Computer-Assisted GOAL-Oriented Walking Robot

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Abstract

The paper discusses a senior design project which was implemented during a two-semester course, Senior Design. These two courses are the capstone courses in Electrical Engineering Technology curriculum offered in seventh and eighth semester. This project and similar projects provides the student a unique opportunity to design and integrate the knowledge and skills acquired through number of different courses.

The paper will elaborate the project "Computer Assisted GOAL Oriented Walking Robot" the design of which requires knowledge in the area of general electronics, speed and direction control of stepper motors, microcontroller embedded system design, firmware design of microcontroller, wireless communication, PC based system design, software design for PC, hardware software integration and use of transducers.

I. Introduction

As per Webster's Dictionary, a ROBOT is an automatic device that performs functions normally ascribed to humans or a machine in the form of a human. The applications for robotics are plenty and everywhere. Most modern assembly lines use robotic arms wherever consistent, quality, tireless work is required. The Mars Rover traversed the surface of Mars for weeks sending back valuable pictures and data about the planetary environment. Robotic toys such as Sony's "Aibo" and "I-Cybie", perform functions that 50 years ago, were science fiction dreams. The following paper will describe the design and construction of Computer Assisted GOAL-Oriented Walking Robot, also known as CAGOR. While this system is not quite ready to take the place of a human, it is possible with more development, that CAGOR could perform more complex functions with complete autonomy. Robots like CAGOR could be used for many applications where it would not be feasible, cost effective, or just too dangerous to use humans. Possible profitable commercial applications include but not exclusive: surveillance, bomb diffusing, mine sweeping, space exploration, remote viewing of hazardous environments and disaster victim detection. With little modification, CAGOR could also be turned into the next generation of interactive pets. The robot could "learn" the layout of a house and navigate the terrain with ease, overcoming obstacles as they arose.

II. System Description

Computer Assisted GOAL Oriented Walking Robot CAGOR is designed to find an object placed in a room by analyzing data from its own internal sensors and instructions transmitted from a local PC. The local PC is equipped with a user interface program written in Borland C++ (Figure 1-1). When an individual accesses the user interface, they will be asked to enter the appropriate grid pattern for the hexapod to follow. The user will be provided with a "hexapod path" sheet to plan the path for the robot. Each box on the path sheet represents 1-foot square on the floor. It is up to the user to "roughly" estimate the distance to the GOAL object. Complete accuracy is unnecessary because the robot's infrared sensor will take over when it gets within 4-feet of the GOAL.

