GPRS-Based Remote Sensing and Teleoperation of a Mobile Robot

Mohammed M. Ali,Kasim M. Al-Aubidy

Ahmad M. Derbas, and Abdallah W. Al-Mutairi

Faculty of Engineering

Philadelphia University, Jordan

moh_19592002@yahoo.co.uk, alaubidy@gmail.com

Abstract- The main objective of this research was to design and implement a remote sensing and monitoring system running on mobile robot with obstacle avoidance capability in unreachable area. A simple mobile robot prototype with onboard sensors has been designed and implemented to scan and monitor several variables in the surrounding environment. Teleoperation of such a mobile robot is a challenging task that requires an efficient interface and a reliable real-time robot control to avoid obstacles. The proposed system enables the user (base station) to send commands to the remote station (mobile robot), and receive scanned data and images from the environment through the internet and mobile DTMF signal. The proposed system hardware and software was implemented using PROTUS development software to obtain the suitable design parameters. Then, real experiments have been achieved to demonstrate the system performance including both the ultrasonic teleoperation of mobile robot navigation to avoid obstacles, and real-time sensing and monitoring in unreachable area.

Keywords- *Mobile Robot, Robot navigation, Remote sensing and monitoring, Wireless sensor networks, Obstacles avoidance*

I INTRODUCTION

There has been a tremendous increase of interest in mobile robots and their applications. One of these applications is using wireless mobile robots to detect several variables in the environment[1]. Using mobile robots equipped with sensors are becoming widely used, especially in environments where human involvement is limited, impossible, or dangerous. These robots can be used to perform some dangerous tasks that are difficult for human to do, especially in hazardous environments. Nowadays, internet-based teleoperation of mobile robots has opened new opportunities in long distance learning, resources sharing, and remote experimentation [2]. A global positioning system (GPS) has become an efficient tool in the civilian and military applications. GPS technology works under different weather conditions and across the world by any person if he has a GPS receiver[3,4]. It provides users to track locations, objects, and even individuals in outdoor locations. However, GPS at indoor locations results poor performance due to its lack of ability to transmit and receive signals across concrete buildings[5]. In such a case, RF communication solution is more suitable for indoor communication. In this project, the GPS technology has been used for mobile robot navigation and positioning in outdoor locations. Wireless Sensor Network (WSN) technology together with mobile robots can be used to detect several variables in the environment[6]. Each mobile robot can be considered as an individual node in the network which can monitor its local region and communicate through a wireless channel with other nodes to collaboratively produce a high-level representation of the environment's states. By using such a network, large areas can be monitored with low cost. There are many published papers combining wireless sensor networks with mobile robots. LaMarca, et al., [7] used robots to increase the feasibility of WSNs, since sensor networks can acquire data but lack actuation, while robots have actuation but limited coverage in sensing. Rahimi et al. [8] describes a method of extending the lifetime of a wireless sensor network by exploiting mobile robots that move in search of energy, recharge, and deliver energy to immobile, energy-dependent nodes. Luo and Chen [9] demonstrated a remote supervisory control architecture which combines computer network and an autonomous mobile robot. A general purpose computer with internet access is required to command the mobile robot in a remote location through

Internet. Hiroshi et al.[10] proposed a method to remotely locate a source using a mobile robot with gas sensors. The proposed method enables the estimation of the distance to the source together with its direction, the source can be remotely located. Wanga et al.[11] present an overview on recent development, future trends and advantages of wireless sensor technologies and standards for wireless communications as applied to wireless sensors. Mandow [12] proposed an autonomous mobile robot system equipped with appropriate sensors and operation devices to substitute hard and unhealthy human work inside greenhouses. Axaccia et al.[13] proposed a service robot for health monitoring and localized chemical, drugs and fertilizers dispensing to plants in greenhouses.

This paper presents the first stage of a project developed at Philadelphia University-Jordan. The main objective of the project is to use concepts of reverse engineering to design and implement a reliable and cheap communication channel running on mobile phone to guide a mobile robot with safe and efficient operation. The mobile robot can operate and perform scanning, monitoring and control tasks that are tedious and repetitive in a dangerous environment. The mobile robot is provided with microcontroller-based data acquisition unit and a real-time control and navigation algorithm to avoid obstacles.

