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Design and Implementation of a Wireless Security Robot

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ABSTRACT

Senior students in the Engineering and technology programs are challenged to thoroughly apply their learned technological knowledge and skills toward design and implementation of a challenging engineering product in senior deign or capstone courses. In this paper, a successfully implemented comprehensive design, which utilizes a synergy of competencies gained from undergraduate academic and research experiences with insight to the efforts concerning senior design project is presented. The main goal of this project was to design and implement a wireless security robot with camera and joystick control and obstacle avoidance capabilities. Initially, two goals concerning the final product were identified. These goals included a camera system to allow the user to capture pictures at variable angles and an obstacle avoidance system to detect obstructions.

Keywords: Wireless robots, Security robots, Senior design projects

1. INTRODUCTION

With the development of society and economy, as more and more high buildings and large mansions come forth, it is crucial to seek an automatic patrol solution (Zeng et al., 2007). Such automated patrol system may automatically detect the abnormal and hazardous situations and notify the user (Luo et al., 2005a). For instance, the indoor security problems such as fire, intruder, smog, etc can be solved by development of general type of security robot (Li et al., 2007). A security robot is characterized by mobile robot technology, security and information technology (Li et al., 2007). A functional security robot contains different working systems. These systems may include motion planning system, obstacle avoidance system, sensor system, image system, remote supervisory system, software development system and other systems (Luo et al., 2005b, Chien et al, 2005, Luo et al., 2005c). These systems can all communicate with each other through intelligent automation robot system (Luo et al., 2005c). Motion planning system is the system that drives and navigates a security mobile robot. As a robot navigates through a pathway, it needs to avoid obstacles on its way. An obstacle avoidance system provides such capability to a security robot. In order for the obstacle avoidance system to operate reliably, a sensor system needs to provide reliable information on the surrounding working environment. A sensor system may also detect abnormal and hazardous situations. Such situations are communicated with a remote supervisory system. An image system transmits the video of the situation to a remote supervisory system. A software development system is the program that overviews the operations of all the systems described. Proper operations of these systems enable a security robot to guard the safety of life and wealth of a building (Luo et al., 2006b).

In the recent years, much advancement has been achieved in the research and development of security mobile robots (Zeng et al., 2007, Lou et al., 2005a, Li et al., 2007, Lou et al., 2005b, Chien et al., 2005, Lou et al., 2005c, Lou et al., 2006a). (Luo et al, 2005a) developed a security robot, which was controllable from a remote supervisory station. The robot was capable of detecting fire and intruder. In such events, the robot transmitted the detection results to a cellular phone or client computer through internet. (Luo et al., 2005b) also developed a touch panel interface to control the robot from a remote supervisory station. (Chien et al., 2005) developed multiple interfaces to communicate with a security robot. This robot communicated with personal computer through wireless RS232, and communicated with a sensor node system using Infra Red (IR) interface, and communicated with other robots using Radio Frequency (RF) interface. (Luo et al., 2005c, Luo et al., 2006a) successfully utilized ultrasonic sensors, IR sensors, body sensors, a USB web camera in their obstacle avoidance system and implemented an adaptive fusion method for fire detection(Luo et al., 2006b). (Zeng et al., 2007) put the capabilities of their designed security robot in test by patrolling a supermarket over the course of three months. The results of the experiments indicated that the performance of their robot was promising. More advanced development was introduced as (Li et al., 2007) developed a team of security mobile robots, which operated in conjunction with an automated security control center. This center was able to assign different tasks and schedules to each robot in the team depending on the situation on the field. Another example of more advanced development is the works of Yoon-Gu et al., 2006a, Yoon-Gu et al., 2006b) where a security robot operates along with a sensor network. More advancement is expected in security robots particularly for the purpose of human face detection (Chia-Wei et al., 2007) and people identification (Treptow et al., 2005).

