Traffic Control Smart System

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Abstract

Traffic control is needed at busy intersections during events such as football games, police incident sites, or other events that cause large traffic at intersections without traffic lights. It is performed primarily by police officers using large traffic wands with vague hand and arm gestures that are hard to understand for the common driver. The officers are also in the field for an hour or two at a time and are required to take shifts to avoid tiring out. This poses as a huge threat to human life at these intersections in the event of an officer losing focus or a driver misunderstanding directions. Team 16's solution is a system of lightweight LED gloves augmented with LED vest panels that can display alphanumeric characters. Fatigue is alleviated by nearly eliminating weight carried in the hands and any confusion in directions given is eliminated by displaying words with clear colors.

Contents

1 Introduction

Traffic control is needed at busy intersections during events such as football games, police incident sites, or other events that cause large traffic at intersections without traffic lights. It is performed primarily by police officers using large traffic wands with vague hand and arm gestures that are hard to understand for the common driver. The officers are also in the field for an hour or two at a time and are required to take shifts to avoid tiring out. This poses as a huge threat to human life at these intersections in the event of an officer losing focus or a driver misunderstanding directions. This problem is so big that the University Police contacted the Siebel Center for Design for help with tackling the issue, and this project aims to remedy their problems.

Our solution to these two problems is a lightweight system of LED gloves accompanied by two LED vest panels. This system alleviates the fatigue from waving around heavy traffic wands to allow a police officer to stay focused and in the field for longer. It also allows them to give clear directions that any driver should be able to understand.

In our design, the gloves are lined with LEDs that can exhibit any color in the visible light spectrum, but only red and green are used in the system as indications of stop and go. The vest panels are lined with the same LEDs except in four 14-segment displays so that alphanumeric characters can be displayed, specifically either “STOP” or “GO”. These LEDs are controlled by easy-to-reach contact sensors on the glove fingers so that officers can freely control the system at will.

This report describes our successfully completed system in detail. From Figure 1, we see that our system has three major components: two gloves and the vest panels. The two gloves communicate with the vest on a one-way line from each glove to the vest through wireless transceivers. The data sent is control data to determine what is displayed on the vest panels. A microcontroller on each subsystem controls its respective transceivers and LEDs and receives input data from the contact sensors on the gloves. Lastly, a pair of rechargeable batteries with voltage regulators powers each subsystem. These components are described in detail in Section 2 with verification of each component in Section 3. Section 4 then looks at the overall cost and timeline of our project.

2 Design

From the physical perspective, our design is divided into a pair of Gloves and a Vest. All the inputs for the system which provide system-wide control are placed on the gloves. Each glove allows user to control Glove LED color, Glove LED brightness and Vest Panel Display. Table 1 provides explicit description of all sensors.