II MOBILE ROBOT DESIGN

The simplest type of mobile robots are wheeled robots that comprise one or more driven wheels and may have optional passive or caster wheels and possibly steered wheels[1]. The implemented mobile robot is a four-wheeled vehicle prototype with dimensions; 32cm wide, 40cm long and 25cm height. Two DC motors are used for driving and steering, the first DC motor is used for driving both rear wheels via a differential box, while the second DC motor is used for combined steering of both front wheels, as shown in Fig.1. The prototype provides support to the batteries, camera, and all elements related to the proposed design.

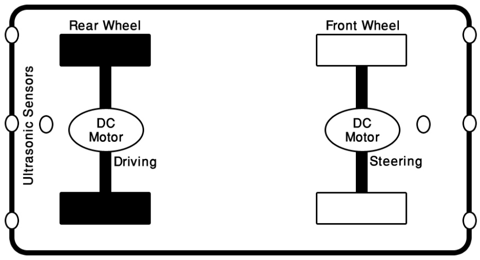


Figure 1: Wheeled mobile robot.

(a). DC motor interfacing:

The first step when building a mobile robot is to select the appropriate motor and its control system. DC motors are the most commonly used in mobile robots, since they are clean, quiet, easy controlled, and can produce sufficient power. H-bridge circuit type (L293D) is needed to drive each DC motor forward and backward, as given in Fig.2. Four output lines from the microcontroller are connected to the H-bridge to drive the DC motors.

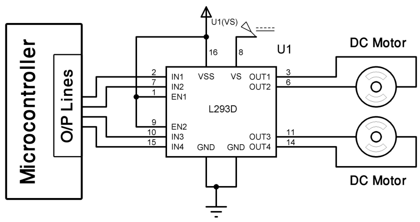
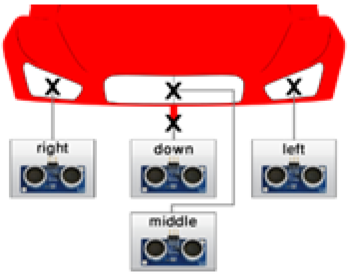


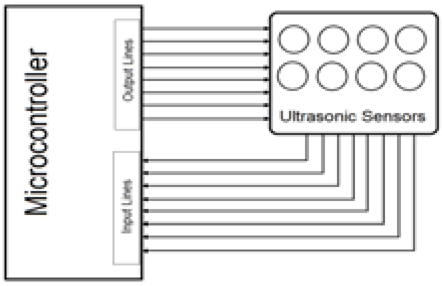
Figure 2: Motor interfacing.

(b). Ultrasonic sensors interfacing:

The mobile robot has eight built in ultrasonic sensors (type HC-SR04) to detect the route and avoid any obstacle in the working environment. Six sensors are distributed forward and backward to detect the route, while the other two sensors are fixed in the front middle and rear middle to detect any hole in its route, as shown in Fig.3-a. Also, an internet camera is used to provide user the required broader area of sensing. The ultrasonic sensor includes an ultrasonic transmitter, receiver, and a simple control circuit. It provides 2cm-400cm non-contact measurement function, and covers good range accuracy (about 3mm) with stable readings that are not affected by sunlight or black material[14].



(a). Sensors distribution.



(b). Interfacing with microcontroller.

Figure 3: Ultrasonic sensors.

To use this sensor, it is required to generate a short 10μsec trigger pulse applied to the sensor input to start the ranging. The sensor will automatically send out an 8-cycle burst of ultrasound at 40kHz and raise its echo. The Echo is a distance object that is pulse width and the range in proportion. In this case 16 input/output lines of the microcontroller are required to connect these sensors, as illustrated in Fig.3-b. The internal timer/counter of the microcontroller is used to calculate the range through the time interval between sending trigger signal and receiving echo signal.

III GPRS BASED COMMUNICATION MODULES

General packet radio service (GPRS) is a packet oriented wireless communication service available to users of the 2G, 3G and 4G cellular communication systems. GPRS offers faster data transmission via a GSM network within a range from 56Kbps up to 114 Kbps. The GPRS technology makes it possible for mobile phone users to make telephone calls and transmit data at the same time[4]. The higher data rates allow mobile phone users to have continuous connection to the internet, and to have web-based applications. In this project the GPRS technology is applied for real-time remote monitoring and control system.

The general layout of the proposed system is given in Fig.4. The major components are the mobile robot, the microcontroller, the camera and two mobile phones. These components are mounted into two parts; the base station, and the remote station. The communication between base station and remote station takes place via mobile phone communication technology.

