March 10th, 2016

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

Re: ENSC 305W/ENSC 440W Design Specifications for CleanLift

Dear Dr. Rawicz,

Attached are the design specifications for CleanLift, a touchless elevator panel system. CleanLift is the inaugural product developed by our company, Porcupine Solutions, and aims to reduce disease and germ transmission between elevator users in disease-sensitive environments such as hospitals and cruise ships.

The overall design of the CleanLift system will be described, including a high-level overview and a detailed design for each subsystem. The proposed design for each stage of the development from proof-of-concept to production version will be defined in reference to the functional specifications. The design presented in this document aims to create a competitive, safe, sustainable and intuitive product so that users can benefit from touchless technology.

The Porcupine Solutions team is comprised of four engineering students: Ryan Goldan, Elizabeth Durward, Lauren Jackson, and Simon Huang. We thank you for your consideration of the CleanLift design specifications. If you have any questions, feel free to contact our Chief Communications Officer, Lauren Jackson, by email at lljackso@sfu.ca.

Sincerely

Ryan Goldan
CEO, Porcupine Solutions

Enclosed: Design Specification for CleanLift: Touchless Elevator Panel

CleanLift

Touchless Elevator Panel

Porcupine Solutions

Design Specifications

Issue Date: March 10th 2016
Revision Number 1.0
Primary Contact: Lauren Jackson - lljackso@sfu.ca

Submitted By:

Ryan Goldan
Lauren Jackson
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Abstract

As world population density increases, the task of keeping surfaces clean of harmful bacteria becomes harder to accomplish without simultaneous increases in technology. Disease transmission through contaminated common surfaces is a growing concern in high-risk environments such as hospitals, and elevators have been identified as a major culprit for harboring significant amounts of bacteria [1]. Using CleanLift touchless elevator panels, bacteria growth and transmission between elevator users can be significantly reduced and even minimized. Touchless panels will provide significant benefits for any user, but will be of greatest importance in disease-sensitive locations such as hospitals, where patients, doctors, staff, and visitors use elevators constantly.

For a touchless system, as for any for new technology, to be adopted by institutions it should satisfy three major requirements: have comparable reliability, safety, and functionality as current systems, be economically viable, and, most importantly, be intuitive to users. CleanLift is designed to meet all of these requirements, as described in this document. Current elevator panels are reliable, easy to use and have minimal safety hazards, and to ensure CleanLift is competitive in the elevator market it is designed to be comparable to standard elevator panels in these categories. CleanLift decreases the cost of maintenance and upkeep for units by decreasing sanitization costs and having a well designed construction, as fully detailed in this document.

CleanLift provides significant health benefits for users by employing a touchless panel system instead of a conventional mechanical button panel, and still needs be competitive in the current market for institutions to adopt this new and beneficial technology. The implementation that best meets the specifications needed to ensure a competitive, safe, and sustainable product shall be thoroughly discussed in this document.

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Glossary

Term	Description
BCSA	BC Safety Authority
CAD	Computer-Aided Design
CSV	Comma Separated Values
DSPDD	Division for Social Policy and Development Disability, United Nations
DTMF	Dual Tone Multi Frequency
FS	Functional Specification
ICSP	In-Circuit Serial Programming
IEC	International Electrotechnical Commission
I/O	Input/Output
IR	Infrared Light: 700 nm – 1 mm wavelength
ISO	International Standards Organization
LEDs	Light Emitting Diodes
ODM	Original Design Manufacturer: a company that designs and manufactures a product to be specified and branded by another firm for sale
RH	Relative Humidity
RoHS	Restriction of Hazardous Substances Directive
SFU	Simon Fraser University
UN	United Nations
USB	Universal Serial Bus

1 Introduction

CleanLift is a revolutionary solution to reduce disease and bacteria transmission via elevator button surfaces. We have designed a simple, yet effective, touchless button panel system to greatly reduce bacterial spread in high-risk places such as hospitals, cruise ships, and residential buildings.