Figure 1: Block Diagram

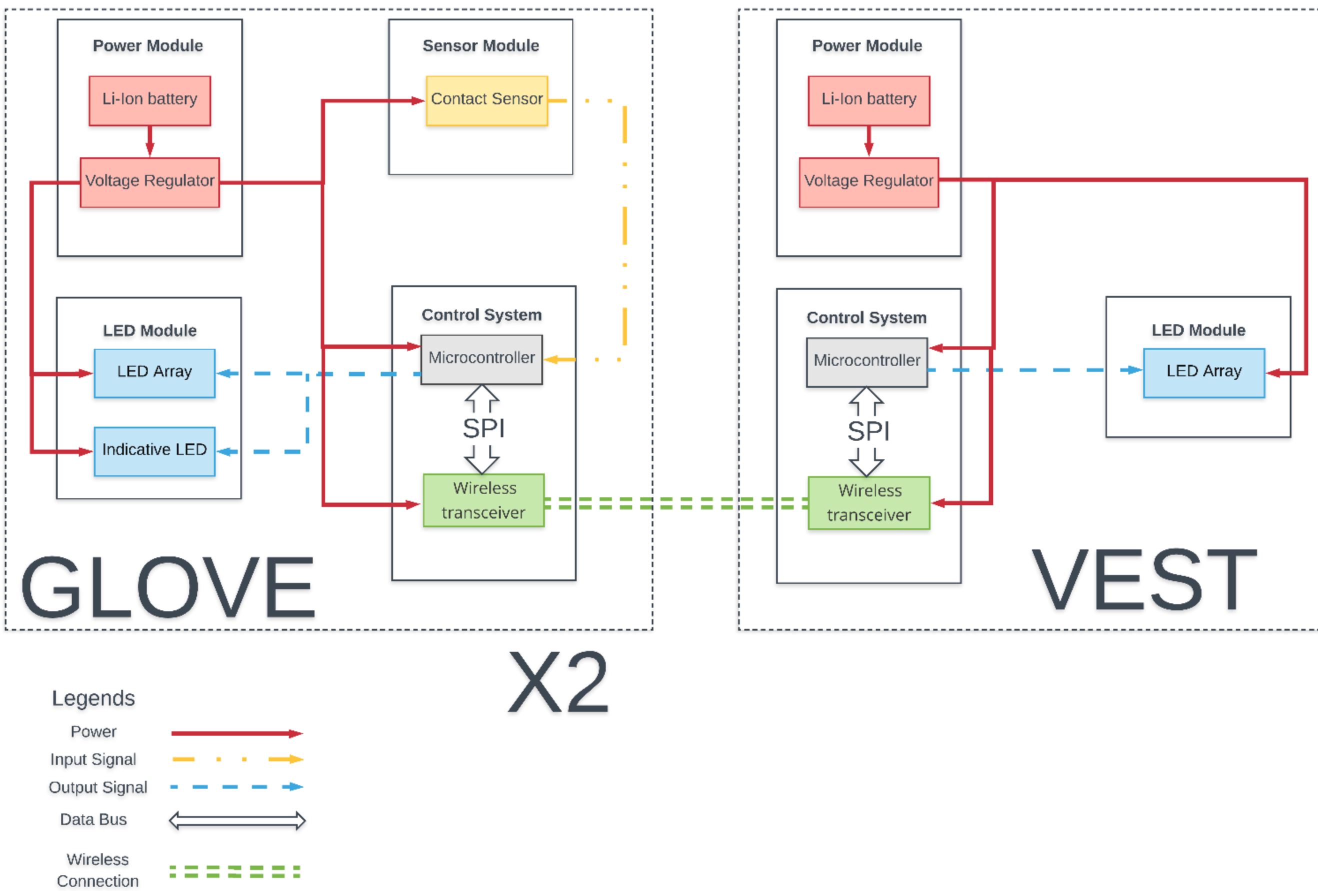


Table 1: Sensor Description

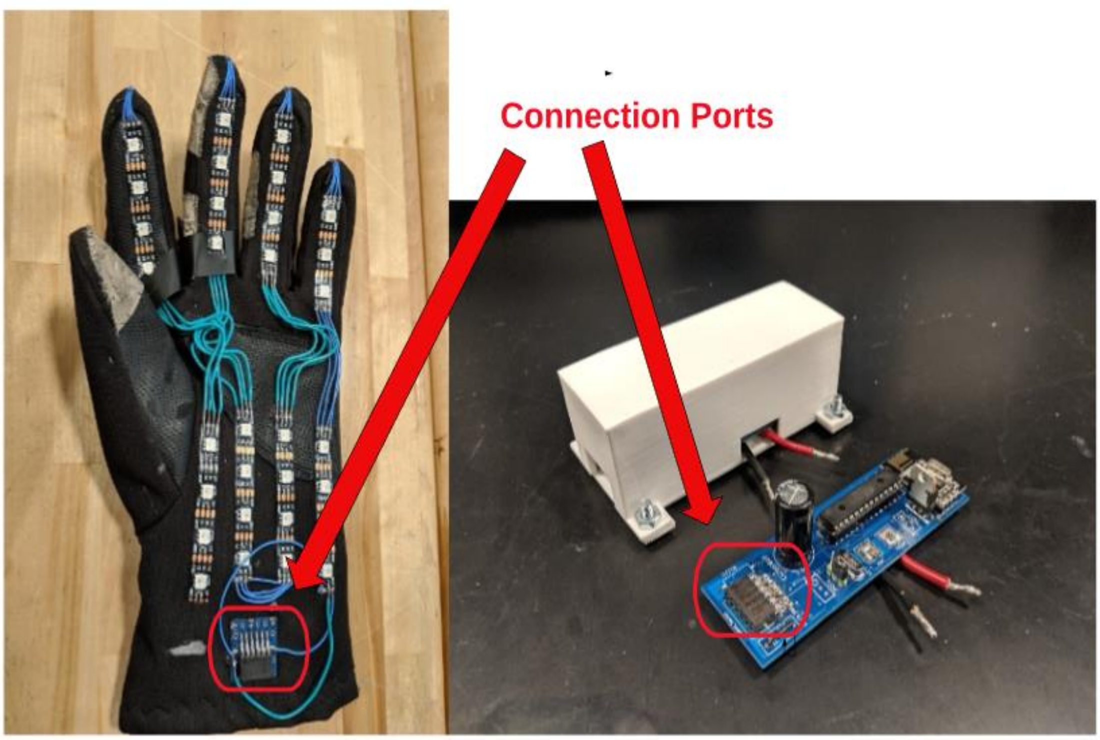
Sensor Number	Location	Modifies
1	Left Ring finger	Front Vest Panel
2	Left Middle Finger (Lower End)	Left Glove LED Brightness
3	Left Middle Finger (Upper End)	Left Glove LED Color
4	Right Ring finger	Back Vest Panel
5	Right Middle Finger (Lower End)	Right Glove LED Brightness
6	Right Middle Finger (Upper End)	Right Glove LED Color