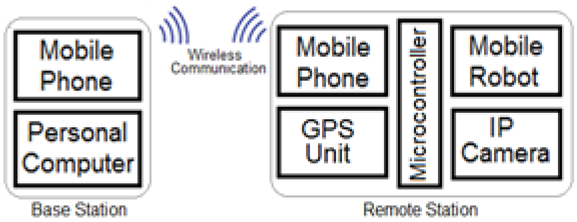


Figure 4: General layout of the proposed system.

(a). Base Station Design:

The general layout of the base station architecture is shown in Fig.5. It comprises a personal computer, a mobile phone, and an interface between personal computer and the mobile phone. The only way to access the mobile robot is to feed robot controller with commands from the base station mobile phone.

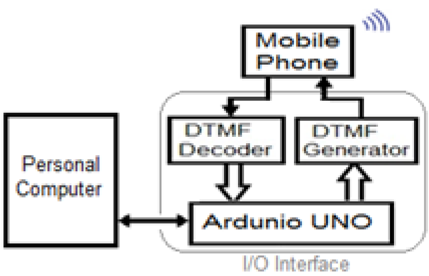


Figure 5: Base station architecture.

Computer interface unit:

The input/output interface of the base station consists of a phone decoder, a phone generator and an interface card type Arduino UNO. It is a microcontroller-based board has 14 digital input/output pins, 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, and a reset button. It contains everything needed to connect a mobile phone to a computer with a USB cable[15]. The embedded microcontroller on the board is programmed to convert the mobile robot commands into an ON/OFF signals applied to the tone generator (TP5088) and then to the mobile phone of the base station. This tone is called dual-tone multiple-frequency (DTMF). Also, this interface converts the tone (send by the remote station through mobile) into a binary code using DTMF decoder (MT8870).

Tone Generator:

The TP5080 DTMF generator provides low cost tone-dialing capability in microprocessor-controlled telephone applications. The 4-bit binary data generated from the base station microcontroller is converted into DTMF signal directly. If the tone enable input line is low, the 4-bit data is latched into the device and the selected tone pair from standard DTMF frequencies is generated. Figure 6 shows a typical interface circuit for direct generation of DTFM signal connected to the phone line of the base station.

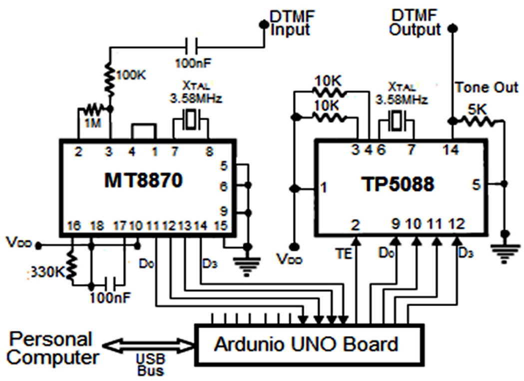


Figure 6: Hardware design of the base station.

Tone Decoder:

The DTMF decoder (type MT8870) is used for decoding the mobile DTMF tone signal received from the remote into 4-bit digital signal. The data acquisition algorithm of the base station converts the received 4-bit data into a digital signal representing the measured variable scanned by the remote station. The DTMF decoder is operated with a 3.579MHz crystal. A capacitor of 100nF is used to filter the noise and two resistors ($100K\Omega$ and $1M\Omega$) help to amplify the input signal using the internal amplifier, as illustrated in Fig.3.

(b). Remote Station Design:

The general layout of the remote station is given in Fig.7. It comprises a mobile robot, a microcontroller, set of environmental sensors, a mobile phone, a GPS receiver, a web camera, and an input/output interface between the microcontroller and the mobile phone.

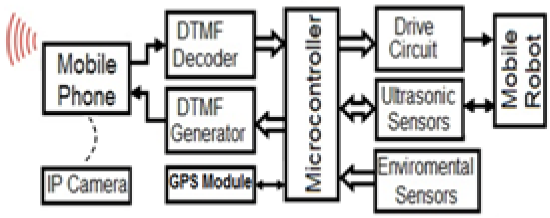


Figure 7: Remote station architecture.

The GPS Unit:

The proposed remote monitoring and control system is based on satellite navigation technology, where a GPS is used to give the mobile robot the ability to determine its position. A GPS provides continuous positioning information, anywhere in the world under any weather conditions so long as the receiver has a direct line of sight to the sky[16]. A commercial GPS module type (SKM53) is used in this design due to its low power consumption which satisfies mobile applications. It has an embedded antenna which enables high performance navigation in the most stringent applications and solid fix even in harsh GPS visibility environments[17].

