# A Step towards a Robotic System With Smartphone Working As Its Brain : An Assistive Technology

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***Abstract*—This paper describes a novel smartphone based navigation application. The smartphone based robotic system is sensitive to both the tactile and head-movement input commands from a user. Here we present our design used for developing a prototype of the robotic system as a proof-of-concept of an assistive technology that could facilitate partially disabled people to navigate effectively. Additionally we designed a usability study where our prototype was validated by seven healthy participants. Such an intelligent robotic system controlled by a smartphone can find a variety of applications based on navigation systems for disabled persons, educational tools especially for children with autism, surveillance and social telepresence. The hardware prototype could then be further used for development purposes to build a variety of applications using Application Program Interfaces (APIs) that can program the robot to do a custom task.**

***Keywords—Human robot interaction, smartphones, navigation, assistive technology.***

## I. Introduction

Independent mobility is very important for individuals, both children and adults [1-2]. Independent mobility and navigation capability increases vocational and educational opportunities, reduces dependence on caregivers and family members, and promotes feelings of self-reliance [3]. For elderly people reduction in navigational mobility is often linked with reduced participation and loss of social connections [4]. This in turn can lead to feelings of emotional loss, reduced self-esteem, isolation, stress, and fear of abandonment [4]. Given the importance of navigational ability, individuals with hemiplegia have been shown to prefer smart manual wheelchair [3]. Literature review shows that several investigators have used alternative input methods, particularly, voice [5], eye gaze [6] and joystick [7]. Satisfactory operation of these interfaces depends to a considerable extent on the user's ability to speak the input commands clearly and rapidly, the accuracy of calibration of the eye gaze interface and the muscle strength needed to operate the joystick all of which can impose constraints on complex maneuvering and effective navigation [3]. Thus development of user-friendly interfaces that can be used for effective navigation is critical.

In our present research, we investigated the use of tactile and head-movement based input commands for navigation purpose. Unlike mouse-based interfaces that require users to visually track an onscreen cursor away from the hand, direct-touch input is advantageous since the input and display are co-located such that users can touch the graphical elements they are interacting with [8]. Again, studies have shown that head tracking is sometimes advantageous in achieving reduced task time [9]. For developing the user interface, we used the multifaceted functionality of smartphones. Recently, there has been a tremendous increase in the spread and use of smartphones. Smartphones have become prevalent in our daily life [10]. Almost everything from bill payments, video calls to locating favorite restaurants is 'on the go' and just a click away. These smartphones are evolving extra-ordinarily and are getting incorporated with a variety of hardware sensors and technologies. They offer considerable computational power and are equipped with powerful processors and graphical processing units. They come with multitude of in-built sensors such as accelerometers, cameras, microphone, wireless connectivity (via Bluetooth, WiFi, 3G) and Global Positioning System (GPS). Most importantly they run operating systems and that too at a relatively reasonable price.

Literature review indicates that considerable efforts are being made to develop technology-assisted interfaces to promote human-robot interaction. Robotic agents with the ability to sense and respond to user's feedback are of growing importance. Many complex autonomous robots with different form factors come with an onboard computer [11]. By employing a Smartphone as an onboard computer, the size of a robot can be reduced to a small size without considerably affecting any computational features. Moreover, combining robotic agents with smartphones will allow the robots to learn, adapt and change themselves rapidly. A similar application store for robots, where the bots can quickly add functionalities based on the application they are running would change how the current single purpose systems are perceived [12].

Using a smartphone as the 'brain' of a robot is already an active research field with several opportunities and promising possibilities [13]. This type of robotic system could find use as assistive technology developed for people with physical disabilities especially paraplegics. Paraplegics rely on power wheelchairs for mobility, but the hands-free controller systems currently available are obtrusive and expensive. In this paper, we present the design of an experimental prototype of a robotic wheelchair that accepts one's tactile and head movement based input commands from a smartphone to carryout navigation task. This paper is organized as follows: In Section II we present the system design. In Section III, we describe our design of the usability study. In Section IV, we discuss the results of our usability study and we conclude

Section V with our conclusions and future directions of research.

