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Feb. 01, 2008

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
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Re: ENSC 440 Post-Mortem for a Smart Traffic Light

Dear Dr. Rawicz,

The attached document, *Post-Mortem for a Smart Traffic Light,* briefly describes the process our team followed during the design and implementation of our device for ENSC 440, which is a smart traffic light that is able to adjust its light output according to ambient light and visibility conditions.

In this document, issues such as deviation from the proposed plan, future plans, budget and time constraints are discussed. Also, we have dedicated a section to inter-personal relations and the experiences we gained during the past five months.

AnoLED Technology Inc. is comprised of four senior-level engineering students, namely, Jamal Bahari, Ighodalo Iyayi, Behrad Kajbafzadeh, and Sara Rokni. Should you have any questions, feel free to contact me at 250.552.4140 or, alternatively, by email at 440-ensc-project@sfu.ca.

Sincerely,

Ighodalo Iyayi
Chief Executive Officer (CEO)
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Post-Mortem for a Smart Traffic Light

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Introduction

Over the past five months we worked tirelessly on the Smart Traffic Light (STL), during which, we underwent the different challenges of designing and producing a product. In this report, we have included some of the challenges we faced, as well as our future plans for the product and the experiences we gained throughout the semester, which each team member discusses individually.

System Overview

STL is an advanced traffic light that uses high intensity LEDs instead of conventional incandescent light bulbs, which significantly reduces power consumption. The device has an understanding of its environment and is able to adjust its output light intensity accordingly.

Current State of the Device

The STL senses the ambient light detectable by human eyes, and if necessary, it will adjust the output light intensity accordingly. A similar principle applies to the visibility sensor. The system adjusts its output light intensity according to the visibility reduction induced by fog in order to make its illumination more conspicuous to motorists and pedestrians.

Figure 1 demonstrates the block diagram of the STL. The above sensors are inputs to the microcontroller, where all decisions with regards to the output light intensity are made. The microcontroller adjusts the output light intensity by varying the duty cycle of the data send to the LEDs. The output data of the microcontroller is first buffered and then stored into the specified latches whose addresses are selected by the addressing decoders. The stored data will then command the driver circuits regarding the on or off states of the LEDs.

Each LED has three separate junctions, each of which is responsible for producing one of the red, green, or blue colors. Each color requires a maximum current of 250 mA, recommended by the manufacturer [1], to generate its maximum intensity. The driver circuits are designed to guarantee current of 250mA through the junctions when the LEDs are on. Fixed current generates fixed output intensity; however, the intensity is also a function of the duty cycle, as mentioned above.

