Design Document

Autonomous Tiny Robots

ECE 445 - Spring 2017

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1. Introduction

1.1 Objective

Swarm robotics is an emerging field of robotics that has a huge potential for application. By having a collection of robots that can work cooperatively and communicate with one another, they can complete complex tasks given the right instruction, much like colonies of ants are able to complete tasks far beyond the capability of the individual. The primary focus of a swarm is to coordinate the motion of the robots to form certain patterns. However, motion coordination for a swarm is challenging due to limitations like the lack of communication between the robots and hardware constraints.[1] As the number of robots increase in the swarm, the failure rate of the swarm increases as the time of operation continues.[2] Given swarm robotics commonly use a decentralised decision system through local robot communication, these failure events in the swarm can greatly impact the correct operation of many neighboring robots, and possibly even the entire swarm itself.

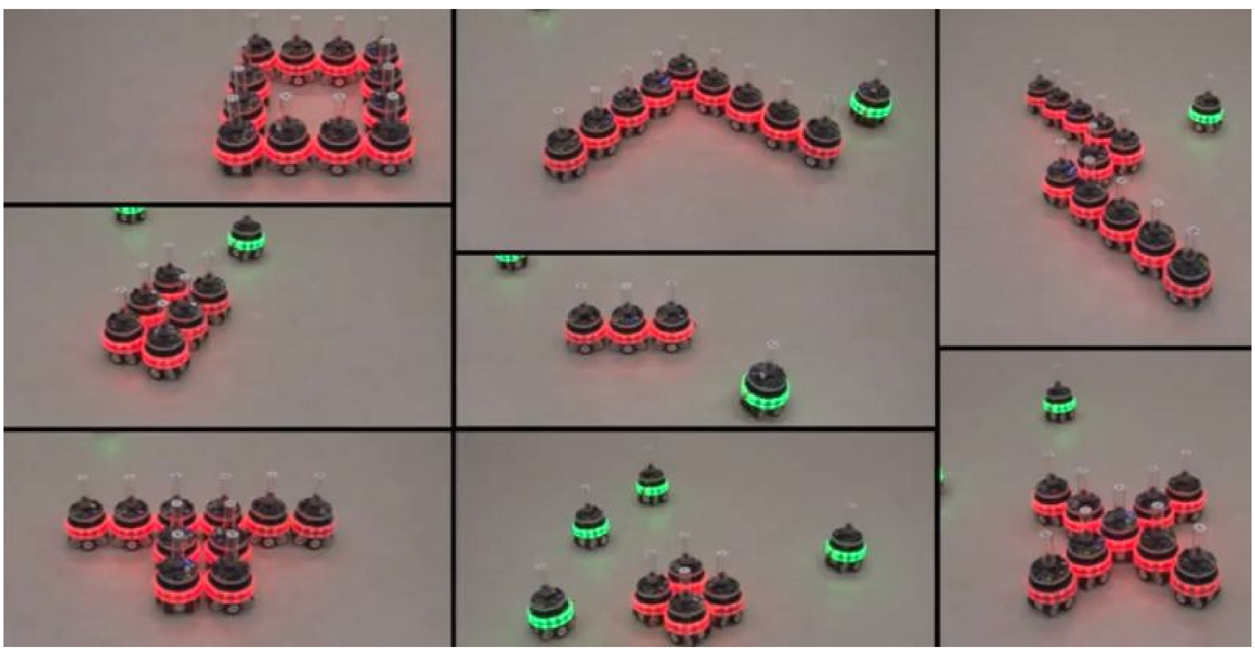

Figure 1: Expected Behaviors of Swarm Robots [3]

Our goal of this project is to investigate the reliability and potential application of a more constant stream of commands from a centralized decision system giving basic movement

[1] Distributed Algorithims for swarm Robots
[2] A. Martinoli et al. (Eds.): Distributed Autonomous Robotic Systems,
[3] Self-Assembly_Robots

commands to the tiny robots in a different way rather than using the wireless communication (such as wifi). We want to create a hardware and software user interface that can be used to control group of robots. The project will try using a projector to communicate movement path commands to the robots with light patterns. Each robot in the group will have a light sensor that allows it to receive the projectors light commands. We plan try to simulate the situation in a lab environment. The type of robots we will use will be very small and simple in design so that we can duplicate them as much as possible. The main functionality of our robots is computer interaction and coordinated movements to create patterns. This is to showcase that we can use a single remote server to control a group of robots to achieve a targeted task with predictable reliability. We will try to develop simple robots to keep costs low, explore and research the possible applications of swarm robotics using the projector method. Also, by keeping the individual cost of each robot low may help investigate the scalability of the swarm and the project.