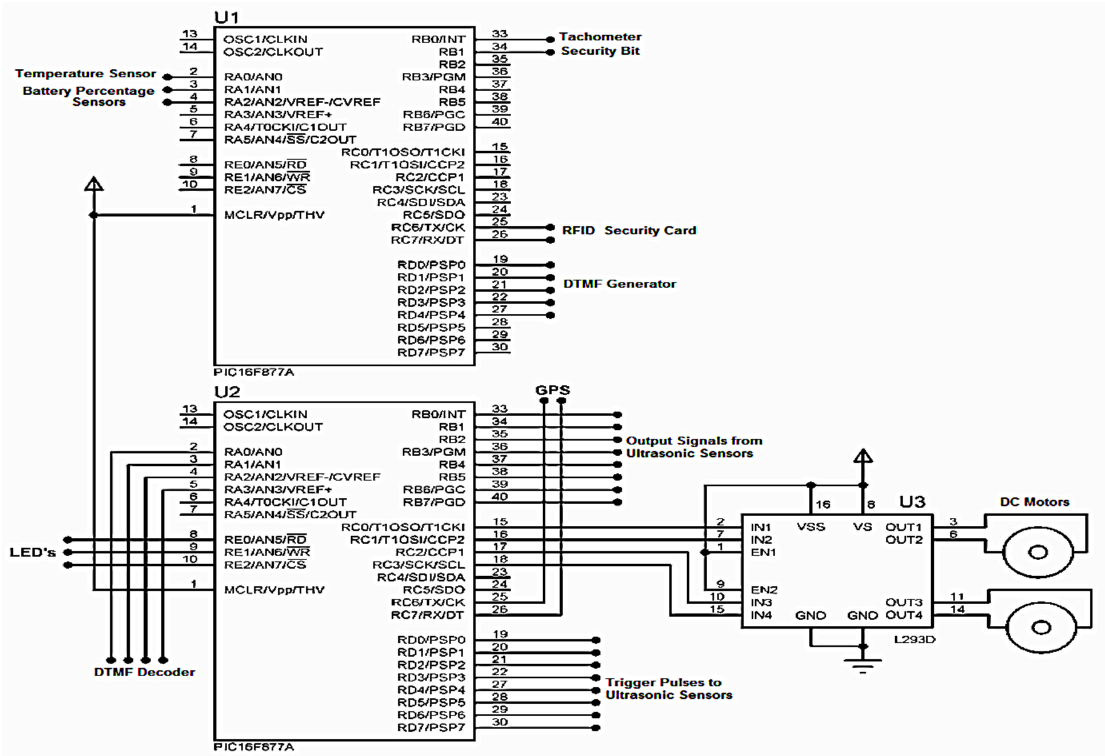


Figure 8: Hardware design of the remote station.

The GPS module is mounted on the mobile robot, and interfaced to the microcontroller, as shown in Fig.7. The data obtained from GPS receiver is processed by the base station to extract the mobile robot latitude and longitude values.

The Microcontroller:

The PIC16F877A microcontroller is used in this project. It is a low-power, high performance, 8-bit microcontroller with 14.3 KB flash memory, 256 bytes EEPROM data memory, 368 bytes of RAM used as internal data memory, 33 individually programmable I/O lines divided into five ports, 2 Comparators, 8 channels of 10-bit Analog-to-Digital converter, 2 capture/compare/PWM functions, 15 interrupt sources and a synchronous serial port.

Figure 8 illustrates the hardware design of the remote station, where all required units are connected to two microcontrollers. The total number of input/output lines required for the given design is 29 lines from the first microcontroller and 12 lines from the second microcontroller. Therefore, there are 6 analog input lines and 15 digital input/output lines available at the second microcontroller for the data acquisition unit.

The Tone Decoder:

Another DTMF decoder is required in the remote station for decoding the received mobile signal. It gets DTMF tone from the mobile headset?s wire and decodes it into 4-bit digital signal to control the mobile robot. The DTMF decoder is operated with a 3.579MHz crystal.

The Tone Generator:

Again, the remote station has a tone generator similar to that used in the base station. The 4-bit binary data generated from the remote station microcontroller is converted directly to DTMF signal.

Data Acquisition Unit:

The mobile robot has two groups of sensors; the first group is composed by eight Ultrasonic sensors which are mounted on the robot as illustrated in Fig.1. The second group is composed by set of sensors to scan and monitor selected variables in the surrounding environment. There are 21 input/output lines available for this unit to interface the required sensors to the second microcontroller.