In a nutshell, both Left and Right Gloves have their own set of Microcontroller, Transceiver, LEDS, Sensors and Power Module (also shown in Figure 1). Left and Right are identical to each other except that Left glove modifies Front Panel and Right Glove modifies Back Panel. The microcontroller acts as a common interface to all the sub-systems and allows them to interact with each other. It takes input from the sensors and accordingly sends instructions to transceiver and LEDs. However, the microcontroller on the vest take input from the transceiver (receiving signals from the gloves) and modifies the Front and back panel. As shown in Figure 1, Gloves and Vest have their own independent Power Source, hence Gloves are capable of functioning regardless of the status of the Vest. However, Vest cannot function independently, since it relies on the input given by the gloves.

2.1 Physical Design

To get input from the user, we needed some form of button press. However, attaching mechanical buttons to the gloves is not a robust solution. Hence, we used conductive fabric to simulate a button which brings two different ends in contact to trigger an event. Importantly, we have programmed the contact sensors to register input only after the contact is held for about a second. Since the contact produces a bouncy signal at the instant of touching, the hold feature helps us eliminate that uncertainty. The conductive fabric is sewed on the glove using conductive thread and connected to the 'connection port' show in Figure 2. The glove is finally connected to the PCB through 'connection port' using jumper wires.

Figure 2: Glove Physical View



To implement the LEDs, we used WS2813 which have a double data line feature [3], meaning that in the event that one of the LED in the series connections is damaged, the other LEDs will continue to function without any side effects. One important design choice here was to add LEDs in series. As shown in the Figure 2, we have two different panels on the vest, one in front and other on the back. Although, they are two different units, the LEDs within them are connected in a single series, meaning both front and back panels are controlled by a single control signal. The LEDs on the Glove are connected using wires as they have solderable ends.

To implement the Vest Panels, we used laser-cut lightweight Plywood, as it sturdy enough to provide support to LEDs and offering clear, robust 14-segment display. As seen in figure 2 and figure 3 we use 3D printed boxes to provide an enclosure to Li-ion batteries as well the entire circuitry.

Another feature implemented on the front vest is 'back panel indication'. Since the user cannot practically view the back panel, we added this feature to aid user to see its current. On top of the front panel there is a dedicated LED which indicates what is currently being displayed on the back panel. The LED is placed behind the plywood such that only the user wearing the vest can see the LED. The LED changes only when back panel changes indicating the its current state.

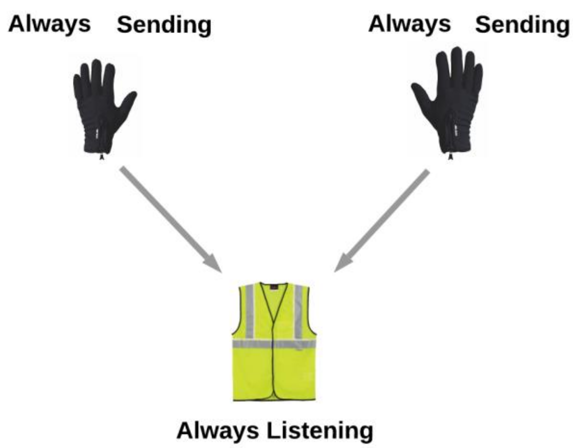
Figure 3: Vest Physical View (Front View on Left, Back View on Right)

2.2 Wireless Communication

To implement the wireless feature for our project, we used three nRF24L01 modules connected to their respective microcontrollers. The wireless transceivers establish unidirectional communication (Gloves to Vest), as shown in figure 4.

