Reconnaissance Robot

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Abstract

This report aims to show the design details and outcome of our project, reconnaissance robot, including design considerations, costs, requirement and verifications. The purpose of the robot is to recon unknown area for police officers and transfer back image and sound data, so the robot carries a control unit, a camera, a microphone and several other assisting components. To help collect data, users can control the robot to move in different directions and rotate the camera lift through a remote controller; the remote controller and the robot communicates through WiFi. In the end, we successfully implemented most of the designed features, but fails to implement two-way audio, LED and PIR sensors. We will discuss our design decisions, verify the requirements for each subsystem and explain why some functionalities do not work.

Contents

1. Introduction

1.1 Background and Purpose

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[1]. The NYPD (New York City Police Department) gave some recommendations to reduce the 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 [2]. 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. There are already some devices that allow police officers to recon the environment, but they are either too big and heavy, or they will get stuck in some narrow entries [3].

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. The purpose of the robot is to help the police officers gain a better knowledge of the surrounding environment and communicate with the suspect or control the suspect.

1.2 Functionality

There are three high-level requirements for our robot. First, the user should able to control movements of the robot (move forward, move backward, turn left, turn right) at one preset speed and allow the camera lift to rotate at a preset angular speed. The user should also be able to 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 in open space. This ensures the user to move the robot to a preferred location and angle at which they can collect the data they want.

Second, the robot should transfer back images(at least 352*240 resolution) and sound data under dark conditions below 10 lux (with the help of light). Without the data transferred back, the robot would be no use to the officers. This requirement ensures that the robot can provide useful data.

Last, the power system should sustain the robot for at least half an hour of full operation when it has all its components operating at full power. This is an underlying requirement that can support the first two requirements.