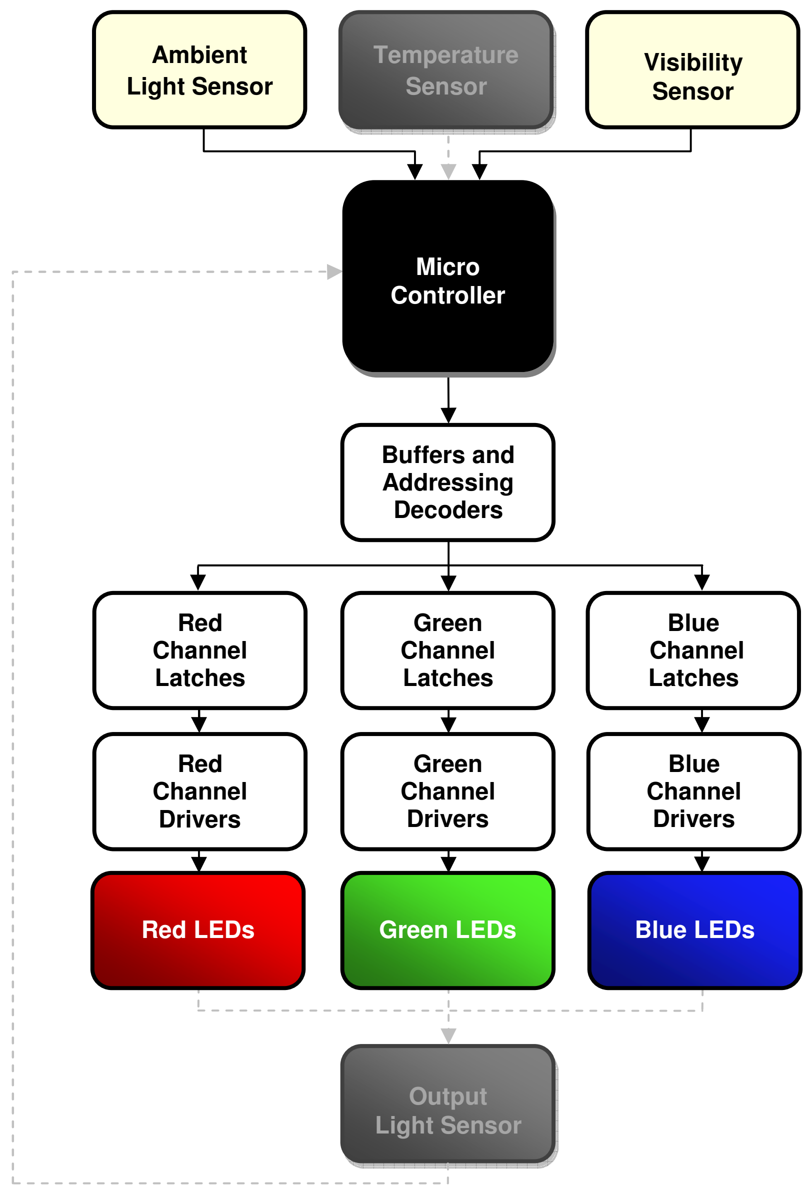

Figure 1: System Block Diagram

Deviation of the Device

The initial STL design was gradually modified as our team was evaluating and testing the pros and cons of alternative methods for achieving higher performance and efficiency of the device. In the following sections, the overall and individual system deviations are discussed.

Overall system

STL was initially designed based on TDM, Time Division Multiplexing, to update its LED boards at a refresh rate of 100Hz that is not detectable by most human eyes. Having tested TDM on a bicolor 8x8 LED Matrix, as well as a single tricolor LED, we confronted the following major problems.

Firstly, the maximum duty cycle applied to each color was divided by the number of LED columns. For instance, a duty cycle of 100 behaved similar to a duty cycle of 12.5%, in the case of the 8x8 LED matrix. As a result, the desired maximum output light intensity could not be obtained using the TDM method. It should be mentioned that we had predicted such lower output intensity, and we had decided to compensate for it using the maximum allowed pulsed current, 500mA, through the LED junctions. However, due to LED thermal management barriers, we avoided passing such high currents through the LEDs.

Secondly, the state of the output light was heavily reliant on the performance of the microcontroller. Any malfunction by the microcontroller, would switch all the columns off, except the most recently updated column. Therefore, motorists would have no idea regarding the state of the traffic light until the microcontroller recovers.

Although the former problem could be partially eliminated, the latter breached R02.15 of the STL's functional specification and forced our team to modify the design. According to R02.15 of the functional specification, no more than 5% of the output light should be lost during a catastrophic failure. Consequently, there was a need for an interface board between the microcontroller and the LED boards to hold the information sent by the microcontroller until a new set of data arrives. In the case of microcontroller malfunction, the LED board obeys the interface board and continuously shows the most recently updated traffic symbol until the microcontroller recovers and updates the interface board.

Interface Board

As mentioned above, an interface board was necessary to hold the data sent by the microcontroller to improve both the output light intensity and the reliability of the STL. The interface board consists of buffers, octal latches, and decoders.

Buffers isolate the output port of the microcontroller from the input pins of the 21 octal latches, each for a column of similar colors. The octal latches preserve the current on or off states of the LEDs. Since the microcontroller sends 8 bits of data at an instance, the addressing decoders determine which latch should store the present data.