From educational standpoint, the design of a mobile robot is an ideal activity for learning by doing (Ahlgren, 2002). In such an activity, student teams create complex mechatronic systems by applying principles of physical science, mathematics, electrical engineering, mechanical engineering, and computer science (Ahlgren, 2002). To complete such activity, students must integrate knowledge gained from different classes such as circuits, controls, signals and systems, instrumentations, computer programming, mathematics, and engineering mechanics (Pack et al., 2004). The completion of such activity involves significant hardware and software development and integration applicable to mobile robots (Saad, 2007). Students become familiar with a variety of sensors, wireless digital cameras, and remote control systems (Saad, 2004). They also get exposed to sophisticated systems such as path planning systems, motion planning systems, obstacle avoidance systems, vision systems and feedback control systems (Paulik and Krishnan, 1999). The challenging nature of the activity generates excitement and motivation for students (Paulik and Krishnan, 1999). At the same time, it helps students gain experience working in interdisciplinary teams and learn the importance of technical communication through the written reports and oral presentations (Swift, 2003). Meanwhile, faculty members engage substantially with comprehensive design activities to support and supervise students (Paulik and Krishnan, 1999). For all that, it appears that the design of a mobile robot can be a very beneficial project for senior design capstone courses. Such a practice has been adopted by many engineering departments (Ahlgren, 2002, Pack et al., 2004, Saad, 2007, Saad 2004, Paulik and Krishnan 1999, Swift and Neebel, 2003, Paulik and Krishnan, 2001). In such departments, mobile robots may have been designed for different purposes. For instance, (Pack et al., 2004) designed a fire fighting mobile robot. (Saad, 2007, Saad, 2004) used mobile robot systems development in capstone design projects. (Paulik and Krishnan, 1999, Paulik and Krishnan, 2001) designed a mobile robot in a form of an autonomous ground vehicle in a capstone course. They imposed a competition-driven format to mimic the need in industry to carry out deadline-conscious products design. To the authors' knowledge, the design of mobile robot as security robot in a senior design capstone format is a relatively novel idea. It provides similar benefits to students and faculty as discussed earlier. For this reason, the design of a mobile security robot was assigned to engineering students as a senior design project.

2. DESIGN AND DEVELOPMENT

The designed robot consists of three servos. These motors control the motion of the robot in whichever direction the user desires. A joystick controller controls all the robot's servo motors. A four channel camera wirelessly transmits images to a receiver and the receiver sends the images to a screen with a user interface. The camera is mounted on top of a platform which contains a gear system.

The structure of the wireless robot consists of two mobile platforms, a vision system, a wireless control system, and an obstacle avoidance system. The main design is based on a development board by STAMP microcontroller, but many parts such as remote controller, camera, gears, electronic components, specialized servos, sensors, and the receiver board was produced by other retailers.

2. 1 THE MOBILE PLATFORMS

The robot consists of two mobile platforms; one for movement of camera and the second one for mobility of robot.

The camera platform is based on a gear system that contains three small gears of 60 tooth with 14.46mm in diameter and three big gears with diameter of 65.04mm. In addition to the gear system, the platform consists of a motor that is connected to the base of the platform, a flatbed that is a flat surface at the top of the platform which host the camera, two plastic poles that hold up the flatbed, a stopper that was designed so that the camera does not rotate to an undesired angle, and a color four channel camera which wirelessly transmits 0.3 mega pixels resolution images to a receiver that sends the images to a screen with a user interface. The motor receives its command of motion from a signal which is transmitted from a receiver.

A stopper had to be placed either at the gears or on the motor controlling the gears so that when the appropriate angle is reached, the platform would stop rotating. The maximum angle the platform should rotate is 45 degrees from its base of origin in both directions. This will ensure that other components are not damaged on the robot. The stoppers would ensure that the gears would not rotate past the set limit and thereby eliminating the concern that other parts of the robot would be damaged extensively due to over rotation of the platform.

The robot mobility platform consists of a chassis, two wheels on the back, and one wheel in front. Two servo motors provide the force needed for robot motions through the two back wheels.

2.2 THE VISION SYSTEM

The vision system consists of a camera platform, a color camera unit, a camera receiver, an RCA cable, and a control unit.

The camera is mounted on the top of the camera platform. The operating range of the camera is about 150 feet and its frequency is 2.4 GHz. The camera does not require a separate battery because it uses the same 9 volts power source as the robot. The weight of the camera is 0.15lbs. The camera receiver requires four AA batteries (6v) as separate power source to function and receive the transmitted images from the camera. The transmitted images are sent to a computer or an external screen via an RCA cable which is 6ft long. The weight of the transmitter without the batteries is 0.25lbs. The approximate dimensions of the camera receiver are Length 4.0 in., Width 2.8 in., Height 2.9 in. and it weighs 0.25lbs.

The gear system and camera platform as shown in figure 1 provide the camera system with the ability to take pictures with great angular freedom, thus, satisfying one of the design goals.

2.3 THE WIRELESS CONTROL SYSTEM

The control system is made up of two different units; a joystick controller unit and an electronic receiver board.

