LUMO TECH
WRITE BRIGHT

March 30, 2017

Andrew H. Rawicz
School of Engineering Science
Simon Fraser University
V5A 1S6

Re: ENSC 405W/440 Design Specifications for ***StyLight*** by ***LumoTech***

Dear Dr. Rawicz

The attached document, LumoTech's design specifications for *StyLight*, provides a summary of our capstone project. Our goal is to design a cost effective and portable system to turn any cellphone to a notepad for taking electronic notes.

The purpose of this proposal is to outline technical details necessary for the implementation of the *StyLight*. This includes system overview, overall device design and components, engineering standards, as well as sustainability and safety issues both at the prototype and product release phases of design. The specifications outlined in this document will serve as a guide throughout the implementation and production of the *StyLight*.

LumoTech consists of 6 determined, talented senior engineering students ranging in concentrations from Computer Engineering, Electronics Engineering, and Systems Engineering: Alexis Golding, Ahmadreza Edalat, Alex Kim, Fatemeh Darbehani, Hamed Mahdi, and Mohammad Shakoory. Complete profiles are available at the end of the proposal.

We appreciate your time in reviewing our functional specifications for *StyLight***.** If you have any questions or concerns regarding our proposal, please do not hesitate to contact our Chief Communication Officer, Hamed Mahdi, by phone at (778) 986-7601or by email at hmahdi@sfu.ca.

Sincerely,

Fatemeh Darbehani

Fatemeh Darbehani
Chief Executive Officer
LumoTech

DESIGN SPECIFICATIONS FOR *STYLIGHT*
BY

LUMO TECH
WRITE BRIGHT

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Issue Date:

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Abstract

This document describes the design specifications and outlines the details for the *StyLight* projector and pen. A detailed look at each specific engineering subsystem along with a complete analysis of the problem is also included. The goal is to give the reader an explanation of the design choices and justifications. Preliminary future design goals are also provided.

The *StyLight* is system of two parts: a pen and a projector aimed at helping students and professionals to take notes digitally. Consisting of intuitive software controls along with an easy to use UI, while seamlessly integrating with the firmware and hardware, resulting in a product that creates the most efficient note taking experience possible. It's a product that couldn't exist without innovation across many engineering fields.

This document focuses on the technical details of hardware, firmware/software, physical/operational and mechanical components along with the justification of the chosen parts and design decisions that were made. The engineering standards that are being followed are also included in this document as well as the User Interface design. A high-level test plan is also presented in order to comprehensively test all the different components of the *Stylight* system and ensure full functionality. A fully functional proof-of-concept system is to be delivered by April 5th, 2017.

Table of Contents

List of Tables

List of Figures

Glossary

Bluetooth	A short range radio technology aimed communication method between devices and the internet
Modular	A design approach that subdivides a system into smaller parts which can be independently created and then used in different systems
Real time embedded programming	The art of programming a system with a dedicated function within a larger mechanical or electrical system considering the specified time constraints
Pico projector	A pocket or a handheld device that projects the content of a smartphone, camera, tablet, notebook or memory device onto a wall or a flat surface
HDMI	An audio/video interface for transmitting uncompressed video data
Infrared Camera	A non-contact device that detects infrared energy(heat) and converts it into electronic signal
Arduino Board	Refers to an open-source electronics platform or board and the software used to program it
ADB	A versatile command-line tool that lets you interact with an android device or emulator
Magnetometer	An instrument that measures magnetism
Microcontroller	A small programmable computer on a single integrated circuit
Electromagnet	A type of magnet in which the magnetic field is produced by an electric current
PDF	A trusted file format standard for viewing and printing documents
Keystone Effect	A function that allows rectangular from skew projection
Micro USB	A miniaturized version of the Universal Serial Bus(USB)
LED	A semiconductor diode that emits light when conducting current

Electromagnetic Flux	It is the number of magnetic field lines passing through a surface
AC signal	Voltage is produced with alternating current as oppose to a DC signal
Wi-Fi	A wireless networking technology that uses radio waves to provide internet and network connections
FPS	It is the frequency at which consecutive images called frames are displayed
Homography	It is a bijection that maps an image to another image
IEEE	An organization composed of engineers, scientists and students
I/O	Short for input/output. Any devices that transfers or receive data
Lumen	SI unit of luminous flux, equal to the amount of light emitted per second
User Interface(UI)	The means by which the user and a computer system interact
Frame Buffer	A portion of RAM containing a bitmap that is used to refresh a video display
Perspective Correction	A transformation of an object and its surrounding area that differs from what the object would look like
Processor	A machine that processes something
Raspberry Pi 3	A high performance programmable minicomputer with high processing power
NRF52 DK	Stand-alone development board for Bluetooth applications
Human Interface Device (HID)	A computer device that interacts directly with, and most often takes input from, humans and may deliver output to humans

1. Introduction

The *Stylight* uses a combination of different technologies such as Pico projector, magnetometers, microcontrollers and low energy Bluetooth 4.0 to provide a unique and inexpensive solution to note taking needs of tech savvy individuals. The end product will be a self-contained unit powered by battery capable of operating on any flat surface.

The *Stylight* will be broken into two separate communicating subsystems: the projecting unit and the stylus. The projecting unit consists of a Pico projector and a raspberry pi for real time projection of the android device. The stylus consists of an Arduino UNO for reading the values of the magnetometers and calculating the coordinates of the stylus, and an NRF52 development kit responsible for communicating with android device via Bluetooth 4.0 to send the events of the notes taken. For the prototype we are going to use a power supply to power this unit. The stylus consists of an electromagnet, which is powered by a battery and a coil with a core of nickel for a better range. The electromagnet in the stylus is powered when the pen touches a surface indicating the user is writing.

The design specifications of the *Stylight* provide details pertaining to the specific computational, physical, mechanical and electrical, safety, and environmental requirements necessary to develop the proof-of-concept and the prototype for the *Stylight*.

The design specification document will outline the following:

- The *Stylight* product and its subsystems
- An overview of the proof of concept model and its product features
- Technical details of system design to support the functional requirements
- Test plans to examine proper functionality (Appendix A)
- User Interface Design (Appendix B)

1.1 Background

In today’s ever advancing society, technology has been the catalyst behind improvements in accessibility and convenience, two things that have become increasingly important to students. In the face of notebooks and binders that never seem to have enough paper, pens with no ink and pencils with no lead, and the added weight of textbooks, students have eagerly transitioned to solutions that remove those hassles. With the help of smartphones, tablets, and notebook computers, students’ lives in the classroom and at home have become easier. Of these products, tablets running mobile operating systems with large screened peripherals have, and continue to see, the largest segment growths. Although these devices have made it easier to be a student, buying a tablet and stylus while already paying for a personal mobile device is not always affordable.

While students can get away with accessing class materials solely on their smartphones, the screen is often too small, and does not allow for clear and convenient note-taking. This motivated us to look for a more robust way to make note taking easier. Since smartphones are able to access lecture notes and textbooks online and download them as modifiable PDF documents, the *StyLight* allows the entire smartphone screen to be projected onto any surface in front of you, enlarging the smartphone screen to a size that allows for easy note-taking and modification of those lecture notes. The notes can be written directly on the projected image with the *StyLight* stylus, and then saved to the PDF document on the smartphone for future access.

Currently, there is no product like this on the market, only similar ones in production which feature one functionality of our product. For example, a pen exists to take notes, but does not deliver any real time visual feedback [1]. This is where we differentiate ourselves from the competition. Our product will include a system that communicates with itself to provide fast and responsive feedback.

1.2 Scope

This document supports the previous Functional requirements document for the *Stylight*. It provides a detailed description of design specifications for the projection unit and the stylus software and hardware as well as the housing designs. This document will outline design decisions and discuss in detail our design process. This document also includes the functional test plan of the *Stylight* in Appendix A, and its User Interface Design in Appendix B.

1.3 Intended Audience

This document in intended to be used by the members of LumoTech for development of the *Stylight*, as well as the TA's marking this document, and senior engineers who are interested in this project. It can be used throughout the research and product development stages as a reference to provide the overall view of the product. The hardware, software and design engineers can refer to the system requirements, hardware and software details contained in this document to aid in product development. Engineers performing quality assurance can focus on the test plan Appendix and sustainability and safety section of the report to ensure that safety concerns have been addressed and that the product meets all the goals and standards regarding its development and usage.

2. System Overview

2.1 Product Design

The purpose of the *Stylight* is to enable users to interact with an enlarged projected mobile phone screen on any flat surface for mainly note taking purposes. This product is recognized as an affordable alternative to tablets. As can be seen in Figure 1 *Stylight* is consisted of two main modules: Pen tracking module, and projection module.

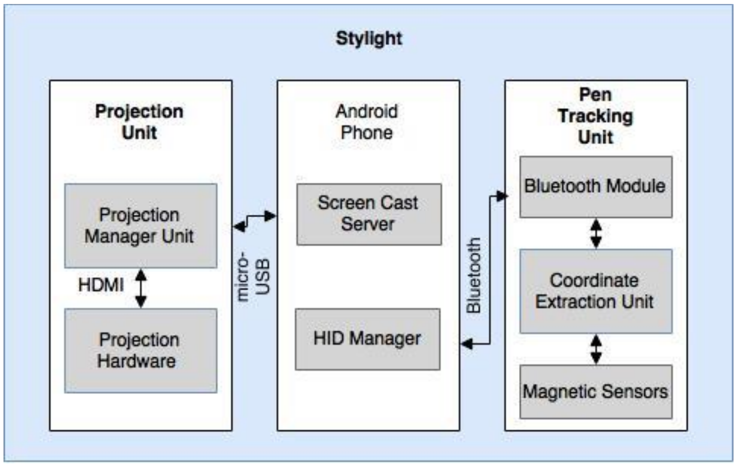

Figure 1- Subsystem Layout for the Sylight

Below are the main components of *StyLight*:

2.1.1 Projection Module:

As shown in Figure 2, user's cellphone will be connected to the Pico projector through LumoTech's image processing system. The image processing system will set up HDMI connection with the cellphone and corrects any distortions in the image dimensions due to angle of projection. With the help of this system, the screen of the user's smartphone is projected onto any flat surface and an efficient keystone correction algorithm corrects the image distortion in real time so the user will not see a skewed image.

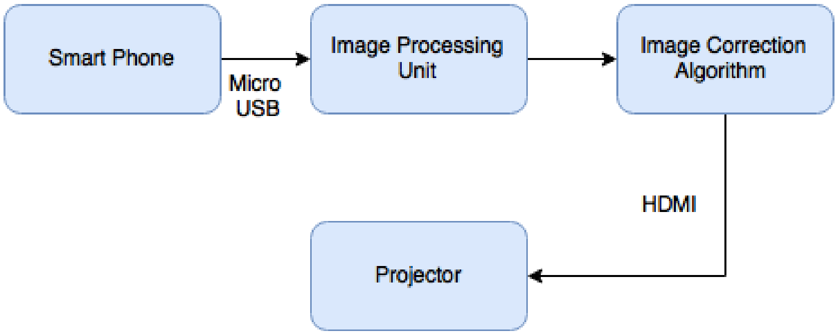

Figure 2- Conceptual Diagram of the Projection Unit

2.1.2 Pen Tracking Module:

User can take notes with the use of the *StyLight* engineered remote stylus in conjunction with any note-taking application. The remote stylus resembles a typical pen, aside from an LED that turns on when the stylus tip is pressed onto the surface during writing. As shown in Figure 3, the remote stylus consists of an electromagnetic coil that creates a constant magnetic field around it. The magnitude of this electromagnetic flux is sensed by a pair of magnetometers inside the *StyLight* box. The data is then read by an Arduino board for further processing.