IP Camera:

An internet camera is used as a remote sensing sensor to monitor the working area of the remote station. Requirements such as energy consumption, size and weight are very important in such application. The integrated wireless camera type ”Tenvis JPT3815W” is used in this design. It provides 12 meters night vision functions, high quality video and two-way audio monitoring. It supports remote viewing and recording from anywhere anytime via web browser[5]. The IP camera uses WiFi technology, so it can be connected to a router and accessed across the internet.

Challenges of implementation

1. As for the design of the DTMF circuit, there are ICs in market that do this job but with low quality the main reason is related to crystal inaccuracy besides power supply harmonics thus the detection especially when voice received is not very clear.

2. Motor driving was one of biggest troubles we faced, since of heavy robot weight so we had to find a way to drive motor without using mechanical parts such as relays. Once correct motor driver was found we had troubles with harmonics because of high starting current of motor, it forces controller board to reset, at same time we did not want to use a costly driver to keep design as cheap as possible.

3. Design and implementation of wireless charging unit in robot took a lot of trials, each time we lost something to work and mostly the MOSFET transistors cause of overheating, at end we synchronized circuit without using expensive parts like function generator.

4. Isolating controller from electromagnetic fields took some time, it is not because of the design issue but we were testing the robot inside strong magnetic fields to see if it can resist.

5. Programming was a challenge also; we wanted to design a stable control algorithm for robot with fast operation to serve real time needs.

IV MOBILE ROBOT TELEOPERATION

Controlling mobile robots through teleoperation is a real challenging task that demands a flexible and efficient user interface. In this project, the mobile robot is equipped with numerous sensors including ultrasonic sensors, environmental sensors, positioning sensor and an IP camera. These sensors provide a high volume of data to the user, and the received information from the robot are used by the base station. In fact, teleoperations are necessary in such application where mobile robot is not able to deal with a certain task autonomously.

The mobile robot is controlled by a mobile phone (base station) that makes a call to the mobile phone attached to the robot. During a call, if any button is pressed, a tone corresponding to the button pressed is heard at the remote station. This tone is converted into binary code using DTMF decoder. The microcontroller is preprogrammed to take a decision for any given input and generates its decision to drive circuits of the driving and steering motors.

The mobile robot has two modes of operation; the manual mode, and the automatic mode. In manual mode, the mobile robot reacts directly to the user commands. The user can guide the mobile robot to move forward, backward, turn left or turn right. If any obstacle is found, the robot will be stopped. Then, through the real-time images from the IP camera, the user will send the required commands to avoid obstacles. While, in the automatic mode, the ultrasonic sensors are used to assess the working environment in which the robot is moving. Upon detection of an obstacle or a hole by any of these sensors an action is taken by the control algorithm to avoid collision with any obstacle in the environment. Here the statuses of the sensors are read by the microcontroller to monitor the environment surrounding the robot.

V MOBLE ROBOT NAVIGATION

Localization is the most important task for robot navigation and control. It is very important to know the robot position and its orientation at all times to make sure it reaches the final destination and covers the scanned area. This localization issue can be solved by using a global positioning system for outdoor scanning. In the case of indoor scanning, a GPS with infrared, sonar, laser or radio beacons can be used[1]. The driving system can update their position and orientation from time to time.

For remote control of Mobile robot, a rule-based control algorithm is used for obstacle avoidance. The IR sensors provided on front and back of the mobile robot are used for this purpose. The ultrasonic sensors can detect the obstacles at a distance of 400cm from the robot. So these sensors provide the robot controller with the necessary information before collision takes place.

For the teleoperation, the mobile robot takes images of the remote environment and sends the visual information back to the base station over the Internet. In sometimes it is not possible to watch certain regions due to the limitations of communication bandwidth and narrow view-angles of camera. To avoid this problem, new commands are generated from the base station to adjust the position of the IP camera and to move the mobile robot to new position according to the ultrasonic sensor data.

It is demonstrated by experiments that such actions improves the performance of the sensing and monitoring tasks achieved by the remote station significantly.