1.3 Subsystems

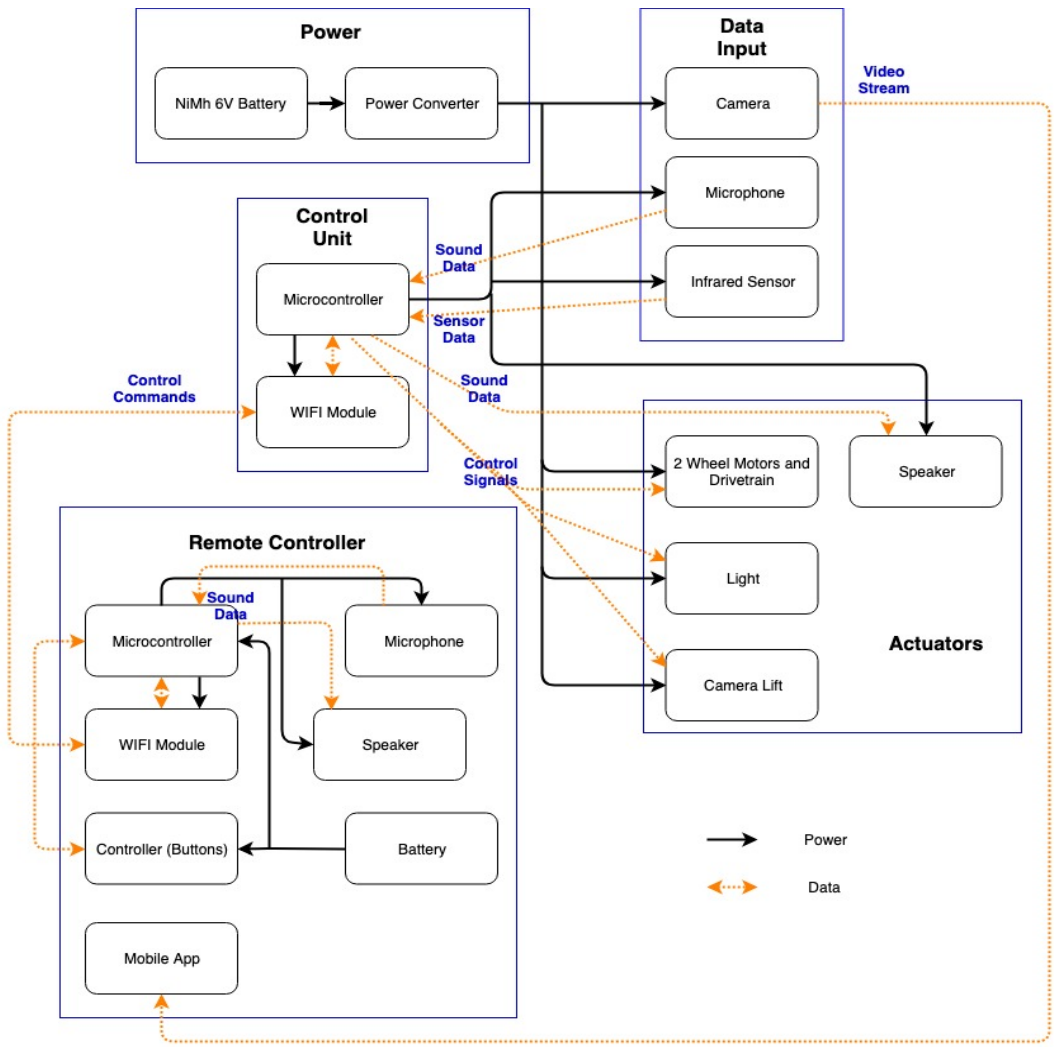


Figure 1. High-level block diagram of the whole system.

The block diagram of our robot is shown in Figure 1. Our robot consists of five subsystems. The modules have to work together to achieve the 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 the tool of communication, which can be replaced by an RF transceiver pair. The control unit 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 movements of human beings. The data input subsystem is mostly powered by the power subsystem and sends its outputs to the control unit, with the exception of the camera which sends its data to the mobile app. The actuators of the robot contain wheel motors, a camera lift, a LED light, a speaker and 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 control unit. The remote controller consists of two parts: one is a mobile app that receives 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. The mobile app communicates with the camera while the physical controller talks to the control unit on the robot.

2. Design

2.1 Power Unit

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. This block supports all other blocks to do their work so the robot could not operate at all without it. An alternative would be to use several different batteries for different voltage outputs, but then the user would need to recharge several batteries and this would deteriorate their user experience. Figure 2 shows the relationship between power unit and other components.

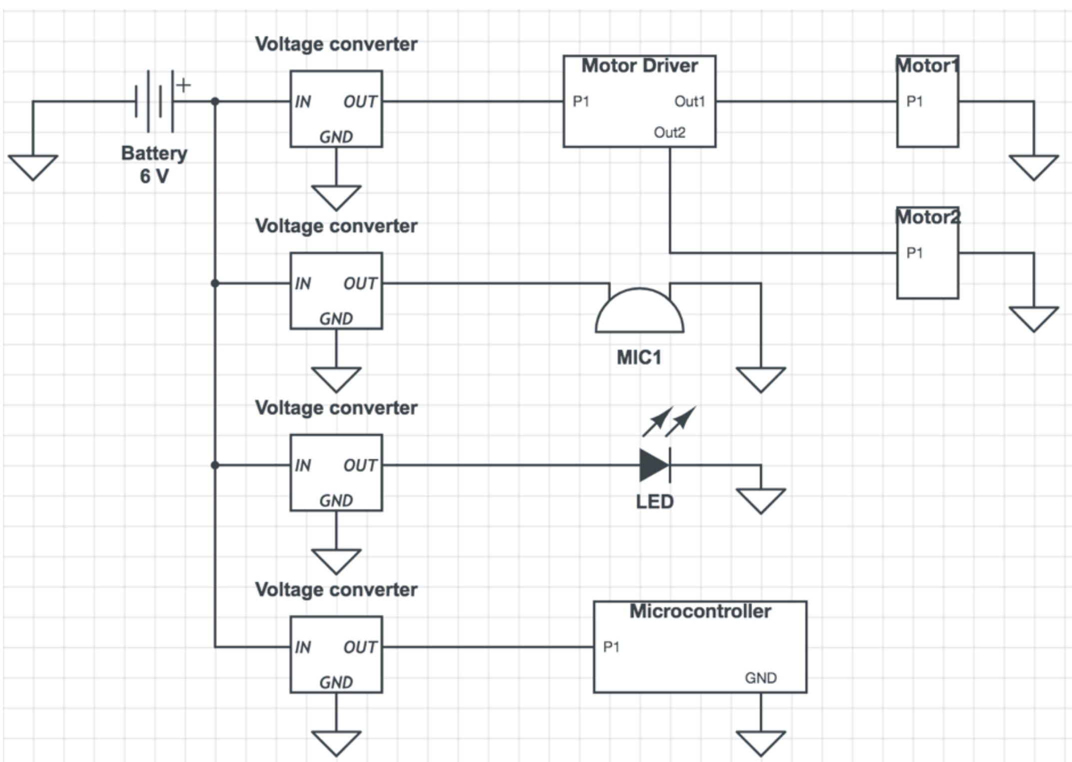


Figure 2. Schematics of the power system.