The joystick controller, which is shaped like a video game controller, controls all the servos on the robot. The robot consists of 3 servos; two on the chassis of the mobility platform that are connected to the two wheels and one at the base of the camera platform which is connected to the gear system. These motors control the motion of the robot in whichever direction the user desires.

A wireless controller sends the signal to the receiver and indicates the direction that robot should navigate. The extent of gear rotations depends on the extent the button on the controller is pressed.

The joystick controller transmits at a frequency of 27MHz to the receiver circuit which is mounted on the rear end of the robot. It requires a 9V battery to be powered and it transmits to a receiver circuit on the robot which in turn transmits the signals to the three servos which are on the robot. The joystick on the controller controls the motion of the robot while the buttons control the camera platform. The figure 2 represents the receiver board that has a separate housing at the rear of the mobile robot.

Figure 1: Camera Platform of the Vision System

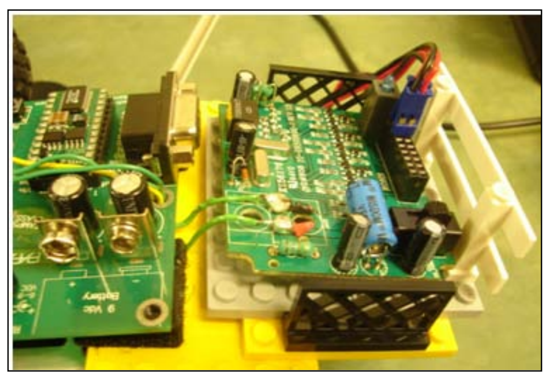

Figure 2: The receiver Unit of the Wireless Control System

2.4 THE OBSTACLE AVOIDANCE SYSTEM (OAS)

The objective of obstacle avoidance system is to navigate around an object of any size by going from on-course to off-course and back to on-course. This is an autonomous feature that allows the mobile robot to distinguish obstacles and execute the proper protocol which manages its behavior. Therefore, the mobile robot had to successfully be outfitted with a comprehensive system for obstacle detection and avoidance. The mobile robot's obstacle avoidance system has been designed with three elements; ultrasonic sensors, an Obstacle Avoidance Circuit (OAC), and an Obstacle Avoidance Program (OAP).

The obstacle avoidance system was developed to prevent the mobile robot from accidentally be driven into an object in its path. The figure 3 represents the block diagram of the Obstacle Avoidance system. As shown in the figure 3, the OAS's digital logic structure reflects the output of the ultrasound sensor. The OAS generates two ultimate outcomes: "Power ON" and "Power OFF". If the power for the receiver board module is ON, then communications between the joystick and the mobile robot is functionally intact. But if the power for the receiver board module is OFF, then the communications between the joystick and the mobile robot is severed. As the diagram illustrates, there is a complex structure of events involved in the mobile robot and the OAS's "powering ON" and "powering OFF" procedure. This is mainly due to the fact that the Obstacle Avoidance Circuit (OAC) has been "coupled" to the mobile robot's multiple power supplies.

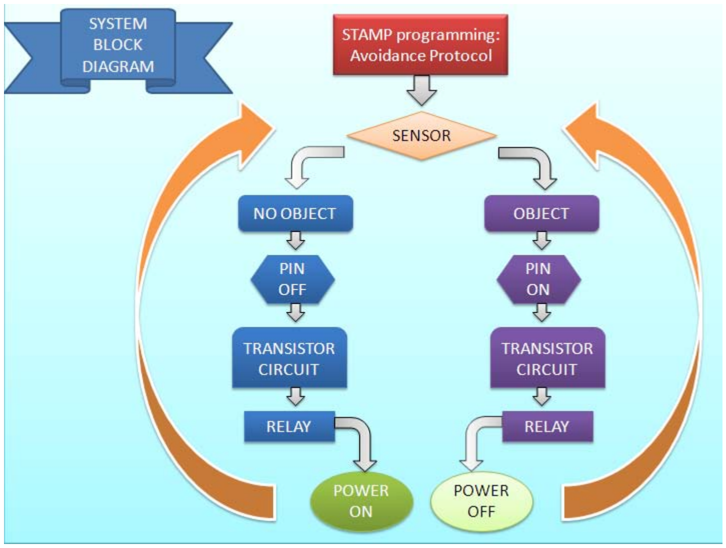

Figure 3: Block Diagram of the Obstacle Avoidance System

The Component Block Diagram of OAS as shown in figure 4 provides a physical representation and pictorial analysis of the OAS. The flow of the chart mirrors the System Block Diagram but more emphasis is laid on the physical realization of its block components. Additionally, the "Transistor Circuit" and "Relay" diagrams are shown along with their implemented versions on the mobile robot.

