Reconnaissance robot (SCD pitch)

ECE 445 Senior Design

Team 55

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1 Introduction

1.1 Objective

According to preliminary data provided by the National Law Enforcement Officers Memorial Fund, as of December 27, 2018, 144 federal, state, and local law enforcement officers have sacrificed their lives in the line of duty this year. This number has increased 12 percent from 2017, where 129 officers were killed [1]. Various factors have lead to such statistics. Main causes include car crashes, bomb-related incidents and amushes [2]. Among all these, firearms-related fatalities are the leading cause, with 52 officers shot and killed in 2018 [1]. Unfortunately, almost 43 percent of these 52 occurred when conducting investigative activities and serving warrants. The NYPD (New York City Police Department) gave some recommendations to reduce risks of potential shootings. One of which is to conduct a realistic security assessment to determine the facility's vulnerability to an active shooter attack [3]. One way to provide this kind of assessments is by using a robot to do some recon on the area that needs to be investigated before the officers need to go in. During an interview with former METRO (Metropolitan Emergency Tactical Response Operations) team officer Mike Unander, he stated that the more information police have, the higher the success rate of the operation. Our goal is to send a robot to do recon work as well as build up a communication channel between officers and suspects. The robot is designed to investigate areas or spaces that have potential hazards. The robot should be able to move freely in such spaces and transfer back live video and sound data, as well as enable communication between officers and suspects.

1.2 Background

A lot of effort has been made to solve this problem. Police officers have throw-phones, which they can throw through windows to communicate with suspects. There are also various cameras that have been used to preview the area that suspects are located in, such as snake cameras, pole cameras. However, these cameras are not only expensive, but also provide poor video quality[4]. Sometimes, police officers would also like to send items to suspects, but it is hard to conduct such activities without exposing the positions of officers. According to officer Unander, there are existing robots that are being applied to such occasions, such as TALON [5], which is a tactical robot used for disposing bombs as well as reconnaissance. But unfortunately, they are either too big and heavy, or they will get stuck in some narrow entries.

Our goal is to have a robot that can combine those technologies and requirements police officers have. We are also partnering up with Siebel Design Center and UIPD to provide a more customized solution than those existing robots.

1.3 High-level requirements list

1. The user is able to control movements (move forward, move backward, turn left, turn right at a one preset speed; allow the camera lift to rotate at a preset angular speed; turn on and off the light) of the robot on flat ground through a physical device with buttons and switches within a range of 10 meters on open space.
2. The robot can transfer back images(at least 352*240 resolution) and sound data under dark conditions below 10 lux (with the help of light).
3. The power system can sustain the robot for at least half an hour of full operation when it has all its components operating at full power