Temperature sensor

The initial design of the STL included a temperature sensor to trigger an interrupt to lower the output light intensity, if temperature was beyond 85˚C. As grayed out in Figure 1, the temperature sensor was omitted since we realized most of the voltage regulators have automatic thermal shut down features. Future generations of the STL are based on DC to DC converters that utilize such component features for thermal management. If the voltage regulator of a column shut downs, its corresponding LED column will switch off while the remaining columns are operating properly.

Output Light Sensor

The grayed out block at the bottom of Figure 1 shows the omitted output light sensor. In the initial design, we were thinking of measuring the output light intensity of the system. However, a precise measurement requires a closed system whose inner surface is reflective to direct all the light rays to wards the sensor. On the other hand, the STL knows its output intensity at a given instance, based on the duty cycle applied to the LEDs. Consequently, the output light sensor would unnecessarily have increased the complexity of the system.

Visibility Sensor

Initially, we adopted the back scatter method of visibility detection, which had several limitations that caused us to re-evaluate our approach. Firstly, due to the inconsistent nature of visibility reducing particles, we required a sensor with a relatively large surface area, or reflectors to direct back scattered waves towards the sensor. The motivation for this requirement was that we needed to detect significant amounts of back scattered waves, regardless of the visibility reducing medium and with minimal calibration. Sensors with a large surface area are relatively expensive, and the inclusion of wave reflectors would increase the cost and complexity of the system.

Secondly, in the back scatter configuration, the sensor was sensitive to ambient lighting conditions, which resulted in inaccuracies in our measurements. The solution to this problem was to utilize optical filters, which would again increase the cost and complexity of the system.

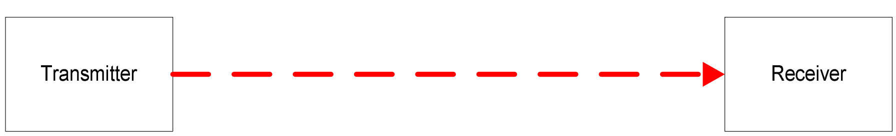

Figure 2: Block Diagram of the Forward Scatter Sensor

Our final visibility sensor was implemented using a variant of the forward scatter technique, which is illustrated in Figure 2. During clear visibility conditions, the receiver senses the full power of the laser transmitter, and reduced visibility degrades the laser power detected. The detected signal is then fed to the microcontroller for processing. The advantages of this method are that the receiver requires less calibration, is insensitive to the ambient light intensity and thus exposure to direct sunlight does not affect its effectiveness. The schematic of the forward scatter sensor is illustrated in Figure 3.

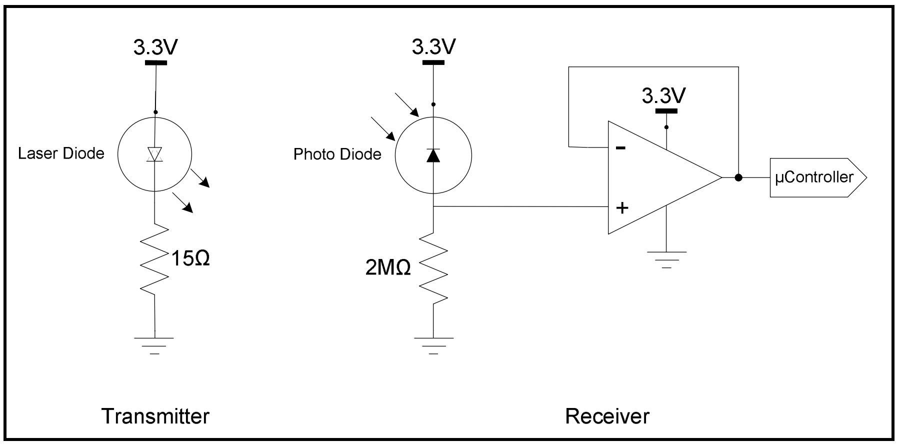

Figure 3: Schematic of the Forward Scatter Sensor

Future Plans

The STL is a product with a wide range of potential capabilities which can be included in the future. We shall briefly mention some of them in the following.