2.1.1 battery

We use a 10000mAh NiMH rechargeable battery to power the entire system.

$$E(Wh) = Q(mAh) \times V(V) / 1000 \quad (2.1)$$

Use equation (2.1), we could calculate that the battery's capacity is 60Wh. This is the battery with the largest capacity with all robot batteries we found. There are many alternative batteries we could choose from, but the NiMH battery is considered to be safer, and most alternatives have a small capacity.

2.1.2 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 satisfy the needs of multiple components.

2.2 Control Unit

The main purpose of the control unit is to process data and communicate with the remote controller, so our original thought was to use a microcontroller and an RF transceiver pair to communicate between the robot and remote controller, which can help us get rid of the dependency on the WIFI connection. However, later we decided to implement a two-way audio connection and decided to switch to WIFI communication which has higher transfer speed. The current design would provide higher quality audio communication and is easier to implement compared with the previous one.

The control unit mainly consists of a microcontroller and WIFI modules. 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.

2.2.1 microcontroller

We use the ATMEGA328P microcontroller chip in our project. Our PCB mainly consists of the microcontroller and supporting components for the microcontroller chip. We also add jumpers on our PCB for the convenience of connection. Figure 3 shows the schematics design for our PCB.

Figure 4 illustrates the control algorithm on the microcontroller.