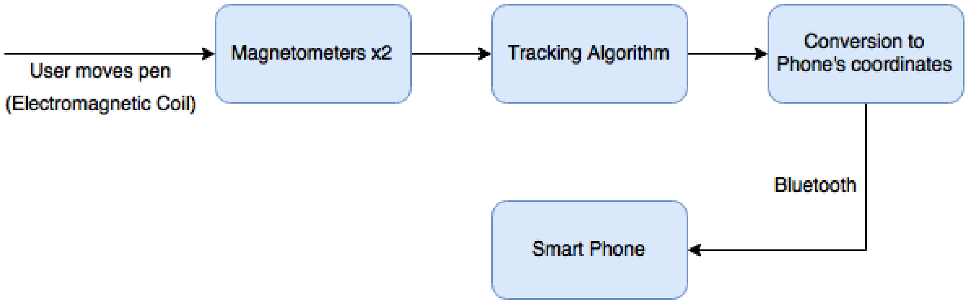

Figure 3- Conceptual Model of the Pen Tracking Unit

The pen-tracing module is responsible for providing the positional data of the pen by detecting the motion through use of an elector-magnetic field and two magnetic sensors. By instrumenting the pen with an electromagnet created from ferrite wrapped around in coil and supplying an AC signal with a certain frequency, we are able to generate a large enough magnetic field in order for the two magnetic sensors to measure the strength of the field. This frequency is chosen to be greater than 60 Hz and around 70 Hz in order to avoid the interference from the electronics devices nearby. Figure 4 demonstrates both the magnetic field generated around an electromagnet and the sensor detecting the strength of the field.

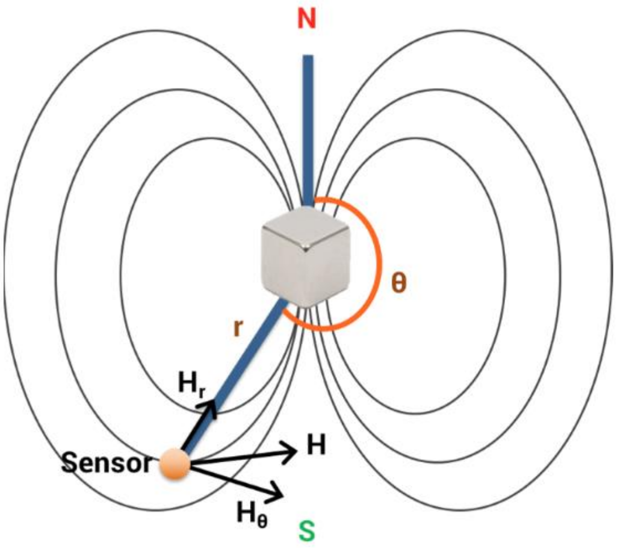

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Figure 4- Magnetic Sensor in Proximity of a Magnetic field

The magnetic field vector detected by the sensor, H, can be further broken down into X and Y directions, H_r and H_θ respectively. H_r and H_θ can be both mathematically represented in terms of r and θ,

$$H_r = M \cos\theta / 2\pi r^3 \tag{1}$$

$$H_\theta = M \sin\theta / 4\pi r^3 \tag{2}$$

where the value of M is permeability of the core material.

By using equations *(1)* and *(2)*, we can write the equation for the norm of magnetic field in terms of r,

$$H^2 = {H_r}^2 + {H_\theta}^2 = K * r^{-6} * (3\cos^2\theta + 1) \tag{3}$$

Where K is proportional to four factors:

$$K \propto \mu * N * I * A \tag{4}$$

where μ is permeability, N is the number of turns in the coil, I is the current flowing and A is the section area. The variables r and θ can be represented in terms of X,Y and Z coordinates for each sensor depending on the position of the sensors. If the first sensor is at (0,0,0) then the equations are as follows,

$$r_1 = [x^2 + y^2 + z^2]^{1/2} \tag{5}$$

$$\cos\theta_1 = z/r_1 \tag{6}$$

Same set of equations apply to the second magnetic sensor which is placed at (-1,1,0)

$$r_2 = [(x+1)^2 + (y-1)^2 + z^2]^{1/2} \tag{7}$$

$$\cos\theta_2 = z/r_2 \tag{8}$$

The Z coordinate value is always 0 since we are only dealing with 2 dimensional coordinates. Thus, the value of θ_2 is also always at 180 degrees for both sensors. Using these two equations we can calculate the X and Y coordinates of our pen.

The advantage of using electromagnetic sensors over optical methods is the elimination of the need for line-of-sight. Regardless of the position of the pen, or the magnet being covered by user's hand and even in low-light conditions, the movement of the remote stylus should be tracked by the two magnetic sensors. Data is then converted into coordinates that correlate to those on the user's smartphone screen to reconstruct the writing onto the PDF document. The processor will send data to the smartphone via Bluetooth.

2.2 Deliverables

2.2.1 Deliverables for Alpha Production (ENSC405):

- The projection unit makes a connection from cell phone to the Pico projector and enables the user to project their cellphone's screen on a flat surface.
- Pen's position (x and y coordinates) on a 2D surface is determined using magnetic sensors

2.2.2 Deliverables for Beta Production (ENSC440):

- The image correction system fixes any distortion of the image dimensions due to angle of projection.
- Luminosity of the projector can be adjusted by the user
- Pen's position is converted into correlated coordinates of the smartphone's screen.
- Pen's movement is sent to the smartphone as touch events using android libraries and are inputted by the note-taking application.
- A battery bank is added to the system that can last for minimum of 4 hours powers *StyLight*.
- At least one popular PDF note-taking application works with the *StyLight*.

3. Design Specifications

This section will identify the different hardware components that will be used in our product. These components have been manufactured by third party sources and will be integrated into our system.

The following sections will cover the justification for the use of each component, a technical description, and how they integrate into the *Stylight*.

3.1 General Requirements

Requirements such as temperature, humidity and altitude were taken from datasheets of the components used in the final product. As we can't test the system and every maximum and minimum, we will assume it works for the specified conditions as long as it works in normal operating ranges

3.2 Physical and Operation Requirements

The physical design consists of the design of a mechanical case and the design of a pen.

3.2.1 The Mechanical Case

In the proof of concept stage, the case was designed to be functional and aesthetically pleasing with precise and accurate measurements based on all of the components used by the *StyLight*. Using a 3D CAD tool, the final design of the case was drawn out and prepared to be 3D printed in the next stage.

In accordance to the dimensions of the physical requirement Req 3.2.11 - PT, the main body design of the *StyLight* in the prototype stage will be a rectangular cube that will have enclosed and secured all components with the following dimensions: 10cm x 10cm x 15cm. Although the aim is to design the main body in such a way that it remains as small and compact as possible, the dimensions may be forced to change throughout the production process depending on internal components. The material used to design the prototype of the main body will be a hard plastic through 3D printing as mentioned in the requirements Req 3.2.7 - PC in order to withstand collision and impact. At the same time, the material has to endure the operating temperature of 0˚ to 40˚ Req 3.1.2 - PC and a maximum weight of 10 pounds as per Req 3.2.13 - PT. Therefore, nylon will be used as it meets all of the physical requirements. The material may change to pc polycarbonate or PET (CEP) in the production stage depending on cost, safety requirements, and sustainability.

3.2.2 The Remote Pen

Based on Req 3.2.6 – PC the system should be able to track the pens tip when writing. To do so, the pen is designed in way that a circuit will close only when the tip of the pen is in contact with a surface. In the proof of concept stage, a CAD program is used to design the inside of the pen in a way that all the requirements are met and the components will fit properly while keeping its aesthetical looks. In the next stage, the CAD design is used to 3D print the shell of the pen with the same material as the enclosure. Then, all the components are assembled in place and various tests are conducted to see the strength of electromagnetic field. In the production stage, the design is developed to improve the functionality and decrease the budget for mass production.

3.3 Hardware Requirements

3.3.1 Electrical Requirements

The hardware systems diagram is shown in Figure 5.

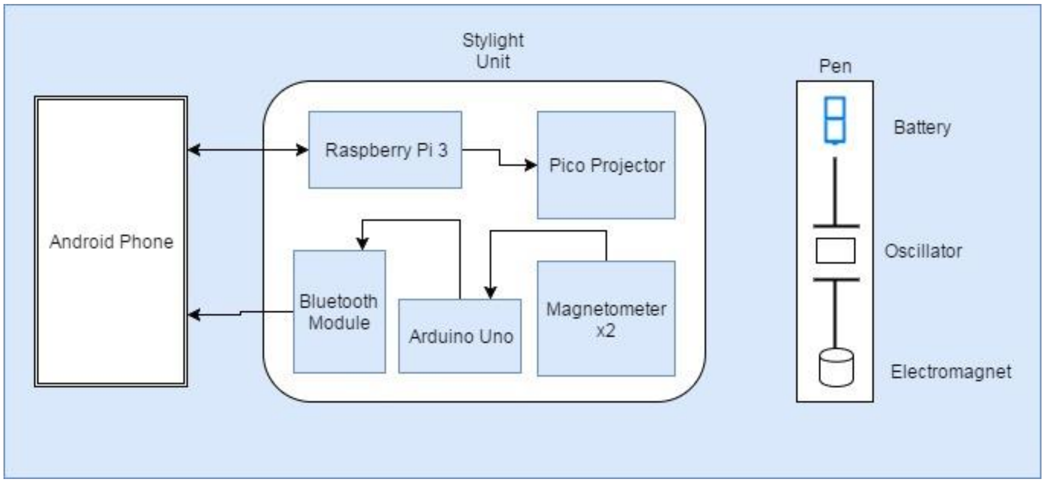


Figure 5 - Block Diagram of the Hardware Architecture

Two magnetometers will read the strength of an emitted magnetic field from an electromagnet in the pen. The electromagnet will be powered by a Pierce oscillator resonator, which will convert 3 V DC into an AC signal. The Pierce oscillator resonator consumes very little power. An Arduino board will read data from the magnetometers, and will digitally filter out electrical noise and the Earth's magnetic field. From there, calculations will be performed to ascertain the coordinates of the electromagnet. The coordinates of the electromagnet will correlate to pixels on the phone's screen for accurate placement of writing on the PDF document. The Arduino board is connected to the phone via HDMI connection.

3.3.2 Magnetometers

The magnetometers sense the magnetic field emitted from the electromagnet. For both proof-of-concept and final product, the MAG3110 magnetometers by NXP will be used instead of the obsolete HMC5883 chip due to the sensitivity, power, and size requirements the chip satisfies. A summary of the salient features and the correlating satisfied requirements is shown below in Table 1.

Table 1- MAG3110 Magnetometer Specification [2]

	Feature	Satisfied Requirement
Maximum Voltage	3.6 V	Req. 3.3.2.1-PC
Connectivity	I2C bus	Req. 3.3.2.3-PC
Sensitivity	0.10 T	Req. 3.3.2.4-PT
Range	1000 T	Req. 3.3.2.4-PT
Turn-on Time	25 ms	Req. 3.3.2.5-PT

Output Rate	80 Hz	Req. 3.3.2.7-PT
Size	2.0 mm x 2.0 mm	Req. 3.3.2.8-PT

The MAG3110 magnetometer does not satisfy the power consumption requirement of 0.36 mW, instead drawing 500 A during operation and consuming 1.8 mW worth of power. Although this is an 80% increase in power consumption, the performance increase the MAG3110 offers over the HMC5883 will be a fair tradeoff. Quality of the sensitivity of the magnetometer will increase the range that the electromagnet can be sensed, improving user experience.

