiver, at a fixed frequency of 75 Khz and possess a narrow beam: 7 degrees. Its role is the detection of holes and small obstacles protruding into the path below the user's waist; it points towards the floor.

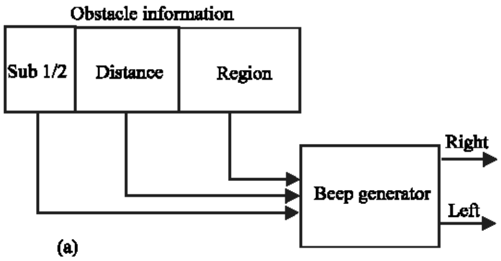

Fig. 3a: Principle of beep generation

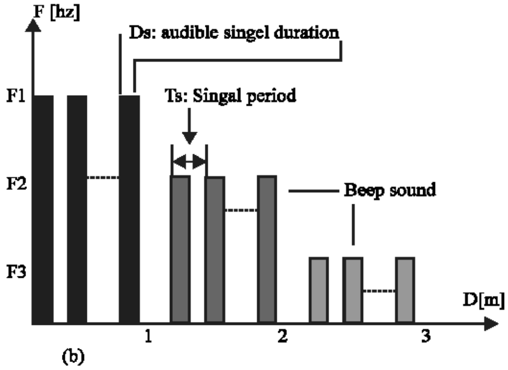

Fig. 3b: Acoustic sweep for environment recognize

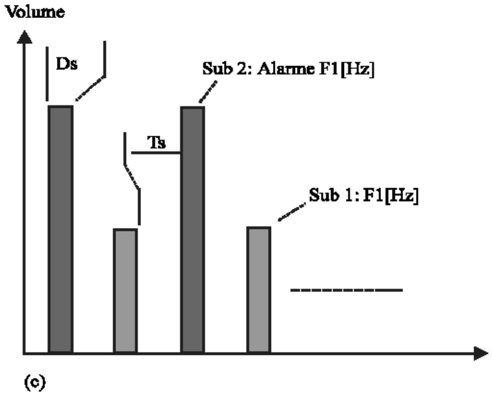

Fig. 3c: Activity of two subsystems

This arrangement of the sensors avoids all interference between the emitted signals, because the emitter of Sub1 radiates in horizontal plan whereas the one of Sub2 emitted a narrow beam ultrasonic energy towards the floor. The two emitters are fired simultaneously.

Sound generation: In our system each item of spatial information of obstacle detected by the environmental sensing and floor sensing are transformed into sound features as shown by Fig. 3b and Fig. 3c:

The blind recognizes the direction of the obstacle through the activated corresponding channel:

Obstacle on the left	beep sound on left ear
Obstacle on the right	beep sound on right ear
Obstacle to the center	beep sound on left and right ear

The exploration of the environment by the two subsystems Sub1 and Sub2 takes place with a period of 30ms and when an obstacle is detected its localization is validated after 10 measures. Information on the obstacle is therefore available 300 ms after its detection. This information on the obstacle is a variable containing the descriptors of the object (Fig. 3a). The descriptors are updated every 300ms by software once the detection of obstacle is validate. This variable is read by our generator (Timer + program) that converts it into an audible signal of period T_S (Fig. 3b). The user can adjust the period T_S by a sliding switch between two boundary values: This is a simple control button, easy to use by the blind. As much as the descriptors didn't change the generator continues to produce the same audible signal with the period T_S, if the descriptors change, then the audible sound will also vary accordingly.

When the object is detected between two meters and three meters, an audible sound of F3 frequency is generated. If the object continues to move around and arrive between one meter and two meters, we generate an audible sound of F2 frequency and when it is unless one meter from the user, an audible F1 frequency is generated (Fig. 3b). In this manner we inform the blind on the moving obstacle while avoiding the intolerable continuous sounds for the hearing human. The detection of a hole and small obstacle protruding into the user's path constitutes an extreme danger for the blind, which can cause him/her a serious accident. To warn it of this danger we generate an audible sound of F1 frequency on the two ears, with the period T_S and a high intensity (Fig. 3c). The Fig. 3c represents the case where Sub1 localized an obstacle at unless one meter from the user, whereas Sub2 detected an obstacle at ground level. The user receives beep sound of F1 frequency, but the intensity of this beep is alternated between 2 levels. In the absence of obstacles we have programmed the device to be silent (no audible sounds generated) for this prototype. In the future development, we can add an acoustic signal depending on the requirement of the user.

