Amphibious Spherical Explorer

Project Proposal

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1 INTRODUCTION

1.1 Title and Objectives

This project intends to build a amphibious spherical explorer, which is a spherical robot that can perform data collection tasks on load or in water. Our concentration in ECE is control system. Therefore, we want our senior design to be an application of control. Inspired by spherical robots in movies such as Star Wars and Jurassic World, we decided to create one of our own. After we conduct a series of researches on spherical robots that are currently in the market, we come to realize those robots are run on a fairly unstable mechanism which causes wobbly movements. Therefore, we would like to challenge our knowledge on control by using a different implementation which may eliminate the instability issue that we observe from those other spherical robots.

1.1.1 Goals

- Eliminating wobbly movements.
- Optimizing the size of PCB board.
- Improving the robustness against collision.

1.1.2 Functions

- Traveling in extreme conditions such as water, desert, swamp, etc.
- Collecting data using interchangeable task module
- Sending control signal from PC to the explorer.

1.1.3 Features

- Pendulum drive mechanism.
- Superior mobility and versatility.
- Expandability to various interchangeable task modules

1.1.4 Benefits

- Spherical shape enables the robot to pass low-accessible areas.
- Improvement balance control makes the robot perform stability-demanded tasks like videoing.

2 DESIGN

2.1 Block Diagrams

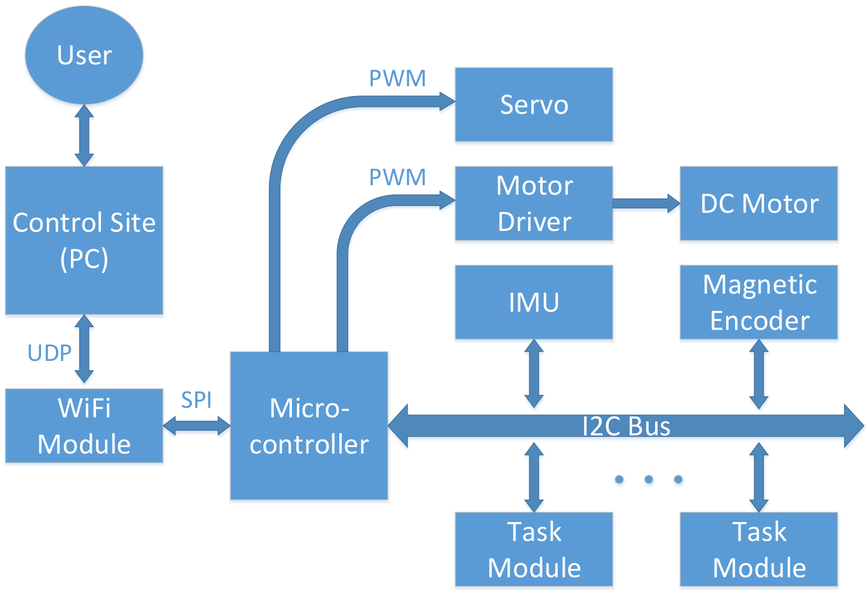

Figure 1. Block diagram of the system.

2.2 Block Descriptions

2.2.1 Control Site

The control site is the personal computer that runs a program (tentatively MATLAB) for communication. This program mainly perform two tasks: sending commands to the robot to control the actions, as well as receiving and decoding the information sent back from the robot. Communications in both directions are completed via IEEE 802.11 (WiFi) and User Datagram Protocol (UDP). The WiFi access point is created by the control site.

2.2.2 WiFi Module

WiFi Module is the communication module of the robot. The WiFi module works in passive mode, which only connects to the access point created by the control site, and works as client, which periodically sends and pulls data from the server, the control site.

2.2.3 Servo

The servo control the relative position between the spherical shell and the internal weight of the robot. By shifting the center of mass with a deviation from the vertical, the servo can adjust the balance and control the turn when moving forward or backward.

2.2.4 Motor Driver

The motor driver is a switch or amplifier. There is a MOSFET H-bridge circuit inside the motor driver. Its on/off state is controlled by the square waves generated by the microcontroller. The duty cycle of the square wave will determine the effective voltage applied on the motor and therefore control the power of the motor. This is known as Pulse Width Modulation (PWM).

