ROVI: A Robot for Visually Impaired for Collision- Free Navigation

A. Allan Melvin, B. Prabu, R. Nagarajan, Bukhari Illias
School of Mechatronic Engineering
Universiti Malaysia Perlis, 02600 Jejawi, Arau, Perlis, MALAYSIA
Email: allanmelvin.andrew@gmail.com

***Abstract* - ROVI is a device used to guide visually impaired people to dwell around. The conventional method is the white cane which will be used to sense the surface and of the obstacle around the blind. In this project, the white cane is attached to a mobile platform which will have an array of sensors used to detect obstacles.. The mobile robot will be given a predefined target to move. The sensors will always look for any obstacles along the path. It will avoid by an angle once the obstacle is detected. The deflection from original path due to presence of obstacle will be controlled by microcontroller. It will also provide instruction to the wheels to return to the original path once the obstacle has been avoided. The feedback signals from the optical encoders attached to the wheels are important to determine the distance travelled by the wheels. This paper will also discuss about the software for the obstacle avoidance and for reaching target.**

***Keywords* - Blind, mobile robot, navigation, mobile structure, obstacle avoidance**

I. INTRODUCTION

The main objective of this research is that of designing, constructing, implementing and testing a mobile robot to guide a blind individual to go from one place to another autonomously collision free. This robot is referred in this paper as Robot for Visually Impaired (ROVI). There are five main aspects of ROVI considered in this paper.

- To construct a mobile platform with suitable servoing facilities.
- To incorporate a set of ultrasonic sensors (sensor bank) to identify the location of any obstacle.
- To incorporate a microcontroller to control the mobile platform and to navigate the robot to move in collision-free directions towards the planned target location.
- To test exhaustively, indoor and outdoor, and to evaluate the performance of robot in guiding blind persons.

II. LITERATURE REVIEW

There are several methods and devices used to guide visually impaired persons. Several research works are being performed by many institutions throughout the world to offer the best navigational robot in terms of cost effectiveness. This section gives a brief review on various navigational aids for blind individuals [14].

A. Guide Dog

Dogs are very capable guides for the blind, but they require extensive training. Fully trained guide dogs cost between RM20000 and RM50000 per year for training, breed and support; they are only useful for about five years [5]. Furthermore, many blind and visually impaired people are elders and find it difficult to care appropriately another living being. As a result, only less than 1% of the estimated two hundred thousand visually impaired people in Malaysia have guide dogs.

B. Kaspa [1]

It is a more complex sonic system for the Blind. Based on technology developed in the early 1960s by Leslie Kay, the KASPA consists of a sweep FM ultrasound emitter and three laterally displaced sensors. The signal received from the echo is beat against the outgoing signal to produce audible sounds. The frequency of the sound is inversely proportional to the range and the timbre carries information about reflection properties of the object. The user must learn to interpret the sounds, a process that can take several weeks of training.

C. NavBelt [2]

The Navbelt consists of a belt, a portable computer, and an array of ultrasonic sensors mounted on the front of the belt [3]. The user wears a “fanny pack” on the abdomen and a portable computer as a backpack [4]. Eight ultrasonic sensors, each covering a sector of 15°, are mounted on the front pack, providing a total scan of 120°. The computer processes the signals that arrive from the sensors, and applies in the robotics obstacle avoidance algorithms [5].

D. Mobile Robots as Guides for the Blind [6]

One of the devices provides navigation through a mobile robot is the GuideCane developed by students from University of Michigan [7]. It is a computerized cane which can steer blinds around obstacles. The sonar-equipped, wheeled GuideCane resembles an upright vacuum cleaner. A semi-circular array of sonar sensors at the bottom projects a beam in front of the GuideCane to detect objects [9]. The computer which is located inside the cane reads the information and constructs a rudimentary map of the environment, then computes a path to guide the cane around obstacles [15]. To prevent the sonar beams from interfering with each other, the sensors, which take 10 readings per second are fired using a technique known as error-eliminating rapid ultrasonic firing [8]. Since the GuideCane is a prototype and is still under research, there is no commercial unit available in the market.