1.2 Background:

There are a lot applications for robot swarms. We try to explore the possibility of control multiple robots using one remote server. I believe that this type of technology can be applied to many types of robots. Some artists use swarm robotics techniques for interactive arts. For example, Intel used a group of drones during the super bowl halftime show. This is just for pure entertainment, and there are some more practical uses as well. We can use distributed robots to perform sensing tasks at different environments. Swarms of robots can be sent to places that are not easy for humans to reach. More controversially, swarms can be used in military to form an autonomous army.

1.3 High-level requirements list:

- The robots should be powered by one single lithium battery
- it should move without any external forces.
- The backend server will be able to track the locations of robots,
- help the robots correct their paths and
- manipulate the robots.
- The robots should move collectively, which means all the units need to move in a coordinated fashion.

2. Design

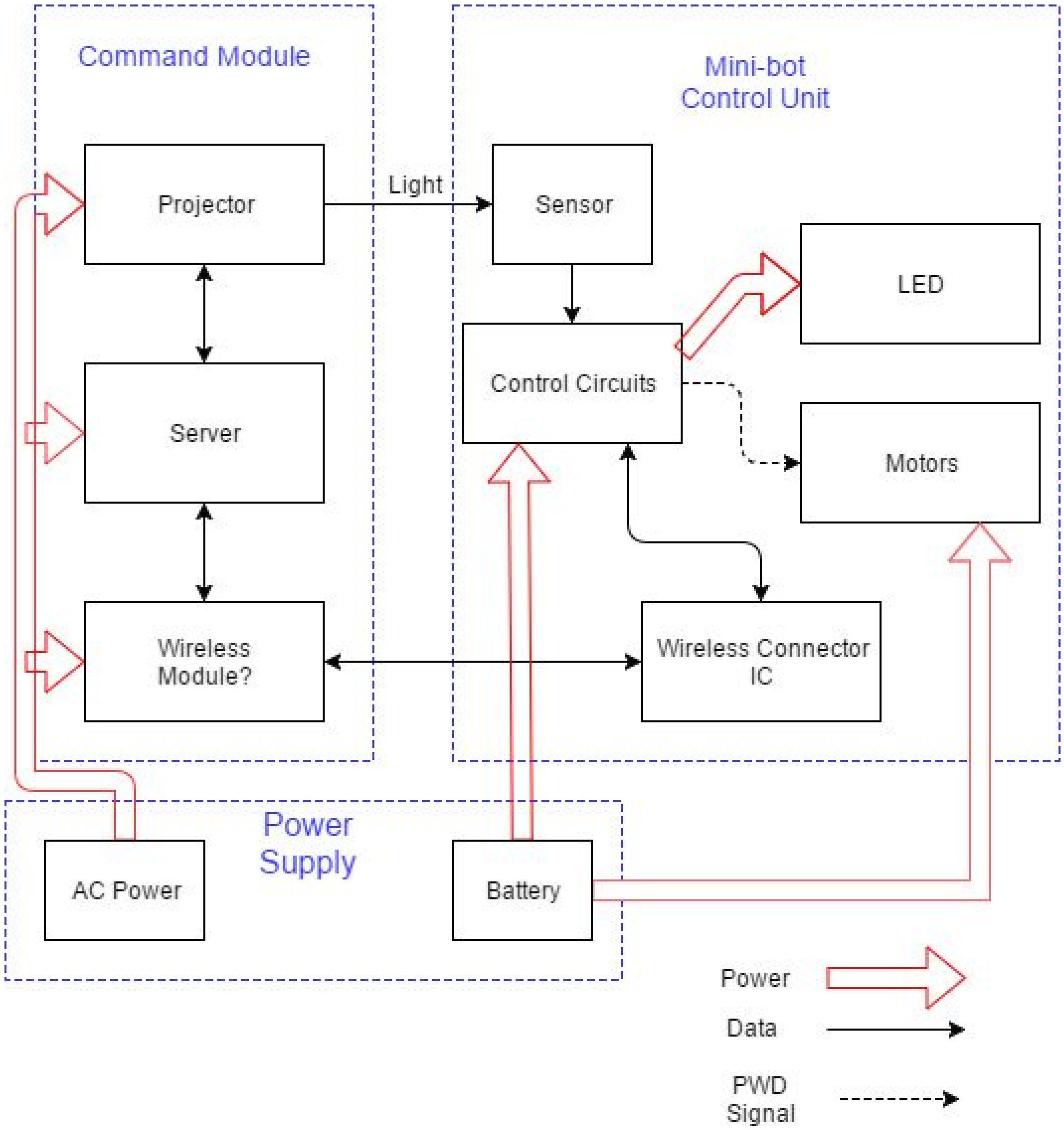

Figure 2: Block Diagram

The graph above covers all the elements we use for this project. The whole design works like this: The server will read any patterns we want to display and the software program will calculate and assign a position for each robot we have. The light projector will project the pattern onto the surface and the Wifi module will stream the position data to the robot. The robots will provide feedbacks to the computers, which will be its latest position. When one robot get to the assigned position, the photodiode attached on the robot will raise the signal and this will be sent back to the server. The robot will stop move and we are done until all the robots get to the targeted spot.

2.1 Command Module

2.1.1 Server - The Server used for this project will be any modern computers that have computing abilities. The control algorithm of the robots will be divided into three main parts. The first step is to assign each robot a targeted location.

2.1.2 Projector - Our system will use a projected-based tracking system. We will use DLP LightCrafter by Texas Instruments. A sequence of black, white, and grey-coded patterns will be projected onto the surface.

2.1.3 Wifi Module - A Wifi device that can communicate with the minibots to provide the computer with the feedback produced from each robot.