One of the limitations of magnetometers that will be taken into consideration is its dependency on orientation. The chip adheres to a set xyz axis that may not be changed, and as such, the chip may not be oriented upside-down with the system, and its PCB must be adhered to the system to prevent any involuntary movement which would otherwise affect the reading of the magnetic field.

3.3.3 Arduino Requirements

Arduino Uno R3 will be used for the prototype stage to test the functionality of the sensor module. The reason Arduino Uno was chosen as the development board in the proof-of-concept stage is that Arduino IDE is user friendly and there is a lot of technical support for it online on the Arduino website as well as other third party websites. The board is also very affordable compared to the other development boards out in the market.

Our design is well implemented by making use of inbuilt MATLAB functions, so we decided to cross compile our design on MATLAB by installing the Arduino package to further process the sensor data. The technical specification of the board is as follows:

Table 2 - Arduino UNO R3 Specifications [3]

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

3.3.4 Electromagnet

The electromagnet is the constant source for the magnetic field sensed by the magnetometers. Provided an AC signal, the magnetic field will change its polarity at a frequency of 70 Hz as it attempts to oppose the change in current. The electromagnet is a solenoid: 34 AWG copper wire wound around a nickel core of diameter 10 mm and length 50 mm 100 times as per Req. 3.3.4.6-FP and Req. 3.3.4.7-FP. The magnetic field inside a solenoid is determined by the Biot Savart Law, which states that a magnetic field in the radial direction is induced by some current I flowing through a length of wire, and Ampere’s Law, which states that the magnetic field is proportional to the current enclosed within a figurative loop, known as an Amperian Loop. If an Amperian Loop in the shape of a rectangle encloses the length of a solenoid with number of turns N, and length l, and the rectangle’s longer side is parallel to the length of the solenoid, then the current enclosed in the loop is [4].

$$I\ enclosed = I * n \tag{9}$$

Where n is the ratio between N and l.

Since the magnetic field, B, is proportional to the current and permeability of the material, then:

$$B = \mu . I\ enclosed = \mu * I * n \tag{10}$$

Thus, we can control the magnitude of B by varying the material of the solenoid’s core, the length of the core, and the number of turns of copper wire. Req. 3.3.4.1-PC states that the core will be nickel, with a relative permeability of 100, as an alternative to ferrite, which has a relative permeability of 16. This will increase the strength of the magnetic field, and thus the range the magnetometers can sense. Should the range need to be adjusted, any of mentioned parameters may be varied to achieve the desired result.

A magnetic field of 590T was calculated using the aforementioned parameters, a current of 2.352 mA supplied by the oscillator circuit, and the above equation, exceeding but satisfying Req. 3.3.4.4-FP (previous calculations were done with the output current of the Pierce Oscillator). Using the result from a previous study with similar conditions [5], the range of the magnetic field can be approximated as 1.47 m with a magnetic field of magnitude 590T. Although this result exceedingly satisfies Req. 3.3.1.5-FP, this calculation was assuming ideal conditions and geometry, so a lower range will be expected, but should still exceed the requirement.

3.3.5 Oscillator Circuit

The oscillator circuit provides the 70 Hz AC signal to the electromagnet. Previously, a Pierce Resonator Oscillator circuit was considered to provide the required signal. Rather, a 555 timer circuit configured to run the timer in a stable mode at 70 Hz will be used instead. The differences between the two circuits are compared in Table 3 below.

Table 3 - Comparison of Oscillators

	Pros	Cons
Pierce Oscillator	• Low Power Consumption: consumed 3 A of current, translating to a 100,000 hour battery life if 2 1.5 V LR44 batteries were used, each with a capacity of 150 mAh (Req. 3.3.1.4-FP).	• Parts were difficult to source; this defied Req. 3.3.1.7-FP. • Circuit size was unsuitable for the pen's small diameter, resulting in an enlargement of the diameter, sacrificing user comfort. This defied Req. 3.3.5.4-FP.
555 Timer	• Easily modified to oscillate at 70 Hz, satisfying Req. 3.3.5.1-FP. • Small circuit size was suitable for pen's diameter, satisfying Req. 3.3.5.4-FP. • Parts are easily sourced and replaced if damaged, satisfying Req. 3.3.1.7-FP.	• Greater power consumption: the 555 timer current draw was measured with an ammeter, and determined to be 2.352 mA. This correlates to approximately 192 hours of battery life, assuming the use of 3 1.5 V LR44 batteries with a capacity of 150 mAh each. This does not meet Req. 3.3.1.4-FP. • The 555 Timer requires 4.5 V, as opposed to 3 V, to power, resulting in the use of a third LR44 battery.

As demonstrated by the above table, there was a trade-off between power consumption and size of the circuit. A circuit that would not be able to conform to the normal diameter of the pen which users are already acclimated to would have resulted in a thicker pen, potentially affecting user comfort, most likely not for the better. The addition of a third LR44 battery is acceptable, as increases in size along the pen's length is not detrimental as there is still space left to consume, even after the addition of an electromagnet 50 mm in length. The battery life of the 555 timer is not ideal in comparison to the Pierce Oscillator, however, considering the electromagnet will only be powered when the pen makes contact with a surface, and not powered for constant periods of time, this life may be acceptable, but high initial values of current that may be conducted by the solenoid as it is powered will need to be taken into consideration. Improvements to the life may be made at a later date and may include the introduction of a rechargeable battery to prevent users from continuously buying and replacing LR44 batteries.

Another advantage of the 555 timer circuit is the relative simplicity of the composition, using resistors, capacitors, and a fairly common 555 timer IC. These common parts are abundant should they need to be replaced in the event of damages. Additionally, in comparison to the Pierce Oscillator, the 555 timer circuit is much cheaper, lowering the overall cost of the *Stylight*. All resistors and capacitors are ceramic (to oppose temperature or piezoelectric effects) with a tolerance of 5%, satisfying Req. 3.3.5.11-FP and Req. 3.3.5.12-FP respectively.

3.3.6 Microcontroller

A suitable microcontroller that will have the performance capabilities to replace both the Arduino and Raspberry Pi in the system is required for the final product. Currently, in the proof-of-concept stage, the Arduino interfaces with the magnetometers with an I2C bus protocol, using the analog inputs of the board, while the Raspberry Pi handles the more computationally strenuous tasks of correlating coordinate points to the phone’s screen and sending data via Bluetooth connection. It was necessary to find a microcontroller capable of both roles, while also consuming low power off of less than 5 V of power.

The microcontroller that meets the above requirements is Texas Instrument’s TMS320F2837xS chip [6].

3.3.6.1 Microcontroller Features

The TMS320F2837xS has a C28x series single-core CPU with MIPS32 instruction set. MIPS was preferable to a processor with an ARM instruction set in this instance, as MIPS has 64 registers, as opposed to ARM’s 32. The additional registers are designated for arithmetic calculation, even having a register specifically for multiply and divide operations. Given the complexity in calculating the coordinates of the electromagnet and mapping to the phone’s screen pixels, this feature is preferable to the efficiency of the ARM instruction set.

If the single-core processor is deemed insufficient for calculating the coordinates and updating the phone’s screen in real time, then the TMS320F2837xS has an identical counterpart with a dual-core processor, known as the TMS320F2837xD, so sensing, calculations, and data transmission may be handled in parallel.

Table 4 highlights basic features that further satisfy requirements:

Table 4- TMS320F2837xS Chip Specification [6]

	Feature	**Satisfied Requirement**
CPU, Oscillator Frequency	200 MHz	Req. 3.3.6.1-FP
Maximum Voltage	4.6 V	Req. 3.3.6.5-FP
Maximum I/O Voltage	3.3 V	Req. 3.3.6.4-FP
Reset Boot Time	160 ms	Req. 3.3.6.7-FP
Price	$42.71, Eval Board $36.81, SMD Chip	Selling point of cheap cost

In addition to the above features, the TMS320F2837xS consumes 360 mA of current while operational, and 186 mA while idle. If the rechargeable *Stylight* battery must last for a minimum of 4 hours, then the capacity of the battery required is 1440 mAh. It can be surmised that the power consumption of the TMS320F2837xS is satisfactory for the capacity and quality of inexpensive batteries available that will supply a maximum of 4.6 V. As such, Req. 3.3.6.6-FP is satisfied.

3.3.6.2 Microcontroller Hardware Peripherals

Table 5 below summarizes the on-chip hardware peripherals of the TMS320F2837xS and the requirements satisfied:

Table 5- TMS320F2837xS Peripheral Specification [6]

Peripheral	Use	Satisfied Requirement
2 I2C bus channels	External communication with magnetometers	Req. 3.3.6.4-FP
4 SPI bus channels, USB 2.0	External communication with Bluetooth module	Communication with phone
12 bit ADC	Conversion of analog data from magnetometers	Req. 3.3.6.4-FP
Direct Memory Access (DMA)	Access to memory independent of CPU	Real time response

One limitation of the proof-of-concept stage with the Arduino is due to the singular I2C bus on board. In order to transmit data properly and in an organized fashion, the I2C protocol requires that slave peripherals, or in this case, the magnetometers, have individual slave addresses. However, since the magnetometers are of the same brand, they share the same address, and the bus cannot determine where the data is originating from. To work around this, another magnetometer with lesser sensitivity and resolution is being used to utilize its individual address. The TMS320F2837xS having two I2C bus channels is an imperative feature so the original pair of magnetometers may be used once again, providing an advantage in the quality of magnetic field sensing.

3.3.6.3 Microprocessor Software Support

Req. 3.3.6.3-FP states that the chosen microcontroller must have digital filtering capabilities. This requirement is met not only through choosing a processor with a MIPS32 instruction set, but through the capability of the C28x processors to compile C/C++ generated code from Embedded Encoder, a compiler that translates MATLAB code into optimized C or C++ code [7]. This capability is extremely useful, as digital filtration of the magnetic fields will be trivial to write using MATLAB functions, as it will reduce time spent writing code and debugging, while accelerating the project timeline.

3.3.7 Battery Module

For the proof-of-concept stage, the system will utilize a 12 V adapter, as required by the Arduino and Raspberry Pi, as per Req. 3.3.1.2-PC. For the final product, the system will utilize a rechargeable 5 V battery, as per Req. 3.3.1.9-FP. The capacity of the rechargeable battery can be determined from the product of the maximum current draw of all components (magnetometer, microcontroller, and Pico projector) and the minimum battery lifetime of 4 hours. Thus, a 9500 mAh battery is required, which is available on the market.

Due to the space constraints of the pen where the Oscillator circuit will reside, the battery was chosen first, and then the lifetime was estimated. With 2.352 mA of current drawn from 3 LR44 batteries of 150 mAh capacity, the battery life is expected to be approximately 192 hours. Requirements were not met in this instance, due to the change in circuitry.

To meet Req. 3.3.1.1-PC, all ICs will use the necessary bypass capacitors and pullup-pulldown resistors across their power supply pins as outlined in their data sheets, and will operate in the suggested temperature range. These bypass components will be present on the designed PCB of the final product. When designing the PCB, care will be taken to keep traces as short as possible and as far away from each other as possible to reduce parasitic inductances and capacitances, as per Req. 3.3.1.8-FP. Additionally, no trace will have more than a 45-degree angle to reduce stress and strain.