2 Design

2.1 Block diagram & Physical design

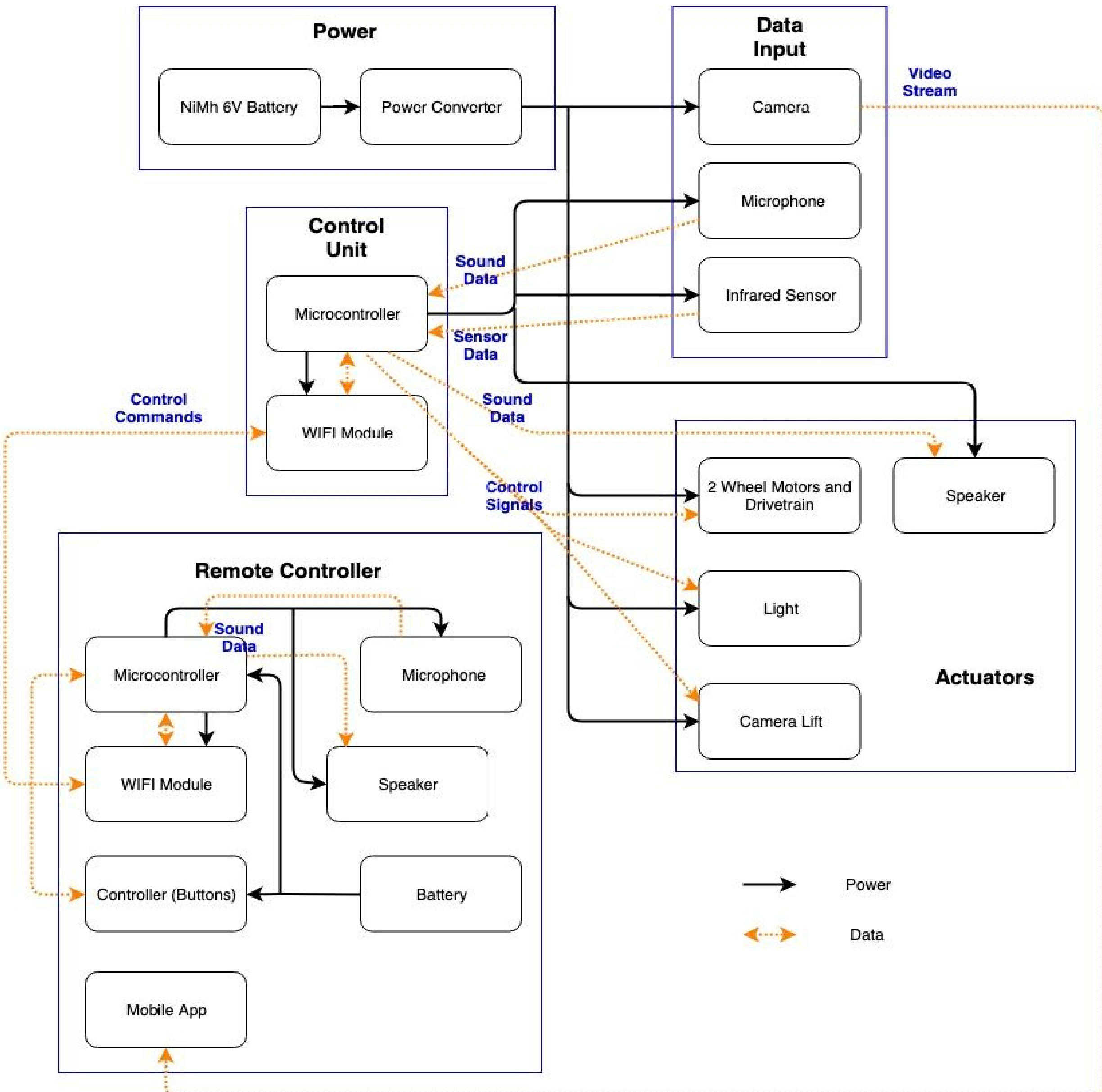

Figure 1. Block Diagram

Our robot consists of 5 large modules. The whole system is similar to a human being to some extent; the control unit is the brain, the data input is the eyes and ears, and the actuators are mouth, arms and legs. The modules have to work together to achieve the high level requirements, which requires the robot to be moved under control and transfer data. The control unit contains a microcontroller and a Wifi module; the Wifi module is a tool of communication, which can be replaced by a rf transceiver pair. It coordinates all other parts on the robot and also communicates with the user end. The user interface includes a remote controller and a mobile app. Users can control the movement of the robot using the remote controller and receive real-time video on the mobile app. An alternative to this design would be to incorporate all data into one mobile app. The data input module includes a camera to capture images, a microphone to capture sound and infrared sensors that could detect the existence of human beings. The actuators of the robot contain wheel motors and the drivetrain, a camera lift, a LED light, and a speaker, among other components. With each block working, the commands from the user would be sent to the microcontroller via Wifi and the microcontroller would send signals to move the wheels, move the camera lift up or down, as well as rotate it and turn the light on or off; the images from the camera are transferred through Wifi to the mobile app; audio data from microphones and data from sensors would be sent to the microcontroller and sent back to the controller.