DATA TREATMENT

Environment recognize: The pair of sensor of 40 Khz (S1 and S2) serves to localize the nearest obstacle by its distance and position. We are interested in the obstacles at a maximum range of 3 m from the user. The blind is informed on the objects in the path of the movement and those at both side of him (Fig. 4a).

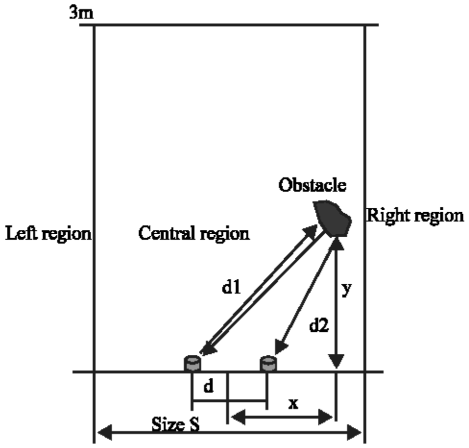

Fig. 4a: Principle of 2-D echolocation

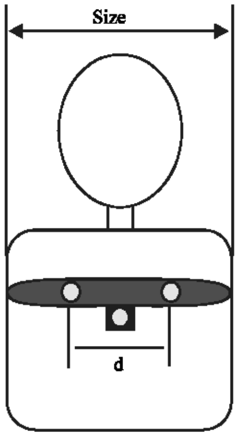

Fig. 4b: Size representation

The emitter transmitted a 1ms ultrasound burst. The two receiving channels capture the received signals that they sample and stock in memory. Then the processor determines the instant of arrival of the echoes in the received signals, by an autocorrelation function (ACF) between the reference signal and the received signal. The distances d1 and d2 are calculated by the time of flight technique as follows:

$$di = C.TFi/2 \quad (1)$$

with $C = 344$ m/s , TFi = time of flight , i : i^{th} sensor

The reference signal is an echo previously recorded in memory of the system. It is a signal reflected by a wall in the range of 1m from the emitter, it possesses the physical characteristics of the channel: air + sensor + electronic circuits. The coordinates (x,y) of the object are calculated by the equations:

$$d_2^2 = y^2 + (x - d/2)^2 \quad (2.1)$$

$$d_1^2 = y^2 + (x + d/2)^2 \quad (2.2)$$

$$x = \frac{d_1^2 - d_2^2}{2.d} \quad (2.3)$$

$$y = \left(\frac{d_1^2 + d_2^2}{2} - \frac{d^2}{4} - x^2\right)^{1/2} \quad (2.4)$$

and its direction is determined by the algorithm:

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if  x = S/2
    then  central region
     else if  x > S/2 and x > 0  then right region
    else  x > S/2  and  x < 0 then  left region
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The S parameter (Size) corresponds to the distance between the two extremities of the user's shoulders (Fig. 4b), the average value of S is about 50cm. To minimize measure errors, the algorithm starts after the realization of 10 measures and software filtering. Each measure is achieved every 30 ms, corresponding to the scan interval in which emitted energy reaches a two-way distance of three meters (including processing time).

Case of separate obstacles: With only one emitter and two receivers, two parallel and separate obstacles by a distance of L meters (trees, people, etc.) are not observed by the sensors S1 and S2 as a continuous wall (Fig. 4c). We notice that S1 receives an echo before S2, the obstacle A is detected before obstacle A', the blind changes direction and move towards A', this will be detected and the blind negotiate another trajectory as indicated on the Fig. 4d.

External source: External source which sends an ultrasonic signal could interfere with our system by receiving this external ultrasonic frequency, notably when two persons carrying the same system meet on their paths, as indicated on the Fig. 5a:

The blind A is able to receive the burst B before the receipt of the echo A (Fig. 5b). By an ACF we detect the burst B that will be considered as an echo whereas it is an undesirable signal. To reject this type of signals we have developed an algorithm that detects the envelopes of the received signals and then analyze their profiles (Fig. 5b). This analysis consists in testing the level of the signal if it remains constant (with a certain precision) during 1ms (corresponding to burst length). So the burst B is rejected from the observation vector. Then we execute an ACF