## II. SYSTEM DESIGN

In our present research we fabricated a small prototype of a robotic wheelchair (henceforth called as the 'bot') and augmented its capabilities by interfacing it with a smartphone. Our robotic system comprises of four modules, namely, (A) User Input Module, (B) Smartphone Module, (C) Controller Module and (D) Bot Module. The Figure 1 below shows a block schematic of our system.

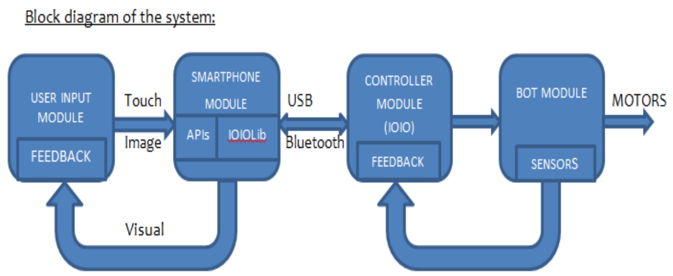


Figure 1. Block Schematic of our system

### *A. User Input Module*

The User Input Module comprises of communicating user-defined input commands to the smartphone to perform the desired task. The commands are transmitted in two modes, namely, as Tactile (Touch) and Head movement (Image).

1. *'Tactile based' input command:* Our system is equipped to respond based on the Tactile (i.e. Touch) input from the user. This application program provides the user with the facility to use the touch screen on the smartphone to maneuver the bot. Every point on the touch screen is mapped to the direction of rotation of the motors connected to the two wheels of the bot. The speed of rotation of the motors is controlled by feeding an appropriate Pulse Width Modulation (PWM) signal to both the motors. The Graphical User Interface (GUI) designed on the touch screen of the smartphone is as shown in the Figure 2.

The Figure 2 shows User Interface on the smartphone and the corresponding mapping rationale. The black solid circle represents the position of the finger/touch. Here the region '++' marked 'Forward Movement' within the red lines indicates the forward motion in which case the output pins of the motor driver (discussed below) controlling the motors are fed with 5V (+Vcc) while the rest of the output pins are at ground potential. Similarly, if the user moves his finger in the region '-+' marked as 'Left Movement' in the above Figure 2, the bot would continue moving left till the user moves his finger onto the other regions on the screen. Now, if the touch input lies in the left movement region of the screen, the voltage levels fed to the motor driver are such so as to stop the left wheel rotation and allow only the right wheel to move clockwise. For a more sharp left turn, the left wheel rotates anticlockwise while the right wheel rotates in clockwise direction. To map the coordinates on the touch screen in the same convention as shown above, it can be seen that the new coordinate axes (indicated in red) is rotated by 135° counterclockwise with respect to the older coordinate axes (indicated by black lines), similar to the research finding made by Monk [14]. The origin of the coordinate axes corresponds to the 'stop' position of the bot i.e. the bot ceases to move. Likewise, the regions '+-'and '--' are mapped to move the bot to the Right and Back respectively. As the user starts to move his finger away from the origin on the screen, corresponding PWM signals (with normalized duty cycle varying between 0 and 1) are fed to the motor based on the distance of the finger's location from the origin. In this way, speed control is achieved.

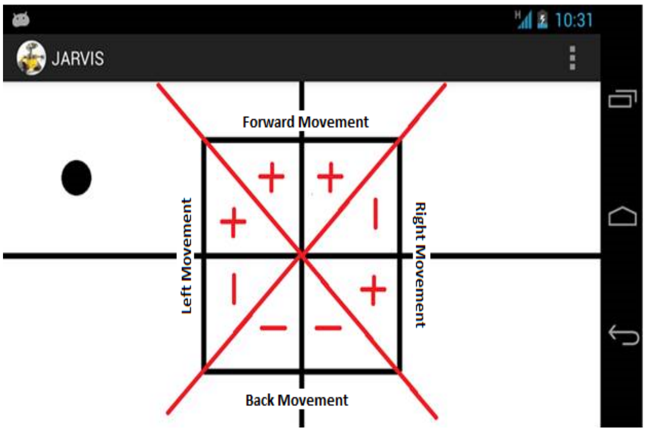


Figure 2. Graphical User Interface (GUI) for the Tactile Input

2. *'Head Movement (Image) based' input command:* Our system is also equipped to respond to the image based input command from the user. The image can be a camera image of any object attached to a user's forehead. Specifically this uses the concept of blob detection. Our developed application program uses the camera on the smartphone to maneuver the bot. This system is designed specifically for paraplegics who have partial paralysis of both arms, both hands, both legs and both feet. So, we have looked at how we could map the head motion of a paraplegic person to the speed and direction of rotation of the motors. The Figure 3 below shows a snapshot of the screen displaying the blob detection and tracking of the blob on the screen of the smartphone.

