March 10, 2016

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440W Design Specification for the Direct Interference System for Coordination Limitation by Amplified and Stimulated Emission of Radiation (DISCo LASER)

Dear Dr. Rawicz:

The following document, *Design Specification for the Direct Interference System for Coordination Limitation by Amplified and Stimulated Emission of Radiation (DISCo LASER)*, contains a set of technical guidelines for the design of our project for ENSC 440W. The goal of the project is to develop a nonlethal alternative to weapons used in war and minimize casualty count by utilizing light to temporarily blind enemies in an area.

The design specifications included in this document apply to the proof-of-concept model for our project only. Considerations for the prototype and final product will be discussed, but not implemented at this stage.

If you have any questions or concerns, please contact Fabio Bollinger at fbolling@sfu.ca.

Sincerely,

Ashley Francke, CEO
DISCo

Enclosure: Design *Specification for the Direct Interference System for Coordination Limitation by Amplified and Stimulated Emission of Radiation (DISCo LASER)*

DESIGN SPECIFICATION

For the Direct Interference System for Coordination Limitation by Amplified and Stimulated Emission of Radiation (DISCo LASER)

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Executive Summary

The DISCo LASER presents a novel approach to non-lethal tactics for use in non-combat scenarios by the military, or other offensive squadrons. The device is portable, and can be mounted onto mobile equipment such that soldier's hands can remain free. It behaves as a shield of light by targeting any individual's face with a powerful and nauseating beam of white light. Doing so causes no permanent damage, and as such can be used indiscriminately between enemies combatants and innocent civilians alike. The design of DISCo LASER is effectively a synthesis of 4 main units: Sensors, Processors, Motors, and Lights; which communicate with each other using a PCB with custom pins, designed in a modular fashion for easy assembly and disassembly.

The aforementioned PCB connects to mains power with 3 separate voltage adapters: 5V, 12V, and 24V. The 5V adapter supplies the rail voltage for the Raspberry Pi processing unit, while the 12V supplies the rail voltage for the lighting unit circuit. Finally, the 24V is connected separately to the stepper motors and to the LED array. Both the motors and the LEDs are only activated once their respective control circuits receive a low voltage digital signal from the Raspberry Pi. The control circuit for the LEDs is a custom design which features an electromechanical relay for power isolation. The control circuit for the motors utilizes an H-bridge to allow bi-directional control.

The motor units are connected in such a way to provide a fixed point of rotation to the LED reflector, which is the source of the nauseating beam of light. By ensuring that the reflector rotates about a fixed point, the sensor unit can remain fixed and process target coordinates much more efficiently, without compensating for the position of the motors. This property is achieved by 3D printing a custom enclosure for the motors and connections for the reflector. The sensors were also selected to allow for finding targets at a large distance from the device. This feature comes from the sensor's 1080p resolution. Other mechanical features include necessary mass and friction to keep the device stationary despite moving parts, and counter weights to properly center the center of mass.

Testing the system will be done with scrutiny, and the test plan is a thorough test of not only overall functionality, but also internal specific functions. The tests involve isolating each of the 4 units and testing to their maximum and minimum input and output specifications. For example, the lighting unit must be able to sustain 10 seconds of continuous light with no disturbances. Though in standard operation it is not expected to operate for that period of time, it's important to know that there is no chance of inconsistencies arising in its operation. Other tests involve supplying a test image to the processor and recording the interpreted coordinates of any faces it might have found; as well as ensuring the processor can coordinate the motors to pre-set angles and positions.

Considering the intended environments in which the DISCo LASER will be used, it has been designed to be environmentally sustainable. This sustainability is accomplished by selecting materials which are not known to have detrimental effects to soil or water should the device be carelessly discarded. For example, all electronic components are certified RoHS compliant. Safety was also a top priority in this design. Many components have been sourced to prevent electrical fires, including a relay to isolate high power circuits from the sensitive electronics, as well as a fuse to prevent more than 750mA from entering the LEDs, which is specified to be maximum tolerance according to the manufacturer. The device is fundamentally designed to be one of the safest pieces of equipment to be used in a battlefield.

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Glossary

Anthropometry:	Science of defining physical measures of a person's size, form, and functional capacities.
Comparator:	Circuit which outputs max voltage if input voltage is above a threshold voltage and zero if input voltage is below threshold voltage.
DISCo:	Direct Interference System Corporation.
DISCo LASER:	Direct Interference System for Coordination Limitation by Amplified and Stimulated Emission of Radiation.
LED:	Light Emitting Diode.
Op-amp:	Operational Amplifier.
Raspberry Pi:	Small, inexpensive computer used as the processing unit for the DISCo LASER.
RoHS:	Restriction of Hazardous Substances Directive.
PCB:	Printed circuit board. Plastic board used to connect circuit components together.
Photo-resistor:	Resistor whose resistance changes with ambient light intensity.
Stepper Motor:	Actuator which only allows movement in small predetermined step sizes. Used when exact position information is desired.
UV:	Ultraviolet. Electromagnetic radiation of wavelength 400nm to 10nm.

1. Introduction and Background

Thank you for choosing DISCo, because you'll never need a phaser…when you have DISCo LASER. That's because for the first time in the security industry, there now exists a truly automatic, hands-free, non-violent method of crowd control. Historically, the military has had to be constantly prepared for combat, even during non-combat missions. As a result, they have had to carry cumbersome lethal weapons everywhere they went. Most importantly, there has been a constant risk of violence and death among the soldiers and innocent civilians who occupy the theater of battle. DISCo LASER provides soldiers with the ability to complete missions while reliably and non-lethally incapacitating all other enemies and civilians within visible range, drastically reducing the risk of death on the battlefield.

This document will describe the design elements which give DISCo LASER its functionality. The device is comprised of 4 main components: Sensor, Processor, Motor and Lighting Units. Each component is integrated using a custom printed circuit board. Both the sensors and processors are part of a development kit for the Raspberry Pi, a small inexpensive computer. The purpose of the Raspberry Pi is to integrate data from the camera sensors and determine geographical coordinates of targets. These coordinates are then converted into data to control the 2 stepper motors, which in turn point the lighting unit LED array and reflector to the targets. More detail can be found in the respective sections of each unit below.

The DISCo LASER operates on the phenomenon of light incapacitation. This phenomenon is due to the human eye having a disproportionate response to very bright light. The light overstimulates the optic nerve and causes collateral effects of nausea, disorientation, and temporary blindness. No real lasting damage is inflicted on the targets, and therefore this technology can be used indiscriminately. By combining the effects of the lighting unit with a fast acting facial detection unit, DISCo LASER effectively creates a shield of light around a squadron, and functions to protect them across all areas of a battlefield.

