Educational Coordinated Robotics

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Project Proposal for ECE 445, Senior Design, Fall 2018

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20 September 2018

Project No. 6

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1 Introduction

1.1 Objective

Coordinated autonomous technologies are currently at the forefront of research efforts in the field of robotics. They enable novel and effective solutions including but not limited to search and rescue operations, distributed sensing applications, and agricultural tasks. However, communication between multiple robots is difficult to implement in educational environments because of the cost of materials and complexity of the systems. As a result, coordinated robotic applications are infrequently taught in high school engineering classes or after-school robotics programs, and students miss out on learning about this exciting new class of robots.

Our project seeks to address this issue through a PCB that enables students to develop their own network of robots with the ability to communicate. The PCB will include an overall system with three subsystems: RF (developed in the ISM band under Part 15) [1], power electronics with motor control, and sensors. Additionally, there will be a battery and motor interface.

We propose to develop between five and ten robots that are equipped with our PCB, a Raspberry Pi for computation, and a camera. We will develop a protocol that allows any robot to talk to any other robot in the network using concepts from Mesh networking and swarm robotics. If time permits, we would like to experiment with implementing various decentralized swarm robotic algorithms and advanced positioning systems using RF trilateration [2]. However, our primary goal is to develop a PCB and accompanying software that enables a student to easily experiment with a network of coordinated robots.

1.2 Background

The motivation for this project arises from the Office of Naval Research (ONR). Currently, ONR funds a national underwater ROV competition each year called SeaPerch [3]. The purpose of this competition is to introduce middle school and high school students to various STEM fields through thinking about problems and building technology of Naval relevance. However, because of shifting applications for robotic technologies in the Naval context [4], ONR is interested in funding the development of a new competition concept. Our team has ties with the Naval Research Laboratory in Stennis Space Center, MS and the lab is very interested in the outcome of our project. The hardware and software libraries we develop this semester may lead to further development to create a coordinated robotics competition.

1.3 High-Level Requirements

- Data transfer must be possible between any two arbitrary robots in the network. The network must be capable of containing at least 3 robots at one time.
- Basic motor control must be possible for at least 2 DC motors on every robot through our board.
- Each robot must be able to take sensor readings (e.g. from an IMU) through our PCB and be able to communicate a subset of the information acquired with the robot network.