2.2 Power Supply

2.2.1 Battery - We will use a 100 mAh LiPo battery for each individual robot. This power supply will be enough our robots since each robot doesn't have too many components.

2.3 Minibot Control Unit

2.3.1 Sensors: We will use touch sensors for sensing if the robot has made contact with another object, and photodiodes for light tracking. These allow the minibots to receive instructions from the projector and aid in location detection by detecting contact with other objects. The IC chip chosen for touch sensors is a capacitive sensor driver, allowing up to 7 channels (keys) of detection, and it also contains much of the signal processing functions needed. This means not much more hardware is required for the correct operation of this part. The photodiodes are configured with 2 op-amps for each diode,

2.3.2 Control IC - The central circuit that will make simple, local decisions on what the robot should do given the input from the sensors and will output signals to the rest of the robot's systems. This will be implemented on a PCB board with the AT89C5132 amtel chip. This chip was chosen for it's 5 bi-directional 8 bit input output ports, USB connectability, 10 bit analog to digital converter, among other reasons.

2.3.3 Wireless connector - This system will receive feedback data from the robot's main circuit and communicate it to the central computer using a NRF24L01+ chip. This chip is connected to the robot's main microcontroller, an antenna, and a required crystal oscillator with typically 1.5pF capacitance load.

2.3.4 LED - RGB LED's will be the best choice because the different colors are easy to distinguish from one another. These will serve as physical indicators for each robot's status, and will also help with debugging.

2.3.5 Motors - The motor is small in order to fit on the small minibot structure and low cost so that it will aid in the scalability of the project. The motor will receive power from the minibots' H bridge motor controller circuit to drive the wheel of the robot, which is activated by the main microcontroller.

Case:	Output[3]
Stall	0.9kg-cm torque, 0.36 A
No-Load	40mA, 120RPM

Figure 3: Brushed DC Motor Specifications

2.4.5 Other parts - We will need an enclosure, a Wheel and a motor holder. We will use CAD tools to build 3D models and 3D print them.