The user could wear some colored object, such as a colored cap or could even have a colored object on the forehead (analogous to the bull's eye). The smartphone with its in-built camera is placed in front of the user in such a manner that the blob/colored object is within the field-of-view of the camera. Once the developed application program is executed, the camera is initialized. For first time use, the blob/object to be tracked is selected by tapping the 'blob region' on the smartphone screen (Figure 3). Thereafter, the blob is detected and tracked in real time. Now, once this is done, the problem statement becomes similar to the previous case which used touch inputs for navigating the bot. As it can be seen from the Figure 3, the blob is seen to be tracked which is indicated by the bounding rectangle that is drawn around it. In order to test our program code, we prescribed certain numbers, such as, '1' for 'Forward movement', '2' for 'Back movement', '3' for 'Right movement' and '4' for 'Left movement'. Now in the snapshot shown in Figure 3, the experimenter moved his head left with the bull's eye (the green colored blob) fixed on his cap. Thus the number '4' above the rectangular blob is an indication of the direction in which the bot needs to move, which in this case is 'Left movement'. Effectively, the coordinates of the blob around the screen is now mapped to the direction of rotation of the motors in the same way as implemented for the 'Tactile based input commands'.

*B. Smartphone Module (based on Android)*

In this project, we have employed Android based smartphone since these devices are becoming increasingly cheaper and being widely used. Our developed applications are compatible with Android 1.6 and above. For developing our application programs, we used certain Application Program Interfaces (APIs) and Input/Output Libraries (IOIO Lib) which makes our application programs compatible with the IOIO Controller (described below) that we have used.

*1) APIs used:*

(a) Android APIs based on touch screen motion events

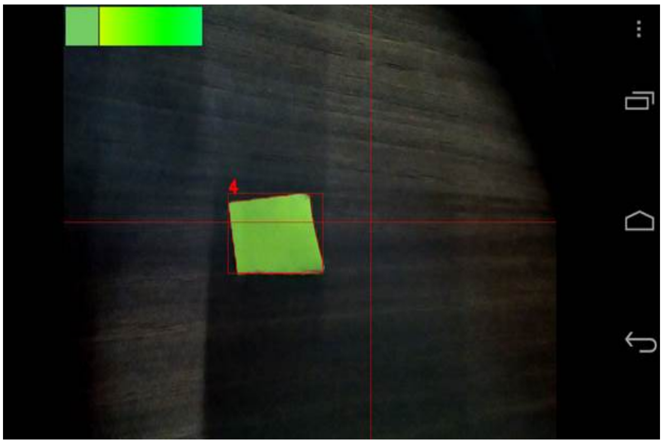


Figure 3. Blob detection and tracking with smartphone camera

and camera hardware.

(b) OpenCV Java API

*2) IOIOLib:*

(a) IOIOLib is a collection of libraries for Android which enables the application to control the IOIO board. This library exposes a set of Java interfaces, covering the various features of the board.

(b) IOIOLib Core API comprises of a platform-independent API for controlling all the IOIO functions.

*C. Controller – IOIO Board Module*

The IOIO board (Figure 4 below) used in our project has the capability to work with Android 1.6 and later devices. This board provides connectivity to an Android device via a USB or Bluetooth connection and is fully controllable from within an Android application using a simple and intuitive Java API. The IOIO board contains a single Microcontroller Unit (MCU) that acts as a Universal Serial Bus (USB) host and interprets commands from an Android application. In addition, the IOIO can interact with peripheral devices with its 48 numbers of Input/Output pins. Digital Input/Output, PWM, Analog Input, Serial Peripheral Interface (SPI), and Universal Asynchronous Receiver/Transmitter (UART) control can all be used with the IOIO. The IOIO board behaves as a USB host and connects to Android devices that have USB slave (device) capability. The connection between the Android device and the IOIO board could be wired over USB or could be made wireless over Bluetooth. In our present application, the IOIO board module acts as an interface between our Android based Smartphone and the bot.