3.3.8 Pico projector

The main hardware device required for the projection is the Pico projector embedded in our device. Since we were severely restricted on size, we opted for a small Pico projector that would provide enough brightness and a high resolution. Insignia DLP Pico Portable Projector was our projector of choice, supporting 640x360 native resolution at a 19:9 aspect ratio. It also supports 50 Lumens of brightness and has a throw ratio of 1.6:1. This projector is small enough (4.55x4.65x4.55 cm) to fit in the *Stylight* case and also has an HDMI port, which works perfectly with the Raspberry Pi 3 board. With its set of specifications, as shown in Table 6, the Insignia Pico Projector is a good fit for our proof-of concept and prototype of *Stylight*.

Table 6 - Insignia DLP Pico Projector Specification [8]

Display	DLP DMD
LED life	20,000 hours
Brightness	45 ANSI lumens
Focus	Manual focusing dial
Resolution	nHD (640 x 360)
Picture ratio	16:9
Max screen size (diagonal)	80 in (203.2 cm)
Max input resolution	1080 p
Dimensions	1.79 x 1.79 x 1.83 in (4.55 x 4.55 x 4.65 cm)
Weight	0.26 lbs. (116 g)
Temperature	32 – 104 F (0 – 40 C)
Humidity	0 – 80%
Operating Time	100 min
Video In	HDMI
Power supply	5.0V 2.0A
Power Consumption	10 W, 840 mAh

The above Pico projector has a throw ratio of (1:1.64) but since we want the *StyLight* to project a required 30cm by 22cm Req 3.2.12 - PT screen on the desk in front of us, we have to magnify the projection. To meet this requirement, a mirror with dimensions of at least 3cm x 3cm is placed 2cm

away from the projector, on an angle of 26˚. This will increase the distance between the projector and the flat surface being used which will magnify the projected screen. As seen in Figure 6, the mirror is designed and placed in a way that the distance between the projector and the flat surface increases leading to an increase in the size of the projected screen of up to (30cm x 22cm).
Furthermore, this design will eliminate any direct contact of the user with the projector keeping the lens safe and decreasing any potential misconduct by the user.

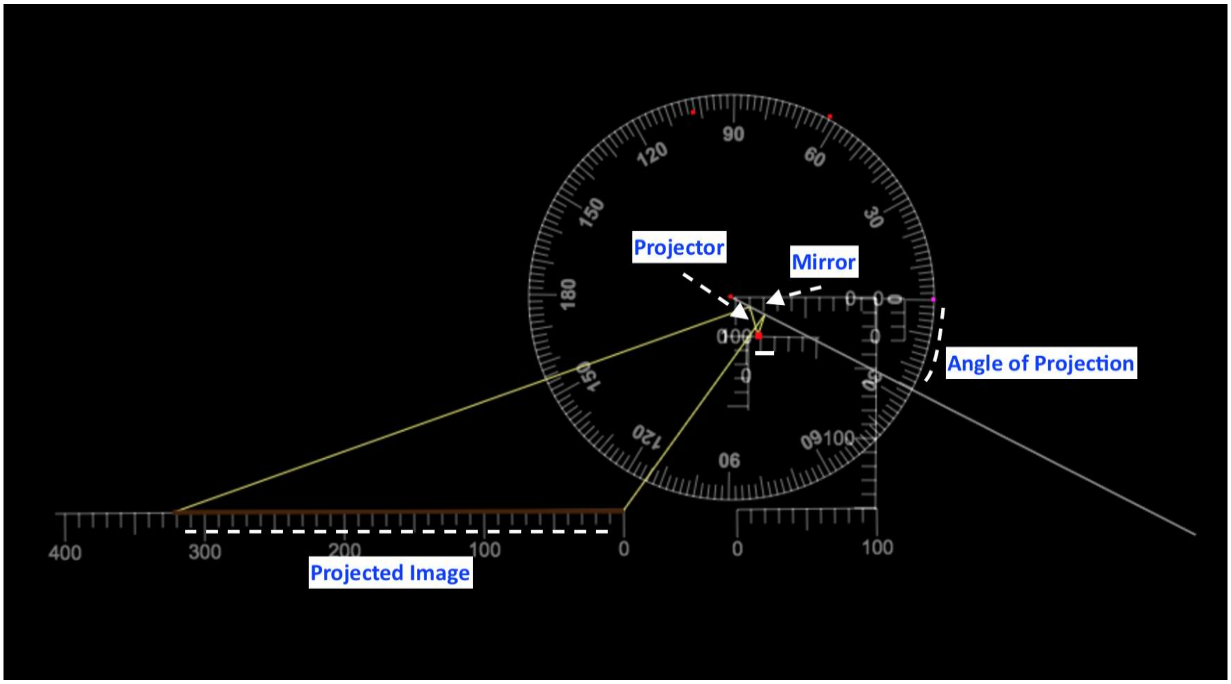


Figure 6- Simulation of Orientation of the Pico Projector and Mirror

To meet the final product requirements, Req 3.3.71 –FP, Req 3.3.72 –FP, and Req 3.3.73 –FP, LumoTech will use a Pico projector that allows brightness adjustment and supports Bluetooth connection.

3.4 Firmware/Software Design

Stylight has two independent software components. The first component, the projection manager, is responsible for displaying the screen content of the Android device in real-time and fixing any distortion in the image due to angle of projection. The second software component, the stylus manager, will convert the coordinates of the pen into Android screen coordinates and send these coordinates as touch events to the phone via Bluetooth.

3.4.1 The Projection Manager Unit:

The Projection Manger Unit consists of two main components. The first component, the Screen Casting App, is installed on the Android phone and is responsible for capturing and transferring the content of the screen. The second component, the Keystone Correction Driver, is responsible for correcting any distortion in the displayed image due to angle of projection.

3.4.1.1 Screen Casting App

In order to cast Android screen without use of any commercial product, the projection manager unit is built on top of an open source Android screen casting application called ScreenCast [9]. This application will communicate to the Android device with the help of Android Debug Bridge (ADB). ADB provides access to UNIX sell that can be used to run commands on the device remotely. It is a client-server program that includes three components:

- **Client**: which sends commands and runs on the Raspberry Pi.
- **Daemon**: which runs commands on the device as a background process. This will enable the user to use other apps on their Android phone.
- **Server**: which manages communication between the client and the daemon. The server runs as a background process on the Raspberry Pi.

To use ADB with a device connected over USB, the user must enable USB debugging in their device system settings, under Developer Options.
USB connection will be used for the proof-of-concept and the prototype models but the final product will provide the user the option to use ADB over Wi-Fi connect to the device by its IP address [10].
Screen capturing is done though the Media Projection Manager Android API that is supported in Android Lollipop and newer version [11]. For the proof-of-concept product, the app will capture the screen at the rate of 25 frames per seconds and transfer the frames to the Raspberry Pi in IVF format [12]. IVF stands for Indeo Video Format and is a simple container format for VP8 encoded frames. For the prototype and the final product, this rate will be increased to 30 frames per seconds or higher to ensure real-time interaction.

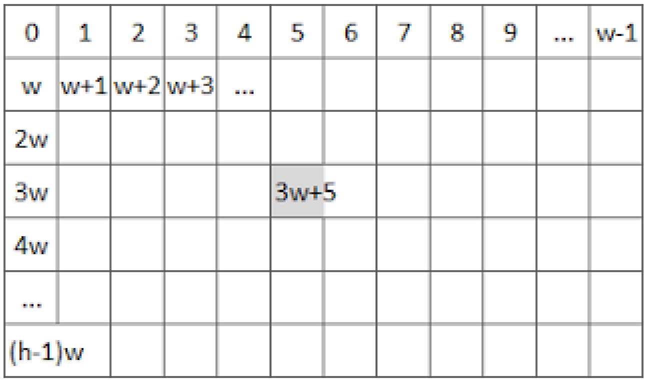
3.4.1.2 Perspective Correction Driver

The Perspective correction driver will be developed for the prototype phase to meet our operational requirements, especially Req 3.2.12-PT, Req 3.2.14-PT.

The source of projection will be at a height of 15 cm with angle of 26 degrees as can be shown in Figure 6. Also, reflection of a mirror causes the image to become reversed. This is solved in the perspective correction driver by flipping the image in so the final image will not be reversed and using keystone correction algorithm to correct any distortion due to angle of projection.

The Keystone effect is the apparent distortion of an image caused by projecting it onto a surface with an angle. The distortion suffered by the image depends on the angle of the projector and the beam angle. Since *Stylight* projects the screen of the Android phone is at an angle, the resulting screen appears as a trapezoid. Consequently, the resulting screen will be skewed. In order to transform this trapezoid screen back into its original rectangular form of the same proportions, the screen must be corrected by pinching in the screen at the top.

To do so, the frame buffer of the Raspberry Pi board is access and written directly. A frame buffer is a large, contiguous piece of computer memory with minimum one memory bit for each pixel. The frame buffer of the Raspberry Pi 3 by default has 16 memory bits (2 byte) for each pixel.
As the frame buffer represents the two-dimensional display surface, we could illustrate the pixels as shown in Figure 7 [13].



0	1	2	3	4	5	6	7	8	9	...	w-1
w	w+1	w+2	w+3	...							
2w											
3w					3w+5						
4w											
...											
(h-1)w											

Figure 7- Illustration of Framebuffer Architecture

The frame buffer therefore can be read and written to like any other computer memory.
To correct the distortion in the projected image, the corners of the trapezoid are found and homography matrix is computed based on the corners. Homography is a 3x3 matrix that describes the relationship between two planes. In this case one is distorted by perspective projection and another is where it is corrected. OpenCV library will be used to implement the keystone correction algorithm. OpenCV has functions to estimate a homography that best fits all corresponding points [14].

Homography estimation is a technique many modern computer vision projects use to perform perspective correction. One of the basic methods of homography estimation is the Discrete Linear Transform (DLT) algorithm. Letting (x, y) represent a coordinate in the source screen and (u, v) represent a coordinate in the destination screen, the mapping of (x, y) to (u, v) can be described by the equation:

$$c\begin{bmatrix}u\\v\\1\end{bmatrix} = H\begin{bmatrix}x\\y\\1\end{bmatrix} \tag{11}$$

Where H is the homography matrix shown as:

$$H = \begin{bmatrix}h_1 & h_2 & h_3\\h_4 & h_5 & h_6\\h_7 & h_8 & h_9\end{bmatrix} \tag{12}$$

Taking our four sets of corresponding corner points, we can find the homography matrix and determine the perspective corrected coordinates for every pixel in the uncorrected screen.

To implement and run the above software components, LumoTech incorporated a Raspberry Pi 3 board. A Raspberry Pi is a general-purpose computer, usually with a Linux operating system, and the ability to run multiple programs. The Raspberry Pi 3 Model B features a quad-core 64 bit ARM Cortex A53 clocked at 1.2 GHz and has a RAM of 1 GB.

These features go well with design requirements of the *Stylight* as they provide fast and real-time operating environment. Although Raspberry Pi 3 has a built-in Bluetooth4.0 module that can theoretically be used to send touch events to the Android phone, it doesn’t meet the functional requirements of the *Stylight*. In order to pair this module with Android as HID, a loadable Kernel module needs to be developed and it requires a front-end application to access the module. Given the Microcontroller’s characteristics of the Raspberry Pi 3, these requirements make the design slow and unreliable. The specification of the Raspberry Pi 3 are documented in Table 7.