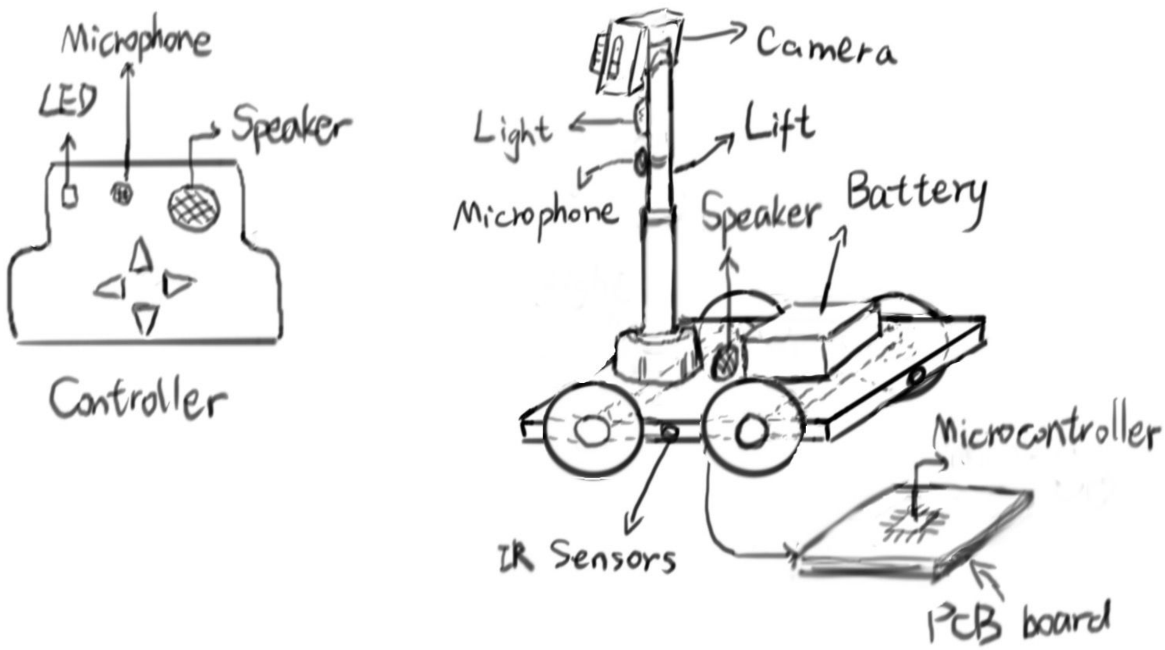

Figure 2. Physical Design
Created by [8]

In our physical design, the robot consists of four wheels which are driven by four motors. Our PCB is in between four motors below the skeleton. A battery is on top towards the end. The robot has a camera lift up front, with the camera attached to the top of the lift. The camera lift is supposed to move up and down as well as rotate and is driven by two motors. A microphone is also attached to the lift in order to capture sound data. There is a light on the lift that would lighten the path ahead under dark conditions. Four infrared sensors are attached on the skeleton in all four directions.
In the remote controller, there are four buttons that allow users to control the robot's movement. There is also a microphone and speaker for communication purposes. A LED light signals the user whether there are PIR sensors detect unusual fluctuation in infrared field, implying there may be human movements in that direction.

2.2 Power

Power Supply is designed to provide power for all electronic components including motors, camera lift, light, microcontroller, transceiver, camera, and microphone. It consists of a battery and a voltage regulator that supplies a suitable voltage to each component; such a regulator would power other blocks through the power interface which provide ports for wires. This block supports all other blocks to do their work so the robot could not operate at all without it. Its interface with other blocks are the ports on the voltage regulator which provides suitable voltage for each component.

2.2.1 Battery

A rechargeable battery must be used to power the entire system. According to the high-level requirement, the battery should keep the whole system operating for an hour under full power; thus, it has to have enough capacity to provide every component enough power to operate for one hour.

Specifications	Verifications
The battery should have a capacity of at least 5000mAh.	Check datasheet of the battery to make sure all these specifications are met.
The battery should be rechargeable.	
The battery should supply voltage between 6V +/-10 % and 12V+/- 10% at full charge.	

Requirements	Verifications
The battery should support the robot for at least 30 minutes when all components are operating at full power.	1. Fully charge the battery. 2. Power all the components on the robot to their nominal operating power (let camera send back data, talk through the microphone,keep moving the robot, keep rotating the camera lift, etc.) 3. Use a stopwatch to verify that the battery can support the robot for more than 30 minutes under such operation.

Battery Sustainability Analysis

One important tolerance that we need to maintain is to have a battery that has at least 3000mAh of capacity rated at 6V. Ideally, the battery comes in with 3000mAh full capacity. However, in reality, the true capacity battery can be lower than 3000mAh. Let’s say that our battery has a 10%off of its capacity, which gives us still 2700mAh. A 2700mAh battery at 6V can supply 16.2W of power supply for one hour.

Let's approximate the power consumption of our robot. The major power consumption of our design is, of course, the motors. This includes four-wheel motors as well as two motors for camera lift. When these motors are operating at full speed, the power needed = 12V*0.07A*6 = 5.04W. For microcontrollers, by looking at the datasheet, while at 20MHz/5V, an active microcontroller draws about 20mA = 100mW. As specified by datasheets, camera consumes 5W of power, light consumes 3W, others we approximate to consume a total of 2 W. As we adding up these power needed, we found the total power consumption to be approximately 10.1W. This is way less than 16.2W. Therefore, even if the battery is not at full capacity, we can still sustain our circuit to operate for at least 1 hour.

2.2.2 Power Converter

The battery only has one fixed, input, although different components require a different voltage input. Thus, a power converter is used to convert the output voltage of the battery to different voltages that satisfies the needs of multiple components.