*D. Bot Module*

In our present study we have designed a prototype version of the wheelchair bot. This prototype version has two wheels similar to a wheelchair. Paraplegics rely on power wheelchairs for mobility, but the hands-free controller systems currently available are obtrusive and expensive. Our present prototype bot, though is a much simplified version of an actual wheelchair, is used to carry out the usability study (discussed below) of our proof-of-concept application. Our bot module comprises of the following components:

*1) Infrared Proximity Sensor:* The sensor outputs an analog signal between 0.4V and 3.1V to indicate distances to obstacles from 80 cm away to 10 cm away. This sensor meant for obstacle detection and avoidance will help in making decisions for effective navigation.

*2) Motor Driver:* It is not recommended to connect a motor directly to IOIO or a microcontroller because they are not meant to provide enough current to drive the DC motors. So, in the bot assembly we have used the Motor Driver IC L293D (Figure 4) that can drive two motors (connected to the two wheels) simultaneously. L293D IC is a dual H-bridge motor driver IC where one H-bridge is capable to drive a dc motor in both directions.

*3) Motors:* We have used 2 numbers of 6V DC Geared Motors of 100 RPM each.

*4) Power Supplies:*

Power supply to IOIO: 5V-15V

Power supply to Motor Driver: 6V-12V

Two 9V batteries are used to power up the IOIO and the motor driver.

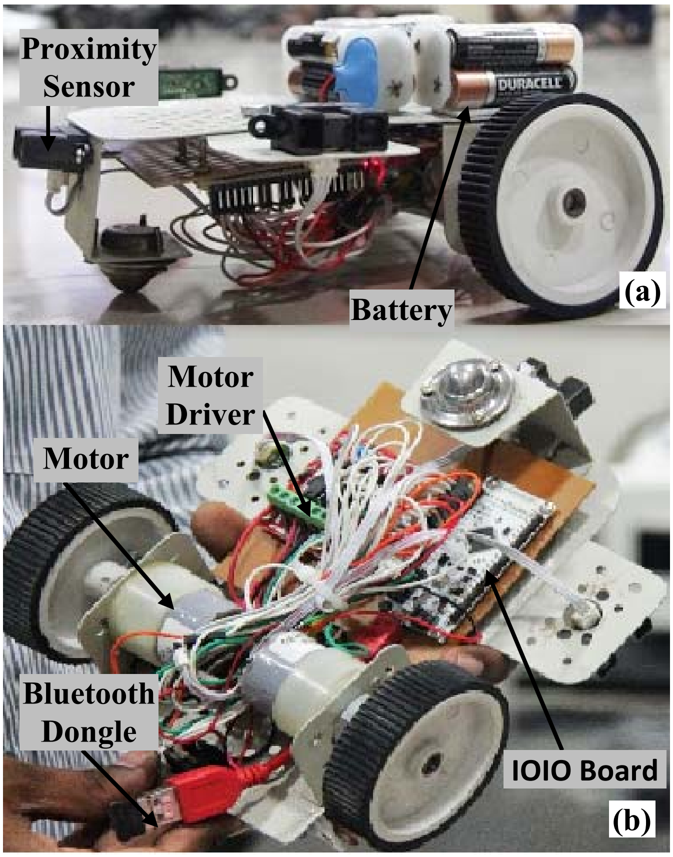


Figure 4. Snapshot of the prototype wheelchair bot module (a) top-side view (b) bottom view.

## III. USABILITY STUDY

We designed usability study to assess the performance and adaptability of users to the tactile based and image based interface developed using the smartphone to maneuver the prototype robotic wheelchair. Additionally, the robot was equipped with a visual alarm facility, which warned the users of possible chance of collision when the obstacles were within the range of the proximity sensors, thereby aiding the user to avoid the collision. For the usability study, we used the Bluetooth dongle (Figure 4) for wireless communication between the smartphone and the bot. The study was based on two experiments, namely, Tactile based navigation and Head Movement based navigation experiments.

### *A. Participants*

Seven healthy (average age – 22 years) and right-handed students of the university participated in the experiments. The experimenter informed the participants about the protocol of the study before starting their practice session. Each participant was offered two trials of practice for each of the tactile based and image based navigation experiments.