The nRF24L01 modules work up to 2 Mbps at 2.4GHz frequency [6], which gives our project imperceivable latency. This module also has the capability to receive data from six different transmitters over the same frequency concurrently, however in out project we use them to receive from only two transmitters. In addition, nRF24L01 draws very low amount of current (12mA) and therefore will not be a risk for power sink. This module was interfaced with ATmega328P since it supports SPI protocol [7]. NRF24L01 modules are powered by battery pack regulated by the LD1117 at 3.3 V. Figure 4 describes the network topology of nRF24L01 in our project, showing two unidirectional channels between gloves and vest.

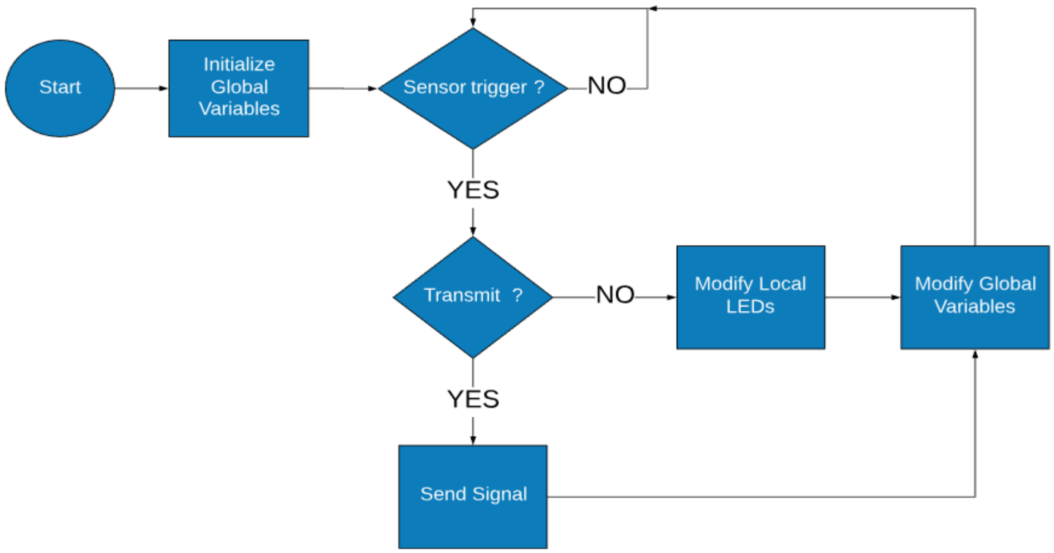
Figure 4: Network topology



2.3 Software Design

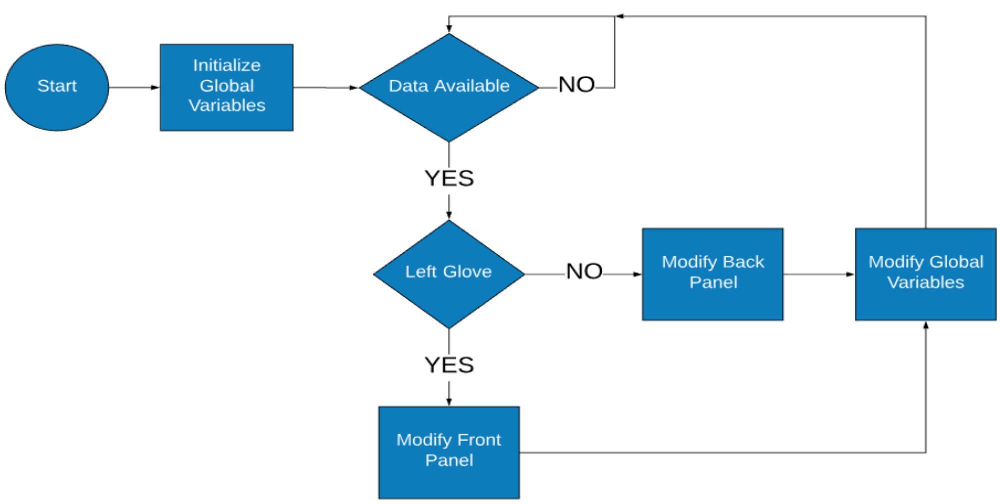
Algorithm shown, Figure 5 is the final implementation of the program executing on the gloves. As shown, the program first initializes the global variables, which includes variables like number of LEDs, communication pipeline number, transceiver address, machine states, etc. Once the global variables are initialized the device then begins polling the input pins of the microcontroller indefinitely and checks if the user has triggered any input. Once the input is registered the device then checks which one of the sensors was triggered. For example, if on Left glove ‘sensor 3’ was triggered, then the glove should transmit the data to the vest, else it must glove LEDs based on whether ‘sensor 2’ or ‘sensor 1’ was triggered. Once the signal is sent or LEDs are modified, the global variables need to be modified, to prepare for the next trigger event.