2.2.5 DC Motor

The DC motor drives the robot forward and backward. Unlike ordinary wheeled vehicle motors, it does not drive the robot directly. This motor, along with the mass, hangs on a fixed axle inside the sphere. When moving forward, the motor gives the mass that hangs on the motor a disturbance to the front, away from the vertical. At the same time, the gravitational torque will drag the whole robot rolling forward. Repeating this process will keep the robot moving forward.

2.2.6 Inertial Measurement Unit (IMU)

The IMU consists of a three-channel gyroscope and a three-channel accelerometer. Data from the both sensors can be transformed into attitude angles with the help of a patented algorithm. However, since we do not pay for such algorithm, a simplified version will be developed and used as substitute.

2.2.7 Magnetic Encoder

The magnetic encoder is a sensor measuring the angular displacement of the rotor of DC motor. The sensor consists of a Hall effect sensor and a magnet. When the magnet rotates along with the rotor, the Hall effect sensor can measure the change of magnetic field and return the angle rotated. Angular speed of the rotation can also be obtained by differentiating the angle measured.

2.2.8 Microcontroller

The microcontroller is the core of the system, which takes charge of control and signal processing. It implements the following functions:

- Reading/transmitting data from/to sensors and the communication module via I^2C, SPI and UART.
- IMU Algorithm implementation.
- Controller implementation.
- Control on actuators using PWM.

2.2.9 Task Module

As a feature of "modular design", the task modules are modules for extended use. The modules communicate with the microcontroller via I^2C (some of them UART) to perform different tests. Some tentative choices, including temperature sensors, audio recorder or even digital camera, are commercially available. As long as the corresponding library are built as interface to the firmware, the users can customize their robot according to their purposes.

2.3 Technical Overview

Due to the inevitable yet unforeseeable adjustments that will be made, this project will require a fair amount of time investment. Unlike a typical embedded systems project, it is much more complicated to modify a control systems project. Changes will more than likely involve changing multiple mechanical parts as well as adding and replacing the existing electrical components. In addition, we also need to make individual parts compact enough to integrate perfectly. This implies that a lot of effort will be spent in minimizing the area of the PCB while being able to integrate all the electrical and mechanical components into one package.

In order for the robot to sustain in harsh collisions, we decided to use soft plastic shell as the outer surface. Interchangeable task module will be implemented to achieve the goal of data collecting. As for communication between PC and robot, our team will be transmitting signal and data through WIFI.

The robot uses the continuous track mechanism to drive the spherical explorer from the inner surface. Comparing to other spherical robots, like Sphero, in the market, this project uses gravitational torque to generate the forward movement.In addition to the gravity torque, a servo will be used to control the position of the mass in a perpendicular axis. This allows us to control roll motion which helps eliminate oscillation during turning. Another unique thing about our robot is the communication via WIFI while most of the others use Bluetooth connections.

3 REQUIREMENTS AND VERIFICATION

3.1 Requirements and Verification

Table 1. Table of Requirements and Verification

Requirement	Verification	Verification Status
Minimum turning radius < 1m	**Theoretical Verification**: • $R = r\cot(\theta - v^2/R)$ is a model of the turning radius relative to the speed and the angle of the mass and the horizon. **Empirical Verification**: • Take a 2 m^2 of an area and operate robot within this specified area. • If full circle can be made without robot leaving the area, then this requirement can be confirmed.	
Average acceleration > 0.2 m/s^2	**Empirical Verification**: • Drive the robot forward (from rest) from point a to b. • Sample speed and time and approximate acceleration by taking several derivatives.	
Maximum Speed > 1 m/s	**Empirical Verification**: • Slowly accelerate until maximum speed is achieved .	

Requirement	Verification	Verification Status
Operating time (power consumption) > 30 minutes	**Theoretical Verification**: • Reading the datasheet gives the power consumption of the basic components under normal operation. A sum of these values will give the theoretical power consumption. **Empirical Verification**: • Fully charge battery and drain it to measure total energy • Fully charge battery again and drain it by operating the robot under treadmill and measure the time taken to consume battery to get power	

3.2 Tolerance Analysis

Due to the nature of the robot being remotely controlled, it is very difficult to change the batteries of the robot. Therefore, power is critical to successful operation. To ensure that the robot can travel to the destination and back, power consumption must be accurately calculated and thoroughly tested.