### *B. Tactile based Navigation Experiment*

Here we designed a path (Figure 5) for the user's bot to navigate. The participants were asked to maneuver the path with two obstacles (Figure 5) such that the proximity sensors (right and left) of the bot indicated the presence of Obstacle1 between T2 and T3 segment and T4 and T5 segment of the path respectively. Similarly, the proximity sensor (left) indicated the presence of Obstacle2 between the T6 and T7 segment of the path. The average length of path between T1 (Start) and T8 (End) was approximately 8.4 meters.

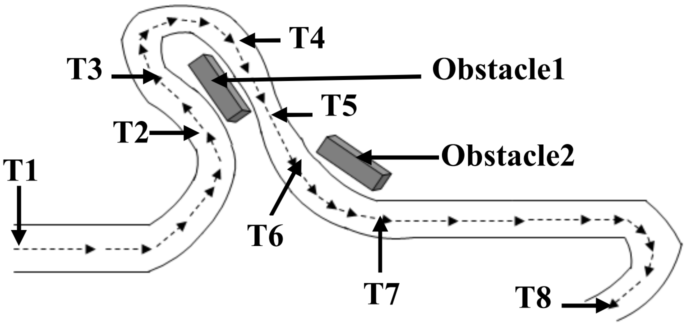


Figure 5. Tactile based Navigation path

### *C. Head Movement based Navigation Experiment*

For this experiment we designed a path (Figure 6) of shorter length (average length – 3.7 meters) because of the higher consumption of the battery power by the smartphone's camera. In this case, the walls 1-4 were arranged such that if the robot deviated from the dotted path (I1-I2-I3-I4-I1), then the proximity sensors would alarm the user by giving a visual display. [During this experiment the users were asked to sit in a separate chair which was fitted with a smartphone mounting arm, and a small green colored sticker (Figure 3) was pasted on the forehead of the user. After the experimenter calibrated the smartphone's camera by touching on the green blob on the smartphone's touchscreen, the user was asked to navigate the robot by nodding his head in different directions.]

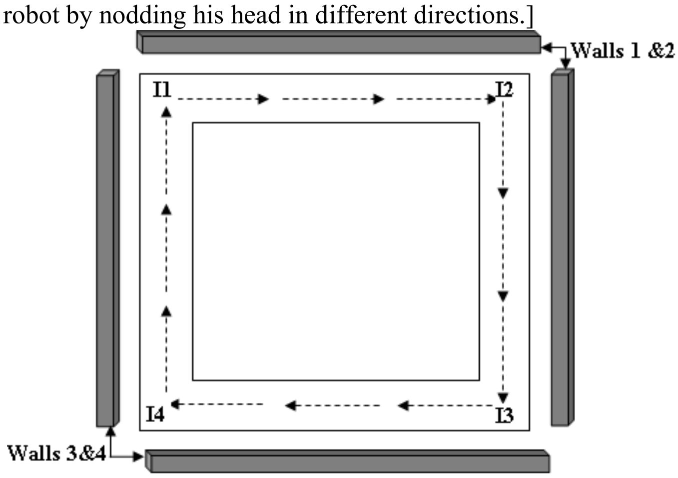


Figure 6. Head Movement based Navigation path

## IV. RESULTS AND DISCUSSION

In order to evaluate the capabilities of our smartphone assisted robotic prototype application, we carried out a usability study. For this we conducted two small experiments: *Experiment1-* for evaluating the bot's navigation capability in response to one's tactile based input command and E*xperiment2* – for the head movement based input command. Here we summarize the results of our observations.