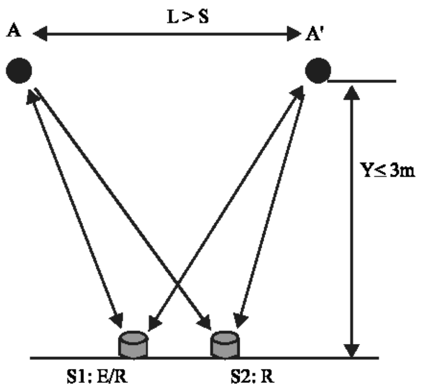

Fig. 4c: Parallel object discrimination objects

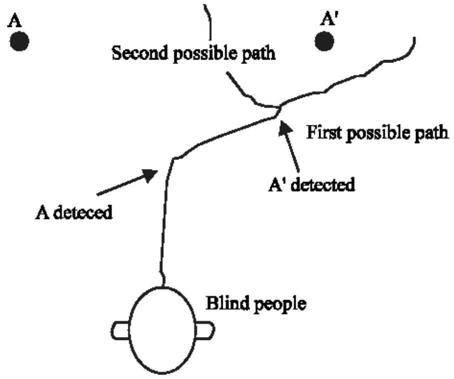

Fig. 4d: Negotiation path in presence of parallel

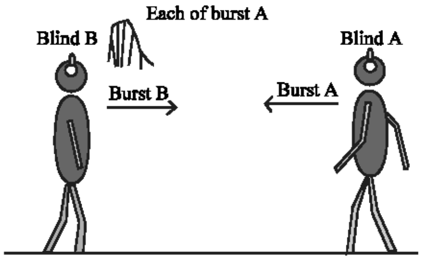

Fig. 5a: Interference of external source

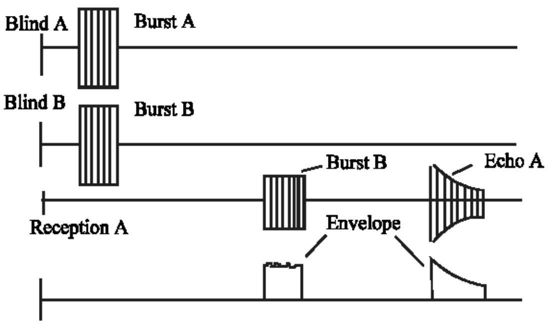

Fig. 5b: Rejection of external source

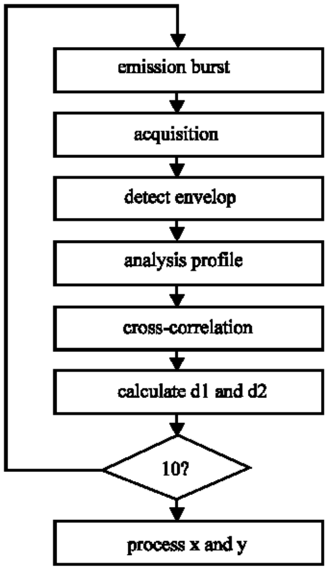

Fig. 6: Process algorithm

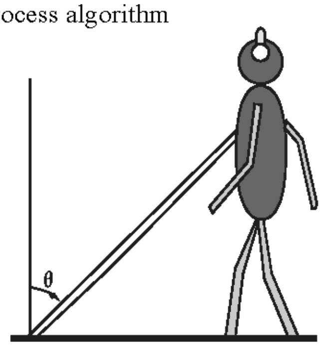

Fig. 7 a: Time of flight TF_0

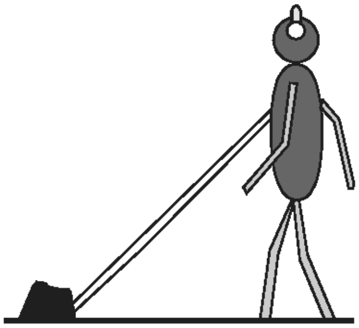

Fig. 7b: Time of flight $TF_1 < TF_0$

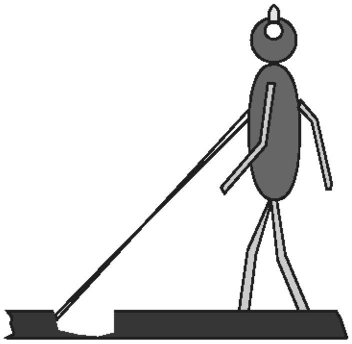

Fig. 7c: Time of flight $TF_2 > TF_0$

with this vector to determine the arrival instant of the real echo (echo A). If we receive a mixture of two signals (echo A + burst B) we accept such a signal because it contains interesting information. In a general manner our algorithm detects all based ultrasonic device, since the mobility aid systems for the blinds based on the ultrasonic detection emit constant amplitude burst, sometimes they are linearly frequency-modulated[5]. We present the general algorithm of treatment on Fig. 6.