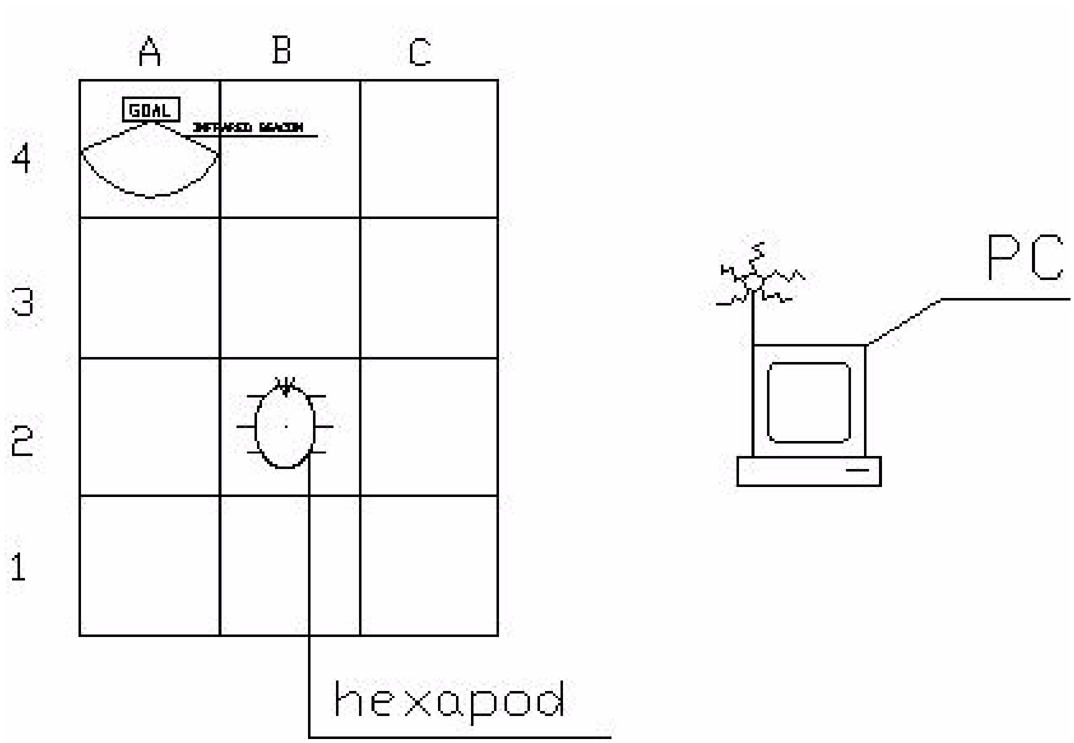

Figure 1: Floor diagram

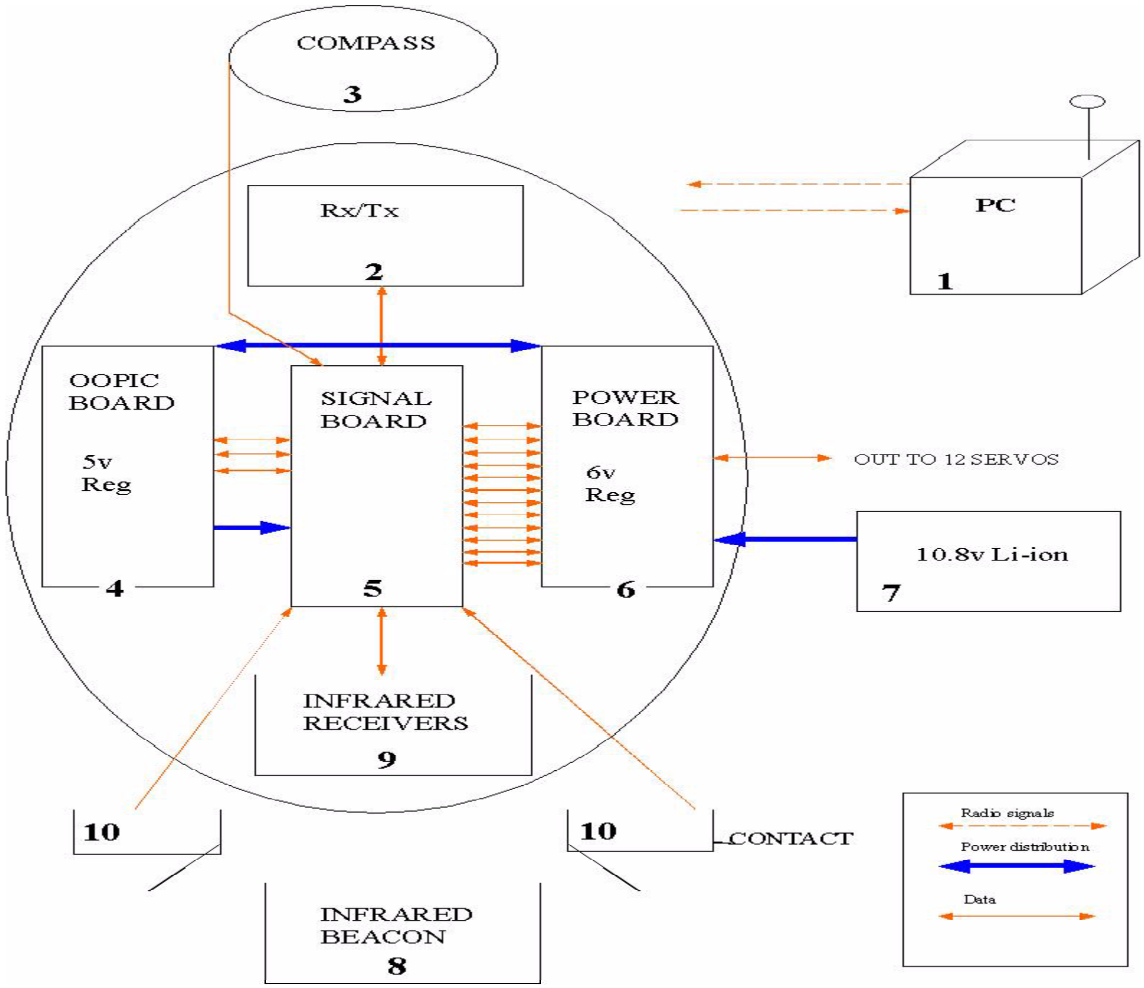

Figure 2: Functional diagram of CAGOR

The GOAL object is designed to emit a light pulse with an adjustable range of 2' – 20" (8 in Figure 2). When the hexapod enters a pre-determined radius, it will detect the infrared signal on one of its three receivers. The robot will then autonomously seek the GOAL object, keeping the object "in its sights". When contact is made with the GOAL, the robot will display a mesmerizing light show, and send a signal back to the PC which will indicate that it has attained its objective.

2.1 Platform Construction

The chassis for CAGOR was designed using "AutoCAD 2000" for its ability to give precision to the drawings and for construction of all parts on the robot.

The structural parts of the robot are composed of a lightweight acrylic thermoplastic resin, similar to *plexi-glass*. Although the motors being used are strong; the weight of the robot is directly proportional to the load that it can carry. Thus, the thickness of the thermoplastic plates must withstand twist and flex and be rigid enough to maintain leg pivot linearity. CAGOR has many circuits on top; therefore the platforms must support this weight while maintaining structural integrity.

Leg Design

A hexapod has a distinct advantage over other land roaming robots; it has ability to cross uneven terrain. Nature has developed, over time, the most efficient ways for animals to roam around. We have keenly observed at what nature has evolved and implemented these ideas into a machine by using legs with articulating joints under software control.

The initial design was developed after researching the leg movements of insects and of previously developed walking machines [1] [3]. The legs must enable lift, support, forward and backward mobility, and the capability to turn the hexapod. We opted for a simple double lever design for the leg assembly.