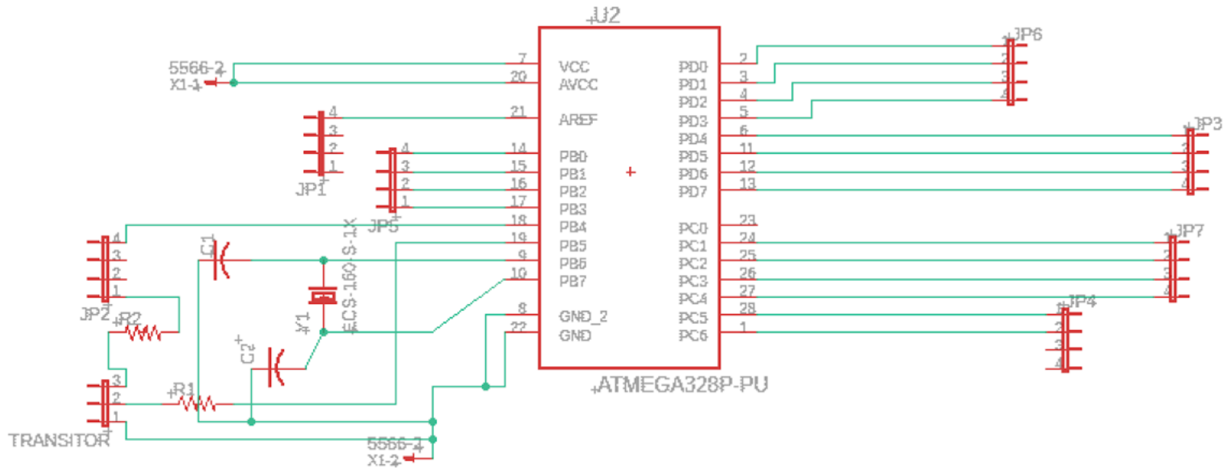


Figure 3. PCB schematics

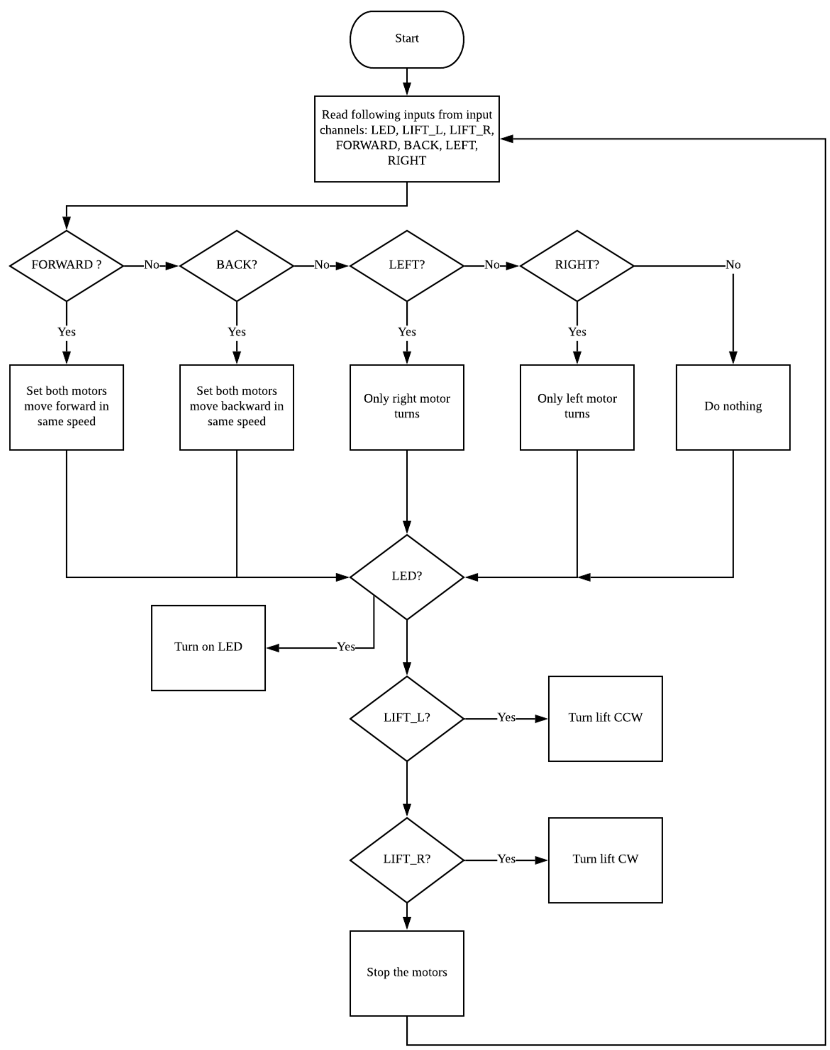


Figure 4. Flowchart of the algorithm on the microcontroller.

2.2.2 WiFi module

We use two ESP8266 chips for WiFi communication. One chip located on the robot and the other one located on the remote controller.

2.3 Data Input Module

The camera and microphone are directly required by the police officers, and we decided to add the PIR sensors to help them detect human motions nearby.

2.3.1 camera

The camera module we currently use is an off-the-shelf product which has its own mobile app. We considered the alternative method of buying a camera chip and transferring the images through the WIFI module, but after calculation, we decided that it may require more bandwidth than our implementation can provide. The calculation can be seen in Appendix A.

2.3.2 microphone

We use two microphone chips, one on the robot and the other on the remote controller, to collect sound on both sides. The microcontroller will receive the sound data from microphones and transfer the data to WiFi chip, then send the sound data to the other end.

2.3.3 sensors

In our design, we would like to place 4 PIR sensors on four sides of our robot. By reading the output of all four sensors, we could know the direction of human beings in the nearby area. To display the output of the sensors, the control unit will read data from all 4 sensors and send the data to the WiFi chip on the remote controller, and we use 4 LEDs to display the value obtained by the 4 sensors. The reason why we use PIR sensors instead of ultrasonic sensors or IR sensors is that we consider detecting human movements is more important than detecting static objects.

2.4 Actuators

Actuators are the operators that perform users' commands. The actuators receive signals coming from the control unit and perform different actions based on those command signals.

2.4.1 Motors and motor driver

We use two 120 V/220 RPM geared motors to drive two front wheels, and TB6612FNG motor driver to control both motors. We also use two ball casters as back wheels. We use two motors instead of four motors with drivetrains because, in our initial design, we didn't think that our robot is that heavy in weight, so we didn't think that we need a 4-wheel drive. Also, none of our team members have the knowledge of how to build a drivetrain, which could take a long time for us to actually accomplish that. This is why we ended up choosing to use the motor drive chip, which serves our need for driving two motors at the same time perfectly.