Blue light: In Canada, a traffic light is occasionally required to generate the white color symbol for buses, as well as the red, green and amber colors. If it is not the case, the blue color LEDs and their associated circuitry could be omitted to reduce the manufacturing cost and system complexity.

LED control: The STL currently has individual control of each of its LEDs. This feature may not be required in some applications of the device. Thus, we could design a simpler driver circuit that controls the LEDs in a series configuration. Series LED control would also result in a lower manufacturing cost.

Power consumption and power supply unit: Each red color driver circuit of the current version of the STL wastes 0.25 watts due to power supply limitations. Unlike the blue and green LEDs, which require 3.5V to pass 250mA through their junctions, red LEDs require 2.3V. Due to time pressure and lack of experience with the design of DC to DC converters, our team used the available 3.3V of two regular PC power supplies to drive all the three colors through their common anodes. Consequently, 0.25 watts (250mA×[3.3V-2.3V]) dissipates across the MOSFET channel of each red driver circuit while the green and blue channels will never reach the maximum 250mA.

Our team will design, build, and test either power supplies or DC-DC converters that provide us with both the 2.3V and 3.5V to utilize maximum capabilities of the blue and green LEDs while preventing wastage of 12.25 watts when all the 49 red LEDs are on.

Visibility sensing system: Our solution, though accurate and cost effective, is limited to detecting visibility reductions in the vicinity of the STL. We feel there is significant progress to be made in this field and are therefore considering further research and modifications.

Enclosure: Current enclosure of the STL is made of wood due to availability of equipment of the machine shop as well as cost effectiveness. Safety, reliability, and the environmental restrictions require us to use better materials for the enclosure. According to the Institute of Traffic Engineers (ITE), LED traffic signal modules must be made of UL94-V0 materials. The UL94 standard classifies plastics according to how they burn in various orientations and thicknesses. In our case, the V0 suffix indicates that any burning must stop within 10 seconds on a vertical specimen with no drips allowed. UL94-V0 polycarbonate is a good candidate for the STL enclosure [1]. We are currently in the process of finding a supplier/manufacturer for the enclosure, so that we can outsource the enclosure manufacturing.

It should be mentioned that thermal conductivity of polycarbonate is 0.19-0.22 W/(m•K) which is much lower than heat conductors such as copper with a conductivity of 401 W/(m•K) [2], [3]. Therefore, enclosures made of polycarbonate cannot be used as LED heat sinks, and thermal management of LEDs must be solved using other methods.

Thermal Management: The STL's LEDs generate a significant amount of heat when displaying at high duty cycles for extended periods. We shall use laminated PCB boards in future productions of the STL, in order to improve its thermal dissipation.

Budgetary and Time Constraints

Budget

Table 1 below compares our proposed and incurred budgets for making the STL prototype. A brief explanation for the discrepancies between the two is as follows.

Lighting (LEDs): We had initially designed the STL as an 8x8 matrix of LEDs; however, due to symmetry and clarity of the traffic symbols, our team eliminated one row and one column of the matrix to have an odd number of rows and columns. As a result, the STL lighting cost reduced by $76.60.

Sensors: Our team was about to purchase a premade fog detection system to be incorporated into our design; however, we designed a cost effective fog detection system which reduced our cost by $63.09.

Controller Unit: Jamal's Co-op supervisor lent us a complete evaluation kit to develop the project. We also ordered a similar evaluation board as a backup, and we plan to return it**.**

Enclosure: Lower cost for the enclosure is due to use of wood rather than the proposed materials such as metal or PVC.

Circuitry: Our initial plan was to mount the LEDs on tiny sheets of wood so as not to waste PCBs by using them to hold LEDs in place. Due to the need for individual control of LEDs and its associated circuitry, we incurred two extra costs. Firstly, a total cost of $127 for the driver circuits, and secondly, a cost of $130 for the PCBs that hold the LEDs in place, as well as catering for driver circuit traces. The interface board, that was necessary for system reliability, also added an extra cost of $37 to the circuitry of the STL.