III. METHODOLOGY

The robot platform is formed as metalic, mainly aluminium, because it can stand greater payload than plastic and has a better strength-to-weight ratio than wood. If plastic were used, the platform would be too light and the vehicle might not move properly on the rough surface as the robot is designed also for outdoor activity. The overall dimensions of the platform are chosen as 37cm x 24cm x 2.5cm. These dimensions were sufficient to hold all of the electrical and electronic parts for the required task.

The design of hardware consists of several efforts such as a ground platform, motor selection, microcontroller, nine ultrasonic sensors and encoders. The microcontroller that is used is the BASIC Stamp 2p (BS2p). BS2p developed by Parallax which is easily programmed using BASIC Stamp Editor. Although the BASIC Stamp has the form of a DIP chip, it is in fact a small Printed Circuit Board that contains the essential elements of a microprocessor system such as a CPU, and a built in ROM [10].

Ultrasonic sensors work on a principle similar to radar or sonar which evaluates attributes of a target by interpreting the echoes from radio or sound waves. Ultrasonic sensors generate high frequency sound waves and evaluate the echo which is received back by the sensor. Sensors calculate the time interval between sending the signal and receiving the echo to determine the distance to an object. This portion is to describe the type number, why selected, the range of distance, sensor bank, the scan range and the scan frequency [11].

Encoder is an essential unit for determining the distance moved by the platform. The encoder developed for this system is based on infrared light reflection [12].

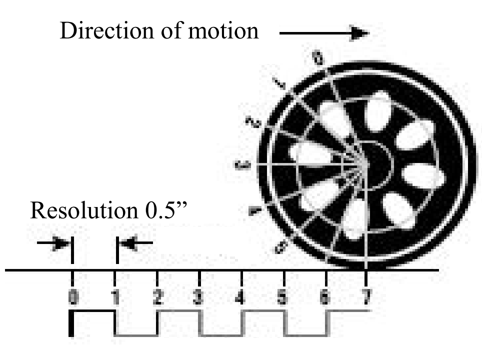

Fig. 1. Operational method of the digital encoder

The encoders are calibrated for optimal sensing of surfaces a few millimeters away. The robot’s wheels, even though they are black, reflect sufficient IR to cause the sensors to respond. When a sensor "sees" part of a wheel, it pulls its output low. When it's looking through a hole, its output floats, and the pull up resistor pulls it high. Since the sensors emit and detect only modulated IR (at about 7.8 KHz), they are relatively insensitive to ambient light.

As the robot wheel turns, the sensor will see an alternating pattern of hole - no hole combination as shown in the illustration Fig. 1.

The drive unit (gearbox, motor and wheels) are selected, so that it supplies a rated torque of 196 mNm. This torque is sufficient for the robot motion even outdoor. Movement is slow, so the ultrasonic sensors could detect its path and allow for adjustments. The motor driver uses 5 lines of digital input and output to control the wheels' movement.

The DC Geared motor (Type number: MO-SPG-50-20K) and its driver (Type number: MD10A) selected are from Cytron Technologies, both driven by DC12V. It gives an output of 3.4W with a maximum current of 1.1 A. It has a rated speed of 170 rpm with a torque of 196 mNm. These ratings are sufficient for the purpose of guiding the blind and to carry the weight of sensors and circuits. In addition, the motor driver can be configured by a microcontroller for a PWM speed control [13].

The robot has two driving actuators and a microcontroller board. The driving actuators need DC12V to drive the motor while the microcontroller board needs DC6V. Rechargeable batteries are used to power the entire system. Two DC6V batteries were connected in series to supply the actuators. Another DC6V battery is used for the microcontroller board.

An algorithm is needed to avoid any obstacles on the path and to drive the system always towards the target location.