Table 7- Raspberry Pi 3 Specifications [15]

Device	Raspberry Pi 3
Microcontroller	Quad Cortex A53 @ 1.2 GHz
RAM	1 GB SDRAM
Storage	Mirco-SD
Video Output	HDMI
Network	Ethernet, Wireless LAN, Bluetooth 4.0
GPIO	40 – pin header

Since Raspberry Pi 3 also supports HDMI output, it makes it a perfect candidate for proof-of-concept and prototype of *Stylight*.
Figure 8 indicates the connection and relationship between each of these components.

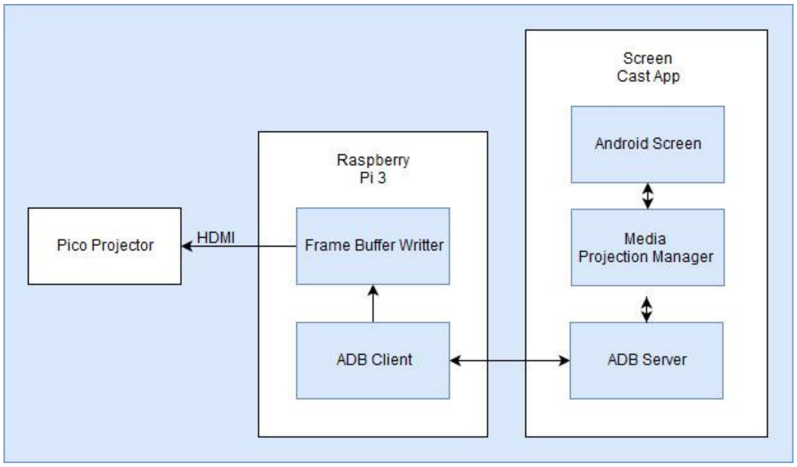


Figure 8- Block Diagram of the Projection Unit

3.4.2 The Stylus Manager Unit

The stylus manager, will find x and y coordinates from the magnetometers and converts them into Android screen coordinates. It will then send these coordinates as touch events to the phone via Bluetooth.

3.4.2.1 Coordinate Extraction

The magnetic field vector H is read using the two magnetic sensors. Using MATLAB, for each axis in H, we apply the bandpass filter to filter the magnetic field with cut off at +2 and -2 Hz from the center frequency. The envelope of the filtered data is extracted using MATLAB inbuilt Hilbert transform function. The L-2 norm of H is then calculated using Equation (3) and variables r and theta are substituted with x and y from Equations *(5)* to *(8)*. We then solve for electromagnet 2D position.

The plots below (Figure 9) demonstrate the magnetic sensor data in X, Y and Z directions. These sets of data were sampled in a span of 40 seconds. The received data contains noise from nearby electronic devices as well as the earth magnetic field. Thus, this extra noise will be filtered in order to collect the desire bandwidth for our electromagnet.

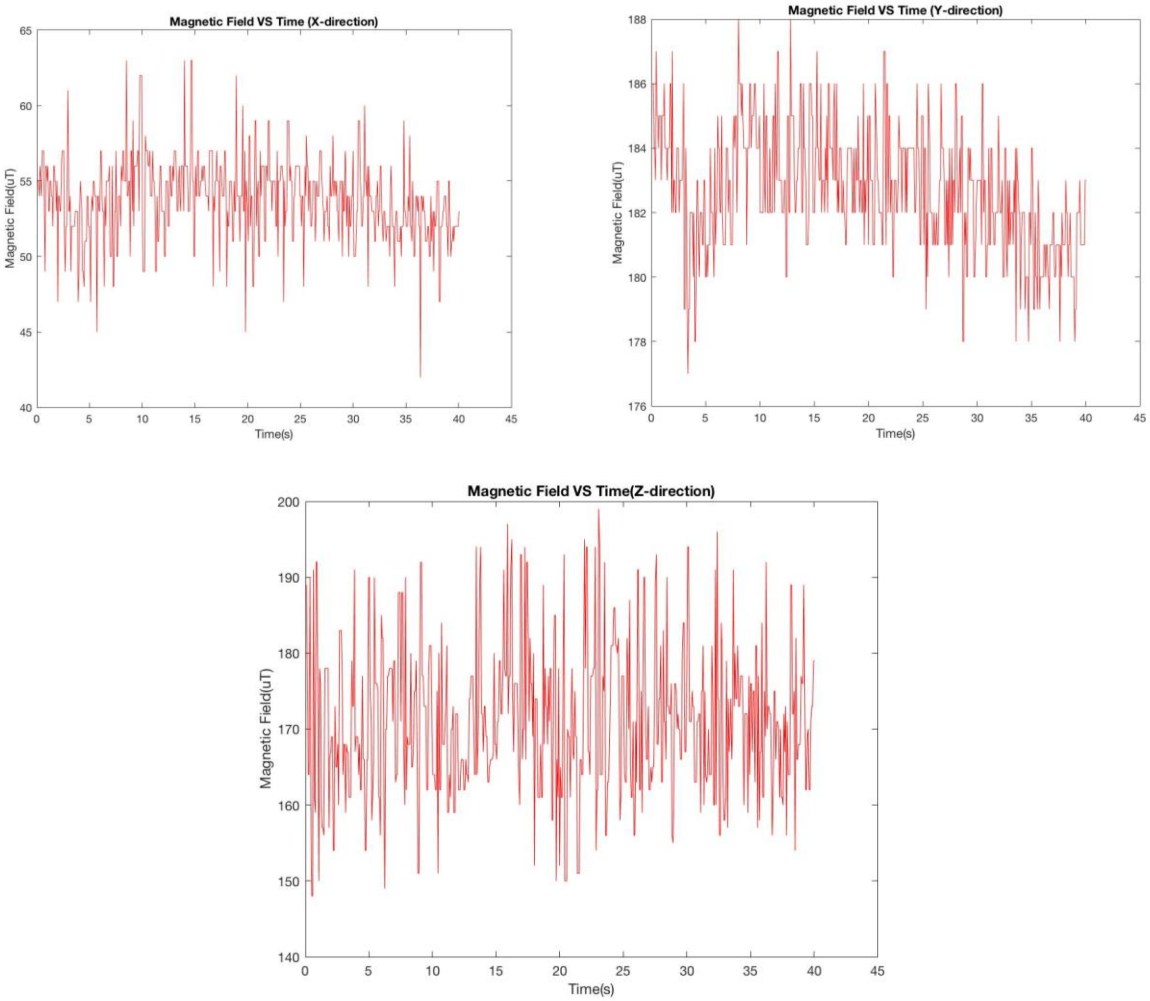


Figure 9- x, y and z coordinates' data received by the Magnetometers

As specified by Req 3.2.12-PT, the supported screen size in the prototype product is 20cm by 13.4cm. To convert any coordinate in this plane into phone screen coordinate, the unit has to find the size of the phone screen first. This is done by accessing Android's WindowManager through adb and finding the width and height resolutions as well as the density of each pixel. The dimensions of the phone screen are then found by the use of the following formulas:

$$dimension = \frac{number\ of\ pixels}{density} \qquad (13)$$

Each point on the surface is then multiplied by a scaling factor that depends on the dimension of the phone's screen. Scaling factors for each dimension is calculated as following:

$$\alpha_w = \frac{Screen\ Width}{Surface\ Width}, \alpha_h = \frac{Screen\ Height}{Surface\ Height} \qquad (14)$$

The scaled points are then sent to the phone as touch events via Bluetooth.

3.4.2.2 Sending Touch Events

In order to send the coordinates of the pen that we read from our stylus to the android device we are using a Bluetooth module. Particularly, low energy Bluetooth 4.0 (nrf52832) which will be configured to be recognized as a HID (Human Interface Device) device through firmware.
The nRF52 DK is one of many development kits with nrf52383 Bluetooth module installed on it. The team at LumoTech, decided upon using this development kit due to its functionality and familiarity of the members with this kit. The manufacturer of this kit, NORDIC semiconductor, has also provides numerous tutorials and sample open-source projects that our team can use a reference.

Below is a description of the development kit we are using:

The nRF52 DK is a versatile single board development kit for *Bluetooth®* low energy, ANT and 2.4GHz proprietary applications using the nRF52832 SoC. The kit is hardware compatible with the Arduino Uno Revision 3 standard, making it possible to use 3rd-party shields that are compatible to this standard. An NFC antenna can be connected the kit to enable NFC tag functionality. The kit gives access to all I/O and interfaces via connectors and has 4 LEDs and 4 buttons which are user-programmable. It supports the standard Nordic Software Development Tool-chain using Keil, IAR and GCC. Program/Debug options on the kit is Segger J-Link OB. Table 8 summarizes the specifications of the board.

Table 8- nRF52 DK Specifications [16]

Device	nRF52 DK
Processor	32-bit ARM Cortex-M4F
RAM	64 kB
Program Memory	512B Flash
Bluetooth module	nRF52382 low energy Bluetooth
clock	64MHz
Sensitivity	-96dBm Bluetooth

As can be seen in Figure 10, the application we are designing includes these three services for the HID functionality:

- Human Interface Device Service
- Device Information Service
- Battery Service

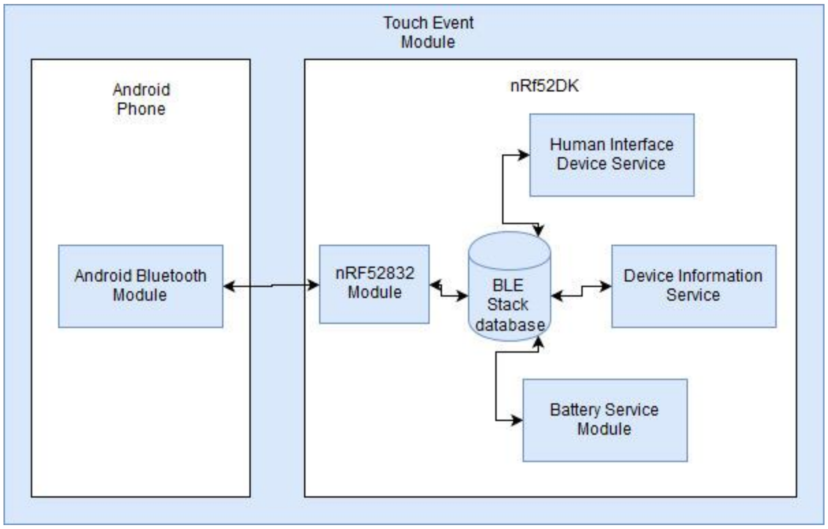


Figure 10- Block Diagram of the Touch Event Module

3.4.2.2.1 Human Interface Device Service

This module implements the Human Interface Device Service with the corresponding set of characteristics. During initialization, it adds the Human Interface Device Service and a set of characteristics as per the Human Interface Device Service specification and the user requirements to the BLE stack database.
If enabled, notification of Input Report characteristics is performed when the application calls the corresponding ble_hids_xx_input_report_send API.
If an event handler is supplied by the application, the Human Interface Device Service will generate Human Interface Device Service events to the application [17].

3.4.2.2.2 Device Information Service

This module implements the Device Information Service. During initialization, it adds the Device Information Service to the BLE stack database. It then encodes the supplied information, and adds the corresponding characteristics [18].