We opted for servo motors as they are small and self-contained as opposed to stepper motors and dc motors. We have used "Hobby" servos but they provide only the rotational movement. The legs on the robot require linear vertical movement. We overcame this in our design by employing an infinitely variable crank design a mechanism that works very much like a shaft-piston in an internal combustion engine. The rod is connected to the servo consisting of a hand bent piece of 4-40 threaded rod with a ball-link socket on one end and a screw clamp fitting to hold the other end. The fitting can be adjusted with a flat blade screwdriver. Lifting distance and space requirements put the leverage at a disadvantage for the servo motor. The fulcrum is located 1/3rd the total distance from the end of the lever. This produces approximately 19 oz-in torque at the maximum voltage during the weakest part of the stroke.

Each motor is gear reduced for strong torque (56.9 oz-in @6V). Our servo has ball bearings around the main pivot gear for smooth motion. Bearings also cut down on noise. Each leg has two Futaba S3004 motors on six total legs; the hexapod will have to support 12 servos simultaneously.

2.2 Microcontroller Based Design

We have implemented the servo control functions using the OOPic II module from *Savage Innovations* (4 in Figure 2). Both the OOPic and the popular Basic Stamp are programmable microcontrollers that utilize a serial EEPROM to store a set of instructions that execute when power is applied. Once a program is written and compiled, it is downloaded to the microcontroller via a cable attached to a PC. The OOPic II comes with a 4k EEPROM installed which can be expanded to 64k. We have used 32k EEPROM.