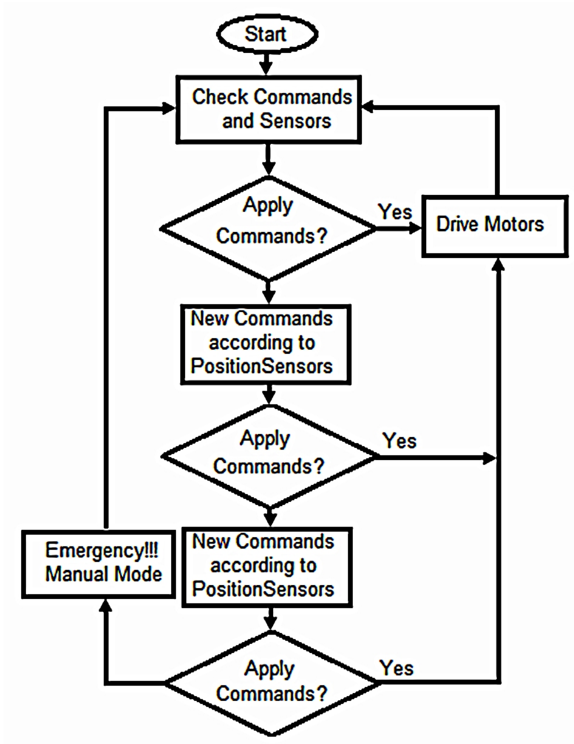


Figure 9: Mobile robot navigation algorithm.

VI RESULTS AND DISCUSSION

There is currently a hot debate among people trying to understand and reproduce intelligent agents that could be stated as follows: "is the simulation a powerful enough tool to draw sound conclusions, or should a theory or an approach be tested on a real agent" , i.e. robot. Although both numerical simulations and physical implementations have their own merits indifferent fields of research, the issue becomes important when one investigate autonomous and intelligent agents using both ways[19].

A basic characteristic of autonomous systems is the ability to self-regulate their own behavior in order to maximize the probability of their implementation. In this sense adaptation is function of the interaction between two variables, the physical properties of the environment and the characteristics of the robot.

In this research a mobile driven robot is successfully built and tested along with a simulation study for its micro-controlled movement made by its two identical DC (Driving and Steering) motors. A simulation of an open loop step response behavior fit to the D.C motors model is achieved.

The robot is also designed to receive commands from mobile phone via DTMF, in simulation we used a programed controller to give same binary output as a DTMF decoder when it receives input via keypad because of DTMF IC unavailability in simulation software, while in reality we used a DTMF decoder by connecting input to mobile phone, and output to controller, results where good with reasonable delay between sending command and actuating it when using a 3G mobile network, vice versa for process is used with DTMF generator.

Our GPS was programmed in simulation to give a random position for check purposes, while in reality we used skylab GPS that connects serially to controller, it gives very accurate position when there is no coverage above it but the sky.

As for battery charge, we used voltage divider rule, which consists of two resistors to divide voltage, and input that voltage to controller. The controller knows maximum and minimum battery voltage while full and empty, it can calculate battery charge percentage and use that value to know the remaining operating time.

Results shown below reflect exactly what the mobile driven robot is designed for. Figure 10 shows the forward response of the driving motor subjected to an actuation ON signal, which clarifies its fast response to get the desired steady movement. The same conclusion is made when it received an OFF actuation order as in Fig. 11.

As mentioned before that the ability of intelligent behavior of avoiding obstacles or getting rid of entering a hole is tested both in hardware implementation and simulation. Figure 12-a shows the ON-OFF-ON signals subjected to the driving motor at a certain period. It clarifies that when the forward motor is in its steady state motion and suddenly sensing a Hole the controller sends an OFF signal to this motor and after a while actuates it to ON state again as illustrated in Fig. 12-b. In the mean while an actuating signal triggers the stand still state of the Steering motor synchronized with the Driving motor late OFF response as shown in Fig.12-c. The combination of both ON motors responses will avoid getting into a Hole or hit obstacles with a very enough safety period of time.

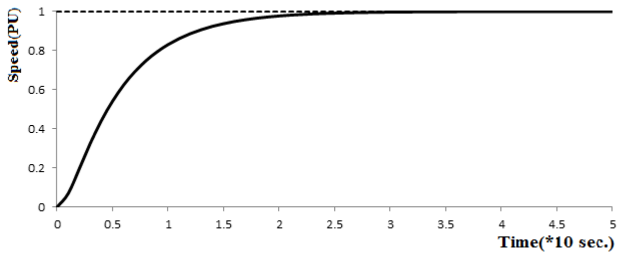


Figure 10: Driving motor response for forward command.

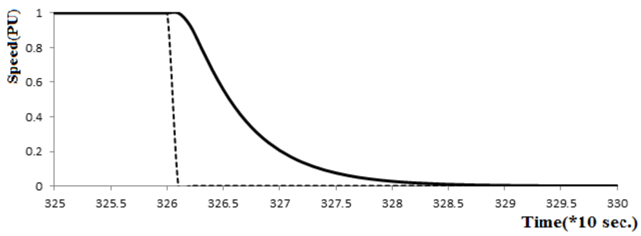


Figure 11: Driving motor response for stop command.