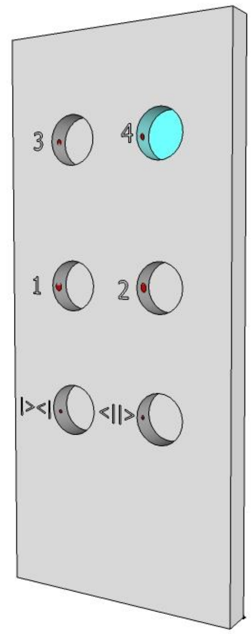

Figure 1: Outer panel of a 3x2 touchless panel

1.1 Background

Several studies have shown that elevator buttons are subject to more bacteria colonization than any other surface in hospitals and other public spaces [1] [2]. Currently, there are only two implemented approaches to address this issue: encourage personal hygiene for users (washing hands, hand sanitizer, etc.), and regularly cleaning and disinfecting elevator surfaces. These approaches are dependant on the thoroughness of hospital administration and staff, and thus may lead to inconsistent effectiveness in reducing the risk of spreading infectious disease.

Over the past two decades, touchless technology has been effectively implemented in nearly all modern buildings. Toilets, faucets, and door handles have been replaced with touchless mechanisms in hopes of reducing the presence of bacteria and improving sanitation on common surfaces. Unfortunately, this trend has yet to transfer over into the realm of elevators. CleanLift is a new technology presented by Porcupine Solutions that aims to introduce touchless technology to modern elevator systems. The system design consists of a sensing grid composed of optical beams oriented both vertically and horizontally across a user interface panel. The system senses when a user's finger has crossed the sensing grid and maps the coordinates of the user's finger to the desired floor.

1.2 Scope

This document is intended to provide the design specifications for the CleanLift system and its subsystems. The subsystems are comprised of the sensing grid, control system, and physical panel. The design for each part will be presented with technical detail and background information which motivated the choices made for the design. The design specifications will be cross-referenced with the Functional Specification (FS) document. Also to be discussed will be a procedure by which we testing should be conducted on the prototypes of the system to ensure it meets the desired functionality.

1.3 Intended Audience

The design specifications are intended for - but not limited to - the engineering staff associated with the development of CleanLift. This document may also be referenced by new engineers joining Porcupine Solutions to work on CleanLift as a starting point for learning about the system design. Upper management, sales, and marketing staff should also be familiar with this document, as it provides important information about CleanLift which will assist in the promotion of the product. Knowing all of the details pertaining to the design of CleanLift will give more points on which to market and sell the system.

2 General System

The CleanLift system has functionality designed to maximize user experience, safety, sustainability, and accessibility, while still being competitive in terms of price and availability. The general system design discussed in this section focuses on how the subsystems – the physical panel, the optical sensing grid, and the physical panel – interact with each other to meet the functionality required of the system. The specific design of each subsystem shall be discussed later in this document, in their respective sections.

2.1 Subsystem Interaction Figures

Much of the explanation of the subsystem interactions will be done through detailed drawings of a 2x3 button system. In these drawings, Figure 3 through Figure 6, system components are designated by a letter (ex. “A”), and dimensions are designated by a number (ex. “7”). Following each figure, the components labelled in it will be defined and discussed. Measurements of dimensions will be presented in Table 5, after presentation of the figures. The design and functionality included in prototype iterations will also be discussed.

An early CAD drawing of the front panel for our initial prototype design is shown in Figure 2 below for reference.

Figure 2: Preliminary drawing of initial prototype

2.1.1 Front View

To ensure user experience (FS - [GS- 2.1.1-I] through [GS-2.1.6-P]) all of the design elements of a traditional system shall be present on the front panel, as shown in Figure 3 below. The size and layout of the touchless buttons shall be comparable to existing mechanical elevator buttons. See Table 1 for component definitions.