Figure 5: Algorithm (Glove)



Similar to Glove algorithm is the Vest Algorithm shown in Figure 6. Polling transceiver rather than the input pin is key difference. The microcontroller indefinitely checks for data received on the transceiver, in other words the vest is always in a listening mode with respect to both left and right gloves. Once a data packet is received, the microcontroller determines the channel from which it was delivered. If the channel belonged to Left glove, then LEDs on the front panel needs to modified else back panel need modification. Once the panels are modified, the global variables must be changed to prepare for the input from the user.

Figure 6: Algorithm (Vest)



Software implementation was not the most challenging aspect for our design, as we used Arduino platform to program our microcontroller. Most importantly, WS2813 LEDs and nRF24L01 transceivers are widely supported devices with 'FastLED' and 'RF24' library respectively. These two libraries abstract's away the lower level details making software development faster and reliable.

2.4 Power

2.4.1 Power Consumption

For this project, there are three major power requirements. Microcontroller consuming 50 mA at 5 V, LED strips consuming 20 mA at 5 V per LED and Wireless Transceiver consuming 12 mA at 3.3 V. As for the power source to satisfy these three needs, we decided to choose Li-ion batteries due to their high energy density. Two cells connected in series are used for each glove and for the vest. Since each cell can supply up to 3.7 V and 3400 mAh of current charge [4], the total power supply of the system is about 7.2 V and 6800 mAh.

In order to calculate the battery life Microcontroller, LEDs and Wireless Transceiver consumption should be considered:

$$Battery\ life\ (hrs) = \frac{6800}{Number\ of\ LEDs * 20 +\ 50 + 12} \quad (1)$$

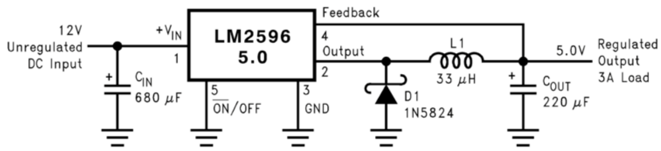
Both gloves have 31 LEDs attached to them which total current draw is 0.62 Amps, so the total battery life for these is around 10 hrs (1). On the other hand, the vest has two panels made out of 48 LEDs in total. The total current draw for this part of the system is 0.96 Amps and therefore its battery would last for 7 hrs approximately (1).

2.4.2 Voltage Regulation

Since the three main components require specific voltages different from the input one provided by the battery, two voltage regulators need to be implemented.

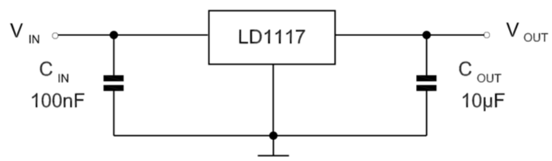
- 7.2 V – 5 V: As explain before, both Microcontroller and LEDs require an input of 5 V, so a voltage regulator is needed to get that voltage from the battery. For this task we decided to use the LM2596 5.0 converter since it is a DC-DC step down power supply module which input voltage can range up to 40 V while the output voltage has a fixed value of 5 V [5]. In addition, the maximum output load current is 3 A, which is more than enough to feed the system. This module's design is the following:

Figure 7: Power supply-5 V voltage regulator



- 5 V – 3 V: Since the Wireless Transceiver requires 3.3 V, one more voltage regulator is needed. The LD1117 component is the one used for this task since its input voltage can range up to 15 V while the output voltage has a fixed value of 3.3 V. Moreover, it admits a load current up to 800 mA what satisfies the nRF24L0 requirements. The design for this module is the following:

Figure 8: 5 V-3.3 V voltage regulator



3 Design Verification

We had three main high-level requirements (Wireless communication, Real-time LED customization and At least two hours of Battery Life) which have been successfully accomplished. In addition, we have also satisfied all the detailed requirements for each sub-system. The verification procedure has been clearly followed and has been clearly mentioned in Appendix A.