2.3 Block requirements and verifications:

[3] https://www.pololu.com/product/992

Module:	**Block:**	**Requirements**	**Verifications**
Command Module	Wireless Module	Wi-Fi device signal should maintain connection within 2 meter range of the robot.	-Make iPhone connect to our wifi router with the distance of 2 meters -Check the wifi signal strength in the setting of iPhone to make sure it can get full signal strength
		The feedback data should be received for each robot within a certain reliability.	-Log the data received from robot to a file and compare it to the sender file
	Server	The command module must be able to manage the operation of at least 10 robots while active, and at most 50.	
	Projector	The projector must be able to illuminate an area of 1 m^2 to 1.5 m^2	-put the projector 1 meter above the white table and shed light on it. -Use a scratch paper to draw the edge of the light and measure the size of it
Minibot	Control Circuit	Total robot size should be near 20 cm wide and 25cm tall.	-measure the width and height using a ruler
		Shouldn't weigh more than 20lbs	-put the robot on the scale
		Maximum pin voltage should not exceed 14 V	During full powered operation, use a voltmeter to measure pin voltage on each power input pin.
		Maximum operating temperature should not exceed 85 degrees Celsius	-use an IR thermometer to monitor -make sure that the operating temperature stays below 85 C
	Motor	The motor must operate with temperatures under 85 degrees celsius	-induce full power stall of motor for 5 minutes, measure local temperature

	Sensor	The light sensor must be able to detect light from the projector in a dark room.	-connect the light sensor to a multimeter -shed light of different brightnesses on the sensor and read the resistance from multimeter -record the the resistance and check if it varies with the brightness of light
	Wireless Connector IC	Must be able to communicate with the wireless module at least 2 meters away	-connect the tiny robot to the wireless module at the distance of 2 meters. -make the server send a file to the robot and log the file and make sure they are the same as the original one
	LED	LED luminosity must operate at an average of about 1,800 millicandelas of light allowing a tolerance of $\pm 15\%$.	During a minute of normal operation, measure the output of the LED's and calculate the average
Power	Battery	100mAh, needs to last more than 20 mins to support the robots moving to desired destination	-Discharge a fully charged battery at 500mA for 20 minutes.
	AC Power	Must have surge protection functionality.	-Directly connect the power to the multimeter -Manually raise the power to above the threshold and read the voltage on the multimeter to see if the voltage is decreased due to surge protection.

Figure 4: Requirements and Verification

Schematics:

Control:

Below is the schematic for the control circuit and the connections to the RF chip. The used microcontroller is the AT89C5132, from Amtel[4], and the RF chip is the nRF24L01[5]