The OOPic module has 32 I/O lines that are user-definable through the compiler. These lines are available for interfacing through the OOPic's 40-pin header making it compatible with a standard IDE cable. CAGOR makes use of all of these I/O lines to function properly:

2.3 Software Design

The software for the robot falls into two categories. The first category of software resides on a PC and is written in C++, developed using Borland Builder. This software accomplishes communication between a remote user and the robot. The second category of software is the embedded software within the robot, is written in OOPic C and is directed towards the OOPic processor which is the heart of the robotic system. This software performs all of its major functions.

2.4 The Tripod Gait

The evolution in Nature has not produced the mechanism of wheels. Most land animals and insects have legs that allow them to move on rough terrain and traverse long distances. CAGOR uses a primitive form of the tripod gait, a simple form of locomotion adopted and perfected by insects, eons ago. The tripod gate has been so successful because its very nature is so stable. Three legs are on the ground at all times, the same reason a 3-legged bar stool never wobbles.

<u>Pulse Width Modulation</u>

The hexapod requires 12 servos for locomotion, two servos per leg. One servo controls the up and down motion and the other controls the pivoting motion, forward and reverse. To understand the fundamental of how the robot actually moves, a brief discussion of how servos work is important.

Servos are commanded through "Pulse Width Modulation," or PWM, signals sent through the command wire. Essentially, the width of a pulse defines the position. For example, sending a 1.5mS pulse to the servo, tells the servo that the desired position is 90 degrees. In order for the servo to hold this position, the command must be sent at about 50Hz, or every 20mS.

2.5 Design of Sensors

Much care was taken in designing the sensor systems for the robot. They needed to be reliable, accurate, and have low power consumption. The following sensor scheme is used in CAGOR:

1. A Vector 2x compass module - used for compass correction.
2. Modulated infrared receivers – used to find the infrared beacon (GOAL).
3. Rx/Tx – used for bi-directional communication with the PC.
4. Contact switches – makes contact with GOAL.

2.5.1 Compass Module

The design of the hexapod calls for the use of a compass module for course correction with a reasonable degree of accuracy (3 in Figure 2). We used the Vector 2x module from *Precision Navigation*. When placed horizontally, this module is capable of producing course headings within 1°. Its moderate price ($59), low power consumption and size also made it appealing for this project [5].

CAGOR utilizes compass data in two ways. When polled by the program, the compass returns a binary value of 0 – 255 to the microcontroller indicating its direction. This direction is then stored in a variable for use later in the program.

1. <u>Direction Setting</u>

   Because the very nature of its locomotion system, the robot may drift off course. The hexapod is designed to compensate for errors. After traveling 1 foot forward, the program makes a call to make a compass reading. To compensate for residual motion in the chassis and for maintaining accuracy, five compass readings are taken, averaged, and the result stored in a variable. The variable is then analyzed by the control program and depending on which of four broad ranges the value falls, the robot will know whether it is going North, South, East or West. This is referred to as "Direction Setting" and is accomplished by the following code:

```
Sub void direction_set (void)                    //Sets the direction for course correction
{
If ((vector.Value < 33) | (vector.Value > 223))
{
dir.Value = 6;                 //NORTH
}
Else
{
If ((vector.Value < 223) & (vector.Value > 160))
{
dir.Value = 8;                 //EAST
}
Else
{
If ((vector.Value < 160) & (vector.Value > 96))
{
dir.Value = 7;                 //SOUTH
 }
 Else
 {
 If ((vector.Value < 96) & (vector.Value > 33))
 {
 dir.Value = 9;          //WEST
 }}}}}
```