4 Cost and Schedule

4.1 Cost

To estimate our labor cost, we assume a $35.00/hour salary and about thirteen hours of work per week for each team member. Our project was completed in ten weeks, so our total labor cost comes out to $34,125.00.

$$Labor\ cost = \frac{\$35.00}{week} * \frac{13\ hours}{week} * 10\ weeks * 3\ members * 2.5 = \$34{,}125.00 \quad (2)$$

The total cost of our parts is $385.08, with individual parts listed in Table 2.

We did not have any machine shop costs in our project, so the total cost of our project including labor and parts costs comes to $34,510.08.

Table 2: Parts cost

Description	Manufacturer	Part Number	Quantity	Total Cost
LEDs	ALITOVE	WS2813	1	$43.99
Vest	HiVisible	-	1	$15.97
Gloves	Terra Hiker	-	1	$15.99
Wireless Transceiver	BephaMart	101	1	$5.89
Conductive Thread	Adafruit	641	1	$11.63
Batteries	Panasonic	18650	4	$111.16
3D Printer Filament	Amazon 3D	0628055207368	1	$15.99
Conductive Fabric	Adafruit	1168	1	$4.99
Microcontroller	Microchip Technology	ATMEGA328P-PDIP	3	$6.42
Electronics Parts for PCB	Mouser	-	-	$109.66
Sweatband Pack	Mcolics	B01BXTUP0Q	1	$8.08
Velcro Pack	Strenco	VC2 15	1	$12.84
SPST Switch Pack	ZUPAYIPA	0602914875493	1	$6.50
			Total:	**$385.08**

4.2 Schedule

Our weekly schedule is outlined in Table 3.

Table 3: Schedule

Week	William	Mohit	María
Week 1 (2/18)	Design gloves and vest, meet with Siebel Center for Design mentors to brainstorm	Design gloves and vest, meet with Siebel Center for Design mentors to brainstorm	Design gloves and vest, meet with Siebel Center for Design mentors to brainstorm
Week 2 (2/25)	Find suitable electronic parts for design and begin ordering them	Practice coding LED colors and research wireless transceiver datasheet	Research potentially more optimal sensors/batteries and begin finding voltage regulators
Week 3 (3/4)	Test LEDs and conductive thread	Test wireless transceivers and make mockup design with dev board	Test microcontroller and voltage regulators
Week 4 (3/11)	Meet with client to update them on progress, begin working on physical frame for vest panels	Design and order PCB, buy remaining parts	Finalize power system on dev board
Week 5 (3/25)	Begin building LED layout and soldering parts together	Begin to assemble prototype and 3D print cases for batteries and PCBs	Begin to assemble prototype
Week 6 (4/1)	Finalize vest panels	Integrate vest panels with gloves and test wireless communication	Integrate vest panels with gloves and test wireless communication
Week 7 (4/8)	Finalize system and put subsystems together for mock demonstration	Finalize system and put subsystems together for mock demonstration	Finalize system and put subsystems together for mock demonstration
Week 8 (4/15)	Ensure system works and prepare for project demonstration	Ensure system works and prepare for project demonstration	Ensure system works and prepare for project demonstration
Week 9 (4/22)	Finish and prepare for final presentation	Finish and prepare for final presentation	Finish and prepare for final presentation
Week 10 (4/29)	Finish final report	Finish final report	Finish final report

5 Conclusion

5.1 Accomplishments

Our Final implementation is very close to the proposed design, with a key difference of number of contact sensors. Initially we proposed a total 16 sensors, however after thorough discussion we optimized to have only six sensors. Our hold features on the sensors make the input from the user more consist and accurate. Without the hold feature, the bouncy signal on the input pin of microcontroller would make operation inconsistent and impractical.