Specification	Verifications
The converter should be able to operate under 6V-12V +/- 10% DC power input.	Check datasheet.

Requirement	Verifications
The converter(s) should be able to output 3 different voltage levels: *1. 3.3V +/- 10%* *2. 5.0V +/- 10%* *3. 12.0V +/- 10%*	For each of the output levels, we supply the converter with an input DC voltage of 12.0V generated from a function generator and measure the output voltage with an oscilloscope. The test is passed if the output voltage is within the assigned range.

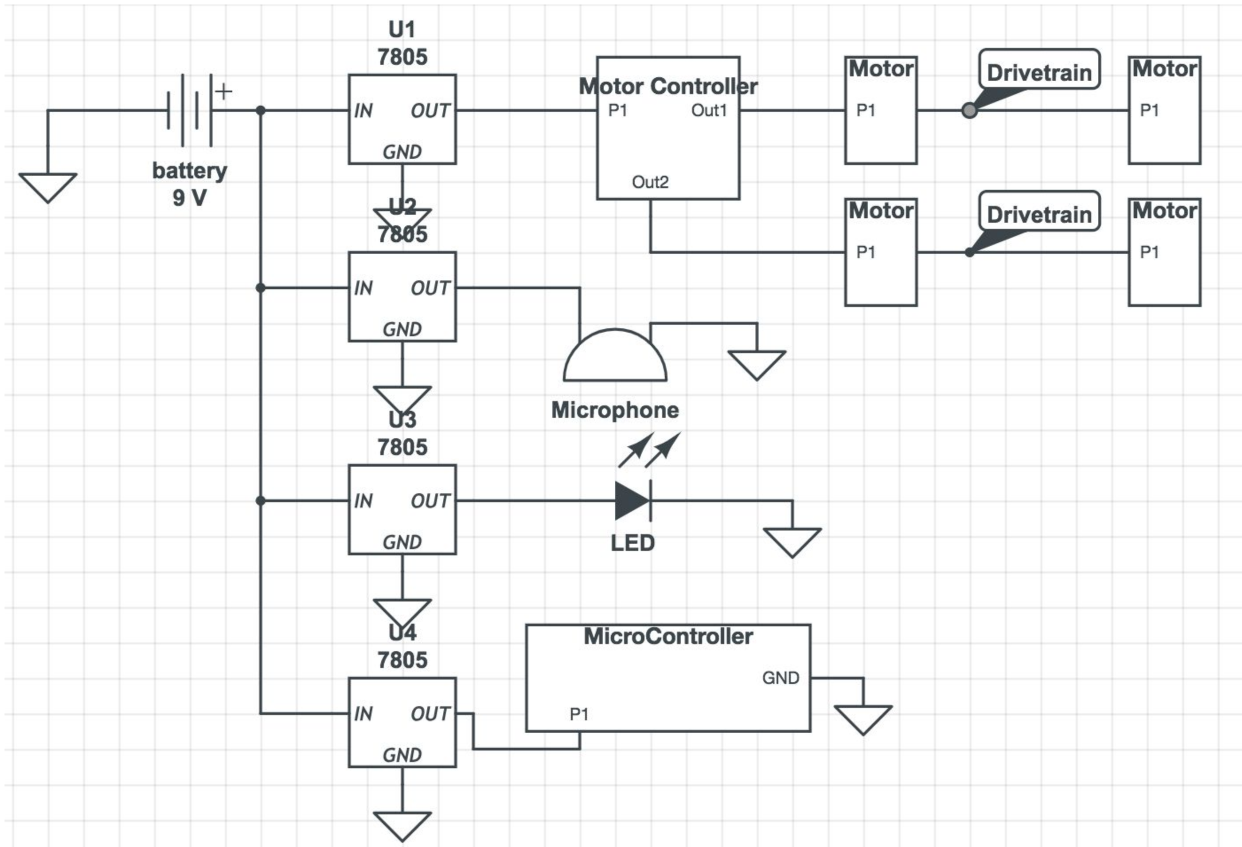

Figure 3. General schematics of the power system

2.3 Control Unit

All data input and outputs are acquired, processed and sent through the control unit. The microcontroller takes charge of the internal operation of the robot while the Wifi module helps it to communicate with the controller. Without the control unit, control of the robot would be impossible. The microcontroller is powered by the power module and it powers the small chips such as the Wifi module, the IR sensors, etc.