In1	In2	PWM	Out1	Out2	Mode
L	H	H	L	H	CCW
H	L	H	H	L	CW

Table 1. Input Output Correlation of Motor Driver

2.4.2 camera lift

The camera lift is made with a length adjustable selfie stick so the user can manually adjust its height before sending the robot away. A servo at the bottom of the lift enables it to rotate vertically, which enables the users to get a side view without having to turn the actual robot. An alternative design, which was also our original design, was to allow users to adjust the height of the lift remotely. After doing some research, it turned out that such adjustment is very difficult and expensive, so we switched to the current design.

2.4.3 LED

We choose a 12 V, 2.5 W LED to fulfill the brightness requirement.

2.4.4 speakers

We chose gravity digital speaker to output sound data.

2.5 User interface

Originally, we were considering using a mobile app as the user interface. However, after doing some research, we decided that creating a mobile app from scratch that contains all our features would be too time-consuming. Instead, we turned to a physical remote controller; the idea was inspired by [3].

2.5.1 remote controller

On the controller, we design to have four buttons indicating the four directions for the robot to move towards, and four LEDs indicating four directions that IR sensor says could have human moving. There are also buttons for switching on/off the light and controlling the camera lift. Beside those buttons and LEDs is a speaker and a microphone to allow police officers to communicate with the target. Inside the case lies other components opaque to the users, including microcontroller, Wi-Fi module, and battery.

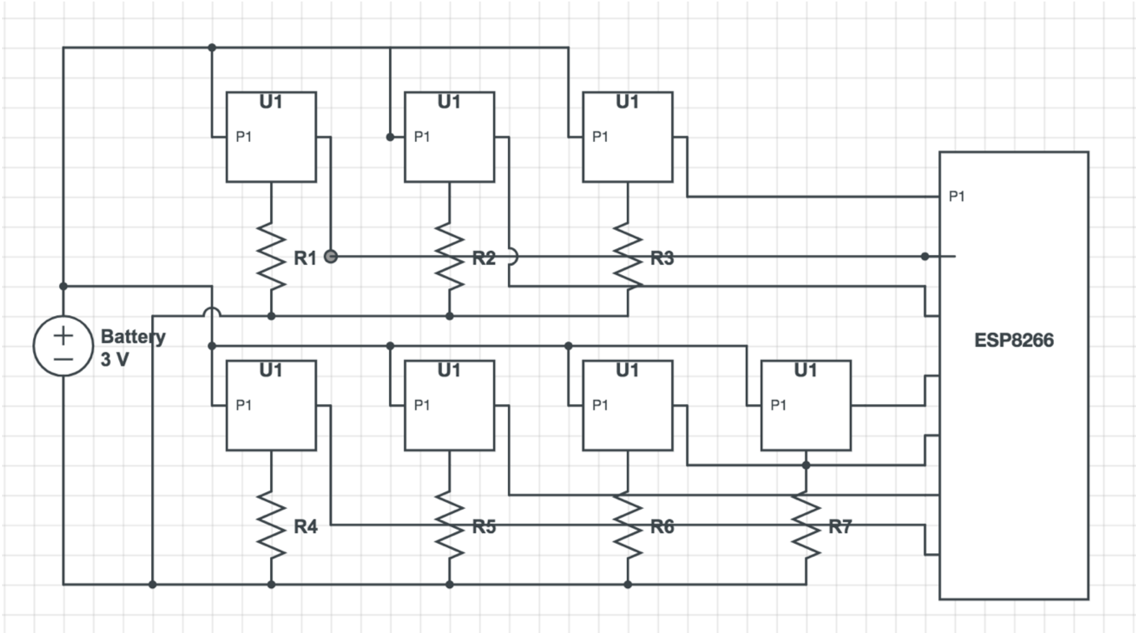


Figure 5. Schematics of remote controller.

2.5.1 Mobile app

Since the camera we use is an off-the-shelf product, it comes with a mobile app that is ready to use. The users simply need to download the app onto their cell phone and connect to the network of the camera.

3. Design Verification

3.1 Power Unit

3.1.1 Battery

In the RV table, we proposed to verify the battery by running all components under full power for half an hour. Since not all components are working, we did not conduct the verification. In the alternative, we estimated the power usage by calculation.

For the motors, we measured the voltage and current, which are 12V and 7.3A respectively. We use formula (3.1) to calculate the power consumed by the motors.

$$P = VI \tag{3.1}$$

For other components, we estimate the power from the datasheet.