A. Robot Moving towards Target

Before the ROVI moves toward the target, the incremental encoders attached to the ROVI’s wheels need to be calibrated [9]. The calibration is done by tuning the wheels to same values of tick. A ‘tick’ is an elemental rotational distance between a hole and no hole in the encoder detection. The blind man should lift the ROVI up, so that the two motors not touching the ground. Once the ROVI is lifted, the reset button on the microcontroller is pressed repeatedly until the wheels are calibrated. The blind man can hear the ‘tick’. Calibration means the occurrence of ‘ticks’ simultaneously in both motors. The left encoder will calibrate first by transmitting the infrared signal. If the receiver could not get the value 1 for a hole, the motor will turn until the value 1 is obtained. Once the left encoder detects 1, the right encoder will transmit the infrared signal.

The same process will be repeated until the wheels are calibrated. After both wheels are calibrated, the ROVI will move towards the target once the switch at the handle is pressed. Nine ultrasonic sensors are used in this work. The ultrasonic sensors are divided into three sets. Fig. 2 shows the ultrasonic sensor bank of ROVI.

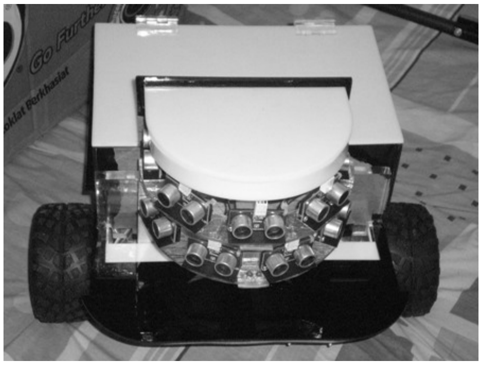

Fig. 2. ROVI: Sensor bank

They are placed in a semi-circle pattern, starting with sensor 1 in the right of the robot to the sensor 9 in the left of the robot. Sensor 2 until sensor 4 are categorised as the right set, sensor 4 until sensor 6 are categorised as the front set and sensor 6 until sensor 8 is categorised as the left set. Sensors 1 and 9 will be used for U- turning since the three sets are enough to cover 180°. The source codes are programmed in such way that when the ROVI turns one step forward, the three sensors will scan environment in the radius of 0.7 meter at 45° in front and increase the encoder ticks for both wheels if there is any transition of state from 0 to 1. When the respective representation of the encoder ticks is achieved, which means the target location is reached, the ROVI stops and does not pull the blind, neither the blind can push the ROVI. Fig. 3 indicates the ROVI with the white cane.

B. Target Registration using X-Y Grid

The ROVI should be adaptable to move to any point in an area. The robot is programmed to move within the area by giving the input of the respective coordinates. The area should be known earlier and all the important target location which the blind person wishes to go to must be defined.

The target coordinate is then inserted to the system and the microcontroller will calculate the orientation and the distance of target. The robot uses the triangulation theorem as shown in Fig. 4 to calculate the distance using (1) and (2). The hypotenuse of the triangle, D, will become the target distance

$$\text{Hypotenuse, } D = \sqrt{(X_T - X_0)^2 + (Y_T - Y_0)^2} \qquad (1)$$

$$\text{Turning angle, } \theta = \tan^{-1}\left((X_T - X_0)/(Y_T - Y_0)\right) \qquad (2)$$

where (X_0, Y_0) is the initial position and (X_T, Y_T) is the target location.

C. Obstacle Detection and Avoidance

The ROVI will move towards the target and reach it if there are no obstacles detected along the path. If one or more obstacles are present in the path, a set of actions will be carried by the ROVI. Here is the part where the knowledge is given to the ROVI using few sets of Fuzzy Logic Controller schemes.