One of the greatest features of the DISCo LASER is that it is portable. The maximum voltage used to control the motors is 24V. The device is also small and lightweight. These features allow the device to be mounted onto moving objects, and allow it to be used in a variety of other scenarios, including financial security, special police forces, riot control, and others. Safe, non-lethal, and autonomous weapons are the future of security, and with DISCo LASER, the future is here.

2. Overall System Design and Specifications

The physical assembly of the DISCo LASER will feature a main PCB which will be central to the processing unit, motor unit, and lighting unit. Figure 1 is a detailed box-diagram of the PCB, showing the connections between all components. The prototype will be powered using three separate connections to main power: a 24VDC adapter, a 12VDC adapter, and the 5VDC adapter for the processor unit. The 24V power supply will be used to supply the motors and the LED array, which use 24V and 20V respectively. During prototyping, it may be necessary to split the 24V to acquire the 12V. The 12V will be the rail voltage for the lighting unit circuit. Finally, the 5V from the processor unit is used in the lighting unit circuit as a reference voltage.

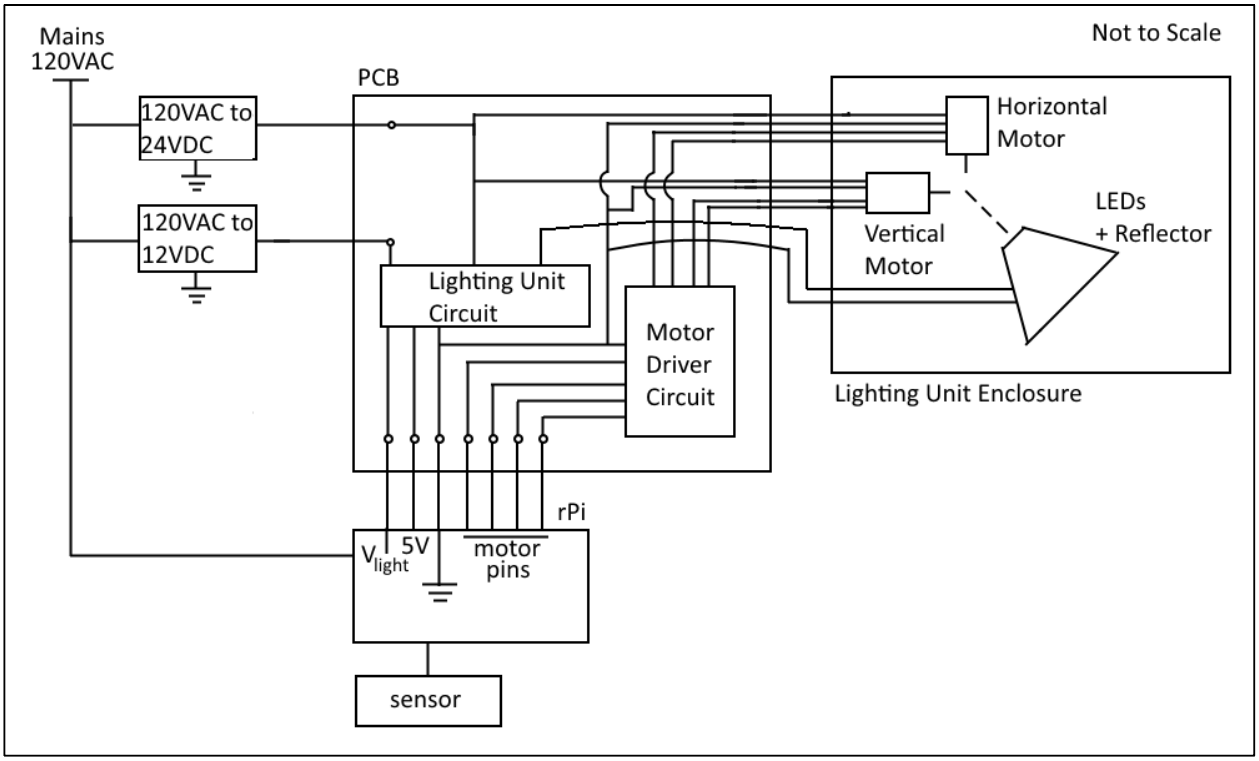

Figure 1: Overall System Design of the DISCo LASER

The processor unit is composed of a Raspberry Pi, and as such, this figure does not show the processors within it, though they are a significant component of the overall design. The Raspberry Pi uses these processors to determine coordinates of target faces from sensor unit data. From these coordinates it determines the angles and related signals to send to motor driver circuit in the motor unit. The output from the Raspberry Pi to the driver circuit is a digital signal with a high of 3.3V. The design schematics of the motor driver circuit were provided by the manufacturer of the motors. Note that there are 4 motor pins originating in the Raspberry Pi, and 4 relative traces leading from the motor driver circuit. Each motor uses 2 low voltage inputs. Further, each motor is directly connected to the 24V supply line and to ground.

As mentioned above, the lighting unit circuit contains three different constant voltage inputs of 24V, 12V, and 5V. It also contains one variable voltage input from the Raspberry Pi control pins labeled as V_{light}. The purpose of V_{light} is to control when the LEDs from the lighting unit are illuminated. There are several layers of control within the circuit, hence the 3 different voltage sources, and the current used to power the LEDs is run through an independent circuit. This circuit outputs a low-resistance current up to 20V directly and is intended to power up to 60W. To prevent damage to the LEDs or to the circuit, the current will be limited by a 750mA fuse. The actual output voltage of the lighting unit circuit depends on the ambient brightness, such that the light intensity increases as ambient brightness increases.

Finally, the mechanical enclosure for the lighting unit and motor unit will be 3D printed, and will be connected to the enclosure of the PCB and Raspberry Pi. The entire assembly will be relatively low-profile, except for the moving parts, such as the reflector. All different units will be modular, and special pins will be used for easy assembly and disassembly. The enclosure will meet all the requirements set forth in the functional specifications, especially those regarding temperature and weather conditions. In order to attain the requirement of not triggering epileptic seizures, the lighting unit output will be filtered by a low-pass filter with a time constant of approximately 0.2s. This filter causes the light to effectively fade in and fade out when triggered, and prevents any issues which might cause the light to flicker rapidly.

3. Sensor Unit

The sensor unit will function as the core human-detection system in the device. To detect and locate faces within the surrounding area, a camera sensor has been selected for cost effectiveness within the proof-of-concept model. Other options previously considered included interfacing an infrared camera with a regular camera to detect individuals based on their heat signatures, utilize anthropometry to locate the head, and then use image processing techniques to perform facial detection. This interfaced infrared camera sensor unit is to be applied within the final production system only, in order to stay within budget. The design specifications given below apply to only the proof-of-concept model to be constructed.

3.1 Physical and Mechanical Design

In order to ensure safe and efficient operation, it is necessary that the position of the camera be fixed in a place that ensures for accurate detection of individuals within the sensor's specified range (approximately 50 degrees). The placement of the sensor module within the overall design is shown in Figure 2, below.