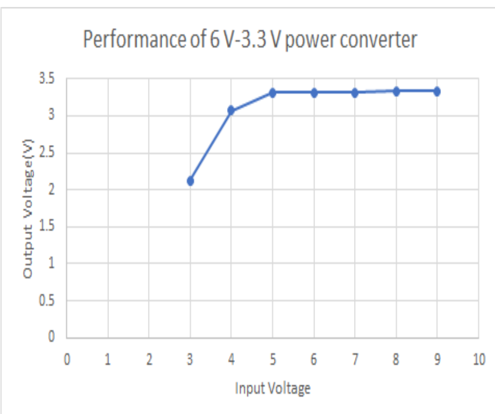
Parts	Power
LED	2.5W
Microcontroller	0.081W
ESP8266	1.056W
Motors	175.2W

Table 2. Power Consumption of Components

The total power consumed is about 178.6W. Our battery is 60Wh, which appears to be not enough. However, since the measurement of power consumed by the motors involves a lot of uncertainty, this is the safest estimation. The real power consumed by the motors might be way less than 175.2W, which means the battery could last longer.

3.1.2 Power converter

We verified the requirements for power converter following the procedure in RV table. The results is shown in Figure 6 and Figure 7.



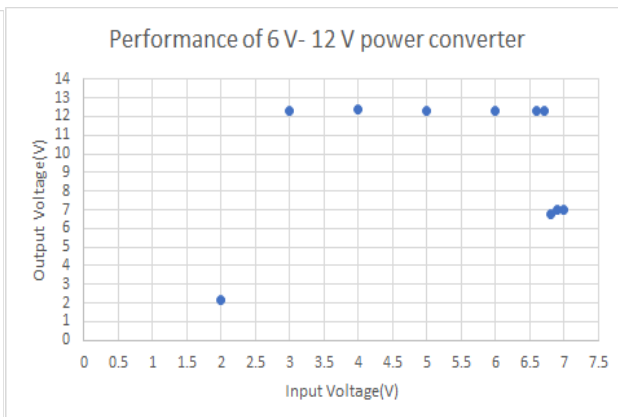


Figure 6. Performance of 6 V- 3.3 V power converter.

Figure 7. Performance of 6 V-12 V power converter.

3.2 Control Unit

The verification of the control unit is actually dependent on the verification of the whole system. We did not perform the verification for the WIFI module since it is not essential for high level requirements. However, the serial communication between the microcontroller and WIFI module, which is not specified in the RV table, failed to work. The reason is unknown, but we suspect it to be incorrect software implementation or defective hardware. This has a significant impact on our whole project; the two-way audio system could not be implemented due to the lack of digital data transfer channels.

3.3 Data Input Module

3.3.1 Camera

The camera we got is an off-the-shelf product, and it meets the specifications and requirements that we originally designed.

Resolution	1080P
Number of frames	30fps
Power Consumption	1.036W
Field of view	140 degrees

Table 3. Specification of Camera

3.3.2 PIR sensors

We performed verification for the PIR sensor but they did not pass the test. The results are shown in Table 4.

Situation	Voltage
Obstruct IR sensor	3.18V/3.25V
Stand away from IR sensor (1 meter away)	170mV/100mV

Table 4. Testing of PIR Sensor

3.3.3 microphone

To test the microphone, we connect the output pin of the microphone chip to Arduino and continuously recording the data received from the microphone. Peaks appear when we make loud sounds. We also connect the microphone to the audio jack, and we can clearly hear the voice captured by the microphone using an earphone.

3.4 Actuators

3.4.1 Motors and motor driver

We connect the motors to the motor driver, and power up the motor driver to test both motors and the motor driver. We feed in HIGH LOW and HIGH HIGH to the input pins of the motor driver to make the motor move forward and backward. Both motors rotate smoothly and have correct rotations with different input values.

3.4.2 camera lift

We verified the requirements for power converter following the procedure in RV table.

3.4.3 LED

Procedure: We increase the voltage supplied to the LED from 0 to 25 V/DC from a function generator to observe the brightness of the LED at different voltage levels. We also provide it with 12 +/- 5% V/DC to examine if it is hot. Resistors of 10K, 1K, 100R are placed to observe the brightness of the LED and decide the appropriate resistor to use. The current was unable to observe due to the failure of the multimeter.