2.3.1 Microcontroller

The microcontroller operates as the core coordinator of the whole robot. It will receive data from the controller through the Wifi module and send the data from passive infrared sensors and microphone back to the user interface. It should coordinate the actuators to work together and fulfill users’ demands by sending them digital or analog signals.

Specification	*Verifications*
The microcontroller should have at least 4 analog I/O pins and 3 digital I/O pins.	Check the datasheet to make sure the microcontroller meet the specifications.
The microcontroller must have at least 4kb of memory.	

2.3.2 Wifi Module

Wifi Module is a significant part of the control unit to make sure user end and the robot controller could communicate with each other wirelessly. We are using the ESP8266 Serial Wifi Module to provide Wifi access on both the robot and the controller.

Requirements	Verifications
The Wifi module should transfer data at a minimum rate of 256 Kbps with a Wifi source that is known to transfer data more than 1 Mbps.	1. After setting up the Wifi module, keep sending random data from the microcontroller to a PC under the desired network condition. From PC, measure the size of data received within 1 second. 2. Keep sending random data from PC to the microcontroller. At the microcontroller, measure the size of data received within 1 second.

This Wifi module is independent of the data transmission of the camera. The network bandwidth requirement regarding the camera below.

The rate of Wifi provided to the robot will affect the quality of videos received by users.
Following are two bandwidth that two cameras with different resolution require.
Case 1:
Suppose the camera’s resolution is: 1920 x 1080
FPS: 30
Assuming: 24 bits (3 bytes) per pixel for colored image
Size of single image: 5.9 MB
Size of all images in a second: 178 MB
Bandwidth needed: 1.6 Gbps

Case 2:
Suppose the camera’s resolution is 1280 x 720
FPS: 30
Assuming 24 bits (3 bytes) per pixel for colored image

Size of single image: 2.64 MB
Size of all images in one second: 79.1 MB
Bandwidth: 700 Mbps

In conclusion, the bandwidth of Wifi highly affects the quality of the video. However, even if the Wifi module fails to reach the specified standard, users are still able to receive video (continuous images), but with lower resolution.

2.4 Data Input

Data input consists of all the information users want to know and the whole point of this product is to transfer this data back to users. Images captured by the camera and audio captured by the microphone would be sent to a mobile app through Wifi independently; the human direction data detected by the passive infrared sensors would go through the microcontroller to be sent to the remote controller.

2.4.1 Camera

A camera is going to capture a large angle of view in front of it with the help of rotation of camera lift. It should be able to capture images in dark environments with help of the light.

Specifications	Verification
*The camera resolution should be no less than 352*240.*	Check datasheet.
The camera should be able to take at least 30 pictures per second.	Check datasheet.
The camera should have a FOV of 110 degrees.	Check datasheet.

Requirement	Verification
The camera should have a FOV of at least 180 degrees (after rotation).	Rotate the camera with the lift. Mark the areas that the camera can capture and measure the FOV.

2.4.2 Microphone

Two microphones are needed to capture sound data from both the robot and the user end. One is installed on the remote controller and the other one is on the robot.

Specifications	Verifications
The microphone should be able to produce peak to peak voltage of at least 200mV.	Check datasheet.
The microphone should have gain of at least 500.	Check datasheet.

2.4.3 Sensors

Passive infrared sensors are used to detect the approximate position of humans (when they move) within the area. With several sensors, we could know the relative direction by comparing the data from different sensors.

Requirements	Verifications
The infrared sensors should be able to detect people at the directions they are facing within the distance of 5 meters.	1. Setup the sensor at the approximate height as it is on the robot, and make it face to the direction of tester. 2. Let a tester walk past the sensor at a distance of 5 meters (perpendicular to the sensor). 3. The sensor satisfies the requirement if it outputs HIGH.

2.5 Actuators

Actuators allow the user to control the robot to help them better collect information. The voltage inputs of motors and the light are sent to the components from the microcontroller.

2.5.1.1 Wheel motors

Wheel motors should have different speeds depending on different voltage inputs. The responsibility of coordinating wheel motors lies in the control unit.

Requirements (wheels and motors)	Verifications
The motor should reach its steady state spinning speed in 2 +/- 10% s.	1. Power the motor when it is at rest. 2. Use a stopwatch to measure the time elapsed until it gets to a steady speed.

The motor should stop spinning within 2 seconds with voltage supply to it becomes LOW.	1. Make the motor spin in a steady speed. 2. Disconnect the power supply to the motor 3. Measure the time elapsed from disconnection of power to the motor totally stops spinning.
The motor should be able to keep a steady rotation speed of 120 +/- 10% rpm under a load of 1 kg.	1. Use a string to attach a load of 1 kg to the motor. 2. Use a function generator to adjust the input voltage to find a proper input that allows the motor to spin at the specified speed steadily. 3. The motor passes the test if such voltage could be found.