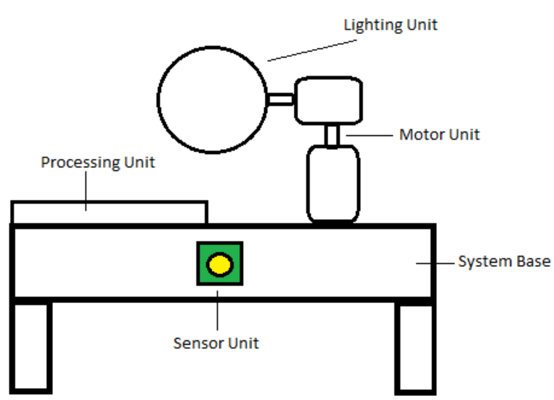

Figure 2: Frontal view of the camera sensor unit placement on the DISCo LASER.

3.1.1 Other Designs

In designing the sensor unit, multiple possibilities in the sensor placement were examined. An idea that was frequently discussed included placing the camera sensor directly onto the reflector of the lighting unit, so that they could move together. Upon further investigation, it was decided that the effort of manually scanning the camera with the lighting unit would cost us too much processing power. In having the camera fixed in one place, frames are continually taken from the same set area, and there is no need to compensate for the movement of individuals across a different image range. It is easier to see the movement of individuals across a frame when it is fixed in one place, since the range in 3D-space will always be the same.

In addition, the image capturing range would continually be changing, so individuals that may appear outside of the specified sensor range (currently 50 degrees for the proof-of-concept model) could possibly be missed.

3.2 Electrical Design

The camera module utilized in the sensor unit is compatible with the Raspberry Pi in the Processing Unit and a summary of its specifications are given in Table 1. It is a low voltage and high performance CMOS image sensor that provides multiple resolution raw images via the control of the serial camera control bus or MIPI interface [1].

Specification	**Value**
Size	Approximately 25 x 24 x 9 mm
Weight	3g
Still resolution	5 Megapixels
Video modes	1080p30, 720p60, 640x480p60/90
Horizontal field-of-view	53.50 +/- 0.13 degrees
Vertical field-of-view	41.41 +/- 0.11 degrees
Power supply	I/O: 1.7V ~ 3.0V
Temperature range (stable image)	0 to 50 degrees Celsius
Maximum image transfer rate	1080p: 30 fps

Table 1: Camera Module Physical Specifications

3.2.1 Camera Module Hardware Specifications

The module consists of a 5 megapixel fixed-focus camera that supports 1080p30, 720p60, and VGA90 video modes, as well as stills capture. It attaches to the Raspberry Pi via a 15-centimeter-long ribbon cable to the CSI port on the Raspberry Pi [1]. The dimensions of the module itself are approximately 25 x 24 x 9 mm, and it weighs approximately 3 grams [1]. The module is placed on the center of the front of the system's base in the proof-of-concept in order to provide the maximal field-of-view for the system, 53.5 degrees horizontally and 40.41 degrees vertically as specified by the module's datasheet [1]. Within the final production system, there would be an array of camera modules in order to cover approximately 180 degrees in front (approximately 3 camera modules, as shown in the Figure 3).

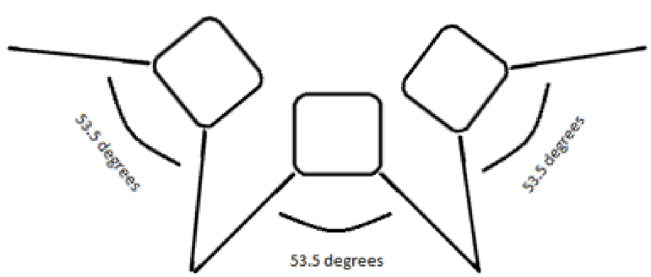

Figure 3: Camera module array design for the final production system.

The camera can be operated with a power supply of 1.7-3.0V and within a temperature range of 0 to 50 degrees Celsius, which matches that of the Raspberry Pi [1]. Since approximately 6 heads should be found each second, the system will be operating at approximately 6 fps, which falls within the maximum image transfer rate for 1080p images from the camera module (up to 30 fps) [1].

4. Lighting Unit

The lighting unit is the core incapacitation implementation in the system. Since it most directly interacts with the individuals around it, there are core requirements that must be met to guarantee efficient non-lethal operation. In order to ensure that the lighting unit is able to effectively neutralize all targets within the specified range, the beam that is fired must be parallel and collimated such that it does not weaken with distance. In addition, the beam must be wide enough to account for positioning errors, and the movement of the lighting unit itself must not alter the targeting system. Finally, in order to ensure that the device is nonlethally efficient, the emitted light must be safe for the eyes and the light must not be able to be easily filtered or dodged.

4.1 Physical and Mechanical Design

Figures 4 and 5 show a simple demonstration of the parts required for the assembly of the mechanical design of the lighting unit and how they interface with each other. They demonstrate how the parabolic reflector will be connected to the motors in such a way that they can rotate both vertically as well as horizontally, independent of each other. The mechanical specifications for the parts are given in Table 2.

Figure 4 shows how the reflector and rest of the lighting unit will be attached to the motor unit. Figure 5 demonstrates the assembled version of Figure 4. Within Figure 4, part A is the parabolic reflector, parts B and C are custom-made 3D-printed cylinders (with the left side of part B being enclosed), and parts D and E are the stepper motors whose shafts will be elongated for the purpose of the attachments. The design of the motor unit is such that there will be one stepper motor with a shaft pointing vertically up (part D). Connected to this shaft will be an enclosure for the second motor (part C), which will be centered above the first. The second stepper motor (part E) will be horizontal and will stick out of the enclosure (part C). Connected to this second stepper motor shaft will be another enclosure, which functions to cover the existing enclosure of the second horizontal stepper motor (part B). The side of B directly opposite the reflector shall be made heavier to counter-balance the weight of the lighting unit. This additional enclosure will connect directly to the reflector of the lighting unit such that the reflector remains centered above the main motor (part A). Through this design, there will only be one point of rotation for horizontal and vertical movement, and the combined actuation of the two motors of the stepper unit will be able to effectively move the lighting unit to specified coordinates within range.

Table 2: Mechanical component specifications for the lighting unit design given in Figure 4.