In addition, our power system design is very efficient which has allowed us to achieve elongated hours of operation of the device. The choice of Buck Converter as step down regulator reduces power loss as well as heat dissipation. The choice of our power levels makes the circuitry to be wearable, since a wrong choice can make voltage regulator dissipate significant heat making the device unwearable.

Our 14-segment display panels with the indicative led have been the key accomplishment of our design, since it removes ambiguity and solves the problem scenario effectively. It gives traffic controller a clear way of communication and ease of use. Using nrf24l01 modules for wireless communication gives imperceivable latency, which allows the panels to changed instantly.

5.2 Ethical Considerations

Some safety and ethical concerns should be considered when creating this traffic control smart system. It is designed to be used by police officers in traffic intersection and since our main objective is to protect them while directing the traffic and also avoid accidents by improving communication between them and drivers, our decisions when developing the project must follow the IEEE Code Ethics, #1: “To accept responsibility in making engineering decisions consistent with the safety, health and welfare of the public” [1].

Firstly, it must be ensured that the color of the gloves and the words written in the panel are the ones chosen by the officers, since an error in either of these would probably endanger not only them but also all drivers going through the intersection. So, based on the ACM Code Ethics Section 1.2 [2], in order to avoid harm, we will ensure that the system works as intended by making it intuitive for everybody to use it.

As for the design, the fact that the user wear gloves and a vest with panels in which batteries and electronic circuits are integrated for a long time while being exposed to any weather condition might be an issue. We have decided to use protected 18650 batteries as they have a small electronic circuit integrated into the cell packaging that protects the user against common dangers such as overcharge, over discharge, short circuit/over current, and temperature. It ensures then the safety and good performance of the battery.

Finally, our voltage regulator has a current limiting protection of 3A, hence in case the protection circuit on the li-ion batteries fails, the voltage regulator will still be able to cut off the power supply. These decisions fall into the ACM Code Ethics Section 2.9 [2] since the objective is to achieve a system usably secure.

5.3 Uncertainties

One major uncertainty we ran into was unintentional electrical connections being made when bending fingers to touch the contact sensors because our soldering ends were fully exposed. Since our contact sensors were conductive fabric, we would essentially send a high signal to whatever input we touched by accident and would perform an unintended action. This issue would not occur every time but occurred often enough where it was an issue we had to address. A band-aid solution was made by covering open connections with electrical tape and it worked fine with it.

Another issue was the bulkiness of our PCB and power units on each glove as the weight made it a little counterproductive to our goal of being lightweight. Given the size of our batteries and PCBs, there was little we could have done to avoid this. While this did not inhibit our system, it definitely made it troublesome to use.

5.4 Future Work

First and foremost, we would like to address the issues we faced as discussed in Section 5.3. To address the open soldering connections, we would like to use a flexible PCB to reduce space taken up on the glove as well as removing the need for open soldering connections. Using custom ICs would also be very beneficial since the microcontroller takes up a lot of space and custom ICs can be as small as a coin. Flexible PCBs will also make the design more flexible allowing the officer more freedom in their hands. On top of that, it would make the gloves weatherproof which is very important to the officers.

Secondly, we would definitely want to reduce our batteries since with our current design the batteries we use give us nearly three times the power we need, this would both save money and also vastly reduce the space taken up by our batteries. With new batteries we would only need one cell and potentially could find a smaller battery, shrinking our design even further.

Thirdly, we noticed that we did not necessarily need so many LEDs on each glove and could achieve the same results with half as many LEDs, so in the future we would want to cut down on them to reduce both cost and space.

Lastly, we would improve the vest panels by replacing wood with plastic to make it weatherproof and more robust as our current design can be rather flimsy.

References

[1] Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html [Accessed: 5- Feb- 2019].

[2] “The Code affirms an obligation of computing professionals to use their skills for the benefit of society.,” Association for Computing Machinery. [Online]. Available: https://www.acm.org/code-of-ethics. [Accessed: 06-Feb-2019].

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[4] NCR18650 Data Sheet. [Online]. Available: http://www.batteryonestop.com/baotongusa/products/datasheets/li-ion/SANYO-NCR18650B-3400mAh.pdf [Accessed: 18-Feb-2019].

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[6] “Arduino Wireless Communication - NRF24L01 Tutorial,” *HowToMechatronics*, 13-Feb-2019. [Online]. Available: https://howtomechatronics.com/tutorials/arduino/arduino-wireless-communication-nrf24l01-tutorial/. [Accessed: 21-Feb-2019].