2.5.1.2 Motor Controller

Specifications	
Output current (average)	1.2A
Supply voltage	2.7 - 5.5 V

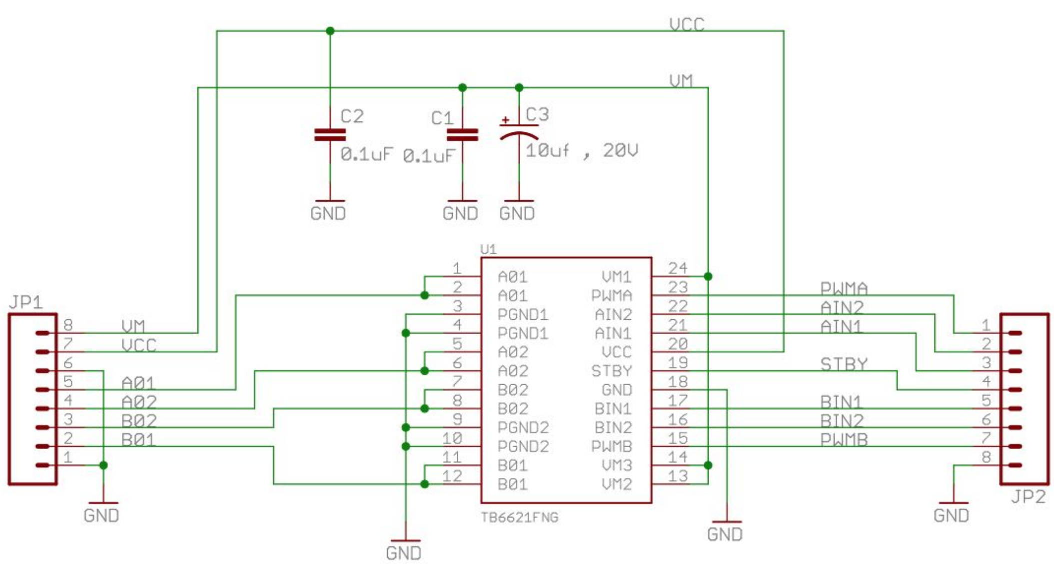

Figure 4. Schematics for Motor Controller [9]

2.5.2 Camera lift

The camera lift will hold the camera. It can adjust the vertical position of the camera by ascending or descending in order to have views of different heights. The lift should also be able to rotate around its axis, so the camera can see different angles without turning the robot.

Requirements	Verifications
The lift should be able to rotate at least 180 degrees about vertical axis.	Rotate the lift and measure the angle from its original position to the position where it cannot rotate anymore. If the angle is larger than 180 degrees, then we pass the test.
The lift smallest rotation angle should be less than 10 degrees.	Give the button that rotates the camera one quick press, measure the angle the camera rotates. If it is less than 10 degrees, then we pass the test.

2.5.3 Light

The light will turn on and off based on commands from the control unit. The light will provide a better view of the camera when the space is relatively dark.

Requirements	Verifications
The light should able to be switched on or off via control signals from the control unit.	1. When the light is installed, it should be off. Send control signals to turn on the light from the microcontroller. The LED light passes the test if it is turned on. 2. Following the above test, send control signals to turn off the light. The LED light passes the test if it is turned off.
The LED light has at least 300 lumens.	1. The datasheet should specify the LED has more than 300 lumens.

2.5.4 Speakers

Two speakers are needed for broadcasting sound data to both the user end and the robot. One is installed on the user remote controller and the other is on the robot.

Requirements	Verifications
The speaker should be able to deliver sound to the user end with volume larger than 50 dB.	Examine the volume of the sound delivered by the speaker and ensure it is larger than 50 dB.

2.5.5 Bucket

A bucket that can hold items is attached to our robot so that items could be delivered to the destination when necessary.

2.6 User interface

The user interface consists of two parts: one is a mobile app that transfers camera data, and the other is a physical controller that allows the user to control the actuators, get information from IR sensors and speak to the target. It is the ultimate port that transfers the data to the user end and allows users to control the robot.

2.6.1 Mobile app

The mobile app is provided by the manufacturer of the wireless camera. It allows the user to access live stream video captured by the camera, as well as change the settings of the camera (such as resolution, mode, etc.)