The third sensor points towards ground in order to detect holes and other small obstacles. Given the incidence angle of the sensor beam (Fig. 7a), the reflected energy could be small and the obstacle undetectable. However the ground surface of the outside environment is rough and the ultrasonic wavelength is equal to:

$$\lambda = C/F = 344/75000 = 4.53 \text{ mm} \qquad (3)$$

Such a wavelength is perfectly reflected by ground and the beam presents in general a small angle of incidence with the obstacle at floor level (Fig. 7b and 7c). This sensor possesses a narrow beam (7°) and radiates an ultrasonic signal with a short wavelength, which leads to a better detection of small objects. The Sub2 system is adjusted to alert the user when it is at one meter from the obstacle. The choice of such a distance possesses two advantages: the first is to allow the blind to plan a better trajectory around the obstacle considering the short distance that separates them. This is not a time-consuming and doesn't need much conscious effort given the small obstacles at floor level. The second advantage is the obtaining of a small incidence angle of the beam, so a great quantity of the ultrasound energy is reflected towards the system (Fig. 7a). We suppose that the sensor attached at a height of 130cm from floor (corresponding height of an individual's middle size) the angle of incidence θ is 38° approximately. With a distance of 164cm separating the sensor from the point of impact of the beam and a high amplification gain, we could detect energy sufficiently to treat the echoes. To decide on the presence of obstacles we compare the time of flight of the emitted signal with the reference time TF_0. This time of reference correspond to an absence of obstacle at ground level. It is clear that in presence of obstacle see (Fig. 7b) and (Fig. 7c), the time of flight will be respectively TF_1 and

TF_2 which are different from TF_0. We triggers the alarm to inform the blind of the danger when the obstacle is 5cm above ground level ($TF_1 < TF_0$), or that the hole is 5cm deep ($TF_2 > TF_0$). This threshold can be modified by software.

Implementation with ADSP-21992: The core of the proposed system is an ADSP-21992 whose capacities are largely sufficient to our application[11]. But the aid to the blind must improve to ensure him a large autonomy. This implies the addition of new functions. The capacities of the chosen DSP can take in charge of new functionalities. It possesses a signal converter from analog-to- digital with 14 bits (ADC), functioning until 20 Mhz with 8 inputs channels and an integrated memory for the programs and data, respectively of 32Kx24 bits and 16Kx16 bits. External bus address 20 bits size permit to address until 1 M-Words supplementary. A module of DMA facilitates the transfer of program or data between external and internal memory and also between other internal modules (ADC, SPIports, etc) and external components. Three timers assure the generation of signals of different wave form, or event counting, as well as sixteen general-purpose I/O signals. We choose this circuit because it offers the huge computation power of the DSP and the integration of several peripheral functions; hence we can produce small system. As indicated on Fig. 8, the transmission and the receipt of the signals are coordinated by the DSP. As the sensor of 40 Khz chosen accepts a maximal signal of 40 V_{PP}, we apply a signal squared of 30 V_{PP} to the two emitters (40 Khz and 75 Khz). The two emitters are fired simultaneously with an ultrasonic burst of length 1ms. The echoes received are amplified and filtered before sampling. The processor achieves signal acquisition on the three channels during 18 ms, corresponding to the two-way traveling time of the signal between the source and a distant obstacle at three meters. For the channel of 75 Khz, this time is less than 18ms, but to simplify the program, we achieve acquisition on the three channels by only one routine. With a sampling rate of 200 Khz ($T_E = 5\mu s$), the size of the buffer for every channel is of:

$$L = TF / T_E = 18000\ \mu s / 5\ \mu s = 3600 \text{ pts} \qquad (4)$$

After sampling, the processor calculate the function of autocorrelation and estimates the instant (TF) of arrival of the echo for every channel. For the channel of 75 Khz this measure is repeated 10 times and we keep the average of this 10 measures. For the two other channels, knowing TF, we calculate the distance to the obstacle, then we repeat the same measure 10 times, it is the average of these measures that is kept for the estimation of the direction.