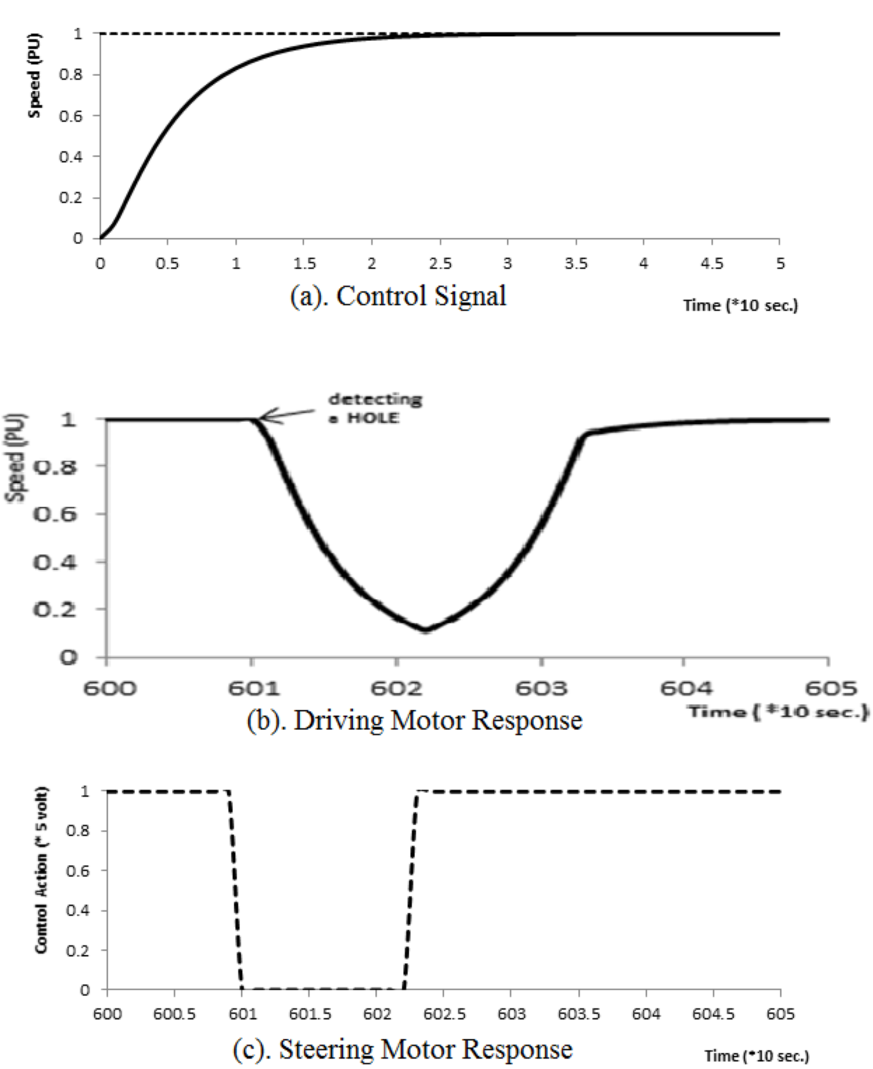


Figure 12: Motors responses when detecting a hole.

VII CONCLUSION

This paper describes the first stage of a project developed at Philadelphia University-Jordan. A reliable and cheap communication channel running on mobile phone has been designed and implemented to guide a mobile robot equipped with data acquisition unit for remote sensing and monitoring system. Such a system can be used for real-time scanning and monitoring of several variables located in environments where human involvement is limited or dangerous.

The designed robot satisfies all basic planned goals that this research seeks for. Hardware prototype is firstly designed and verified using PROTUS workspace along with simulation results for the designed robot movements. These results make us confident in thinking that the underlying design will be encouraging to build a more complex mobile-driven requirements robot later on.

References

[1] T. Braunl, "Embedded Robotics; mobile robot design and applications with embedded systems", 2nd Edition, Springer, Germany 2006.

[2] X. Xue, S.X. Yang, M.Q.-H Meng, "Remote Sensing and Teleoperation of A Mobile Robot Via the Internet", IEEE Intr Conf. on Information Acquisition, July 2005.