2.4.1 The Obstacle Avoidance Program (OAP)

The obstacle avoidance program is a STAMP program which is written to provide the mobile robot with the artificial intelligence capability to conduct a series of calculations based on a varying input gathered by the ultrasonic sensor. The OAP is composed of variable definitions, conversion calculations, and conditional statements associated with their corresponding loops.

The dependant variable, or output, of the Obstacle Avoidance Program (OAP) is an integer value concerning the distance in reference to the detected object. This value is tabulated and recorded through the STAMP microcontroller by the OAP. Then, this distance value is referenced in the appropriate loop outside the body of the OAP. "IF THEN" statements have been implemented for forwarding the program to the approved loop which turns "OFF" or "ON" the I/O. Additionally, each of these loops executes one of several "alarm commands" via the piezospeaker. Every corresponding "alarm loop" features a unique sounding alarm that is determined by a pre-set distance value. The closer the object is to the robot, the more irritable the sound becomes, and the furthest it is;

the less irritable it is. The tones are programmed based on frequency, length of tone, and "pause" parameters. By implementing these "varying tone" alarms, the user will be alerted whenever an object is detected and/or approaching. The OAS has been programmed to shut down the motors once the object is detected 4 inches away from the robot. At this point, for 5 seconds user will lose control of robot. Once the 5 seconds elapses, the user regains control of the mobile robot for just 3 seconds in order to manually, via remote controller, move the robot out of the path of the object. This operation of powering ON and OFF the motors continues until the object is fully out of this "4 inch range" of the robot. The OAP goes through a series of infinite loops; repeating these procedures based on the ultrasound sensor's real time data collection until the mobile robot's power supply is disconnected.

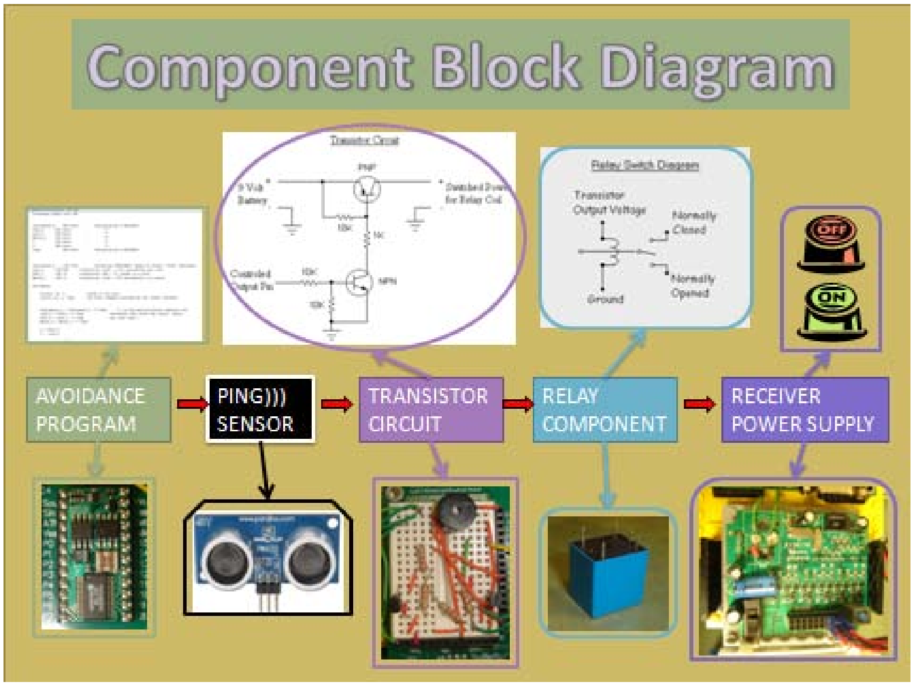

Figure 4: Component Block Diagram of OAS

2.4.2 THE OBSTACLE AVOIDANCE CIRCUIT (OAC)

The control function of the obstacle avoidance circuit as seen in figure 5 utilizes the "switching" functionality of the bipolar junction transistor (BJT) and a relay. The BJT was utilized as a switch because the 5 volts generated from the I/O pin of the microcontroller were not sufficient to power a "7-9 Volt relay". Thus, the relay is powered by implementing a "switching" transistor circuit. The "switching" function of the transistor was utilized for the process of using the voltage between two terminals to control the current flowing in the third terminal and, therefore, the current in the third terminal can be controlled. We adapted the "Darlington Pair" schematic to fabricate our OAC featured.