Fig. 3. The ROVI

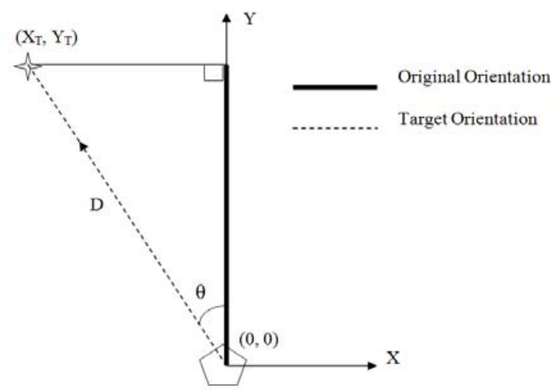

Fig. 4. Calculation to the Target using X- Y Grid

There are two stages involved when an obstacle is detected along the path. The first stage is the obstacle detection and the second stage is the obstacle avoidance. For the first stage, few fuzzy rules have been used to define the conditions. With the detection distance of 70cm, if there is any obstacle within the distance, for example at 60cm in front of the robot, the left set of sensors will sense to check if there is any obstacle at the left side of the ROVI. If the second set also detects obstacle at the left of the ROVI, the right set of sensors will sense to check if there is any obstacle at the right of the ROVI. If all the set of sensors detect obstacles and none of the first three conditions can be applied, the ROVI will choose the U-turn. For the second stage, the obstacle avoidance, the microcontroller will give the instruction to the DC geared motors to turn and avoid according to the chosen fuzzy rules.

If all set of sensors detects obstacles, the ROVI will turn at 100° to the right and recalculate to the angle to the target. Fig. 5 and Fig. 6 show the obstacle avoidance mechanism on 45° left and 100° right respectively.

D. Reaching Target

The ROVI must be programmed to reach the target in both conditions whether there is any obstacle on the path or not.

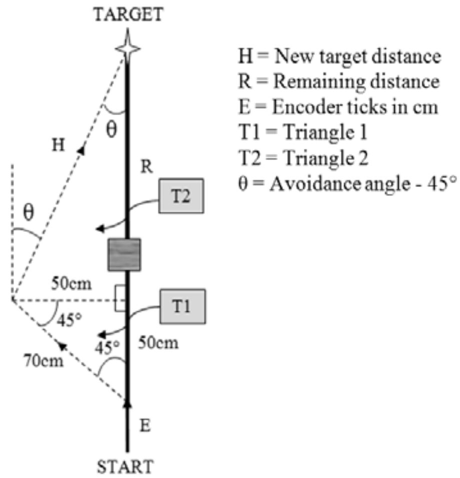

Fig. 5. Obstacle Avoidance Mechanism on 45° left

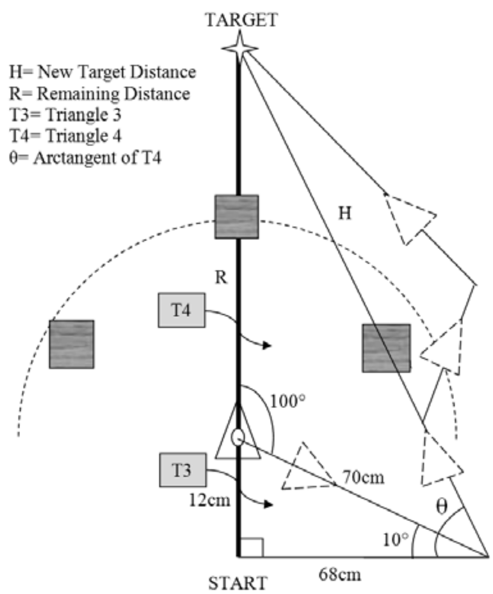

Fig. 6. Obstacle Avoidance Mechanism on 100° right (u-turn)

If there is no obstacle along the path, the ROVI will continually check the environment until it reaches the target. The feedback from the wheel encoders are needed to determine how far the ROVI has travelled. If there is any transition from 0 to 1 of the binary detection values of encoders, the values of encoder ticks will be incremented. The value of ticks will be converted to the distance travelled and will be subtracted from the target distance.