Research components: Creating different versions of LED driver circuits added $37.07 to the estimated research budget.
Tools: We manufactured our own PCB boards, instead of outsourcing them, which required specific tools that caused a rise of $30 in our expected tools expenditure.

Contingency: Due to an accidental damage of two of our LED columns, we had to incur an extra cost of $16.44 as the quantity of spare components we had was not sufficient to repair the damage.

Table 1: Proposed and Actual Budget

Items	Proposed	Actual
Lighting	$400	$323.40
Sensors	$100	$36.91
Controller Unit	$100	$0.00
Enclosure	$50	$17.94
Circuitry	$50	$357.00
Research Components	$50	$87.07
Demo Components	$50	$60.00
Tools	$50	$80.00
Contingency	$100	$116.44
Total	$950	$1078.76

Time

The Gantt charts below, Figure 4 and Figure 5, show our proposed and actual time lines for the project, respectively. We were all thinking of having a product with the highest possible quality within the given timeframe. However, several factors delayed the development of the STL that are briefly discussed here.

Firstly, our driver circuit design and testing consumed more time than expected, and secondly, the visibility sensing system was challenging enough to delay the device integration till mid January. Thirdly, our microcontroller malfunctioned in the first week of January and halted software development for a week. Finally, due to the accidental damage of two of our LED columns our project demonstration was further delayed for another week.

We had made a simple LED display in December and had it ready for demonstration, but our ambitious group decided to create the actual high intensity display that could impress and attract potential investors.