3.4.2.2.3 Battery Service module

This module implements the Battery Service with the Battery Level characteristic. During initialization, it adds the Battery Service and Battery Level characteristic to the BLE stack database. Optionally it can also add a Report Reference descriptor to the Battery Level characteristic (used when including the Battery Service in the HID service). If specified, the module will support notification of the Battery Level characteristic through the ble_bas_battery_level_update() function. If an event handler is supplied by the application, the Battery Service will generate Battery Service events to the application [19].

3.5 Safety Design

Parts for the *Stylight* were carefully chosen to be free of any lead contaminations or any other toxic chemicals, thus making it safe and non-harmful to use. All sharp edges will be sanded and polished to make as smooth as possible. Since the wavelength of the projector being used in the system is under 420nm/visible light spectrum, there will be no damage to the eyes [20]. All wires will be insulated and placed within the 3D printed enclosure, so no harmful electrostatic charge will be collected. As well as all circuits will be grounded, as a result, shocks and electrical fires will be prevented. The *Stylight* will include a cooling system to make sure the unit doesn't overheat. The device will also be implemented using a higher frequency than most common electronics, which are at 60MHz, and then using a band-pass to filter those frequencies.

4. Engineering Standards

The following engineering standards will be accounted for in the prototype and final product stage.

The *Stylight* will follow C22.1-15 Canadian electrical code package standards. These standards cover all electrical work and electrical equipment operating or intended to operate at all voltages in electrical installations. Stylight will meet these standards by some of the following design:

- The enclosure is made up of thermoplastic sheet, which is non-combustible
- The enclosure has no rough edges and burrs.
- *Stylight* will have markings to indicate registered trademark, rated battery voltage, and warning or caution markings related to the battery and the Pico projector.
- *Stylight* has a unique enclosure that does not resemble a toy.

Stylight will also follow CSA-C22.2 No. 0.17-00 – Evaluation of Properties of Polymeric Materials and CSA-C22.2 No. 94-M91 – Special Purpose Enclosures standards. These standards provide procedures for evaluating materials and parts made from polymeric materials intended for application in electrical equipment, as well as design and safety requirements [21] [22]. These standards provide test cases to test flammability, mechanical properties, thermal properties, resistance to weathering and electrical properties of the material. As our enclosure will be made up of polymeric material, we must follow these standards to ensure that the material we choose meets those requirements. We will meet these standards by subjecting the enclosure to the tests outlined by these standards and adjust our design appropriately to pass those tests.

Stylight will meet both CSA-C22.2 No. 107.2.01- Battery Chargers and CSA-C22.2 No. 0.23-15 – General Requirements for Battery-Powered Appliances standards. These standards applied to portable, mobile, and station battery chargers and battery powered devices for indoor and outdoor use [23] [24]. We will meet those standards by the following design:

- Enclosures will enclose all electrical parts
- Enclosure will be made of thermoplastic sheet, which has high strength and rigidity to withstand abuse
- The space within the enclosure of *Stylight* and its stylus is sufficient to provide ample room for wiring.
- All of the wires will be insulated.

5. Sustainability

With the growing concern of unsustainable practices found in design and the corresponding strain on the environment, at LumoTech we believe in providing a quality product while doing our part for the environment. In “cradle-to-cradle” design, emphasis is placed on creating a product with sustainable materials and ensuring those materials can be recycled after the lifetime of the product. It shifts the emphasis from the beginning of the product lifecycle to include the end of the product lifecycle as well. LumoTech will be incorporating “cradle-to-cradle” design to achieve its goal of encouraging sustainability while providing a highly reliably product.

The *StyLight* will consist of relatively few physical parts. Given the small number of components involved, options for sustainability are somewhat limited. In building the product in the first phase, efforts will be made to reuse microcontrollers and sensors where applicable. Additionally, the components that are used may be taken apart and be reused in other projects when the proof-of-concept prototype is no longer needed.

The projector unit consists of a Pico projector and an image-processing unit. When the alpha product is no longer needed, the Pico projector can be used as a regular hand-held projector. The image-processing unit is a programmable Arduino board that can be used by itself in future projects. For the alpha production, the projector and the microprocessor will be bought only if used ones cannot be found.

The stylus unit consists of electromagnetic coil and two magnetometers on the Arduino board along with LED and IR transmitter and receiver. They can all be disassembled from the product and used in future projects.

StyLight also contains a plastic case and a plastic pen-shaped stylus. Efforts will be made to ensure that the components use do not have materials found on the Cradle-to-Cradle Banned List of Chemicals. These chemicals are noted for being damaging to the environment and human health [25]. At the end of the product’s life, LumoTech is responsible for disposing the plastic components according to SPE-890-15 standards [26].

As the product evolves from the alpha production to the prototype stage, our choices may have to change accordingly to meet our goal. The image processing unit and pen tracking system will no longer be implemented on Arduino board. Instead we plan on designing and printing a PCB to do image correction and pen tracking. When the prototype in this stage is no longer needed, we make sure the PCB is recycled according to the standards for waste electrical and electronic equipment (WEEE) in the SPE-890-15 [26].

At the mass production stage, where our product is shipped to the end users, we ensure that the *StyLight* case and the remote stylus are made out of biodegradable materials instead of regular plastic. LumoTech will also demand the manufacturer of our PCB to recycle wasted materials and water used in the chip production. If *StyLight* goes into development of newer versions, LumoTech is committed to recycling older versions of the product for its customers according to CSA standards and free of charge.

6. Conclusion

The *StyLight* is a durable, compact solution to combining the large surface area of a tablet with the communication and file sharing capabilities of a smartphone. Connecting a smartphone to *StyLight* will enable students to project their lecture notes onto any surface, and with a specially designed stylus, write their notes onto the projected screen as they would normally on a tablet, storing the changes to the document for later. The system design consists of three major sections:

- Hardware development aimed to provide high accuracy pen tracking and high-resolution projection of the smart phone screen.
- Firmware development on the evaluation board to enable communication between hardware and software components.
- Software development aimed to develop an android driver, which is capable of casting the screen of Android and sending tough events to the cell phone.

The prioritization system will allow the development team to efficiently allocate resources accordingly. We have put high priority on the features, which are necessary for the device to have basic functionality. Some of these high priority features include the ability to project smart phone screen and track pen movement. Whereas we have put lower priority on features that add extra polish to the *StyLight* but are not as necessary for its functionality, such as correction of the distortion of the image.

The development of the *Stylight* proof-of-concept and prototype revolved around meeting the functional requirements agreed upon by the members of LumoTech. As the functional specification tries to answer “What” to meet, the design specification tries to answer “How” to meet. The intention of the *Stylight* is to be used by students for note-taking purposes. As such, many factors were taken into consideration in order to provide accurate, reliable, and fast functionalities.

Starting with the magnetometers, the choice of using the MAG3110, was based upon selecting one of a high grade and excellent specifications in order to meet the accuracy requirements defined by Req 3.2.6 – PC, and Req 3.2.22 - FP. The software computations used in the motion tracking took into consideration of improving accuracy by implementing software filters to reduce noise. LumoTech decided upon using the Arduino Uno for the finding the pen’s coordinate due to its functionality and familiarity.

Using the Insignia Pico projector, LumoTech was able to meet Req 3.2.4 – PC, and Req 3.2.14- PT. A better choice of projector will be made at the final product stage to meet the final product requirements. The projection unit driver was implemented on Raspberry Pi 3 as it supports HDMI output and has enough memory as well as enough processing power.

To address environmental and safety concerns of the *Stylight*, LumoTech decided upon using an enclosure with thermoplastic sheet, which is non-combustible.

Using the functional specifications as a checklist, the design specification has been composed to guide in the implementation of the *Stylight*. The test plan provided in Appendix A will be used to assess the success of the *Stylight* against the specified functional deliverables

7. Appendix A (Test Plan)

7.1 Introduction

This appendix documents and tracks the necessary information required to effectively defining the approach to be used in the testing of the *StyLight*. Its intended audience is the project manager, project team, and testing team. Some portions of this document may on occasion be shared with the client/user and other stakeholder whose input/approval into the testing process is needed.

In the proof-of-concept phase and a portion of the prototyping phases, most testing approaches will be more focused on requirements, which may not be developed with the release product copy in mind. While in the more design and technical extensive stages of product development, more detailed or lower level testing approaches will be undertaken.

7.2 Unit Testing

Unit testing is performed to check the validity of a specific portion of the device in a particular context. Individuals will test the components they are working on during development in an ad-hoc manner. Due to the dependence of the upper layers on functionality in the lower layers, the system will first be tested in its appropriate sub sections. Once completed, subsections will be integrated together and testing will continue with the full unit.

7.2.1 Projection Unit

Item to Test	Test Description		Test Outcome
Pico Projector Resolution and Focus are correct.	The projector can display image with 640 x 360 resolution and the image is focused		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
Frame Buffer of the Raspberry Pi 3 can be opened and written to.	Frame buffer is opened in software and a test image is written to it, the image is displayed by the projector that is connected to the board through HDMI.		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
The Perspective Correction Unit is able to flip and correct the distortion.	An image is displayed by the program. The projected image should not be flipped or be distorted.		

Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
ADB server connection can be established	Connect an Android phone to the device through micro-usb and receive notification. Name of the android device should be seen after running “adb list” on the client machine		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
Android screen is shown on the projected screen	Media projection manager is able to capture and send the content of the android screen to the client through ADB server		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
Projection starts after starting the app	Screen of Android will be displayed once the start button is pressed		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
Displayed image is not flipped or distorted	Check the projected image is not flipped, distorted or chopped		
Comments:			
Reviewed By		Test Date	

7.2.2 Stylus unit

<table>
<tr><td colspan="2">Item to Test</td><td colspan="2">Test Description</td><td>Test Outcome</td></tr>
<tr><td colspan="2">When the oscillator is powered it can generate a sinusoidal wave at a frequency of 70 Hz.</td><td colspan="2">To make sure the pen does not interfere with any other electronics, monitor the frequency while pen is in use to make sure it is at 70 Hz. As the pen gets closer and closer to the unit, the peaks should be higher and higher with minimum of at least Hz.</td><td></td></tr>
<tr><td colspan="2">Comments:</td><td colspan="3"></td></tr>
<tr><td>Reviewed By</td><td colspan="2"></td><td>Test Date</td><td></td></tr>
<tr><td colspan="2">Item to Test</td><td colspan="2">Test Description</td><td>Test Outcome</td></tr>
<tr><td colspan="2">Pen only functions when pressed on a surface (When user is writing)</td><td colspan="2">To make sure the pen only interacts with the screen when user is writing, it should only be in a closed circuit when pressure is applies to the tip. Apply pressure and write using the stylus. As pressure is applied, the batteries should come into contact creating a closed circuit and generating current flow through the coil. Electric field should change.</td><td></td></tr>
<tr><td colspan="2">Comments:</td><td colspan="3"></td></tr>
<tr><td>Reviewed By</td><td colspan="2"></td><td>Test Date</td><td></td></tr>
<tr><td colspan="2">Item to Test</td><td colspan="2">Test Description</td><td>Test Outcome</td></tr>
<tr><td colspan="2">Pierce Oscillator Resonator Circuit works as expected</td><td colspan="2">Verify the generated AC signal. Using an oscilloscope, view the signal the oscillator is supplying the electromagnets. The output should be a 4 Vpp oscillating square wave at 32.768 kHz.</td><td></td></tr>
</table>