IV. EXPERIMENTAL RESULT AND DISCUSSIONS

A. *Motor Speed Control*

In blind people navigation, speed of the movement is important. The blind man travels at slow speed, approximately 0.1 to 0.2 m/s. Proper measures need to be taken to reduce the speed of the ROVI from original speed of 0.889 m/s to approximately 0.2 m/s to be suited for this application of blind people navigation. The measure taken to control the speed of the motors is discussed in this section. Pulse-width modulation (PWM) of a signal or power source involves the modulation of its duty cycle, to either convey information over a communications channel or control the amount of power sent to a load. PWM is used in efficient voltage regulation. By switching voltage to the load with the appropriate duty cycle, the output will approximate a voltage at the desired level. In this project, the input voltage of 12V is given to the motor driver. Motor driver uses 5 pins, namely, +12V pin, CW pin, CCW pin, PWM pin and GND pin. All the pins must be connected to run a motor. The ROVI requires direct power supply of 12V from the battery, CW and CCW require binary input through programming to control the direction of the motor, the PWM pin is to control the voltage distribution to the motor and the GND pin is connected to the ground. Two motor driver cards are used in this project to control both motors separately. For the application, a relatively low motor speed with sufficiently high torque is needed. The low motor speed is required to slowly bring the blind man around while the high torque is required to overcome the road- roughness and pulls the blind man. Using the PWM signal, the motor speed and the motor torque can be controlled. Using Basic Stamp 2 microcontroller, the PWM signal can be supplied and controlled using the program coding. The motor speed was reduced from its initial speed of 0.889 m/s to the desired speed of approximately 0.2 m/s. The torque of the motor also can be controlled. Based on the experiment conducted, the motor requires at least 1V to start to rotate.

B. *Vehicle Direction Control*

Motor driver is used to control the direction of the motor rotation. Theoretically, the rotation direction of the motor can be changed by inversing the polarity of the motor. But, it is not possible in real-time applications. Thus, motor driver is used to control the switching of the input power to the motor. Two relays are used to control the switching. In this research, the input of direction is controlled by the binary value inserted in the programming. It has to consider the physical direction of motor. The DC geared motors are placed in opposite to each other. So, to move forward, the left motor should turn clockwise while the right motor has to turn counter clockwise. Although the two DC motors used ideally have to be same in its rotation speed, they are not the same. The problem may be caused by some manufacturing errors such as improper gear reduction. The effect of this problem only can be seen when the ROVI moves on the floor. Although the ROVI is programmed to move forward, it is not possible since the left wheel is rotating faster than the right wheel.

Thus, the ROVI deviates to certain angle in respect to the time. To overcome the problem, two methods are tried. The first method is by giving the entire signal as a synchronised output. Sending the output synchronically can reduce the processing time. The output of all the signals are collected first and released simultaneously. Thus, the deflection of the ROVI can be reduced although not fully. To reduce the error further, a programming delay is purposely introduced to the faster motor. The delay is to let the slower motor turn faster few micro step before the two motors are given signal to move one step. The method is found to reduce the error almost entirely.

C. Ultrasonic sensor testing

The ultrasonic sensors are tested to detect the obstacles at certain range. The ultrasonic sensors are programmed one-by-one starting with ultrasonic sensor 1. The sensor is programmed to fire 5 ultrasonic signals and to receive the signal as the distance data. The data is measured in ultrasonic raw data value. The ultrasonic raw data need to be converted into centimetres. An experiment was conducted to find out the scaling factor to convert the raw data into centimetres. An obstacle is placed with a measured distance far from the ultrasonic sensor. In this case, an object is placed at 20cm from sensor. The ROVI's motors are energised using DC power supply. A program coding is written to get the scaling factor. Various parameters are tested. The scaling factor is adjusted until the distance equals to 20cm. The correct scaling factor is obtained as 850.