2. <u>Compass Correction</u>

   Depending on the value of the "Direction_Set" variable, the robot jumps into the appropriate loop where it corrects itself to one of the four magnetic directions, refered to as "True Checking". The following code excerpt demonstrates that depending on the value of the Direction_Set variable (dir.Value), the control program will call a motor control function to make a small course correction. After each correction, the robot confirms its magnetic heading, and continues to make adjustments until it is aligned within ± 7° of the true compass direction. After correction has been completed, the robot contacts the PC for the next step in its path.

```
Sub void true_check (void)
{
switch (dir.Value)
{
Case 6:         //NORTH
while (( vector.Value > 223) & (vector.Value < 248))
{
lcorr;  //TURN SLIGHTLY LEFT
compass_read;
}
while (( vector.Value > 7) & (vector.Value < 33))
{
rcorr;  //TURN SLIGHTLY RIGHT
compass_read;
}
break;
Case 7:         //SOUTH
while (( vector.Value > 135) & (vector.Value < 160))
{
rcorr;
compass_read;
}
while (( vector.Value > 96) & (vector.Value < 121))
{
lcorr;
compass_read;
}
break;
Case 8:         //EAST
while (( vector.Value > 160) & (vector.Value < 185))
{
lcorr;
compass_read;
}
while (( vector.Value > 198) & (vector.Value < 223))
{
rcorr;
compass_read;
}
break;
Case 9:         //WEST
while (( vector.Value > 57) & (vector.Value < 33))
{
lcorr;
compass_read;
```

```
}
while (( vector.Value > 71) & (vector.Value < 96))
{
rcorr;
compass_read;
}
break;
}}
```

CAGOR uses an elaborate infrared scheme to find its GOAL. An infrared beacon or GOAL is set up on the arena floor that emits a modulated infrared signal. Depending on the robots orientation one of three infrared receivers will pick up the infrared beacon when it comes into range.

2.5.2 Infrared

The IR sensors on CAGOR are adjusted in such a way so that it can make course adjustments that will enable it to hit the GOAL "head-on" (8 in Figure 2). In the control program, the forward detector takes priority over the side detector, meaning that as long as the robot "sees" the signal in its forward sensor, it will continue forward. If the signal falls out of range, it will be picked up by one of the side sensors and the appropriate course correction is made until the beacon falls within the range of the forward sensor.

The forward facing receiver has an adjusted field of view of 25° and a range of four feet. The Left and Right receivers were offset from the forward detector by 25° and given a field of view and range of 35° and four feet respectively. This gives the robot a total frontal field of view of 90°-95° in which to locate the GOAL. Obviously if none of the sensors "sees" the beacon, then the robot is either beyond four feet of the GOAL, or the GOAL is not within its field of vision. It is the PC control programs responsibility to get the robot within these ranges until the IR can take over.

2.5.3 Contact Switches

Two contact switches are used to indicate when the robot has made contact with its GOAL (10 in Figure 2). When one or both of the switches are triggered, a logic high is sent to the OOPic. This triggers the control program to send a signal back to the PC indicating that the GOAL has been acquired. A logic high is also sent to the circuitry that controls the lights causing them to flash and give off a celebratory light show.

2.5.4 RX/TX

CAGOR and the PC are equipped with identical transmitters and receivers permitting bi-directional, 8-bit wide, half-duplex communication between the robot and the PC (2 in Figure 2). The TWS-434 transmitter operates at 433.92MHz and has an output of 8mw, allowing for a range of 200' indoors and 400' outdoors when an appropriate antenna is used. The OOPic send data to the HT-640 where it will be encoded serially and then sent to the TWS module for transmission. In the RWS-434 receiver the carrier wave is removed and the data is available serially at the output. This serial data is then decoded by the 8-bit HT-648L decoder and sent to the OOPic for interpretation [6].