Part	Diameter (mm)	Length (mm)
A	111	80
B	55	40
C	45	50
D and E	35	40

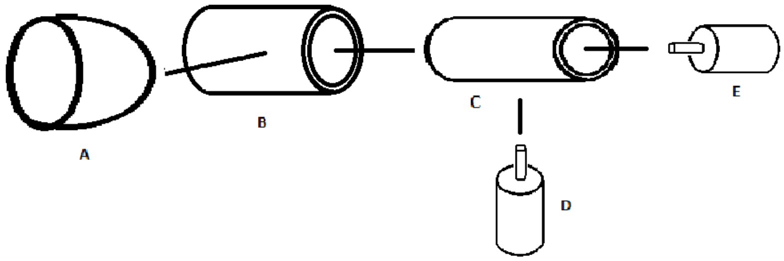

Figure 4: Mechanical Interfacing between Motor and Lighting Units

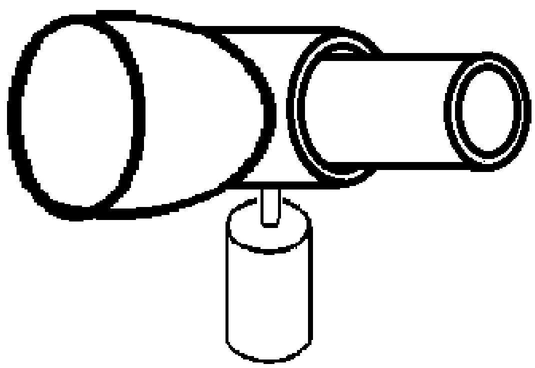

Figure 5: Assembled design of the Lighting Unit as given in Figure 4.

A CN12159_Lena-S-DL 111mm round parabolic reflector will be used as the main reflector, since the parabolic shape ensures the beam will be collimated to a spot of size close to that of the diameter of the mirror. A 111mm diameter reflector was chosen because it is sufficient for a targeting precision of 0.3 degrees over the 10-meter range of which was have specified for testing. In addition, the 111m diameter reflector allows for small accuracy errors within positioning system. The base of the reflector will be attached to a custom enclosure for the stepper motors, which will allow it to rotate horizontally and vertically about one origin. This attachment ensures that the movement of the lighting unit will not cause disturbances to the positioning of the device, as well as giving the unit a sufficient range of motion for targeting purposes.

The LED used within the reflector shall be BXRA-30G0800-B-03, which is an array of white LEDs that produces 86lumens/watt at 500mA with a maximum current of 750mA, meaning it is bright enough to not be filtered by passive filters, such as sunglasses. Despite its brightness, there will be no harm to the eyes as it is completely white light with no UV present in its emission.

The above parts were also chosen for being able to operate in the temperature range of at least -10 to +65 degrees Celsius and because they are RoHS compliant.

4.2 Electrical Design

The lighting unit will have 3 voltage sources: a V_{light} from the Raspberry Pi of either 3.3V for when the LED array should be on, or 0V for when the LED array should be off (decided via a comparator), a 12V external source for powering the relay, and a 24V source for powering the LED array so it can light up. Please note that if V_{light} was 0V, then the op-amp, acting as a comparator, would prevent the 12V from connecting to the relay, which would, in turn, keep the right half of the circuit (the section powered by the 24V source) disconnected and the LEDs would remain turned off. The box diagram outlining the functionality of this system is given in Figure 6, below.

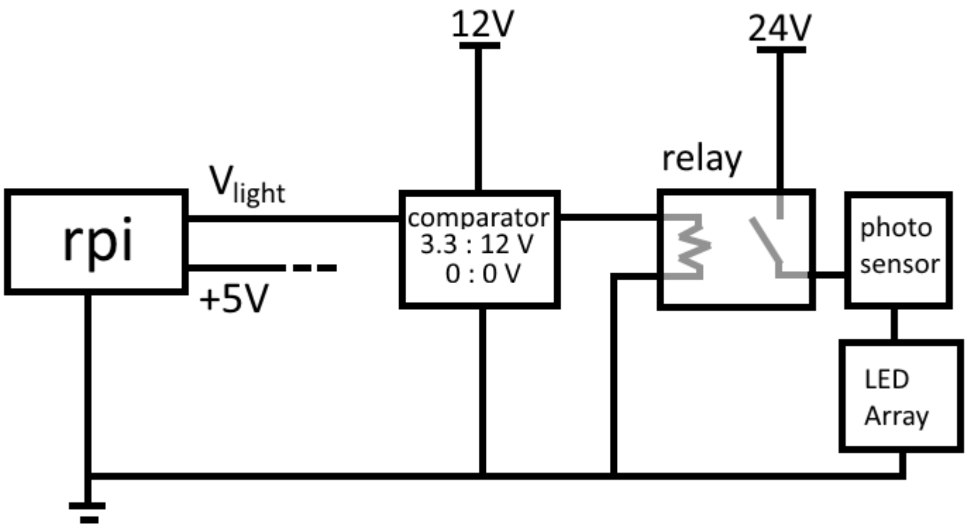

Figure 6: Box diagram for the functionality of the lighting unit.

Figure 7, below, shows the designed schematic for the lighting unit. The comparator holds a reference voltage of approximately 2V at the positive input of an op amp, such that the Raspberry Pi output of 3.3V will trigger a comparator output of 12V, and any small offset voltages are ignored. When the 3.3V signal is sent and the full circuit connects, the photo-resistor in the right circuit (the 24V-powered circuit) detects ambient light and adjusts its resistance accordingly, changing the voltage through the divider, and therefore altering the brightness of the LEDs (dimming the LEDs in dimmer surroundings, and brightening them in brighter surroundings). Through changing the brightness of the LEDs based on ambient lighting, it is ensured that the effect of the light pulse on a person's eyes are unchanged based on the surroundings. The voltage supplied to the LEDs will be between 17 volts for minimum brightness and 21 volts for maximum brightness. A 750mA fuse is included with the LED array to ensure that in the event of a malfunction, the circuit components are protected, as are the users. The capacitor on the far right of the schematic prevents the LED's brightness from changing rapidly and, thus, ensures that the target is protected from seizures as the 0.2s time constant of the capacitor is longer than the minimum flash interval for seizure prevention.

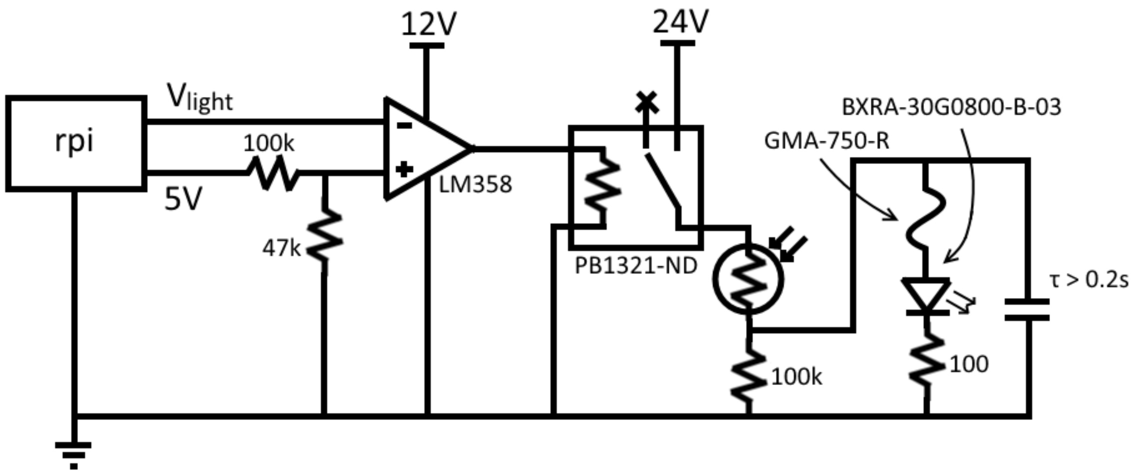

Figure 7: Lighting unit circuit schematic.