[7] nRF24L01 Data Sheet. [Online]. Available: https://www.sparkfun.com/datasheets/Components/nRF24L01_prelim_prod_spec_1_2.pdf [Accessed: 18-Feb-2019].

Appendix: Requirement and Verification Table

Table 4: Requirement and Verification

Voltage regulators		
Requirements	**Verification**	**Working?**
1) Buck converter should provide 5 V +/-5% from a variable source (7.2 V – 8.2 V).	a) Connect the voltage regulator to the Li-ion battery pack. b) Probe the output pin of the Buck Converter using a voltmeter.	Yes

	c) Verify the output reads as 5 V with 5% margin error.	
2) LD1117 Voltage regulator provides 3.3 V +/- 5% from a 5 V +/- 5%V source.	a) Connect the input pin of LD1117 regulator to the output pin of buck converter. b) Probe the output pin of the LD1117 regulator using a voltmeter. c) Verify the output reads as 3.3 V with 5% margin error.	Yes
	Microcontroller	
Requirements	**Verification**	**Working?**
1) Should be able to control the color of the LEDs.	a) Power on the Glove. b) Increase the brightness of the LEDs. c) Tigger color control sensor. d) Observe and Verify the color changes to Green. e) Trigger color control sensor again. f) Observe and Verify the color changes to Red.	Yes
2) Should be able to transmit the correct signals to the vest.	a) Power on the vest and the Left glove. b) Trigger the vest control sensor on the left glove three times. c) Verify the front panel to display 'Go', then 'Stop', and then turn off.	Yes
3) Should be able to control the brightness of the LEDs while retaining the state of LED color.	a) Power on the Glove. b) Trigger brightness control sensor four times. c) Observe three different levels of brightness. d) Verify that LEDs retain the Red color. e) Change the color to Green and repeat steps (a) to (d).	Yes

Wireless Transceiver		
Requirements	**Verification**	**Working?**
1) Left Glove should be able to control front panel on the vest wirelessly.	a) Power on the vest and the Left glove. b) Trigger the vest control sensor on the left glove three times. c) Verify the front panel to display 'Go', then 'Stop', and then turn off.	Yes
2) Right Glove should be able to control back panel on the vest wirelessly.	a) Power on the Right Glove. b) Trigger the vest control sensor on the right glove two times. c) Verify the front panel to display 'Stop, and then turn off.	Yes
Contact sensor		
Requirements	**Verification**	**Working?**
1) Should output 5 V+/- 5% when the sensor on the thumb makes contact with a sensor on the finger or else output Zero V+/- 5%.	a) Probe the output signal pin of the contact sensor using a voltmeter w.r.t. to GND pin. b) Make contact between thumb sensor and finger sensor. c) Verify the 5 V +/- 5% output on the voltmeter. d) Separate the contact sensors. e) Verify a Zero V+/- 5% output on the voltmeter.	Yes
2) Does not draw power when contact sensors are separated.	a) Probe the VCC pin of the contact sensor with an ammeter. b) Ensure no contact is made between the finger and the thumb. c) Verify Zero A+/- 5% of current on the ammeter.	Yes

3) The contact sensors are consistent and allows a single register on microcontroller per trigger.	a) Power the contact sensors. b) Trigger the contact sensor once. c) Verify that the LED effect changes only once. d) Repeat the above process 5-6 times and verify the consistency of the sensors.	Yes
	LED array	
Requirements	**Verification**	**Working?**
1) Should be color controllable in real time.	a) Power on the contact sensor for Left or Right glove. b) Trigger the contact sensor for the color control. c) Verify the real time changes in the color of the LEDs.	Yes
2) Should be brightness adjustable in real-time.	d) Power on the contact sensor for Left or Right glove. e) Trigger the contact sensor for the brightness control. f) Verify the real time changes in the brightness of the LEDs.	Yes
	Indicative LED	
Requirements	**Verification**	**Working?**
1) Should be able respond in synchrony with the back panel.	a) Power the Right Glove and the Vest. b) Bring the sensor in contact which will trigger STOP signal (Red Color) on the back panel of the led. c) Observe and Verify the back panel on the Vest shows STOP SIGNAL	Yes

	d) Observe and verify the indicative LED indicates Red Color.	