D. Digital encoder testing

Digital encoders are used to convert the encoder values to the distance travelled by the ROVI. The encoder detects the holes and no- holes on the encoder plate. The encoder plates are attached to the wheels rotating at the speed of the wheels. Binary values of 0 and 1 are used to define the holes and no-holes respectively. 0 defines surface and 1 defines hole. Whenever there is a transition from 1 to 0, the encoder tick is increased by 1. The digital pulses of the transition are measured using the oscilloscope. The encoder plate is rotated at different speeds and the pattern of the digital pulses is observed at the oscilloscope. Based on the oscilloscope images, it is concluded that the encoder is working perfectly when no disturbance is encountered by the encoder.

E. Obstacle avoidance testing

The ROVI was tested to move on the floor. Although the ROVI moves better when tested on the table with both its wheels are lifted, it has to be calibrated, so that it can move on the floor as desired. Few experiments are conducted to calibrate the ROVI. It includes the determining of angles, the finding of travelled distance and determining the scaling factor for the obstacle avoidance calculation. The program is adjusted based on trial-and–error basis. To find the value of how much a degree can be represented on the programming, the random value was given to the programming and it is adjusted until the desired output is obtained. The similar testing was conducted to find the scaling factor needed to convert the number of wheel turning to the travelled distance. The actual distance was calculated and the distance is shown using the masking tape on the floor. The avoidance path was calculated using protractor and taped on the floor. Starting point and the target point is marked with 'X' symbols. A random scaling factor was given in the program for the target distance. The value was adjusted by trial- and- error. Once the ROVI is managed to reach the target, the second experiment is conducted to find the scaling factor for the turning angles. An obstacle was placed 70cm from the turning place, so that the ROVI will turn and move along the masking tape. The ROVI was placed at starting point and the switch was on. The ROVI moves along the path and turns and stops once the obstacle is detected. The angle is adjusted to get the desired angle. The experiments were conducted for other calculations in the similar way.

F. Outdoor testing

The application for the ROVI is to guide a blind man at the outdoor environment. The ROVI is tested outdoor at two different surfaces. The first environment is on the tar road outside the lab. Tar road has an uneven surface. The ROVI's wheels need to have sufficient torque to overcome the friction caused by the tar road. Although the ROVI can move on the tar, it is subjected to wheel slippage and deviates from its original orientation. The digital encoder used in this research is based on infrared light and it is a retro- reflective type. When the encoder is subjected to the environmental noise, the encoder reading shows some error. Furthermore, the ultrasonic sensors detect the heat from the tar as an obstacle, thus, affecting the smooth navigation. For the second environment, the ROVI was tried on the cement floor on the laboratory corridor. On a smooth cement floor, the ROVI can move with lesser error. The error is caused by wheel slippage which is caused by high torque on the wheels. Due to the wheel slippage, the ROVI could only manage to move for a distance less than the desired distance.

V. CONCLUSION

This research comprises the methods and experimental results in development of software for obstacle avoidance to the mobile platform for blind people navigation. The main task of the ROVI will be to guide the blind person who holds the stick attached to robot to a target location along a street without colliding on any obstacles. The robot has three wheels with onboard sensor bank, encoders and batteries. The sensor bank has 9 ultrasonic sensors. The motors are driven by a microcontroller. A Basic Stamp 2p microcontroller is utilised for programming the ROVI. Fuzzy Logic Controller scheme is utilized for controlling the motor. The motors are connected to motor drivers. The motor drivers are capable of controlling the direction of motor rotation. PWM is used to control the speed of the motor rotation. Accuracy of reaching the target is found to be approximately 0.5 meter around the target point and locating the obstacle is within 45°. The ROVI can avoid the obstacle along the path and is able to recalculate and realign its orientation to reach its target.