2.6.2 Controller

The controller is a physical device similar to a remote controller. On the controller, four buttons represent four directions that the user can make the robot go towards. Four LED indicators remind the user of any suspicious human movements in the corresponding direction. A microphone takes sound data from the user while the speaker displays the sound data collected near the robot. The Wifi module enables the network to connect between a microcontroller and the microcontroller on the chip, allowing them to exchange data. The speaker, microphone, wifi module, and the microcontroller is just a counterpart of a similar system on the robot. A rechargeable battery powers all those components and they are encased in an enclosure.

Requirements	Verifications
The battery should have at least 1000mAh of capacity.	1. Fully charge the battery until the charge indicator light turns on. 2. Use the battery to supply a circuit that needs 1.0A to operate and record the time that the circuit lasts. The operating voltage

	does not matter here. 3. The battery passes the test if it can sustain the circuit for more than 1 hours.
Every button press can be interpreted as a digital signal of 1 in the microcontroller during its press time.	1. Connect a button to a digital I/O port on the microcontroller. Press the button and get the input value on the channel.

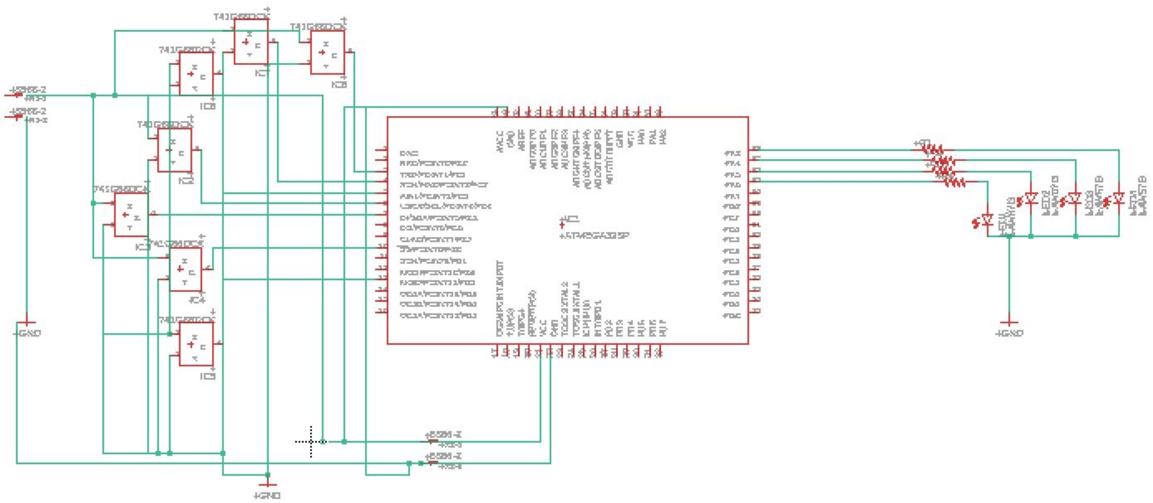

Figure 5. Partial schematics for the controller

2.7 Tolerance Analysis

Network Latency Analysis

One important tolerance that we need to maintain is to have the network latency less than 1 seconds. Usually a WIFI network in good condition has a latency around 2-4 milliseconds. Such latency is almost neglectable and will not affect the performance of our robot.

However, in reality, there are many factors that could lead to huge increase in network latency, such as distance and the size of data to be transfered. When large amount of data need to be transfered, but the bandwidth is limited, network latency will increase dramatically. If the network latency becomes 1 seconds, which is quite large, the user will experience uncomfortness while controlling the robot. For example, if the robot is moving forward at a speed of 3m/s, and the user wants to turn it right at next crossover. However, if the network latency is 1 second, the robot received the command more than 1 seconds after the command was sent, and missed the turning point and might crash into some obstacles.

Admittedly, high network latency (especially a sudden increase in network latency) will undermine user experience significantly. However, out robot could still function. If the above situation happens, the users can stop the robot immediately. The user could decrease the resolution of the image, and also wait for a period of time to allow the congested data to be transferred successfully. Then, user could restart the robot and control it again. Even if some extent of network latency still exist, the users know about the latency and can thus give command in advance.