5. Motor Unit

The motor unit will receive a control signal from the processing unit and move the lighting unit to the proper angle. The motor unit needs to be both high speed and high precision in order to successfully target 6 targets per second as per requirement FR5.3.3. Since high precision is required as well as precise knowledge of the current position of the motor unit, a pair of stepper motors were selected to make up the motor unit. Servomotors were another option which was explored, but to get a servomotor with comparable precision and speed was significantly more costly.

5.1 Physical and Mechanical Design

Two PG35S-D48-HHC2 stepper motors were selected to comprise the motor unit. These stepper motors have a step angle of 0.212 degrees [2], which is within the required 0.3 degree precision required by the lighting unit. They also can be operated at a frequency of 2.2kHz [2], which, with 1698 steps per revolution, results in a rotational speed of about 78rpm. Since the field of view that the target can be located in is only 50 degrees, this rotational speed is sufficient to target more than 6 people per second. At 2.2kHz, the motors provide 0.4Nm of torque, which is greater than the 0.05Nm required to move the lighting unit.

The design of the connection between the motors and the lighting unit are detailed in the lighting unit section.

5.2 Electrical Design

The stepper motors require 24V to operate, and pull a peak current of 450mA each when operating at 2.2kHz [2]. Each of the two motors requires a control signal from the processing unit that must pass through an H-bridge motor driver circuit, such as the one shown in Figure 8 [3]. The controls are connected to the

Raspberry Pi GPIO pins, the 5V logic supply is connected to the Raspberry Pi 5V output pin, and the motor supply is connected to the 24V power supply.

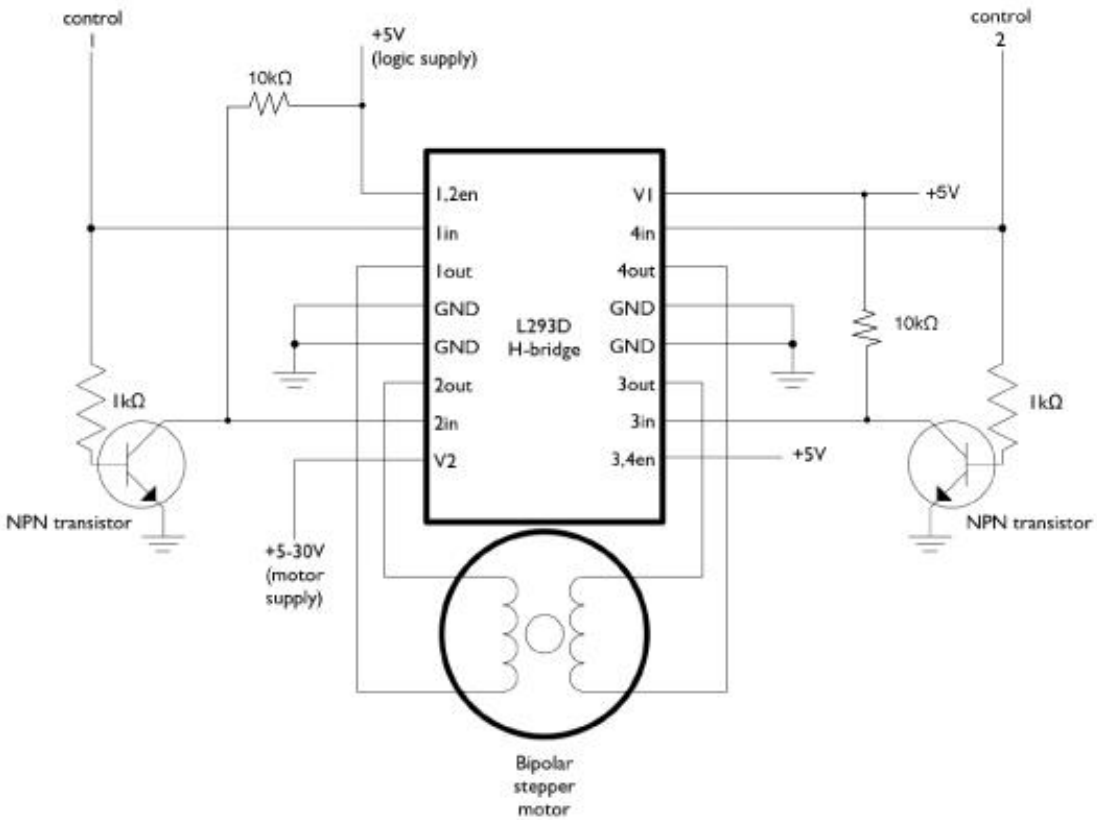

Figure 8: Motor Driver Circuit

6. Processing Unit

The Raspberry Pi is an inexpensive processing unit which will enable the desired budget to be met while still having great performance. With the processing power of the Raspberry Pi, human targets will be able to be identified within the necessary time frame and the co-ordinates will be able to be sent to the motor unit, which will aim the lighting unit quickly. The relevant specifications of the Raspberry Pi are given in Table 3 [1] [2].

Table 3: Raspberry Pi 2 specifications.

Specifications	Value
Processor	BCM2836: 900 MHz quad-core ARM Cortex-A7 CPU
RAM	1 GB
Video/Graphics	VideoCore IV 3D Graphics
GPIO	17 pins
Relevant interfaces	Camera module via CSI port

6.1 Physical and Mechanical Design

The processing unit is composed of the Raspberry Pi unit which has interfaces for connection with the other peripherals. The GPIO pins will be connected to the motor driver circuit, the stepper motors, and the lighting unit through jumper cables. Since there are 17 GPIO pins, there are more than enough output pins for the Raspberry Pi to connect to and operate all peripherals. In addition, the camera has its own interface with the unit, and the processor specifications will allow it to operate within the required timeframe without a large delay. The multi-core processor allows for parallel processing of the motor units and the image processing from the camera.