7.2.3 Sensor Module

Item to Test	Test Description		Test Outcome
The accuracy of the pen tracking should be within 5 millimeters.	1. Movements in all directions must be tested. 2. The speed of the movement of the pen must vary for more accurate test results. The system must be able to track the pen accurately under various conditions		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
The electromagnet will be taken far away from the magnetic sensors to test the range of our motion tracking.	1. The tester will keep on increasing the distance between the electromagnet and the magnetic sensors in all directions. 2. The maximum range in all directions will be recorded and documented for future enhancement. The expected range of the motion tracking should be approximately 12 cm.		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
Effect of type of material in the environment surrounding our device and the magnetometer readings.	1. The test will be conducted in lecture halls, offices and computer labs. 2. The tester will record the magnetometer readings and the data rate in different locations. The sensors must be able to output consistent results in all locations.		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
The magnetic sensors should be able to output coordinates in real time manner	1. The frequency at which sensor data is received and processed to output 2D coordinates will be recorded. 2. Tester will conduct the test at different locations and near other electronic devices to better test the positioning response from the sensors. The motion tracking must be done in real time with respect to the movement of the pen.		
Comments:			

Reviewed By		Test Date	

7.2.4 HID Application with an Android device with a *Bluetooth* radio

Item to Test	Test Description		Test Outcome
Program compiles and the desired state is indicated	Observe that the BSP_INDICATE_ADVERTISING state is indicated		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
Android device can recognize the external Bluetooth device	On the android device, search for *Bluetooth* devices, and connect to the device named 'Nordic Bluetooth'. Observe that the BSP_INDICATE_CONNECTED state is indicated.		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
Board is capable of sending test message to Android	Open a text editing application (write on PDF). Press Button 1 on the board. This will send one character of the test message 'hello' (the test message includes a carriage return) to the computer, and this will be displayed in the text editor.		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
The connection can be ended and all desired states of the program can be observed	Disconnect the Android from the device by removing the device from the android’s Bluetooth devices list. Observe that for the first period, the BSP_INDICATE_ADVERTISING_DIRECTED state is indicated, and then it switches to BSP_INDICATE_ADVERTISING_WHITELIST, then to BSP_INDICATE_ADVERTISING, then to BSP_INDICATE_ADVERTISING_SLOW, and then all off.		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
Board can be reset	Reset the device while pressing Button 2 to erase bond info. Repeat step 2, and check if the device		

	can send messages to the phone.		
Comments:			
Reviewed By		Test Date	
Item to Test	Test Description		Test Outcome
The bond info will be removed from the computer when device is disconnected from Android	1. Disconnect the device from android, thereby removing the bond info from the computer. Start a search for *Bluetooth* devices and observe that while the device is advertising with Whitelist, android is not able to discover the device. 2. The device should be discoverable again after it switches to advertising mode.		
Comments:			
Reviewed By		Test Date	

7.2 System Integration Testing

Integration testing on our product is expected to begin in the prototype stage and once the projection and sensor modules are fulfilling the basic main requirement specifications of each module separately. This is because much functionality will be developed in each version and they must incorporate into each other in unison for complete functionality. During the process of integration testing, all features that have a relation of any sort will be tested to ensure they can function simultaneously and continue to behave as intended. A complete integration test of the whole software bare bone will also be performed after each related feature has been checked to perform accordingly. We will focus on using sandwich testing for the application, as we want to ensure that all features behave according at the fundamental level and at a high level. Sandwich testing consists of bottom up testing, which will be used to verify each component incorporates correctly and does not produce issues, and top down testing, which will be used to verify that there are no gaps in the connection of features.

The required steps to satisfy the completion of this integration tests are labeled in order as follows:

1. The *Stylight* can be powered on when plugged in.
2. When turned on, a welcome screen will be shown.
3. The welcome screen shows instruction on how to connect cell phone to the *Stylight* and how to pair cell phone with *Stylight* via Bluetooth.
4. Once cell phone is connected, the welcome screen should disappear and screen of Android phone should be displayed.
5. The screen will not be flipped or distorted. The size of the screen is 30 cm x 22 cm and the resolution is 640 x 360.
6. Once pen is turned on, a notification is shown on the screen indicating the pen is on and connected to the device.

7. Using the pen, user can interact with their cell phone, click, and swipe.
8. Pen can map all the coordinates of the screen to the phone including 4 outer corners of the screen.
9. A note-taking app can be opened by clicking its icon on the screen.
10. User is able to write on the app using the pen.
11. Device can be turned off by pressing the power button.

This test covers the operation of the *Stylight* without testing its power consumption and heat generation. A stress test then will be conducted on the device to make sure battery will last for at least 4 hours, and the temperature will not exceed 40 C during operation.

7.3 Physical/Mechanical Design Testing

For the proof of concept stage, the aim is to test different designs for the outer case in order to see which one best fits our product. Different designs will be shown to a number of individuals at random and based on the majority's feedback a design that is most aesthetically pleasing as a consumer product will be picked. As a result, the concentration will be focused on these aspects rather than the dimensions.

Later, in the prototype stage, the focus will shift to testing various ways of fitting all components into as compact of a model as possible so that the required dimensions are met. Finally, in the production stage, various tests will be conducted with different materials to test all the requirements mentioned in the physical layout design. Tests will be conducted to check for strength of collision i.e. falling from a person's hand or from a desk in a lecture hall. We will then move onto further testing to ensure to meet the required operating temperature.

7.4 Safety Design Testing

<table>
<tr><th colspan="2">Item to Test</th><th colspan="2">Test Description</th><th>Test Outcome</th></tr>
<tr><td colspan="2">Contact with the enclosure will not cause any injury</td><td colspan="2">Running your hand across any of the edges of <i>Stylight</i> will not cut or scratch you.</td><td></td></tr>
<tr><td colspan="2">Comments:</td><td colspan="3"></td></tr>
<tr><td>Reviewed By</td><td colspan="2"></td><td>Test Date</td><td></td></tr>
<tr><th colspan="2">Item to Test</th><th colspan="2">Test Description</th><th>Test Outcome</th></tr>
<tr><td colspan="2">Wirings are safe and touching the enclosure will not cause any shocks</td><td colspan="2">1. Touching the outer case of the device will not shock you, regardless of how long it has been on.
2. Perform visual check to ensure all wires are properly insulated and the board is grounded.</td><td></td></tr>
<tr><td colspan="2">Comments:</td><td colspan="3"></td></tr>
</table>

Reviewed By		Test Date	

Item to Test	Test Description	Test Outcome
The device will not over heat and harm the user	Measure temperature of the unit after 4 hours of operation. It should not exceed 40 C.	
Comments:		

Reviewed By		Test Date	

8. Appendix B (User Interface Design)

> "*To design is much more than simply to assemble, to order, or even to edit; it is to add value and meaning, to illuminate, to simplify, to clarify, to modify, to dignify, to dramatize, to persuade, and perhaps even to amuse.*" - Paul Rand

8.1 Introduction

StyLight is a modern note-taking device that consists of a projector and a stylus which enables students to take notes on their cell phones. The User Interface (UI) design of the *Stylight* consists of designing a mechanical case that contains the electrical components of the *Stylight* and the design of the remote stylus.

User Interface design involves those aspects of a product that affect the performance, safety, and experience of users. In the user interface design of *Stylight*, LumoTech focuses on maximizing usability and the user experience. The goal of user interface design is to make the user's interaction as simple and efficient as possible, in terms of accomplishing user goals.

8.1.1 Purpose

The purpose of this document is to define and analyze User Interface design of the *Stylight* and to provide an overview of the software and hardware parameters in the design of the *Stylight*.

8.1.2 Scope

Primarily, this document focuses on the proof-of-concept and the prototype UI. It contains the required user knowledge, and restrictions as well as the usability testing approaches with the designers and potential end users.

8.2 User Analysis

StyLight is designed in a way that makes it very simple for the user to utilize the product. The outer shell will have a USB and charging port on the side to connect the cellphone and charge the projector. On the front surface, there will only be a power button and a retracting slider that hold the phone. The power button turns on the projector which will then allow the user to connect their device using Bluetooth. When the device is connected to the projector a green light will flash around the power button. The user can then connect the *StyLight* by turning on the switch located on the pen.

Some helpful experience which the user may have previously acquired could be experience using an android phone, a tablet with note taking applications or using a stylus to take notes on a tablet. Another useful experience could be the use of similar devices using a Pico projector. The power button turns on the projector. Then, the user connects their device to the projector via wired connection or Bluetooth. This same concept is used for the *StyLight*.

The intended audience of the *StyLight* are people who have the ability to use their hand to take notes using a pen (stylus) and are not visually impaired as well.

8.3 Graphical Representation

Figure 11 is a rendered model of our device prototype to show some of its design aspects. As can be seen in this figure, user's phone will be placed in the front of the *Stylight's* case so the user is able to press the buttons of the phone and interact with it directly. A big power button is placed in the front of the case so it would be easy for the user to discover how to turn the device on. The open area in the front of the case is used for projection of the image while vent is placed in the back close to the fan.

Figure 11- Graphical Representation of the Enclosure $\begin{bmatrix} a & b \\ c & d \end{bmatrix}$

The stylus pen is designed in the shape of a regular pen with a movable pin, so its circuit will only turns on when the pin is pressed on a surface. Therefore, writing only happens when the user is writing on a surface and not when they are simply moving the pen in the air. Figure 11 shows a CAD design of the pen.

Figure 12- Graphical Representation of the Pen [$a \quad b$]

8.4 Technical Analysis

This section analyzes the UI of the *Stylight* and how "Seven Elements of UI Interaction" outlined in Don Norman's text have been considered it this design [27].

8.4.1 Discoverability

Discoverability is one link in the chain of elements that makes for good design. However, not every feature of the design can be discoverable. This means as designers, we need to consider what things need to be discoverable first, and where the emphasis of the design should be. In order to decide what to make discoverable in the design of the *Stylight*, we prioritized the tasks we assumed users would do. To focus more on the perspective most people would have when using our device, we created a list base of user research, for the typical tasks users need to accomplish with the design.

- **User needs to plug in the device:** Power plug has been placed on the side of the case as shown in Figure 11 - a, b.
- **User needs to turn on the device easily:** A big power button has been placed on the front of the case as shown in Figure 11 – a, c, and d.
- **User needs to be able to connect their cell phone by micro-USB cable:** A USB plug has been placed on the side of the mechanical case as shown in Figure 11 – a, c, and d.
- **User needs to turn on Bluetooth and pair their cell phone with the device via Bluetooth:** On turn-on, *Stylight* will display a message prompting the user to turn on their Bluetooth and pair it with the device.
- **User needs to turn the pen on:** On-turn on, *Stylight* will display a message asking the user to turn on the stylus by pressing the power button on the pen.

8.4.2 Feedback

Feedback is used to engage and explain, and can improve user satisfaction. To improve user experience of our device, we tried to give feedback to the user at every step.

- When plugged in a green LED by the power port will turn on.
- When power button is pressed, green light around it will turn on. If low battery, it will turn red.

- When low-battery shows notification that battery will die in 10 minutes.
- When Bluetooth paired, blue LED on the side of the case will turn on.
- When pen is pressed on a surface and is working small blue led on the pen will turn on.
- On the start-up, a welcome screen and instruction to connect cellphone will be displayed.
- User will see what they are writing with the help of the projected screen.
- Goodbye message on the turn off will be displayed so the user knows the device is being turned off.