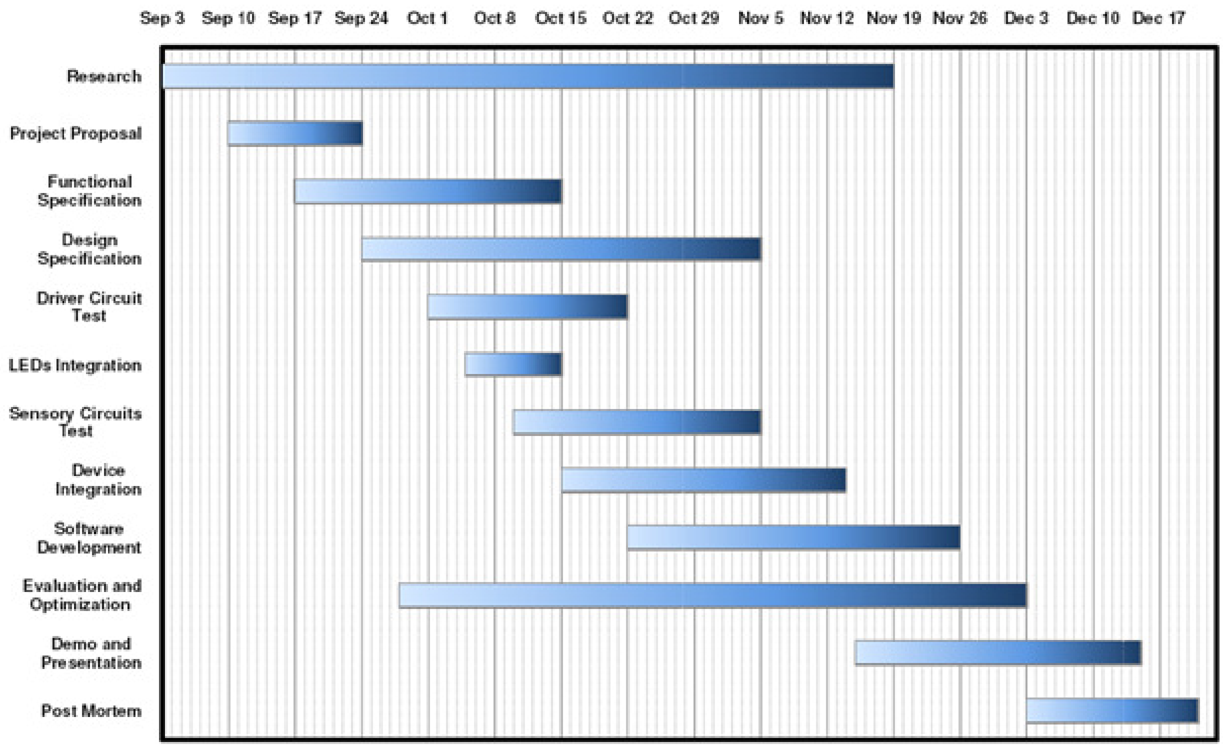

Figure 4: Proposed Gantt Chart

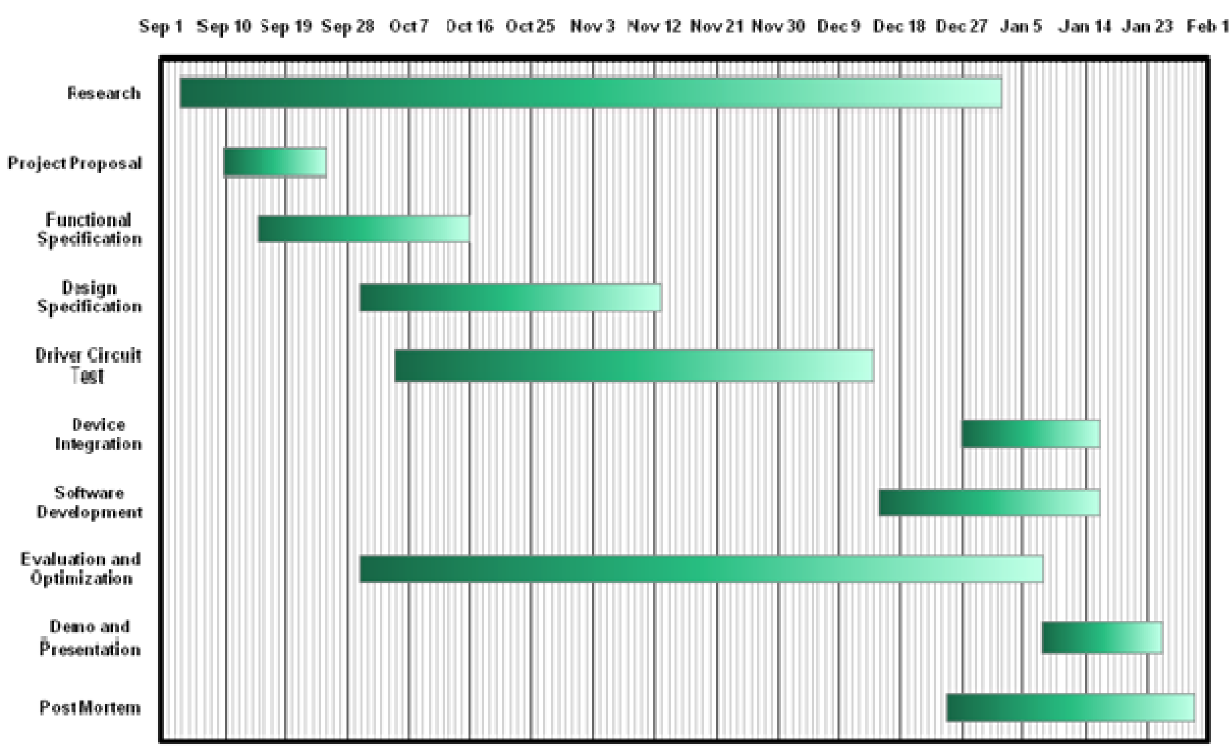

Figure 5: Actual Gantt Chart

Ecological Footprint

The STL is a energy efficient device since it utilizes high power LEDs instead of incandescent light bulbs. The ecological footprint of the STL can be reduced by several actions which are proposed below.