6.1.1 Enclosure

The entire unit will be housed in a 3D printed enclosure of original design composed of recyclable plastic. The enclosure will protect it from the elements and prevent parts from moving around too much and causing any wires to disconnect or be damaged by external objects. This enclosure will protect the device and the components from varied environmental conditions. It will be opaque to prevent sunlight from passing through enclosure material and degrading the electrical components inside. The enclosure will be easily disassembled for maintenance or troubleshooting. There will be extended brackets from the enclosure to allow for mounting of the device on top of vehicles or drones.

6.1.2 Motor Unit Interfacing

The motor drivers and stepper motors are attached to another PCB and the GPIO pins will be running wires to connect that circuit board to the Raspberry Pi.

6.1.3 Sensor Unit Interfacing

The camera will be directly installed into the Raspberry Pi through the camera interface.

6.2 Electrical Design

The Raspberry Pi is relatively a low powered processing unit (5V) [2] which should be able to be operated device on battery and still perform the desired functions [3]. The processor will not be under-clocked and will be performing at maximum processing speed to ensure there is no delay in targeting.

6.2.1 Signal Processing and Computation Unit

The processor’s multi-core architecture, as well as the 1GB of RAM, will come into play for the functioning of the product. The software will be implemented in a multi-threaded manner, so that multiple cores will be capturing an image from the camera and processing it for faces. The other cores will then compute the coordinate data that is received from the image processing and create angular data to send to the stepper motors so that they may move to the correct position.

6.2.2 Control Hardware

Through the GPIO pins, the processor unit will be able to provide the coordinate data to the stepper motors which will move the lighting unit. The angular data for moving the stepper motors into position will be provided by the processing unit, once it has been analyzed from the data from the sensor unit.

6.2.3 Control Software

The Raspberry Pi will run off a Linux-based operating system called Raspbian which allows easy development of the image processing, facial recognition, and targeting with the lighting unit. Since it is a Linux-based system, open-source libraries such as OpenCV can be utilized to quickly and efficiently develop the required software.

The software will be coded to allow the image taken by the camera to be processed and the coordinates of all the faces will be thrown into a queue which will then be sent to the motor unit as angular coordinates. The coordinates will be used to move the horizontal and vertical motors into the correct position. The attached lighting unit will be aimed as the motor unit moves to the given coordinates. The processing unit will then turn on the light when the motor unit is at the specified coordinates and sends a signal back to the processing unit to communicate that it is ready.

6.2.4 Main Processes of the Processor Unit

The main process of the sensor, processor, and motor units are given in Figure 9. This figure functions to explain how the software will operate within the fully functional system. When the system is initialized, the sensors will be turned on, and the motor unit will be calibrated to zero. From there, the sensor unit will activate and will obtain a frame from within its viewing range (10 meter, 50-degree horizontal field-of-view). Once the frame is obtained, the processing unit will selectively target the location of the faces within the frame in a FIFO (first in first out) queue. The first set of coordinates will then be sent to the motor unit, the motor unit will position the lighting unit, the lighting unit will fire, and once the pulse has completed, the next coordinate in the queue will be read.

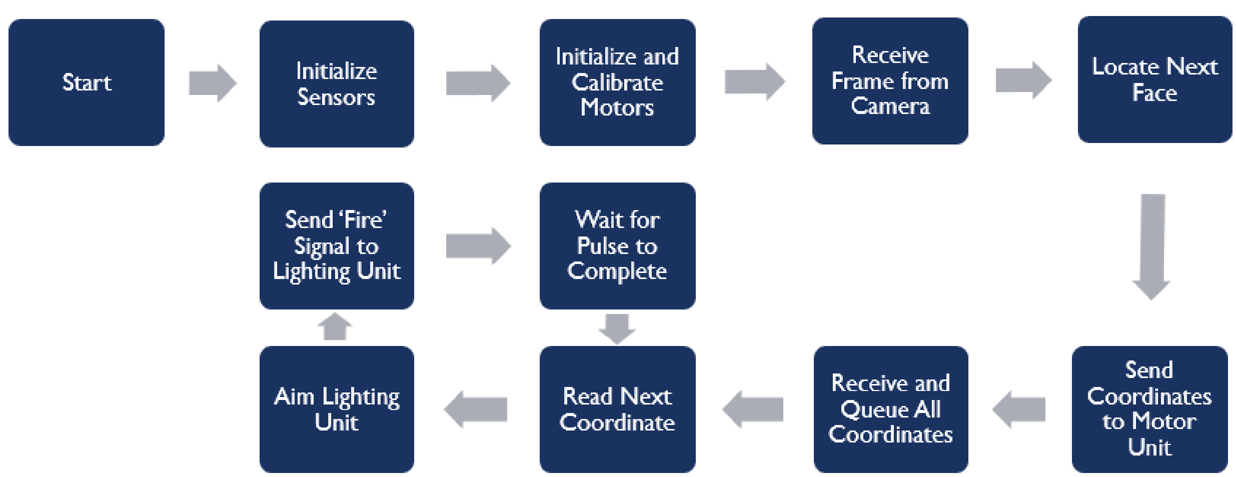

Figure 9: The main process of the sensor, processor, and motor units.

In addition to the main process, a secondary process within the lighting unit in order to adjust the intensity of the fired pulse based on the environmental lighting conditions is employed. This process is shown in Figure 10. In order to calculate the environmental lighting conditions, the lighting unit uses a sensor to calculate the ambient light each time the lighting unit is set to fire. Through this process, it can be ensured that a light that is too bright or damaging for the environmental conditions is not fired (for example, maximum brightness in dim conditions).

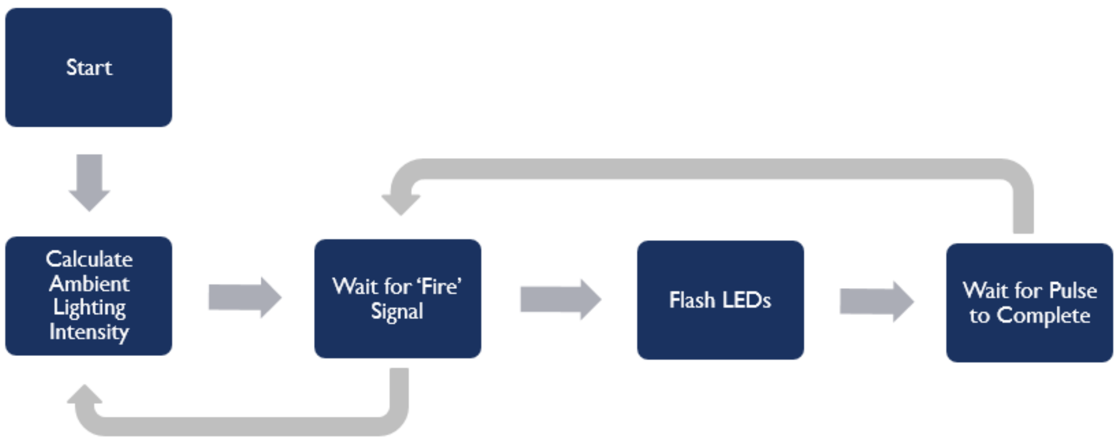

Figure 10: The secondary process employed by the lighting unit.