3 Cost and Schedule

3.1 Cost Analysis

Labor cost:
We have three members, whose estimated working time is 10 hours per week and there are 11 weeks counting from now to the end of this semester.
Cost for each member:
$25/hour * 10 hours/week * 11 weeks *2.5 = $6,875
Total cost:
$6875 * 3 = $20,625

Parts cost:

Part	Quantity	Cost
Wifi chip(Hiletgo, ESP8266)	2	$12.99
Microcontroller (Mouser, ATmega328PU)	2	$1.95*2 = $3.90
LED (Amazon, I-SHUNFA 10 pack bi-pin)	1	$14.98
Wifi camera (Amazon, Ansteker 1080P Mini Portable Wireless Wifi Security Camera)	1	$39.99
Motors (Product Code: RB-Ban-80 by Banebots)	4	$7.25 * 4 = $29
Wheels (Product Code : RB-Dfr-184 by DFRobot)	4	$6.95 * 4 = $27.8
Microphone(SODIAL(R), MAX9814 Electret MIC Microphone Amplifier Module Auto)	2	$7*2 = 14

Battery(10000mAh) (by Starlight Power Technology Product Code : RB-Sta-11)	1	$59.99
Battery(2800mAh) (Product Code : RB-Sta-14 by Lynxmotion)	1	$48.99
Robot body and supplementary materials	N/A	$150

Total parts cost = $401.64

Grand total = $21026.64

3.2 Schedule

Week	Xuqing Sun	Shenyi Wang	Pu Jin
02/18/2019	Finish circuit schematics and order parts for the controller circuit	Find and order parts needed for the project	
02/25/2019	PCB schematic design		PCB soldering
03/04/2019	Solder the remote controller circuit, setup IDE for microcontroller	Build the basic skeleton of the robot	Install motors and write code to test them
03/11/2019	Write code to transfer data between microcontroller and rf module	Build the camera lift	Build a power supply module
03/18/2019	Finish building data path from user to the robot	Place all components onto the robot skeleton. Connect all power supply connections and make sure each component received appropriate voltage input.	
03/25/2019	Build a mechanical case for the controller and finalize the design	Install the camera module and test the performance.	Install the microphone module and test the performance.

04/01/2019	Test camera module and sensors	Test actuators	Test microphone and speaker
04/08/2019	Finish prototype and test the remote controller	Test the movement of the whole robot and LED.	Test all data inputs
04/15/2019	Environmental test & interact with UIPD to get some feedback		
04/22/2019	Integrate modules	Detail improvement	Further development possibilities
04/29/2019	Presentation & poster session		

4 Discussion of Ethics and Safety

4.1 Ethics

The main ethical concern of our product is that it has a camera and microphone that transfers real-time data and that may lead to infringement of privacy. This may conflict with the IEEE ethics code #2 which states we ought to "to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist" [6]. Although the robot is designed to detect suspects, it may also detect and transfer pictures of irrelevant people. For us as engineers, we are unable to distinguish between targets and irrelevant people and it is difficult to monitor the use of the product once it is sold. We can only make sure the product is placed in the right hands and expect the police will follow their own ethical code of not infringing privacy.

4.2 Safety

Potential safety concerns in this project include both electronic and mechanical aspects.
A rechargeable battery is an important component of our robot. Since many batteries have the potential risk of overheating and ignition, we should ensure a compatible charger and voltage inverter are used, and we will strictly follow the lab rules and datasheets when charging, discharging or handling a battery.
Also, electricity leakage and circuit shortage might happen during the building and operating phase. According to the Occupational Safety and Health Standards from the United States Department of Labor, "To ensure safety, the circuits and equipment to be worked on shall be disconnected from all electric energy sources. Control circuit devices, such as push buttons, selector switches, and interlocks, may not be used as the sole means for de-energizing circuits

or equipment".[7] While building and operating the circuit, we would strictly follow the safety guidelines.

While constructing the robot, we need to solder components which may have the potential risk of burning, not only on ourselves, but may also set the lab on fire. We will follow the lab safety procedures carefully while using the soldering iron.

On the mechanical side, the spinning motors may lead to injuries, and the robot may crash into people and hurt them. While building and testing the robot, the motors might spin out of control, especially while testing our code. We should write an emergency halt program in our code in case the motor is out of control. We will construct and test our robot in an empty room so that no bystanders would be hurt by accident. Also, though acknowledging those concerns, we think those problems are rare and mostly caused by misuse of the device. We would make the motor unaccessible from the outside and try to avoid sharp angles on the physical design to avoid serious injury to people.

Reference

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[3] New York City Police Department (NYPD), 'Active Shooter: Recommendations and Analysis for Risk Mitigation', 2012. [Online]. Available: https://www.nccpsafety.org/assets/files/library/Active_Shooter_Recommendations_and_Analysis.pdf. [Accessed: 08-Feb-2019].

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