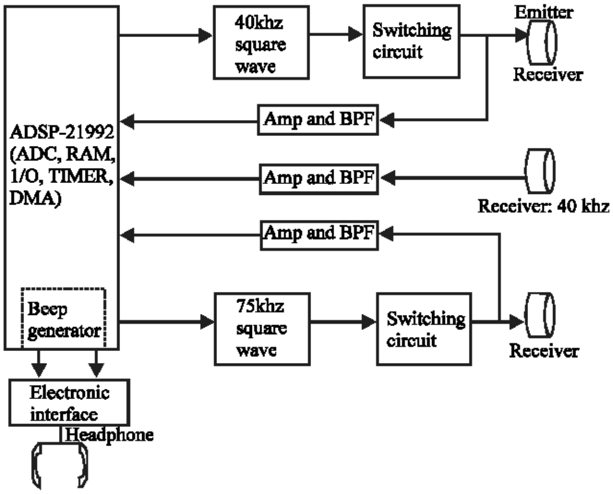

Fig. 8: Block diagram of the ETA system

RESULTS

Test methodology: To evaluate the system we developed a method of test. A group of 5 young blind people participated in the experimentation. They followed a training phase of 20 h. The tests take place along a corridor of a length of 50 m. To achieve the test the subject wears the experimental prototype and executes a one-way walk through the corridor. In the middle of corridor is a pillar made of concrete and other sighted people move around in opposite sense: among these people only one wear a simple ultrasonic emitter of 40 Khz, we try to observe the influence of an external source on our system. The blind subjects preferred to keep their cane; they should not use their cane during the tests. They have not been informed of the presence of the other people moving in opposite sense, nor of the pillar, nor of the opening door (large of 2 m) at the end of corridor and that must across. The indoor simulation is conceived to reproduce real conditions for the application.

DISCUSSION

These results have been obtained by passing the same tests on five subjects. The graph of the Fig. 9 shows four sets of test. The first column represents the time of attempt of each user without the port of the help system

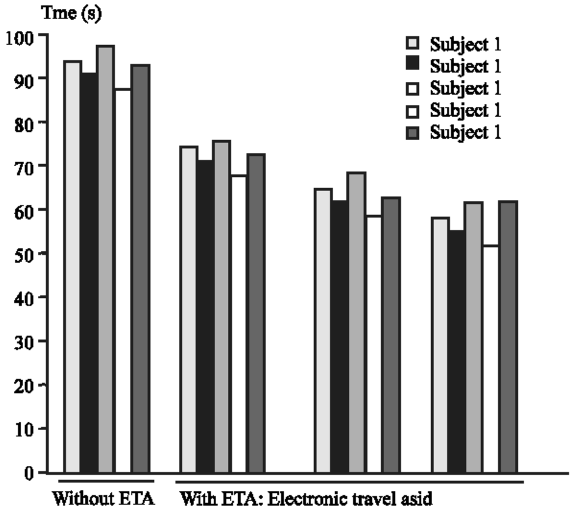

Fig. 9: Validation test results

(ETA). The three other columns show their performances when they use the system of help. We notice two observations on these results. The first remark is the difference of the times of attempts between the first set (without ETA) and the other sets (with ETA): The subject has a confidence in the system since it accelerated his walk. The second observation concerns the progressive reduction of the times of tests with an ETA: It is the effect of the training. The fifth subject has been slowed down during the fourth test by collision with a sighted people whereas he searched to get round the pillar. The four other subjects avoided people in the corridor; the system perfectly determined their position. For the fastest subject, the velocity passed approximately from 0.5 m/s (without ETA) to 0.9 m/s (with ETA). Our main objective is not to accelerate the blind's walk but to ensure him a safely travel, without collision. Our system is capable to detect dynamic obstacles, because we have observed that the subjects get ready to avoid the person coming in the face, as taking the left side or the right side: it also shows that the external ultrasonic source didn't interfere with our system. They have all crossed the door without difficulty. As approaching the door, the subjects follow a trajectory towards a one side of the door and then they move towards the opposite side and pass through the door. This demonstrates the efficiency of the system to help the blind to weave one's way through two separate obstacles. Our system is conceived for an external use, it can help the blind to pass through the door at the entry of a building. For the narrow doors it would be necessary to add other sensors. We also noticed that the arms of the subject don't occlude the sensors when he moves around, considering the aequate placement of the sensors.

CONCLUSION

In this study, we described electronic travel aid for blind using ultrasonic sensors and auditory information. The method that we developed proved its efficiency by a better localization of the objects. The blind receives quantified information on the objects, he perceives the environment better. Our system integrates two functions. One subsystem equipped with wide beam sensors collects some information on the environment that they transform into audio stimuli. The second subsystem equipped with a narrow beam sensor protects the blind from obstacles at floor level. The presence of external ultrasonic source does not interfere with our proposed device. We will wish to improve our system by two functions: an electronic compass and odometer system to allow user to know his/her position. The method of the GPS (Global System Positioning) is not conceivable by our research, because this technology is expensive for the community of the blinds.

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