Resistance(ohms)	Threshold voltage(V/DC)	Max Voltage(V/DC)	Comments
10K	9	25	Dim at 12V
1k	8	25	Brightness grew linearly between 8-22V
100	7	25	Very bright, LED becomes hot in 1 min at 12V
None	7	25	LED becomes hot immediately

Table 5. LED's behavior with different resistance

2.4.4 speakers

Speaker is able to produce different tones by giving commands from the microcontroller. It meets the requirement of providing sound data higher than 50dB. However, it failed to deliver sound data collected from the microphone due to the fact that we couldn't be able to successfully make the conversion between digital and analog data.

3.5 User Interface

3.5.1 Remote Controller

We test the functionality of the remote controller by monitoring the data received by WiFi chip. We use Arduino IDE to output the data received from the buttons. When buttons are pressed, we could clearly see the change in value from Serial Monitor, so we could verify the remote controller is working well.

Since the ESP8266 chip could only send out one message at a time, we have to integrate all buttons into one message. We use a 3-digit code to represent the command pressed by the users.

3.5.2 Mobile App

Since the whole camera module is an off-the-shelf product, to verify the mobile app works, we simply test it together with the camera. Downloaded the app and connected to the camera, we could successfully watch the live stream, which verifies the functionality of the mobile app.

4. Costs

4.1 Parts

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
DC 6 V to 12 V boost voltage regulator module	Banggood	2.5	2.5	2.5
6pcs AMS1117-3.3 V DC-DC converter	LL LAKASARA	4.99	4.99	4.99
10pcs G4 LED bulb 12V	I-SHUNFA	14.98	1.50	14.98
2pcs ESP8266 NodeMCU ESP-12E	HiLetgo	12.99	12.99	12.99
WiFi camera, 1080P mini portable wireless security camera	Ansteker	35	35	35
Adafruit electret microphone amplifier	Adafruit	9.96	9.96	9.96*2=19.92
Project case DIY box	YeaCCC	30	30	30
Standard economy servo	Hitec RCD USA	11.95	11.95	11.95
DC 12 V 220 RPM encoder gear motor	uxcell	19.01	19.01	19.01*2=38.02
5pcs DC PIR motion sensor	Anmbest	14.99	14.99	14.99
Energizer AA Batteries	Energizer	5.21	5.21	5.21
5 pcs Yootop 2 Slots 1.5V AA Battery Holder	Yootop	8.99	1.8	8.99
buttons	Cylewet	6.99	6.99	6.99
SparkFun Motor Driver	SparkFun	5.45	5.45	5.45
6V 10000mA Battery	Starlight Power Technology	59.99	59.99	59.99
Gravity Digital Speaker Module	DFRobot	6.19	6.19	6.19*2=12.38
Ball Caster with 3/4" Metal Ball	Pololu	2.99	2.99	2.99*2=5.98
Total				**290.33**

Table 6. Parts Cost

4.2 Labor

Labor	Cost ($)
ECE Machine Shop	60*7 = 420
ECE Electronic Shop	60*4 = 240
Each Team Member	25*6(week)*10(hr/week)*2.5 = 3750
Total	11910

Table 7. Labor Cost

Grand total = $290.33 + $11910 = $12200.33

4.3 Schedule

Week	Xuqing Sun	Shenyi Wang	Pu Jin
02/18/2019	Finalize design and order parts	Find and order parts needed for the project	
02/25/2019	order parts	Refine PCB design	PCB initial design
03/04/2019	test wifi module	Design basic structure of robot	Design basic structure of robot
03/11/2019	test power converter, LED, PIR sensors	Design the camera lift	Design the motors and wheels
03/18/2019	order parts, test buttons, draw PCB	Communicate and finalize the robot construction with machine shop	
03/25/2019	set up microcontroller development environment	Install the camera module and test the performance.	Test Camera, connect camera with mobile phone
04/01/2019	refine PCB, test battery	Test motors, wheels and servo	Test microphone and speaker
04/08/2019	set up wifi to microcontroller communication	Test the movement of the whole robot and LED.	Test and install motors; connect motor with motor driver

04/15/2019	Develop algorithm for control unit		
04/22/2019	build remote controller and integrate systems	Detail improvement	Integrate systems, solder PCB
04/29/2019	Presentation & poster session		

Table 8. Schedule

5. Conclusion

5.1 Accomplishments

For our final prototype, we successfully built our robot body as well as the remote controller. The robot has two front motors and they are able to be driven by the motor driver. The two WIFI modules are able to make wireless communications with each other. Motor driver can receive commands given by remote controller when the user press the buttons, then drive the motors to rotate clockwise, counterclockwise and stop. The camera lift is able to rotate unidirectionally 180 degrees controlled by commands from the remote controller. A LED light mounted on the camera lift can also be controlled by the user from the remote controller. The camera is able to transfer back high-quality live video stream to a mobile app on the user's phone with no apparent delay.