[3] Engineers garage, "How to interface GPS with PIC18F4550 Microcontroller", Available: http://www.engineersgarage.com/articles/global-positioning-system-gps.

[4] Cellular-news, "What is GPRS?" Available: http://www.cellular-news.com/gprs/what_is_gprs.shtml.

[5] V. Nakka & A. Kabirdas, "Design and realization of augmented reality based navigation assistance system", Intr. J. of computer science and information technologies, Vol.2(6), 2011, pp2842-2846.

[6] G. Amato, M. Broxvall, S. Chessa, M. Dragone, C. Gennaro, & C. Vairo, "When wireless sensor networks meet robots", The 7th Intr. Conf. on Systems & Networks Communication (ICSNC2012), pp35-40.

[7] A. LaMarca, W. Brunette, D. Koizumi, M. Lease, S.B. Sigurdsson, K. Sikorski, D. Fox, and G. Borriello, "Plantcare: an investigation in practical ubiquitous systems", The 4th Intr. Conf. on Ubiquitous Computing, UK 2002, pp316-332.

[8] M. Rahimi, H. Shah, G. Sukhatme, J.Heideman, and D. Estrin, "Studying the feasability of energy harvesting in a mobile sensor network", IEEE Intr. Conf. on Robotics & Automation (ICRA03), September 2003, pp.19-24.

[9] R.C. Luo, and T.M. Chen, " Remote supervisory control of a sensor based mobile robot via Internet", Intr. Conf. on Intelligent Robots and Systems (IROS97), 1997.

[10] H. Ishida, T. Nakamoto, and T. Moriizumi, ? Remote sensing of gas/odor source location and concentration distribution using mobile systems?, Sensors and Actuators B: Chemical, Volume 49, Issues 1?2, June 1998, pp52?57.

[11] N. Wanga, N. Zhangb, and M. Wangc, "Wireless sensors in agriculture and food industry-Recent development and future perspective", Computers and Electronics in Agriculture , Vol.50, No.1, January 2006, pp1?14.

[12] A. Mandow, "The autonomous mobile robot AURORA for greenhouse operation?, IEEE Robotics & Automation Magazine, Vol.3, No.4, December1996, pp18-28.

[13] G.M. Acaccia, R.C. Michelini, R.M. Molfino, and R.P. Razzoli, "Mobile robots in greenhouse cultivation: inspection and treatment of plants" , First Intr. Workshop on Advances in Service Robotics, 13-15 March 2003, Italy.

[14] ELEC Freaks, "Ultrasonic Ranging Module HC-SR04". Available: http://elecfreaks.com/store.

[15] Arduino, "I/O Interface Board (Arduino UNO)". Available: http://arduino.cc/en/Main/arduinoBoardUno.

[16] S. V. Ragavan, & V. Ganapathy, "A unified framework for robust conflict free robot navigation", World academy of science, Engineering & Technology, 25, 2007, pp.88-94.

[17] SKYLAB, "SkyNav SKM53 Series, Ultra High Sensitivity and Low Power, The Smart Antenna GPS Module", Available: http://ar.scribd.com/doc.

[18] Tenvis, "IP Camera data sheet", Available: http://www.tenvis.com/jpt3815w-hot-pantilt-ip-camera.

[19] D. Floreano, F. Mondada, ?Automatic Creation of an Autonomous Agent: Genetic Evolution of a Neural-Network Driven Robot?, SAB94 Proceeding of the 3rd Intr. Conference on Simulation of adaptive behavior, USA 1994, pp.421-430.

Mohammed M. Ali received his BSc, MSc, and Phd degrees in computer and control engineering from The University of Technology, Iraq in 1981, 1993, and 1998, respectively. he is currently an assistant professor in the Department of Computer Engineering at Philadelphia university, Jordan. His research interests include fuzzy logic, neural netwiorks, image processing, and computer interfacing. he has 12 published papers related to neuro-fuzzy and real-time computer control applications.

Kasim M. Al-Aubidy received his BSc and MSc degree in control and computer engineering from the University of Technology, Irag in 1979 and 1982, respectivly, and PhD degree in real-time computing from the University of Liverpool, England in 1989. He is currently a professor and dean of Engineering Faculty at Philadelphia University, Jordan. His research interests include fuzzy logic, neural networks, genetic algorithm and their real-time applications. He was the winner of Philadelphia Award for the best researcher in 2000. He is also the chief editor of two international journals, and a member of editorial board of several sceintific journals. He has co-authored 4 books and published 76 papers on topics related to computer applications.