The obstacle avoidance circuit is initialized through the obstacle avoidance program. The ultrasound sensor was used to transmit and receive a chirp signal in robot direct line of path, and then, the OAP is executed to calculate an object's distance relative to its sensor. This distance value is crucial, for it will govern all operations for the greater obstacle avoidance system.

The 9-Volt battery is connected to the "common contact" because it provides ample voltage to power all our components from the receiver board, i.e. the servos and the camera system. Since the coil is not energized, it is "normally closed" contact, will power the receiver board with all its 9 volts. Therefore, the receiver module is powered up and at its ON setting.

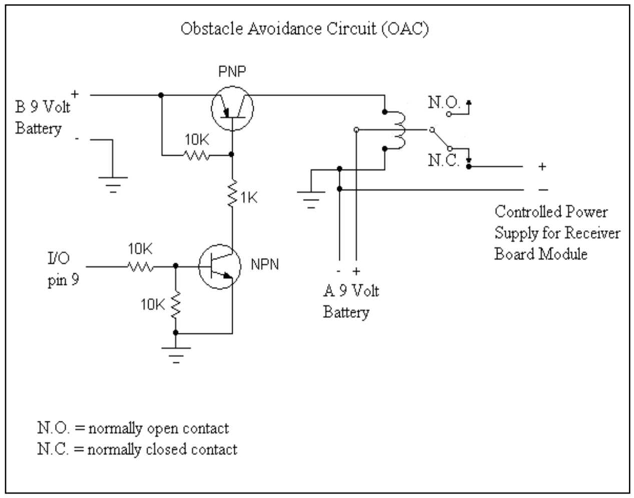

Figure 5: The Obstacle Avoidance Circuit

In order for the OAS to "power down" the receiver module, it has to execute the following procedures sequentially: the OAP will turn ON the 5-Volt I/O pin, which in turn, is inputted into the transistor circuit as the "Controlled Output Pin", which in turn, passes the current from the "B 9-Volt battery", consequentially, generating the necessary 9 volts current to energize the coil of the relay, which in turn, moves the armature up from its "normally closed" contact to the "normally open" contact. Therefore, the receiver board will turn off because the receiver board's power is connected solely to the "normally closed" contact. If the receiver board is turned OFF then, the radio link between the remote controller and transceiver module is severed. Therefore, the joystick will no longer control the mobile robot unless the power is re-routed via our OAP. The OAP has been programmed in such a way that it returns "remote control" to the user after a "5 second period" elapses. But, the OAP re-routes to "remote/user control" only for 3 seconds before the OAP resets and restarts. Thus, it runs the entire program with a newly sensed distance value. The OAS repeats this process every 50 microseconds, depending on object detection, and is designed to continue this operation through an undefined/infinite number of loops in real time, autonomously.

The OAC as shown in figure 6 is fully realized on the main breadboard and underneath the mobile robot as depicted in figure 7.

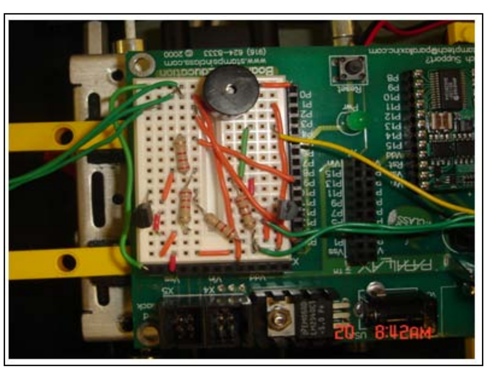

Figure 6: The Obstacle Avoidance Circuit

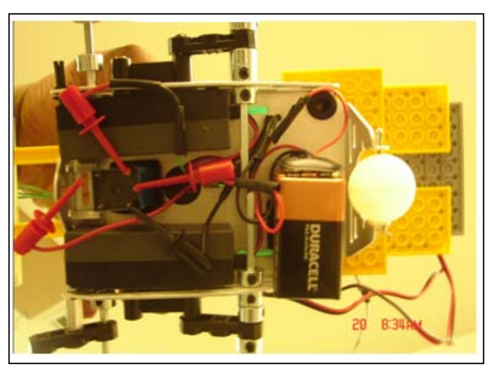

Figure 7: The Obstacle Avoidance Circuit

The “neck” as shown in figure 8 was designed to provide ample space for the sensor to execute its ultrasonic bursts without signal interferences. The ultrasound sensor sits securely on the auxiliary breadboard and is connected to the main breadboard via three jumper wires.