5.2 Uncertainties

The connection between WiFi chips has uncertainties. While testing, the connection between the two WiFi modules would get lost after a period of time. Sometimes the connection lasts for more than half an hour, but sometimes the connection breaks after several minutes.

Another uncertainty is our motors and wheels. When we tested the movement of the robot on a flat wooden floor, it was able to drive the robot. However, our motors don't provide enough torque to support the robot move smoothly on certain surfaces, for example, on some soft surfaces. This is due to the fact that we didn't provide enough voltage for the motors, because we only feed in digital inputs to the motor driver hence no actual alteration of voltage.

Our camera also has some connection problems. When we use the point-to-point connection between the camera and mobile phone, it is hard to get a mobile phone to connect to the camera's WIFI hotspot. Also, the connection may get lost after some time.

5.3 Ethical considerations

The main ethical concern of our project is that the camera and microphone which transfer real-time data 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" [4]. 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.

5.4 Future work

There are many places to improve. First, we should fix the 2-way audio communication to make sure users could talk to and hear from the robot side. Besides, a better physical case could make the remote controller better in appearance, and also protect the circuit from potential hazards. Soldiering all wires and chips will also improve the stability of the project. Furthermore, we should refine the actuators to make the robot act more accurately. Last but not least, we could add more add-on items, such as a basket or a protective case to make the robot more useful in real work.

There are also many design alternatives we could consider. For the user interface, allowing users to control the robot with their cell phones or laptops could make the project more user-friendly. In addition, there are other wireless communication models we could use and might have better stability and reliability.

References

[1] National Law Enforcement Officers Memorial Fund, 'Preliminary Law Enforcement Officers Fatalities Report', 2018.

[2] National Law Enforcement Officers Memorial Fund, 'Causes of Law Enforcement Deaths', 2018. [Online]. Available: https://nleomf.org/facts-figures/causes-of-law-enforcement-deaths. [Accessed: 08-Feb-2019].

[3] Mike Unander, personal interview, February 7, 2019.

[4] IEEE.org, "IEEE Code of Ethics", 2019. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 08-Feb-2019].

Appendix A Calculations of WIFI bandwidth required by camera

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

Appendix B Requirement and Verification Table

Table 9. Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
The battery should support the robot for at least 30 minutes when all components are operating at full power.	Fully charge the battery. 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.) Use a stopwatch to verify that the battery can support the robot for more than 30 minutes under such operation.	N
The converter(s) should be able to output 3 different voltage levels: *3.3V +/- 10%* *5.0V +/- 10%* *12.0V +/- 10%*	For each of the output levels, we supply the converter with an input DC voltage of 6.0V 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.	Y
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.	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. Keep sending random data from PC to the microcontroller. At the microcontroller, measure the size of data received within 1 second.	N
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.	Y
The infrared sensors should be able to detect people at the	Setup the sensor at the approximate height as it is on the robot, and make it face to the direction of tester.	N

directions they are facing within the distance of 5 meters.	Let a tester walk past the sensor at a distance of 5 meters (perpendicular to the sensor). The sensor satisfies the requirement if it outputs HIGH.	
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.	Y
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.	Y
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.	Y
The battery of the remote controller should have at least 1000mAh of capacity.	Fully charge the battery until the charge indicator light turns on. 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. The battery passes the test if it can sustain the circuit for more than 1 hour	Y
Every button press can be interpreted as a digital signal of 1 in the microcontroller during its press time.	Connect a button to a digital I/O port on the microcontroller. Press the button and get the input value on the channel.	Y
The motor should be able to keep a steady rotation speed of 120 +/- 10% rpm under a load of 1 kg.	Use a string to attach a load of 1 kg to the motor. 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. The motor passes the test if such voltage could be found.	N