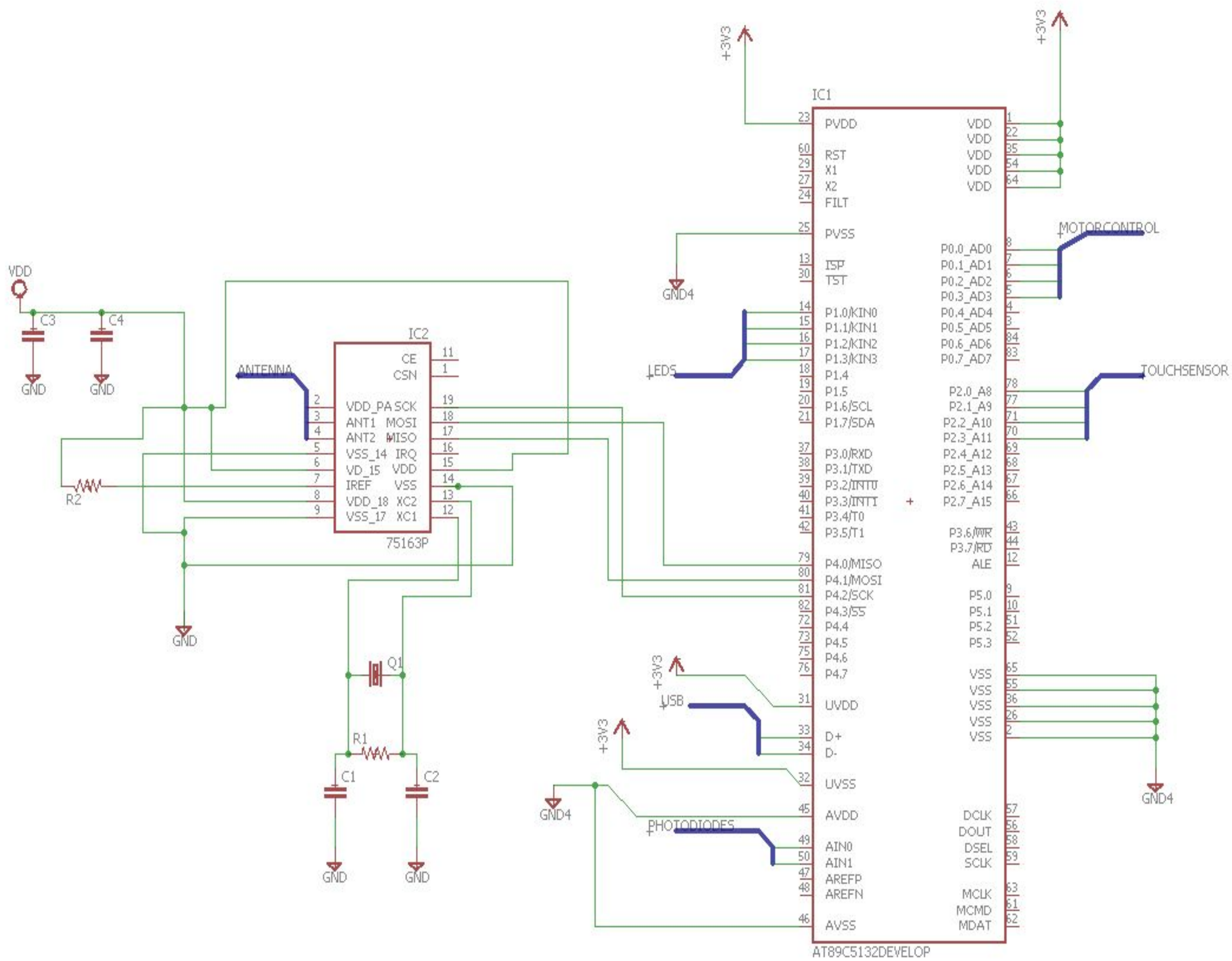

Figure 5: Microcontroller and RF Schematic

LED's: Red, green, and blue LED's will be used to help with debugging and robot status signals. Each LED is connected to a pulldown resistor and the power supply. The activation of the LED's is controlled by the robot's main microcontroller IC.

4 http://www.atmel.com/Images/doc4173.pdf

5 http://www.nordicsemi.com/eng/content/download/2730/34105/file/nRF24L01_Product_Specification_v2_0.pdf

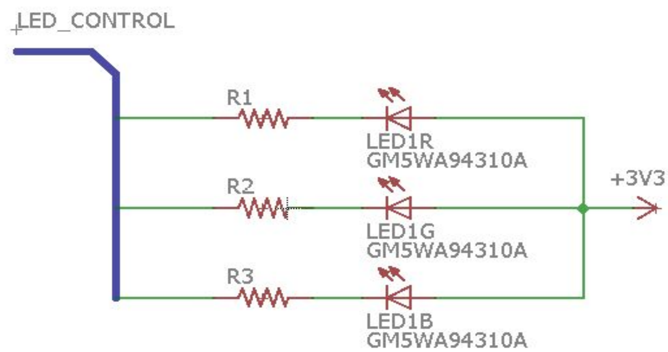

Figure 6: LED Schematic

Motor:

H Bridge drivers control the motors to allow bidirectional movement of the motors, allowing turning functionality.