2.6 Power Considerations

Under full load, the robot draws around 2.5A. We selected Lithium Ion (Li-Ion) batteries (7 in Figure 2). Li-Ion batteries are used in many applications such as laptop computers and cell phones because they are extremely lightweight, space saving, and long lasting. They are expensive, however. The battery pack used for CAGOR is from a *Gateway* laptop. CAGOR can run off of this 10.8v, 2600mAH for over an hour before it needs a 4-6 hour recharge.

III. Summary and Future Work

The CAGOR was built and tested. It performs all the basic functions for which it was designed. However, there is room for improvements; most notably in the construction of the legs. The plexiglass used for building the legs is too weak and bends easily. Because of this the robot "jerks" and "wobbles" when it walks, forcing us to reduce its forward speed.

A more versatile user interface can be written. The original proposal included a provision for a Graphical User Interface at the PC. Due to time limitations, we were forced to write a DOS based program. While the DOS program adequately does its job, a GUI program might prove to be user-friendly.

New sensors could be installed allowing ranging capabilities that the hexapod currently does not have. Perhaps a camera could be mounted that could wirelessly transmit video data to the user interface program. A camera could allow a remote user to control and access the robot via the Internet.

During the course of this project we have worked with wireless data transmission, microcontrollers, C++ programming, Assembly programming, schematics, soldering, mechanics and interfacing computers with "real world devices". We have worked with enough power tools to open up a small machine shop that specializes in Acrylics. And have learned first hand about importance of precision and accuracy in our cuts and measurements. This is an important project, one that can easily be expanded on in the future. With continued research and development, project CAGOR will most certainly "evolve" to perform even more complex tasks and operations.

IV. PEDAGOGY

This project was accomplished by a team of two students for the Capstone course "Senior Design I & II". These two courses are required in the Electrical Engineering Technology Curriculum. These two courses are taken in the 7^{th} and 8^{th} semester of bachelor degree program. In this project students were able to integrate different segment of competencies from their discipline into a viable commercial grade end product. The team concept is emphasized and provides an environment for Cooperative and Discovery Learning. The role of faculty adviser is to facilitate and guide the students. At the same time being cognitive of the fact that faculty should shun from leading the students. These courses further provide the students a platform to engage in Interactive Learning. This process of self directed learning once triggered translates into a life long learning process which is both rewarding and intellectually stimulating.

References

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[6] Reynolds Electronics 3101 Eastridge Lane Canon City, CO. 81212. www.rentron.com

Biography

CHANDRA R. SEKHAR is a member of the faculty of the Electrical Engineering Technology at Purdue University Calumet. Professor Sekhar earned a Bachelor's Degree in Chemistry from the University of Madras (India), a Diploma in Instrumentation from Madras Institute of Technology and Master's Degree in Electrical Engineering from University of Pennsylvania. Professor Sekhar's primary teaching and research focus is in the areas of Biomedical and Process Control Instrumentation and Clinical Engineering.

OMER FAROOK is a member of the faculty of the Electrical Engineering Technology Department at Purdue University Calumet. Professor Farook received the Diploma of Licentiate in Mechanical Engineering and BSME in 1970and 1972 respectively. He further received BSEE and MSEE in 1978 and 1983 respectively from Illinois Institute of Technology. Professor Farook's current interests are in the areas of Embedded System Design, Hardware – Software Interfacing, Digital Communication,

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THEO MARYONOVICH received his B.S. in Electrical Engineering Technology with an option in Computers, Telecommunications and Networking from Purdue University Calumet in 2003. He is currently working as an independent consultant in the area of robotics. His current interests reside in software design using C^{++} and in embedded systems. He has received numerous awards for the development of "Computer Assisted GOAL-Oriented Walking Robot" and various other semester honors.

CHRIS NETHERTON received his B.S. in Electrical Engineering Technology from Purdue University Calumet in 2003. He currently is working as an independent consultant in embedded systems design. His current interests reside in control systems, programming in C^{++} and Assembly. He has received numerous awards for the development of "Computer Assisted GOAL-Oriented Walking Robot" and various other semester honors.