2 Design

2.1 Block Diagram and Physical Design

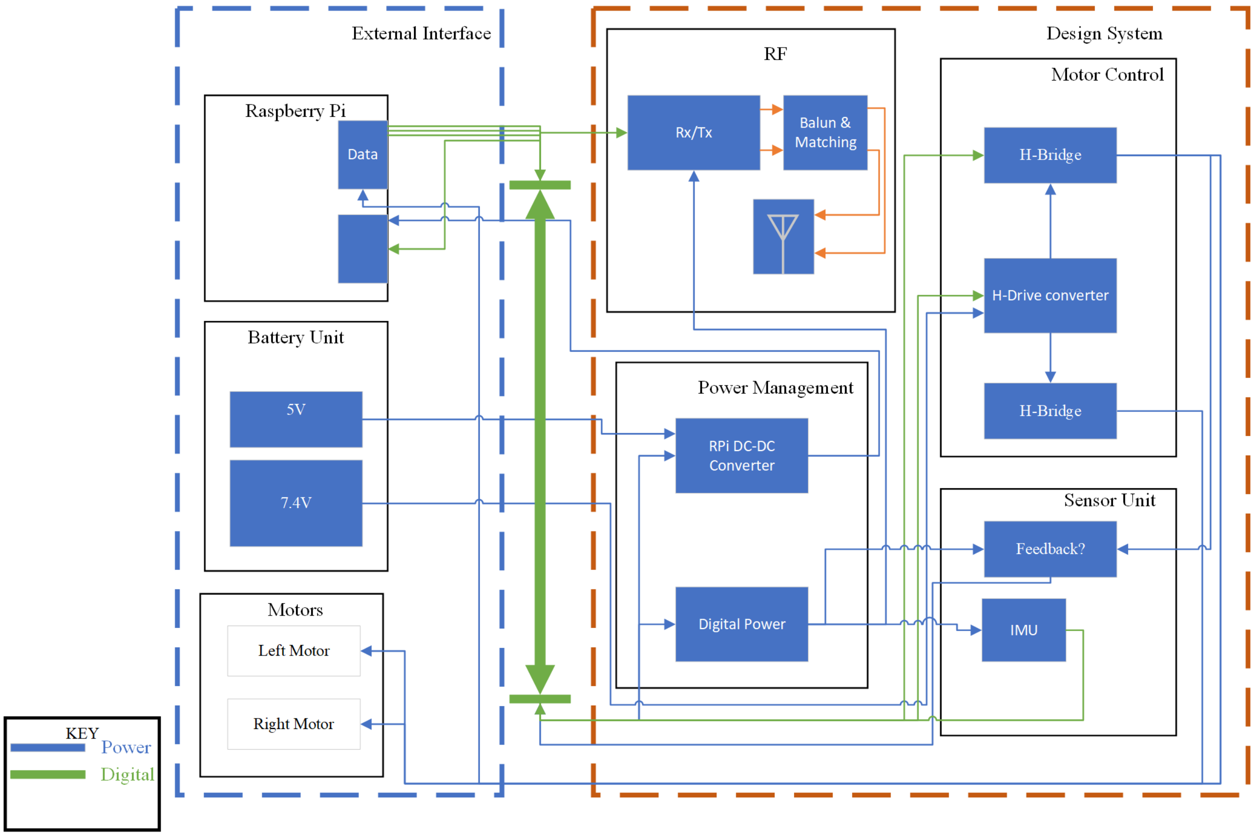

Figure 1: Block Diagram

2.2 Functional Overview and Block Level Requirement

Essentially there are two different main sections: (1) external connections with peripheral devices and (2) the main system. The external systems include two DC motors, a Raspberry Pi, and batteries. The main system is broken into four main sections: RF, power management, sensor control, and motor control circuit. The main system will be controlled by a digital system run through the Raspberry Pi.

2.2.1 Radio Frequency (RF) Communication Module

The RF section of our board will ultimately allow communication and connection between a large group of robots. To communicate between the robots, an MCU IC will be used to receive and generate the proper analog signals using the ISM band of 2.4 GHz. An external antenna will be used to gain the proper range necessary to transmit through a group of devices and proper matching circuits will be designed between the IC and the antenna. Additionally, in order to simplify the system, Bluetooth protocols will be used for communication between the robots. Use of a well-documented protocol is necessary to ensure the wireless system is able to withstand a variety of problems, from issues with noise to signal integrity issues. Thus, the RF section is critical for communication between robots.

- ***Requirements***

  1. Communicate on ISM band (2.4GHz)
  2. Operate according to Bluetooth Protocol
  3. Allow multicast and multiple device communication
  4. Interface with Raspberry Pi

2.2.2 Power Management

The main power section of this project comprises of various dc-dc converters to ensure everything is powered correctly. Because we need to provide power to the Raspberry Pi, we will map one pin out on our board carrying 5.1V to the Vin port on the Pi. Additionally, power for digital circuits will be converted using DC-DC converters to a voltage level of 3.3V.

- ***Requirements***

  1. Distribute 3.3V (+/- 5%) power to sensors, RF modules
  2. Distribute 5.1V (+/- 5%) power to Raspberry Pi
  3. Interface with Raspberry Pi

2.2.3 Sensor Unit

The sensor unit will include an IMU to give each robot a relative pose estimate. At first we will aim to integrate just an IMU and its peripheral circuits onto our PCB. However, if time permits we would like to experiment with various other sensors for positioning. For instance, there has been some prior work done on RF trilateration [2] using fixed beacons and a radio IC from DecaWave [5]. Additionally, we would also like to equip each robot with a camera driven over USB. This camera would allow for optical sensing to detect features around each robot. This data could then be relayed through the RF ICs on each robot in the network.