7. System Test Plan

In order to ensure ideal operation of the DISCo LASER system, unit validation testing followed by full system testing will be employed, including corner cases such as multiple targets in different orientations and extreme environments.

7.1 Unit Testing

7.1.1 Processor Unit Testing

In order to ensure that the processing unit in the system is functional, individual unit testing to the processor, a Raspberry Pi, will be employed as shown in Table 4. This testing will function to ensure that the processor unit is able to turn on and interface with the sensor, motor, and lighting units. In addition, this unit testing will ensure that the basic facial recognition image processing is working as expected.

Table 4: Processor Unit Testing

Test Case	Procedure	Expected Result
Processor Unit Activation	1. Boot up the Raspberry Pi	1. The Raspberry Pi boots up successfully
Sensor Unit Interfacing	1. Capture an image in jpeg format using “raspistill -o image.jpg” at the prompt	1. Image is successfully captured
Target Identification	1. Obtain an image through the sensor unit	1. The software is able to selectively identify the heads of targets from data obtained from the sensor unit 2. The software is able to selectively identify whether the individual is facing the sensor module 3. The software is able to selectively identify the eyes of the individual
Motor Unit Interfacing	1. Provide coordinates to the motor unit via the Raspberry Pi	1. The motor unit moves to the specified coordinates
Lighting Unit Interfacing	1. Fire the lighting unit via the Raspberry Pi 2. Fire the lighting unit 10 times	1. The lighting unit fires without significant delay (half a second) 2. The software shall be able to selectively fire the lighting unit at a repetition rate of at least 6 Hz

7.1.2 – Sensor Unit Testing

In order to ensure that the camera module in the sensor unit is working as expected, individual unit testing will be employed as shown in Table 5. This testing will function to ensure that the camera module is able to turn on, take images, and record video. In addition, this testing ensures that the facial features of an individual in average conditions (room temperature and average room lighting) from the maximum defined range (10 meters) can be identified.

Table 5: Sensor Unit Testing

Test Case	Procedure	Expected Result
Camera is Enabled	1. Boot up the Raspberry Pi 2. Run “sudo raspi-config”	1. Raspberry Pi successfully boots 2. Camera option is listed in configuration menu
Test Image	1. Capture an image in jpeg format using “raspistill -o image.jpg” at the prompt	1. Image is successfully captured 2. Image shows the entire 53.5-degree horizontal field-of-view
Test Video	1. Capture a 10-second video using “raspivid -o video.h264 -t 10000” at the prompt	1. 10-second video is successfully captured
Test Image Range	1. Capture an image of a target 10 meters from the sensor unit	1. Can identify individual’s facial features from the image 2. Can identify individual’s facial features at all angles within the 50-

	2. Move the position of the individual within a 50-degree viewing angle to the lighting unit	degree viewing angle, as long as they are facing the sensor

7.1.3 – Lighting Unit Testing

In order to ensure that the core incapacitation implementation in the system is functional, individual unit testing will be employed as shown in Table 6. This testing will function to ensure that the lighting unit is able to turn on, vary its output, be viewed within the specified range (10 meters with a 50-degree horizontal field-of-view), and that it cannot be blocked out by passive filters (sunglasses).

Table 6: Lighting Unit Testing

Test Case	Procedure	Expected Result
Lighting Unit Activation	1. Provide a voltage of 20V to the lighting unit 2. Provide a voltage of 17V to the lighting unit	1. LED Array turns on to maximum allowable brightness with a delay of no more than 50 milliseconds after power is supplied 2. The LED Array appears to be dimmer at 17V than 20V
Lighting Unit Output	1. Provide a voltage of 20V to the lighting unit for 30 seconds	1. The LED Array outputs a uniform intensity light for the duration (the output does not appear pulsed)
Lighting Unit Range	1. Position an individual 10 meters from the lighting unit 2. Move the position of the individual within a 50-degree viewing angle to the lighting unit 3. Move the individual incrementally 1 meter from the system to 10 meters (1 meter every 3 seconds)	1. Lighting unit output is clearly visible 10 meters from the system 2. Lighting unit output is clearly visible 10 meters from the system at all angles within the specified range 3. Lighting unit output does not significantly vary with distance
Lighting Unit Robustness	1. Have an individual stand 10 meters from the lighting unit with average-grade sunglasses on	1. Lighting unit output should not be significantly filtered out by passive filters
Ambient Light Detection	1. While light is activated, suddenly black out the ambient light sensor	1. Light should quickly dim to a lower brightness without turning off

7.1.4 – Motor Unit Testing

In order to ensure that the motor unit in the system is functional, individual unit testing will be employed as shown in Table 7. This testing will function to ensure that the motor unit is able to turn on and move per the coordinates provided by the Raspberry Pi. In addition, this testing will ensure that the motor unit is successfully moving using a combination of both of its stepper motors at the same time, and that it is able to successfully provide the correct torque in order to move the lighting unit.

Table 7: Motor Unit Testing

Test Case	Procedure	Expected Result
Motor Unit Activation	1. Provide coordinates to the motor unit through the Raspberry Pi	1. The motor unit begins moving to the specified coordinates nearly immediately 2. The motor unit reaches its specified destination with 1/6th of a second 3. The motor unit is able to move both horizontally and vertically at the same time 4. The motor unit provides sufficient torque to accelerate and stop the motion of the lighting unit

7.2 – Full System Testing

In order to ensure that the overall system is functional in all specified conditions, an overall system test will be employed as shown in Table 8. This testing will ensure that the entire system is able to power on, that one or more targets are able to be identified in all specified conditions, that the lighting unit is able to vary intensity based on the environmental conditions, and that the overall mechanical design of the system is sturdy enough to be able to withstand the movements of the motor unit.