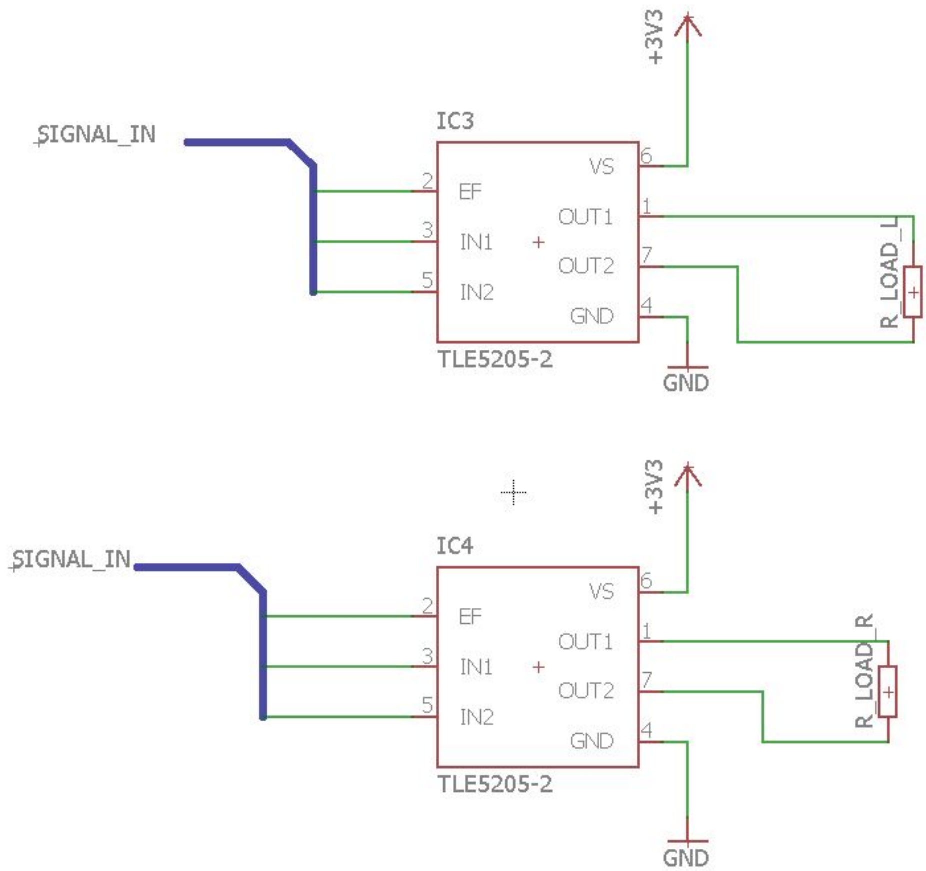

Figure 7: Motor controller and Motor Schematic

Sensors:

Photodiode: The photodiode signal is sent through two amplifiers to boost the signal. The first (left) op-amp is in a non-inverting amplifier configuration, while the second is in an inverting amplifier configuration.

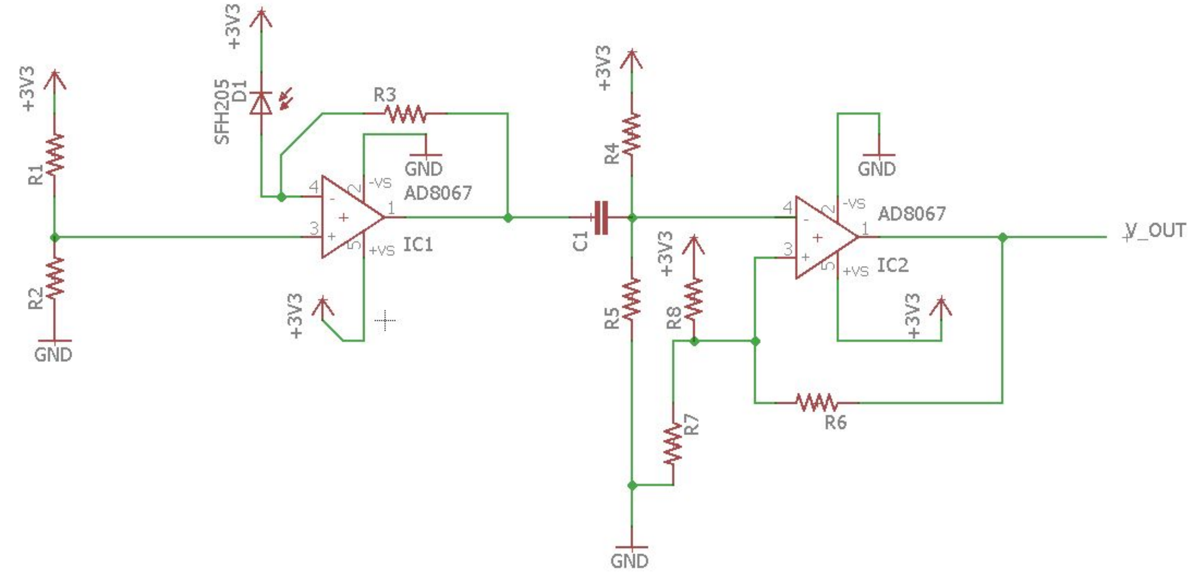

Figure 8: Photo-sensor Schematic

Power supply:

The lithium ion battery provides 6 volts of power and is small in size, thus are favorable to the design. The batteries power is sent through a voltage regulator and over capacitors to limit noise and maintain a smoother output of electricity.