- ***Requirements***

  1. Detect acceleration and orientation of robot
  2. Relay data back to Raspberry Pi

2.2.4 Motor Control

A simple open-loop system using an H-bridge will allow the motors to be controlled from the GPIO pins on the Raspberry Pi. A separate battery will be connected to this section, and the proper step-down DC-DC converter will be used to provide power to the two motors. A feedback loop could potentially be implemented to provide precise speed control for better pose estimates.

- ***Requirements***

  1. Control Motors using two H-bridge drives
  2. Power motors using separate battery and dc-dc down converter

2.2.5 Raspberry Pi

The Raspberry Pi is not a part of the development for this project, but is a necessary external input and output device. Each robot will have a Raspberry Pi in order to collect data, make decisions, and process commands from internal sensors and from other robots in the network. The Raspberry Pi will be connected in some way to every module designed for this project, including the RF chip, sensors, power management, and motor drive modules.

- ***Requirements***
  1. Must be able to effectively communicate with the RF, sensor, and motor control units
  2. Must be able to configure as either a master or a slave
  3. Must have enough physical interfaces (GPIO and SPI) in order to control and manage data input
  4. Must utilize under 4Wh of power (consistent with battery supply needs)

2.2.6 Battery Unit

The battery unit will contain two separate power sources. This is because of the broad range of devices our system will need to support. Bluetooth Low Energy devices such as the Nordic Semiconductor chip, typically draw around 13.5 mA of current at 3.3V in an on state and 26 μA of current in a low power state [6]. This power need contrasts with the power needs of the motors, which generally require 6V and can consume up to 1.2 W of power per motor[7]. These different power needs require various voltages and dc-dc converters. Thus, we will use 2 power sources for the scope of this project.

- ***Requirements***
  1. Supply enough power (8W) for approximately 30 minutes (4 Wh)

2.2.7 Motors

The motors must be low-cost but must provide enough torque in order to move the robot. The motors will interface with the H-bridge unit, and will draw power from the 6V source in the battery unit. The motors will be part of the external interface devices, and will be bought from a supplier.

- ***Requirements***
  1. 6V DC input (+/- 60%)
  2. Able to move a robot that is approximately 2 kilograms or less