The designed wireless security robot is shown in the figure 9. None of the components from the bottom of the mobile robot were glued to the platform because several of these components would eventually need replacing. Instead, Velcro squares were selected as the preferred choice opposed to gorilla glue or metals-to-plastics glue. Velcro not only provided us with plenty of surface area grip, but it also allowed the platform to be easily taken apart and rebuilt.

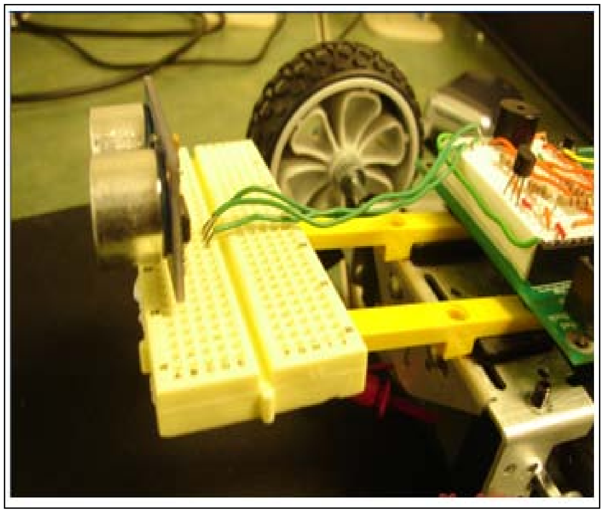

Figure 8: The Ultrasound Sensors of the Obstacle Avoidance system

Figure 9: The Designed Security Robot

3. CHALLENGES AND ISSUES ENCOUNTERED

Initially, the first gear system was constructed out of metal which consisted of two L shaped metals and a flat platform at the top which host the camera. The two L shaped metals was used side by side from the top of the platform to the bottom of the platform and provided the support for the flat surface on top where the camera sits. The gears were located in between the L-shaped platforms and the motor was placed at the bottom of one of the L-shaped metals. The motor was connected to a 14.46mm gear at the bottom of the platform which was connected to a 65.04mm gear.

After the platform was completely assembled and placed on the robot, a few problems were encountered. Due to the metal material which was used to construct this platform, the platform was too heavy for the chassis of the robot. The weight of the platform slowed down the mobility of the robot because of the weight of the platform and the other components which were present on the robot exceeded the weight limit which the chassis of the robot could handle.

The issue had to be resolved by constructing a completely different camera platform out of another material which would not weigh down the chassis of the robot thereby causing immobility or speed reduction.

After research and trial/error, it was decided that the appropriate material for the platform would be plastic. A plastic camera platform was constructed using the previous metal prototype platform. The new plastic platform is similar to the metal platform but it is smaller and more durable than its predecessor. It weighs less than a quarter of the metal platform because of the plastic components. The plastic platform was assembled and a few test-runs were done off the robot to see how well it functions. At first, there were a few kinks but after adjustments and alterations, the platform was finally complete and ready to be mounted on the robot.

4. CONCLUSIONS

The undergraduate students have difficulties making decisions based on their knowledge, information gathered, budget, and time limitations. The education experiences were enormous for the students involved in this project. They gained valuable insight of systematic approach to design process and implementation of many areas offered in their curriculum.

Students have successfully designed a comprehensive wireless security mobile robot which incorporates the criteria that originally aimed to satisfy. The robot is remote controlled and has the capability of capturing pictures at various angles as it moves throughout its environment. Additionally, a comprehensive obstacle avoidance system has been designed which successfully detects and prevents the mobile robot from hitting nearby obstructions.

Implementation of this project was requirements of two consecutive capstone design courses and was accomplished through numerous hours each week for a year by three senior electrical engineering students. The educational experiences gained in this project were invaluable for the students and they had great collaboration and interaction with each other and course instructor who acted as project mentor. Though each individual team member had their own unique assignment with regard to the project, they were able to combine all their individual efforts into one form as a team and designed a new product. This senior design project has been challenging for students. But they, as a team, were able to pull together and build the mobile robot which satisifies all the design requirements that were laid out as project criteria.

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