The LED boards use RoHS compatible LEDs and opamps; however, they include non RoHS compatible components such as resistors and MOSFETs. The interface board also has non RoHS latches and resistors. On the other hand, the type of solder and soldering irons used are not RoHS compliant. All these non RoHS components and tools have increased the ecological footprint of the STL. The replacement of these non RoHS components and tools with RoHS equivalents will significantly reduce the ecological footprint of the STL.

We used developer and etchant chemicals in making the PCBs, which have large ecological footprints. The ecological footprint of the STL can be reduced by alternative methods of PCB manufacturing such as mechanically milling the boards.

The ecological footprint of the STL could be further reduced by eliminating the two PC power supplies and designing the required power efficient DC-DC converters. Finally, we should mention that the current version of the STL has a wooden enclosure which is completely recyclable.

Inter-Personal and Technical Experiences

Jamal Bahari

Since the initial proposal of the STL, I had always been trying to visualize the finalized functional device. However, the inherent nature of design and development distorted the appearance of the presented system to a device completely different from what I had initially pictured in mind.

The main challenge differentiating the STL from my previous projects was increasing the level of abstraction while pursuing the project. I am usually involved in all aspects of a job without even missing a tiny piece of information. However, due to the load of the work, uncertainty in designs, and time constraints, I soon realized the project should be divided into tasks and subtasks, passed to the individuals, and merged later on. Each member was then required to inform the group regarding the status, accuracy, and deviation of results. In the case of a group member struggling, another group member would help. However, if the issues remained unsolved, I would interrupt my tasks and join the other group members to evaluate, resolve, or sometimes modify the task.

The design of the high power LED driver circuits was another challenge which depended on LED layouts as well as LED choices. Throughout the development of the STL, we several times modified our LED driver circuits until we achieved a method of implementation that eliminated the need for driver circuits. Having built and tested the targeted method, in December, our group was not satisfied with the output light intensity, and we reverted back to the use of our initial driver circuit. Although we might have been expected to stop designing, building, and testing driver circuits, within the first two months, we would not have had variant practical circuits to accommodate for other limitations of our system, such as power supply.

Digital hardware and programming are very natural and desirable to me. I have also conducted several successful programming projects and simulations in the past. However, the complexity of STL firmware challenged me several times. Firstly, since the development of the actual LED board was postponed until all the heat and current handling issues of the board were evaluated, there was a need for a modular, reusable program to control any arbitrary number of LEDs. In the early stages, the program was just required to control our test LED. However, as the LED boards were completed one after the other, the program needed to control a multiple of seven LEDs with minimal modifications. Secondly, due to time and budgetary constraints, we decided not to implement and test the PWM circuitry. Individual control of LEDs, on the other hand, had provided us with the opportunity of incorporating the PWM into the firmware. Taking care of the three R, G, and B channels and smoothly varying their corresponding PWMs were complicated and time consuming tasks that had to be executed in a few days. Thirdly, the interrupt service routines of the two sensors demonstrated unexpected behaviours. Since the routines were developed by one of my colleagues, he needed to familiarize me with the structure of those routines, so we could troubleshoot the problem together. Having spent hours, we were able to simplify the routines to achieve predictable behaviours.

Choices of component selection, ordering, testing, reselection, and reordering have armed me with invaluable experiences that could be applicable in my future career as an engineer. Since LEDs were the only visible actuators of our device, they required significant amount of research, experimentation, and dollars to be invested in to achieve the desired output light qualities. Eventually, dedications paid off, and the selected LED turned out to be one of the highest quality LEDs available in the market, at the lowest price.

The studied materials of text books, attained Co-op experiences, and the acquired life skills allowed me to design, develop, and demonstrate the introductory, versatile version of the STL prototype. The versatility of the presented prototype will be utilized towards the development of future generations of STL, as well as our other LED products.

Ighodalo Iyayi

From a technical perspective, I became familiar with lasers, sensors and the Philips ARM7 family of microcontrollers. I further increased my knowledge of PCB design and manufacturing, gained experience in working with surface-mount devices (SMD), improved my hardware troubleshooting skills and learned about the practical considerations that go into system integration.