Many exhaustive tests have been carried out to minimise the errors during implementing the ROVI in real-time application. It is envisaged that the ROVI can create a commercial product very useful to the unfortunate blind people for their collision- free navigation. The GPS calibration, the hole in the road identification and the navigation through indoor mapping are some of the aspects being considered for upgrading the ROVI facilities.

ACKNOWLEDGMENT

This work is financially assisted by the Fundamental Research Grant Scheme (FRGS) grant: 9003-00115 by Ministry of Higher Education, Malaysia.

REFERENCES

[1] Peter B.L. Meijer, "Sensory Substitution- Vision Substitution", URL: *http://www.seeingwi-thsound.com/sensub.htm*, 1996

[2] Borenstein, J, "The *NavBelt* - A Computerized Multi-Sensor Travel Aid for Active Guidance of the Blind," *Proceeding of the Fifth Annual CSUN Conference on Technology and Persons With Disabilities*, pp.107-116. Los Angeles, California.: Annual CSUN Conference on Technology and Persons With Disabilities, Inc., 1990.

[3] Shoval, S., Borenstein, J. and Koren, Y.. "The *Navbelt* - A Computerized Travel Aid for the Blind," *Proceedings of the RESNA '93 conference*., 1993

[4] Shoval, S., Borenstein, J., and Koren, Y, "Auditory Guidance With the NavBelt - A Computerized Travel Aid for the Blind," *IEEE Transactions on Systems, Man, and Cybernetics*, pp.459 – 467, 1998

[5] Shoval, S., Borenstein, J., and Koren, Y. "The NavBelt - A Computerized Travel Aid For The Blind Based On Mobile Robotics Technology," *IEEE Transactions on Biomedical Engineering*. vol.45(11), pp.1376-1386, 1998.

[6] Iwan Ulrich. and Borenstein J, "The GuideCane- Applying Mobile Robot Technologies to Assist the Visually Impaired," *IEEE Transactions on Systems, Man, and Cybernetics.* URL: *http://www.personal.umich.edu/~johannb/Papers/paper72.pdf,* 2001

[7] Borenstein, J. and Ulrich, I, "The GuideCane - A Computerized Travel Aid for the Active Guidance of Blind Pedestrians," *IEEE Int. Conf. Robotics Automation*, pp. 1283-1288, 1997

[8] Borenstein, J. and Koren, Y, "Error Eliminating Rapid Ultrasonic Firing for Mobile Robot Obstacle Avoidance", *IEEE Transactions on Robotics and Automation*, vol. 11(1), pp. 132-138, 1994

[9] Geppert, L. "Seeing- eye cane steers the blind". *IEEE Spectrum* , vol. 34, Issue 10, pp. 17- 17, 1997

[10] Parallax Inc., "Basic Stamp 2p 40-Pin Module", URL: *http://www.parallax.com/Store/Microcontrollers/BASICStampModules/tabid/134/CategoryID/9/List/0/SortField/0/Level/a/ProductID/8/Default.aspx,* 2008

[11] Parallax Inc., "PING))) Ultrasonic Distance Sensor (#28015,". URL: *http://www.parallax.com/Portals/0/Downloads/docs/prod/acc/28015-PING-v1.5.pdf*, 2008

[12] Parallax Inc., "Boe- Bot Digital Encoder Kit", URL: *http://www.parallax.com/Portals/0/Downloads/docs/prod/robo/DigitalEncoderDoc.pdf,* 2008

[13] Cytron Tech., "Controlling DC Brush Motor using MD10A or MD30A," URL: *http://www.cytron.com.my/attachment/Details%20Description/PR10_DD.pdf*, 2009

[14] F. van der Heijden, P. R, "Wearable Navigation assistance - a tool for the Blind", *Measurement Science Review* , vol. 5, pp. 53-56, 2005

[15] Mounir Bousbia-Salah, M. F. "A Navigation Tool for Blind People," *Innovations and Advanced Techniques in Computer and Information Sciences and Engineering* , pp. 333-337, 2007