An estimation of the total power is calculated by extracting information from the datasheets of the basic components. For bare minimum functionality at normal operation mode, the following items are tested: DC motor, High Speed Servo, Freescale MK20DX256 MCU, and a AS5048A Magnetic Encoder. The power consumption of each component is extracted from datasheets as follows:

Table 2. Power Consumption of Components

Components	Power
Maxon A-max 22 diameter DC motor	0.5 W (loaded)
HD-3688HB High Speed Servo	1.3 W
Freescale MK20DX256 MCU	108 mW
AS5048B Magnetic Encode	150 mW
Estimated Total Power	2.058 W

4 COST AND SCHEDULE

4.1 Cost Analysis

4.1.1 Labor

$$\begin{aligned} \text{Labor Cost} &= \text{Hourly Rate} \times \text{Total Hours} \times \text{Number of People} \\ &= \$25.00 \times 400 \times 3 \times 2.5 \\ &= \$75000 \end{aligned}$$

4.1.2 Parts

Table 3. Parts Costs

Part	**Quantity**	**Cost($)**
WiFi Module	1 pc	34.95
Servo	1 pc	19.95
Motor Driver	1 pc	4.49
DC motor	1 pc	20.00
IMU	1 pc	6.84
Magnetic Encoder	1 pc	15.00
Microcontroller	1 pc	19.80
Camera (task module)	1 pc	7.27
Plastic Ball	1 pc	2.49
3D Print Filament	1 roll	18.00
Gears	2 bags	3.92
Li-Po Battery	2 pcs	49.88
Total		202.59

4.1.3 Grand Total

$$\text{Grand Total} = \text{Labor Cost} + \text{Part Cost} = \$\ 75202.59$$

4.2 Schedule

Table 4. Project Schedule and Weekly Deadlines

Week	Tasks	Students	Major Tasks Due
8-Feb	Work on proposal together.	All	Project Proposal due (Wed). Mock Design Review Sign up (Thu).
15-Feb	Write firmware for controlling motor using motor driver.	Kaiwen Chen	Mock Design Reviews (Tue-Thu). Eagle Assignment due (Fri).
	Attached axle to ball and 3d printed motor/servo chamber.	Zhong Tan	
	Rough estimation of component placement on PCB.	Junhao Su	
22-Feb	Write firmware for servo.	Kaiwen Chen	Design Review Sign up (Mon). Eagle Assignment due (Fri). Soldering Assignment Due (Fri)
	Attach gears to axle and align gears properly.	Zhong Tan	
	Sketch PCB layout according to rough draft.	Junhao Su	
29-Feb	Write I^2C code for gyroscope.	Kaiwen Chen	Design Reviews (Mon-Wed).
	Attach mass to servo.	Zhong Tan	
	Continue with PCB layout.	Junhao Su	
7-Mar	Ability read signal from magnetic encoder.	Kaiwen Chen	
	Ensure the stability of the mechanical infrastructure.	Zhong Tan	
	Submit first PCB to manufacturer + prototype board .	Junhao Su	
14-Mar	Ability to control speed of motors and servo orientation.	Kaiwen Chen	
	Placement of the magnetic encoder into mechanical design.	Zhong Tan	
	Test protoboard.	Junhao Su	
21-Mar	Attempt to integrate separate components into one package and testas a team.	All	

Week	Tasks	Students	Major Tasks Due
28-Mar	Ability to connect WiFi module to WiFi network.	Kaiwen Chen	R&V Table (2nd Attempt) due (Mon). Individual Progress Report due (Mon).
	Revisit any mechanical failures.	Zhong Tan	
	Receive PCB board from manufacturer. Solder and test. Solder and test. Submit second edition of PCB layout to manufacturer if first try doesnt work.	Junhao Su	
14-Mar	Ability to send data over WiFi.	Kaiwen Chen	R&V Table (Final Attempt) due (Fri).
	Prepare final form of robot.	Zhong Tan	
	Prepare an alternative for PCB while waiting for second edition.	Junhao Su	
11-Apr	Ability to receive signal over WiFi.	Kaiwen Chen	Mock Demos during TA meeting
	Create spare parts for robot in case things go wrong for demo.	Zhong Tan	
	Finalize components into PCB.	Junhao Su	
18-Apr	Finalize robot for demonstration.	All	Demonstration Sign up (Mon). Mock Presentation Sign up (Mon). Presentation Sign up (Mon).
25-Apr		All	Demonstrations (Mon-Wed). Mock Presentation (Thu,Fri).
2-May		All	Presentations (Mon-Wed). Final Papers due (Wed). Lab Notebook Due (Thu).