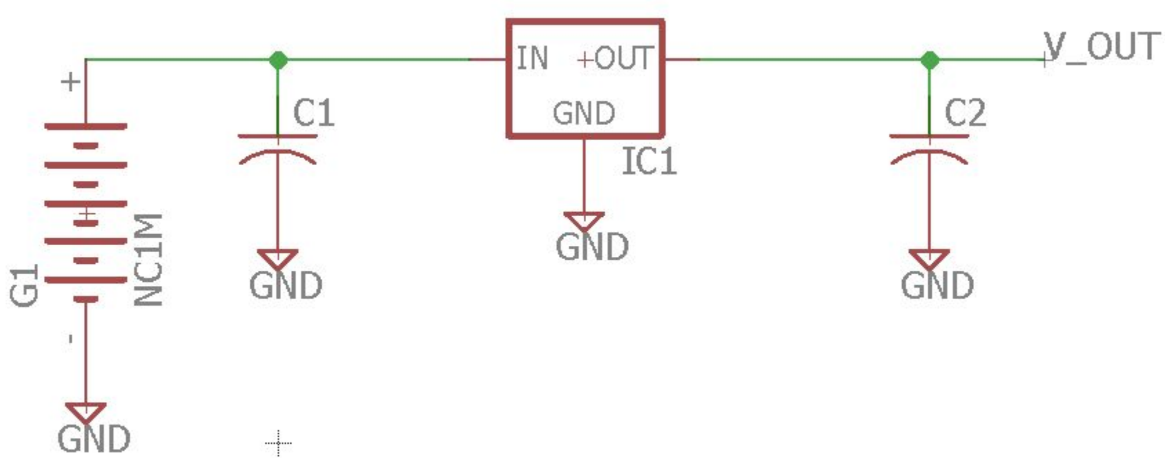

Figure 9: Power Supply and Voltage Regulator

Software:

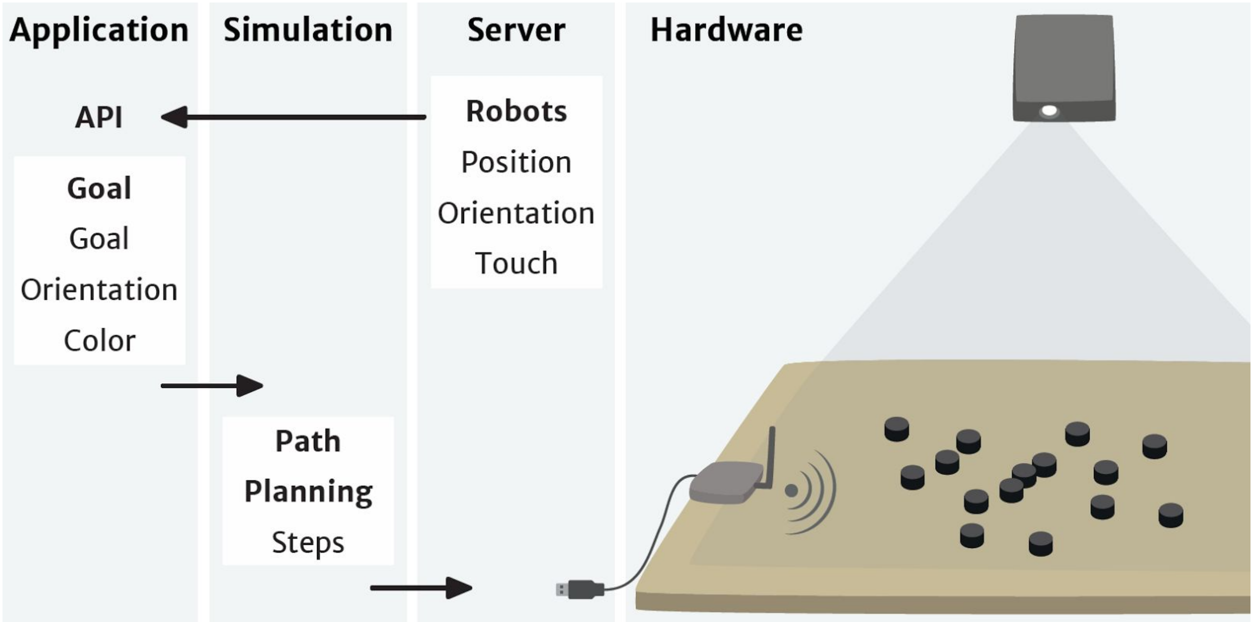

Figure 10: Software Flow Chart [5]

Tolerance Analysis: One important aspect about our tiny robot project is the stability and preciseness of our wifi signal transmitted from our server router to the robots. We set up the situation that all of the robots are within 2 meters from the server. So we need to the calculate the signal to noise ratio of our wifi signal. According to Shannon's Law,

$$SNR_{dB} = 10log_{10} * \frac{Signal\ Power}{Noise\ Power}$$

Thus we can get the SNR in dB, and we need to maximize this value to reduce unnecessary noise and improve efficiency and clarity.

Another aspect that brought to mind is that the the efficiency to transfer the power from the motor all the way to the wheel. The way to calculate the efficiency is through:

Efficiency = F * S (distance) / V * I

In this case we need to connect the motor to a circuit with multimeter and get the current and voltage to calculate power input to the motor. And then we could measure the distance the robot went through and then calculate the actual power output from the motor to the wheels.

Motor power consumption varies depending on what resistance the motor encounters while a voltage is applied to it. The motors used in this design require 6 volts for best operation, but the Amperes consumed vary. When the motor is pushing but stuck, also known as stalled, it consumes the most power, while when there is no resistance for motor movement (no load), it consumes much less power. Power is calculated by the equation:

$$P=IV$$

Thus in the stalled case, the motor consumes:

$$6V*0.36A = 2.16 \text{ Watts}$$

In the no load case:

$$6V*40mA = 0.24 \text{ Watts}$$

2.4 Risk Analysis:

The Mini-bot unit presents the largest problem to successfully completing the project. The bot design is simple and small, but it does not allow a whole lot of functionality in terms of debugging. In addition, since there will be a number of these tiny bots, there will always be a possibility when a bug is found that it may also be in other robots, which will greatly increase the time spent testing each bot and fixing them. Using LED's and building the robots with the same design will mitigate some of this risk, but not completely. Another risk associated with the robots is the wireless connection to the controlling server. Again, to keep the bots small, a smaller IC will be used to allow communication to the controller, which limits the ability to debug any problems that may appear.

3. Ethics and Safety

One of the safety issue that comes to my mind is the safety of our power supply- lithium-ion battery. Recently Samsung smartphones were banned on US domestic flights because it carries lithium battery which has a possibility of exploding when pressure changes, i.e. when plane taking off. It was also reported that several incidents occurred on these types of batteries. Also when these types of batteries ignite, the gases emitted are very toxic. So during our development and testing, we need to take care of all kinds of environmental issues that might be critical to the safety of our power supply: temperature, pressure and so on.

The radio frequency chip datasheet, nRF24L01, warns that the chip is not to be used in life support products since it is not designed for the application. Since the intended application on our robots are not life support related, this device can be reasonably used. [6]

According to IEEE Code of Ethics #7, " To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;". In order to meet the requirement brought out here, we decided to encourage members who dared to come up with criticism and different ideas. This is the proper way to do it because it can let everyone in our team contribute to the project. We also brought out the idea that everyone should be treated equally in the process of group work regardless of race, religion and nationality. As a really diverse team we believe this will help us achieve a positive atmosphere.

[6] http://www.nordicsemi.com/eng/content/download/2730/34105/file/nRF24L01_Product_Specification_v2_0.pdf, page 2

REFERENCES

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