*Experiment1*

TABLE I. VALIDATION OF TACTILE BASED NAVIGATION

| | Travel Time (Experimental) t1 (seconds) | Travel Time (Actual) t2 (seconds) | Number of Alarm Indications | Difference in Travel Time Δt (seconds) |
|---|---|---|---|---|
| P1 | 31.88 | 22.91 | 3 | 8.97 |
| P2 | 30.61 | 22.91 | 3 | 7.70 |
| P3 | 36.84 | 22.91 | 3 | 13.93 |
| P4 | 34.00 | 22.91 | 3 | 11.09 |
| P5 | 33.25 | 22.91 | 3 | 10.34 |
| P6 | 29.40 | 22.91 | 3 | 6.49 |
| P7 | 28.51 | 22.91 | 3 | 5.60 |

The Table I above shows the results of the participants (P1 – P7) from Experiment 1. Here 't1' represents the time taken by the bot to maneuver the path (Figure 5) in response to the tactile input command from the smartphone given by the user. The time 't2' represents the least time (Actual) that the robot might take to travel a path of length 8.4 meters with its wheels actuated by motors rated at an average of 100 rpm. The number of alarm indications given to the user was 3 in each case for the two number of obstacles (Obstacle 1 and Obstacle 2) as was expected for this experiment (Please refer Section III.B). The time difference 'Δt' is the difference 't1-t2'. Thus the *experimental travel time* was found to be quite close (average deviation- 9.16 seconds and standard deviation – 2.88) to the *actual travel time*.

*Experiment2*

TABLE II. VALIDATION OF HEAD MOVEMENT BASED NAVIGATION

| | Travel Time (Experimental) t1 (seconds) | Travel Time (Actual) t2 (seconds) | Number of Alarm Indications | Difference in Travel Time Δt (seconds) |
|---|---|---|---|---|
| P1 | 24.56 | 10.09 | 5 | 14.47 |
| P2 | 22.44 | 10.09 | 2 | 12.35 |
| P3 | 19.14 | 10.09 | 2 | 9.05 |
| P4 | 23.67 | 10.09 | 4 | 13.58 |
| P5 | 19.28 | 10.09 | 1 | 9.19 |
| P6 | 29.50 | 10.09 | 5 | 19.41 |
| P7 | 24.77 | 10.09 | 3 | 14.68 |

The Table II above shows the results from Experiment 2. Here 't1' represents the time taken by the robot to travel the path (Figure 6) in response to the head movement by the user. The time 't2' represents the least time (Actual) that the robot might take to travel a path of length 3.7 meters with its wheels actuated by motors rated at an average of 100 rpm. The time difference 'Δt' is the difference 't1-t2'. Thus the *experimental travel time* was found to be quite close (average deviation- 13.25 seconds and standard deviation – 3.57) to the *actual travel time*. In this experiment, the bounding edges were arranged around the track in such a way, that if the robot deviated from the desired path (Figure 6), the proximity sensors will give a visual alarm to the user (please refer Section III.C). From Table II we find that the lesser is the number of alarm indications, the closer is 't1' to 't2' implying that the lesser is the deviation 'Δt'.

## V. CONCLUSION AND FUTURE DIRECTION

This paper describes the use of smartphone to maneuver a prototype robotic wheelchair that is equipped with obstacle detection facility. The designed applications can maneuver the robot based on the user's input command delivered through the use of tactile and head movement based interfaces developed by using the smartphone. In order to validate this proof-of-concept application, we designed a usability study comprising of two experiments. Though the initial results are satisfactory which shows the feasibility of such a design application, yet our usability study has its own drawbacks. First of all, though our system has been designed for use by hemiplegic individuals with limited physical flexibility, our usability study was carried out with healthy participants. In future we plan to test our system with hemiplegic participants. Secondly, we have tested our prototype application in experiments carried out indoors. In future we plan to test our system outdoors where we have to face challenges like dynamically moving obstacles, multiple images being captured by the smartphone's camera module.

We envision that in future our system will take the form of a smart autonomous wheelchair and being actually put to use. As an extension to the project, in future, we would also like to explore autonomous navigation both for indoor and outdoor applications. For indoor application, we plan to use artificially intelligent search mechanisms for automated navigation. For outdoor application, we plan to make the automated navigation intelligent by incorporating Google Maps on the smartphone into our search algorithms. The challenge lies in identifying and tracking the obstacles and also updating the route to the destination accordingly.

This is one of the major applications that we could see coming out of this unique assembly of a robot and a smartphone. This concept is scalable and a variety of Android/smartphone based intelligent applications can be developed that can allow the bot to perform numerous tasks. The robotic system, thus is no longer a single purpose machine, but is easily customizable by just a click. With this project, we would like to put forward a hardware prototype with software API's that could be further used to build other customized intelligent and adaptive robotic systems.

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