Interpersonally, I learned how to capitalize on the strength of individuals and how to motivate people to perform their tasks to the best of their abilities.

The experience I gained from my ENSC 440 project is invaluable and will certainly accelerate my professional development in the future.

Behrad Kajbafzadeh

ENSC 440 has been the first project that involved massive team work for me. Being able to work as part of a group taught me how to be responsible for the work I am doing as it directly affects group's overall progress.

The technicality of the project was such that not only should everyone maintain a great level of understanding of the whole but also should get familiar with the details as well. I personally gained a better understanding of transistors, especially the FET family, and now my knowledge is not just limited to theoretical analysis of the components.

LEDs were the other part, as far as I can remember, we have never gone through, in details, different characteristics of LEDs, specifications such as their output color temperature, wavelength, power consumption, and color mixture in any of mandatory courses offered at SFU.

Also, I would like to emphasise on the general practical electronics experience I gained by working with LED driver circuits. There are several components involved in making a driver circuit, although simple, it is really a challenge to obtain the desired output current. At times, we had to work on a driver circuit for several hours; however, the process boosted my troubleshooting abilities to a large extent.

Sensors such as ambient light sensor and temperature sensors, again although appear simple, I had to spend some time to obtain the desired result.

During my undergraduate studies, I never had a chance of familiarising myself with the process of PCB manufacturing. During our project, I experienced the whole process from the scratch. My soldering skills have also improved tremendously.

Power supply selection was a major challenge too. Factors such as the amount of current to be drawn and heat dissipation were to be considered which, in turn, made me familiar with voltage regulators and switching power supplies.

Finally, the microcontroller section, which I was not directly involved with, provided me with the opportunity of working with people that have better understanding of embedded systems, from whom you can learn a lot.

As for the group dynamics, group members should have mutual understanding of each other. You should sometimes sacrifice time and energy for the other members. You should always be appreciative of other's work, encouraging and motivating. Patience is a key factor.

Time management is of paramount importance in this course. During the course of the project, I discovered that without setting deadlines for your work you cannot reach your desired goal. You should always work with a deadline set beforehand. Also, in big projects it is important to work on different parts in parallel. This cannot occur without planning ahead.

After taking this course, I can see myself as a more productive member of a team in the future. I am now familiar with the basics of the design process, documentation, and group dynamics which can be a stepping stone towards my future career.

Sara Rokni

ENSC 440 was very enjoyable in a way that it gave us the ability to build a product from scratch. We all had an idea in our mind but we never knew what it would look like and it was very satisfactory to build a well-designed traffic light that worked in the end. In the course of this project I learned that the design process is very iterative, the first solution is not always the best solution and the first design may not always work. To design our LED driver circuit, we started with a circuit and we made several changes and modifications to get the desired output values. This project gave me the ability to use my understanding and knowledge that I obtained from my other engineering courses and life.

As for technical experiences, I learned a lot about the process of designing, testing and implementing, also, I significantly improved my knowledge of circuitry. I also had a chance to participate in programming the Philips ARM7 microcontroller which was a great experience for me. One of the most interesting parts of our project was making the PCB boards and in my opinion it was all worth the time and the money we invested. Even though we spent a lot of time etching the boards and soldering the components, we all enjoyed it and it was one of those skills that not every student will learn at university and I consider myself very lucky for that.

Finally, I was very fortunate to work with three knowledgeable team members and I learned a lot from all of them. In the past five months I learned how to work as part of a team and not individually. It was a great experience working in a team, I learned that each person has strengths and weaknesses and if we combine all those strengths we can achieve our goal, which in our case, was designing the STL.

Conclusion

AnoLED Technology Inc. has successfully created a prototype that demonstrates the functionality of a traffic light that is sensitive to visibility reducing weather conditions such as glare and fog. The presented prototype allows us to explore other applications of our system and can be further improved according to the modifications outlined in this document. We believe that our device holds a certain novelty and will consider conducting a patent search to verify the authenticity of our ideas.

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