Table 8: Full System Testing

Test Case	Procedure	Expected Result
System Activation	1. Provide power to the system	1. The system boots up and is operational
Lighting Unit - Firing	1. Move an individual slowly within the system's range, staying at each position for at least 3 seconds	1. The system does not move until the previous pulse was completed, and does not fire the lighting unit until the motor unit has positioned it to the correct coordinates
Target Identification – Accuracy	2. Place an individual within 10 meters of the sensor module	2. The system targets the individual's eyes and fires the lighting unit with enough accuracy to be within 0.5 degrees of the target
Target Identification – Range	1. Place an individual within 10 meters of the sensor module 2. Move an individual within the 50-degree sensor range incrementally (3 seconds per 10-degree interval) 3. Have an individual slowly walk from 10 meters away to 1 meter away from the system	1. The system is able to identify human targets within 10 meters of the sensor module 2. The system is able to identify human targets within a 50-degree scan range 3. The system is able to identify the target and position the lighting unit within a vertical field-of-view of approximately 40-degrees

	incrementally (move 1 meter every 3 seconds)	
Target Identification – Multiple Targets	1. Place 6 individuals within 10 meters of the sensor module and within the 50-degree horizontal field-of-view 2. Place 10 individuals within 10 meters of the sensor module and within the 50-degree	1. The system is able to identify and lock-on up to 6 targets per second 2. The system is able to identify and lock-on to up to 6 targets per second. The system is able to identify and lock-onto all 10 targets within 2 seconds
Target Identification - Selectivity	1. Place an individual within the device's range, but facing away from the camera 2. Place 3 individuals facing forwards towards the sensor module and 3 facing away from the sensor module within the device's range 3. Have an individual stand within range for 10 seconds	1. The system does not lock-on and fire at the individual 2. The system only locks-on and fires at the individuals facing the sensor module 3. The system only fires at the individual once
Target Identification - Speed	1. Move an individual slowly within the system's range, staying at each position for at least 3 seconds	1. The system is able to move the motor unit to the final targeting position no more than $1/6^{th}$ of a second after the coordinates have been received from the sensor module
Target Identification – Environmental Conditions	1. Operate the system in dim lighting conditions (half the room's lights) 2. Operate the system in bright lighting conditions (turn on all of the room's lights) 3. Operate the system in an environment that is $<$ 10 degrees Celsius 4. Operate the system in an environment that is $>$ 30 degrees Celsius	1. The system is able to target individuals in dim lighting conditions 2. The system is able to target individuals in bright lighting conditions 3. The system is able to operate in a cold environment 4. The system is able to operate in a hot environment
Lighting Unit Intensity – Environmental Conditions	1. Operate the system in dim lighting conditions (half the room's lights) 2. Operate the system in bright lighting conditions (turn on all of the room's lights)	1. The system adjusts the lighting unit's output to less than 20V (less bright) 2. The system adjusts the lighting unit's output to the maximum 20V (brightest)
Lighting Unit Intensity – Multiple Targets	1. Place 6 individuals within 10 meters of the sensor module and within the 50-degree horizontal field-of-view	1. The system employs a uniform lighting unit output to all individuals it targets

Mechanical - Device Base	1. Move an individual slowly within the system's range, staying at each position for at least 3 seconds	1. The base provides sufficient friction with the external surface such that it remains stationary as the lighting unit rotates

8. Safety and Environmental Considerations

The DISCo LASER is proudly RoHS compliant. All parts sourced are verified to be compliant to this standard, meaning the device does not contain significant amounts of toxic metals or compounds, and does not pose a threat of exposing such compounds to the soil or water near landfills where the device may be discarded. Given the variety of intended environments in which this device may be used, it's important to assume it could end up discarded anywhere. During normal operation, the device may emit heat, especially near the lighting unit from power dissipation in the resistors. This heat is not expected to be noticeable more than a few centimeters away from the device, as such, heat pollution and environmental damage will not likely occur. There are no other sources of pollution generated from this technology

Given the nature of the device, there is very little safety risk. It is, after all, designed to save lives. However, there are a few areas of design which must be considered. First of all, the lighting unit is a moving part, with two relatively strong motors driving it in the horizontal and vertical directions. The parts have been designed to minimize the risk of pinching, but as an added safety feature the enclosure will be labelled with warnings. Further, if the resources permit, capacitive sensors on the lighting unit parts that disable movement if a hand or finger touches it during movement will be installed. The torque is not sufficient to cause serious injury regardless of this feature. The other area of potential safety risk comes from a risk that the high-voltage 24V source shorts and overheats the device. This risk has been remediated by using an electromechanical relay to separate the 24V source from the smaller voltage circuits in the lighting unit circuit. There is also a 750mA fuse installed before the LED array, which is rated up to that value.

The device's output is naturally a very bright light, however no UV waves are present in the LED output, so risk of eye damage at power is very small. That being said, the device is designed to nauseate and incapacitate its targets. This effect could pose a safety hazard if the targets are in a vulnerable position when they are targeted. For example, if a target is running across a road and is stunned, they may be vulnerable to stray vehicles. However, the device is not intended to be used in scenarios where there are many random dangerous events. To remedy some of the risks associated with the light intensity, there is an ambient light sensor which attenuates the maximum intensity of the LEDs. This light sensitivity ensures that in darker scenarios, the relative intensity of the light stays constant, and doesn't cause additional disorientation or danger to the targets.

9. Conclusion

The DISCo LASER features many design decisions which allow for safe efficient performance. Given the features laid out in this document, the product will effectively neutralise most unknown personnel during non-combat missions without risking permanent injury, and allowing for indiscriminate target selection. This goal is achieved with careful design of a combination of the four major component blocks: the processing unit, the motor unit, the lighting unit, and the sensor unit.

The specifications of the chosen processing unit as well as the numerous GPIOs and camera interface of the raspberry Pi give an easy way to connect with each component. The raspberry pi simply uses its software to select the appropriate unit, and a digital signal is communicated to that unit. For example, the lighting unit is activated by a sustained 3.3V output to the lighting unit circuit. The amount of memory and processing power also allow it to capture images from the camera and process it at the desired speed. It is capable of detecting faces and then processing the co-ordinates to send to the motor unit which further moves the lighting unit within a fraction of a second.

To ensure functionality at the distances from the targets as outlined in the functional specifications, the camera was chosen with a sufficient resolution and fast interfacing with the raspberry Pi. The enclosure was designed to keep the camera at a fixed location, such that it will queue coordinates for subsequent targets without having to reposition itself after each image is taken. Combined, the camera offers up to 30 frames per second at 1080p resolution which is more than enough to meet these requirements. This speed allows the stepper motors to operate as fast as possible, and control the direction of the lighting unit. They are supplied with 24V and controlled by the raspberry pi 3.3V output pins.

Finally, the lighting unit operates using a segmented approach and signal isolation. The control signal is initially amplified, which activates a relay to close the LED circuit, which further draws power from an independent power source. This use of a relay is one of the ways the design is safe and sustainable, by preventing the chance of overpowering the passive components. Another design feature was the addition of an ambient light sensor, which attenuates the output power of the LED array as ambient light dims.

The DISCo LASER is a full security system for the next generation of non-lethal weaponry. The system has many possible applications that reach further than the military. For example, this system could be utilized in any situation in which a squad of officials needs to incapacitate a group of people, such as riots, robberies, or police busts. In every situation, the safe incapacitation ensures that the number of casualties from either side of the conflict is significantly reduced. This system is a functional alternative to dangerous and imprecise non-lethal weapons such as stun grenades or rubber bullets. It also allows the squadron to move more freely, as it is fully autonomous and can be mounted on nearly any surface or vehicle. The DISCo LASER is the future of security.

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