2.3 Risk Analysis

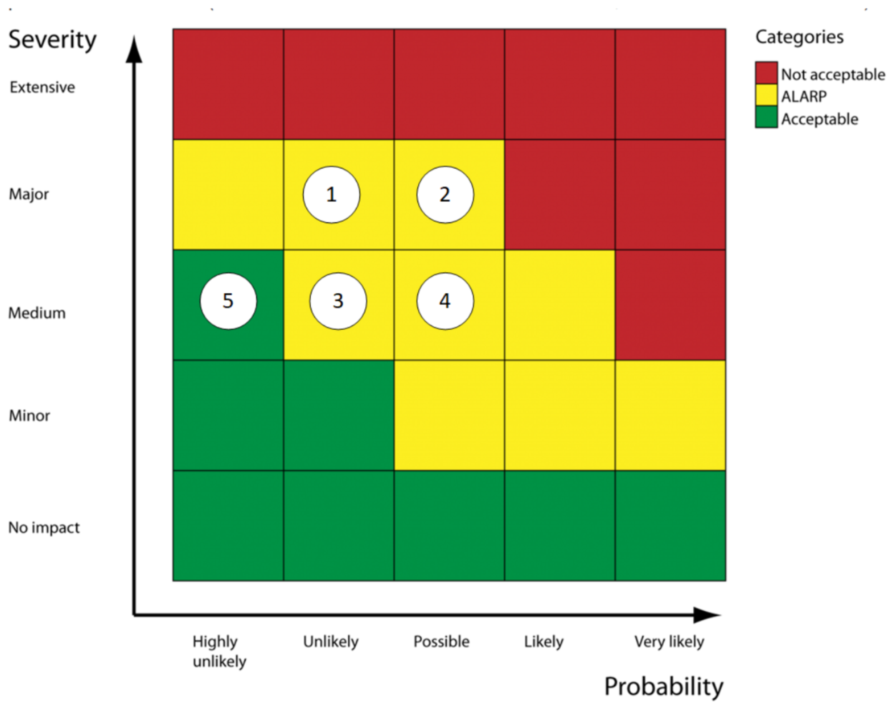

Figure 2: Risk Assessment

For the above figure 2, the numbered bubbles represent:

1. Sensors
2. RF Communication
3. Power Distribution
4. Motor Control
5. External I/O

A couple sections of this project have some risk, but overall, the risk is either ALARP or acceptable. The sections with the greatest amount of risk include RF communication modules and the sensor modules. The power management system, while important, has low risk as they are generally simple to construct and debug. The sensor system is most likely lower risk than the RF communication module, because the entire idea of coordinated robots hinges upon the communication between multiple robots using an RF signal. Thus, in order to ensure that one of the basic requirements are met, an RF communication system must be completed. Thus, it is the most high-risk section of this project. Following the RF system, the positioning and sensor unit is the next highest risk area as the movement of the individual robots depends upon the sensory data. Finally, while integral to the operation of the project, the power section of this PCB is a lower risk area than the communication and sensing section of the robot.

3 Ethics and Safety

Since we are using RF bands for communications, we are making sure we do not violate FCC regulations on the frequency and transmitter power. Because we are buying an MCU using a well-established Bluetooth technology specified in IEEE 802.15 [1], our RF usage is legal, safe, and will conform to the IEEE Code of Ethics Article 1. It is important to use radio bands that will not interfere with sensitive devices or with restricted bands, such as the aircraft communication band. Thus, using the RF band specified in IEEE 802.15 [1], and used in this project allows for the safety that is required in Article 1.

We are considering using NiMH nine-volt batteries to power our systems. NiMH batteries, according to Energizers guide [8], are cheap, made of environmentally friendly materials, only contain mild toxins, and are recyclable. These conditions are perfect for our use case. NiMH batteries are also fairly safe to use. However, one needs to watch out for overcharging and potential failed valves on the battery causing gas to build up inside rupturing the cell.

Additionally, this project has a variety of moving parts, which may cause a hazard to human health. In order to comply with the IEEE code of ethics part 9, "to avoid injuring others"[9], each module will have a software turn-off switch (in order to remotely shut down the robots), as well as a hardware switch readily available to power down the robot. This ensures that if the robots are found to be headed to an area where they could potentially cause harm, such as with pets and young children, or even sensitive equipment, that the robots can be shut down remotely or through manual shutdown.

Additionally, each robot will have a number of sensors that will collect data about the outside world. All data can be used in a way that is harmful to other people, and since a camera may be used for object detection and local position sensing, this camera may have data that could be used in a malicious manner. To conform to Article 9 of the IEEE Code of Ethics,"to avoid injuring others...[or] their reputation..."[9], a key detail is that the the information collected by these robots will not be stored in a long-term manner, that is, all video sensing data will not be stored except in temporary memory for object detection. All data that is collected will be clearly marked and indicated to all users so they realize the privacy constraints with these devices.

Finally, this project is intended to be used by young people and students in order to understand more about coordinated robotic systems. Because of this education based focus, there will be an emphasis on upholding the IEEE Code of Ethics Article 5, which seeks to "improve the understanding of individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems",[9]. In order to properly educate the users of these robots, a great deal of discussion in the final project and documentation of these robots will detail the science, engineering, and ethics of networks of robots.

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