8.4.3 Conceptual Models

A good design should project all the information needed to create a good conceptual model of the system, leading to understanding and a feeling of control. The conceptual model can enhance both discoverability and evaluation of results.

In the case of *StyLight*, prior experience of the user with smart phones and projectors will be a great help in building a conceptual model of the *StyLight*. The user who has worked with a smart phone will know how to connect their phone through micro-USB and use note-taking applications to take notes and save them for future access and use. Furthermore, prior experience with a projector is an advantage for *StyLight* users since they operate similarly.
Because the *StyLight* pen has the shape of a regular pen, the user would have a good conceptual model of how it works and how it gets connected to the phone via Bluetooth.

8.4.4 Affordances

An affordance is a quality of an object or an environment that enables an individual to perform a specific action or ability. The affordances of *StyLight* are as follows:

- **Screen Projection:**
  StyLight will enable the user to magnify their cellphone's screen by projecting it onto a flat surface. This is done with the use of a projector.
  The underlying components of this affordance are the embedded Pico projector and the image projection manager module.
- **Interaction:**
  StyLight also enables the user to interact with the projected screen using a remote stylus. The underlying hardware of this affordance is the magnet inside the pen and the two magnetometers in the stylus unit.
- **Cellphone affordances:**
  StyLight allows for full functionality of the cellphone including access to all the applications however with a bigger screen.

8.4.5 Signifiers

Effective use of signifiers ensures discoverability and that the feedback is well communicated and intelligible. *Stylight* uses LEDs and notification messages as signifiers.

8.4.6 Mappings

The relationship between controls and their actions follows the principles of good mapping, enhanced as much as possible through spatial layout and temporal contiguity.

We put the power button on the front surface of the case so that it is easily found and accessed by the user. Also, all ports are placed on the side of the case so that the wires are out of the way.
Cell phone is placed in the front so the user can interact with it.

8.4.7 Constraints

Constraints are powerful clues, limiting the set of possible actions. The thoughtful use of constraints in design lets people readily determine the proper course of action, even in a novel situation. Physical, cultural, semantic, and logical seem to be universal, appearing in a wide variety of situations. The visible affordances of the pieces are also important in determining just how they fit together.

In the case of the *Stylight*, every Android phone user knows how to plug in a micro USB cable. It is a physical and logical constraint and is the same in every culture. The shape of the power button is also universal and known.

The user would know where the cellphone should be placed from the shape of the cellphone's placeholder; it is one of the physical and logical constraints of the *Stylight*.
The remote stylus has the familiar shape of a pen. It provides cultural and semantic constraints results in strong restrictions on who to use the device.

8.5 Engineering and Safety Standards

9.5.1 Engineering Standards

The following engineering standards will be accounted for in the prototype and final product stage of the *Stylight*.

Stylight will contain Bluetooth® radio transmitter and will be designed, manufactured and tested to meet the Federal Communications Commission (FCC), Industry Canada and European guidelines for RF exposure and Specific Absorption Rate. In particular, the device will comply with Industry Canada Statement CES-003 — Information Technology Equipment [28], and CAN ICES-005 — Lighting Equipment [29].

Stylight is classified as Class B device and will meet all requirements of the Canadian interference-causing equipment regulations as part of the Bluetooth Industry Canada license-exempt Radio Standards Specification (RSS) standard(s) [30].

8.5.2 Safety Precautions

8.5.2.1 Electromagnetic Compatibility (EMC)

Stylight will conform to IEEE139-1988 - IEEE Recommended Practice for the Measurement of Radio Frequency Emission [31]. Note that any change or modification to this product not authorized by LumoTech could void the electromagnetic compatibility (EMC) and wireless compliance and negate your authority to operate the product. *Stylight* will demonstrate EMC compliance under conditions that included the use of compliant peripheral devices and shielded cables between system components. As some components of the device are magnetic, it may attract metallic materials. In order to reduce the likelihood of magnetic fields interfering with compass readings, disrupting the proper operation of pacemakers, or corrupting magnetically stored data, do not place credit cards or other magnetic storage media or magnetically sensitive devices near this device.

8.5.2.2 Medical device interference

The *Stylight* pen and enclosure will contain components and radios that emit electromagnetic fields. These electromagnetic fields may interfere with pacemakers, defibrillators, or other medical devices [32]. Please maintain a safe distance of separation between your medical device and the pen. Consult your physician and medical device manufacturer for information specific to your medical device. Stop using *Stylight* if you suspect it is interfering with your pacemaker, defibrillator, or any other medical device.

8.2.2.3 Heat Related Concerns

The device may become very warm during normal use if the temperature goes beyond 40 C or below 0 C, turn off the device immediately. The device will comply with the user accessible surface temperature limits defined by the International Standard for Safety of Information Technology Equipment (IEC 60950-1 [33]).

To reduce heat related concerns, follow these guidelines:

1. Set up your device on a stable work surface that allows for adequate air circulation under and around the device.
2. Use caution when operating your device on a pillow, blanket, or other soft material, because the material can block the airflow, which may result in the device overheating.

8.2.2.4 Safety and Handling

Stylight may present a choking hazard or cause other injury to small children. Keep the *Stylight* pen away from small children.

Handle *Stylight* with care. It contains sensitive electronic components, including a battery, and can be damaged or cause injury if dropped, burned, bent, crushed, or if it comes in contact with liquid. Don’t use a damaged *Stylight*.

8.2.2.5 Cable and cord safety

Arrange all cables and cords so that people and pets are not likely to trip over or accidentally pull on them as they move around or walk through the area. Do not allow children to play with cables and cords.

To avoid damaging the power cords and power supply:

- Protect the power cords from being walked on.
- Protect cords from being pinched or sharply bent, particularly where they connect to the power outlet, the power supply unit, and the device.
- Do not jerk, knot, sharply bend, or otherwise abuse the power cords.
- Do not expose the power cords to sources of heat.
- Keep children and pets away from the power cords. Do not allow them to bite or chew on them.

- When disconnecting the power cords, pull on the plug—do not pull on the cord.
- If a power cord or power supply becomes damaged in any way, stop using it immediately.
- Unplug your device during lightning storms or when unused for long periods of time.

8.2.2.6 Battery Safety

Stylight will contain a built-in battery, improper use of which may result in explosion. Do not heat, open, puncture, mutilate, or dispose of the product in fire. Do not leave the device in direct sunlight for an extended period of time, which could cause melting or battery damage. The battery in this device is not user replaceable and should only be replaced by LumoTech service engineers.

8.2.2.7 Cleaning

To clean the outside of *Stylight*, use a lint-free cloth. Don't get moisture in any openings or use aerosol sprays, solvents, or abrasives.

8.2.2.8 General Safety Guidelines

Please follow these instructions for a safer usage of *Stylight*:

- Do Not Attempt Repairs.
- Do Not allow children to cling to or climb up to the enclosure – This may cause the projector to fall, causing injury or death.
- Do Not place flammable materials such as aerosols near the enclosure – This may result in fire.
- Do Not place the enclosure in direct sunlight or near heat sources such as radiators, res, stoves, etc. – This may result in fire.
- Do Not use the *Stylight* outside and do not expose the product to any humidity or water – Since the product is not waterproof, this may result in electric shock.
- Do not block the vents on *Stylight*.
- Do not expose the product to extreme vibrations. It may damage internal components.

8.6 Analytical Usability Testing

This section will outline the analytical usability testing taken by the designers, using the heuristics evaluation. This evaluation is a report used to identify problems in the user interface design and is in the form of a checklist [34]. The designers complete it independently at least twice. The heuristics are the following:

1. The status of the system is visible through appropriate feedback within reasonable time
2. The system doesn't use any engineering-related terms, but instead only uses conventional words and text
3. A button to go back or stop is always be present
4. The system follows the same conventions throughout the system
5. The user is presented with a confirmation option before committing any type of action
6. Instructions on the use of the system are either visible or easily retrievable
7. Users have the option to create shortcuts to certain functions in order to speed up the interactions

8. Any text is kept to a minimum as to not diminish the relative visibility of the important information
9. Errors messages are displayed in plain language, indicate the problem and suggest a solution
10. Any help and documentation is easily found, which lists concrete steps to be carried out to fix the problem

The evaluation is to be completed without any interruptions from anybody and should not be discussed until everyone finished. Once every designer completed the evaluation, they come together and discuss everything that has been discovered.

The following are test scenarios the designers should take to set up the device in its final product stage before completing the heuristics:

1. Power the pen and the enclosure
2. Connect the phone via HDMI to the enclosure
3. Connect the phone via Bluetooth to the unit
4. Open a note taking app of your choice using your phone
5. Verify that the display is projected through the projector onto any proffered surface
6. Calibrate the pen by pressing on all four corners
7. Verify that the pen can now be used to interact with the projected surface

8.7 Empirical Usability Testing

Empirical testing will be incorporated as part of our development process in order to receive feedback from potential users. This will only occur at prototype stage before finalization, as we believe it is better to provide users with a complete sample of our product.

In earlier stage of our design, key components will be in development, thus conducting a user test at these stages will be less effective as their feedback is only limited to how the system works at that time.

For the proof of concept stage, the aim is to test different designs for the outer case in order to see which one best fits our product. Different designs will be shown to a number of individuals at random and based on the majority's feedback a design that is most aesthetically pleasing as a consumer product will be picked. As a result, the concentration will be focused on these aspects rather than the dimensions.

In the prototype stage, the aim is to design and test a component that will hold the case firm in case the surface (desk or table) moves or shakes. This will help avoid any damages and will make the case safer in general. One concept that can be implemented is a clamp that clips and holds the case firm to the desk it is on. Another design are suction cups at the bottom of the case that will attach to the surface it is placed on. Tests will be conducted and results will be used to further improve the design.

To perform usability testing in this stage, a selection of students and faculty members from the faculty of applied sciences who can evaluate our product in a more technical way will be provided with our product to conduct the testing. This test will also be conducted with non-technical members from other faculties. This is so that we are provided with constructive feedback from both technical and non-technical users. During the testing phase, we will provide a documentation that outlines the intended usage, safety and troubleshooting information of the product, and encourage users to interact with all the major components. An overview and flow of the system will also be available in the documentation to help users understand why and how each key feature is related to one another.

During this period of Empirical testing, comments, feedbacks, suggestions, complaints and bug / error are to be recorded by the user. We will also maintain contact with all the users and provide support as necessary. At the end of the Empirical testing period, an online survey will be released to all participants to help us further understand their overall experience with the product. Users will be asked to rate the usability of all the features, how likely would they purchase *Stylight* and would recommend it to other SFU students and finally, any other comments and suggestions they may still have.

All the collected comments, feedbacks and suggestions will be reviewed and we will update our design accordingly to produce the final product. We will then run one last iteration of unit and integration testing before releasing the final version of our product.

8.8 Conclusion

The UI appendix gives a concise overview of all aspects affecting performance, safety and user experience of the *Stylight*. It also covers the software and hardware parameters in the design section. The ultimate goal of LumoTech in the proof of concept stage is to design the mechanical case and remote stylus in a way that makes the user interaction as simple and efficient as possible. A review of different required knowledge and restrictions are specified for the user. In addition, various usability testing approaches are given for both the designers and end users.

The current state of UI concentrates on designing a product that is safe, meets all relevant engineering standards and performs to its full potential. To do so, various tests are conducted and results are used to improve the design. Furthermore, the prototype stage concentrates on further improving our design to be aesthetically pleasant and easy to use by end consumers while meeting all the requirements of the prototype stage.

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