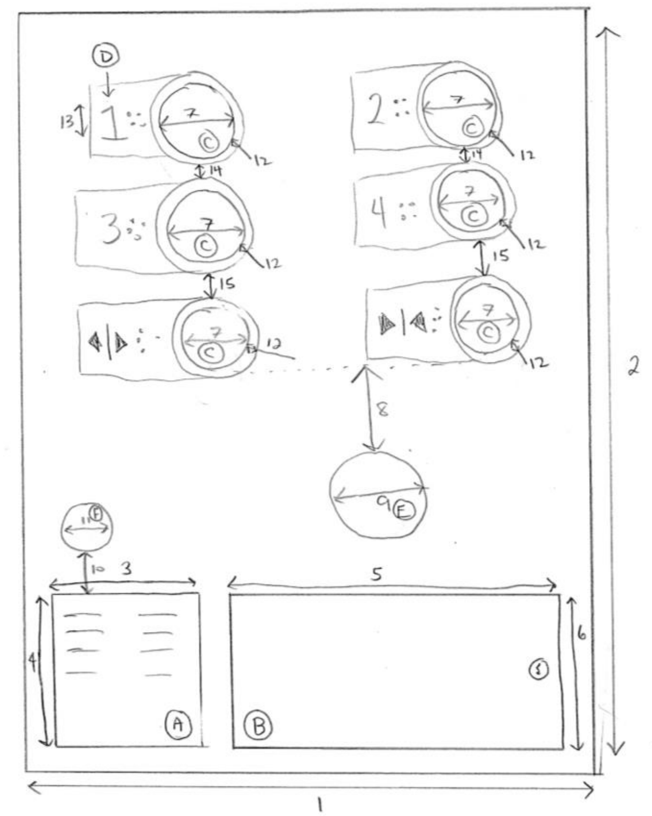

Figure 3: Front view of the CleanLift panel

Table 1: Front View Components

Letter	Component	Details
"A"	Voice control panel	Integrated with the emergency call function; microphone and speaker are placed behind panel and small slits allow sound to reach users
"B"	Locked maintenance panel	Lockable panel that swings open to access to internal components, aiding in maintenance and troubleshooting
"C"	Touchless button recess with LED indicators around recess	LED and audio feedback will be provided to the user when a button area has been activated. Implementation details will be discussed in subsequent sections
"D"	Floor numbering	Letters and numbers will be printed directly onto the panel with braille embossed on their right
"E"	Alarm button	Mechanical button
"F"	Emergency call button	Mechanical button

2.1.2 Cutaway Side View 1

CleanLift's lasers and photocells are placed behind the front panel, as seen in the side view of the CleanLift system in Figure 4 below. Positioning the sensing grid (see Section 4) behind the casing reduces ambient light reaching the optical sensors. While having the sensors behind the front panel means users must push further to trip the beam, it also provides significant safety advantages, required by Functional Specification [GS-2.5.1-I], as the optical beams are contained and cannot be tampered with. See

Table 2 for component definitions.

Note that the upper left hand portion of the panel (containing components "G" and "H") in Figure 4 below is solid, except where specified.

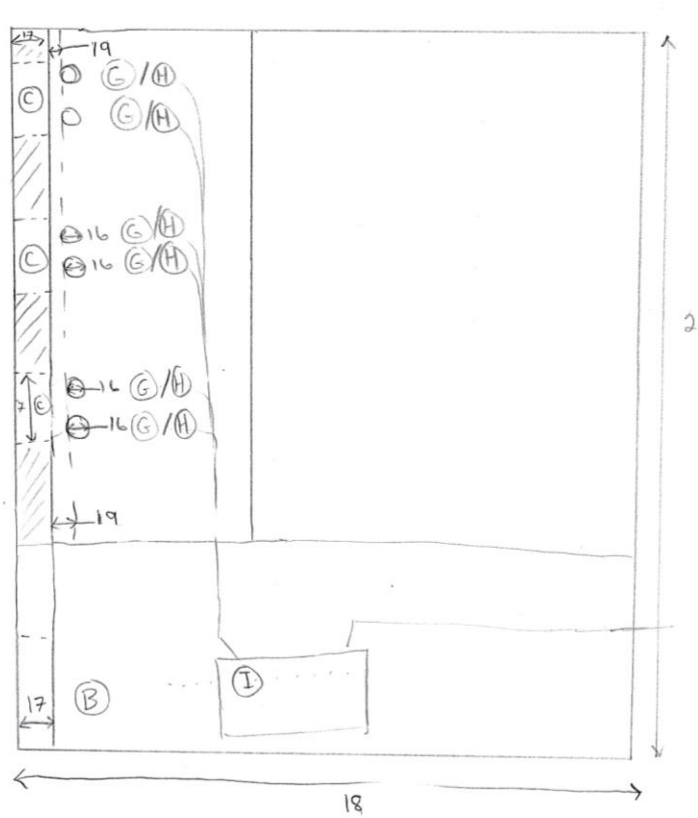

Figure 4: Cutaway side view 1 of the CleanLift panel

Table 2: Cutaway side view 1 components

Letter	Component	Details
"G"	Lasers	In this image, they point into the page. Beams follow tunnels through the panel to reach photoresistors on the other side
"H"	Photoresistors	In this image, photoresistors will be on the opposite side, in line with the laser beam
"I"	Control unit enclosure	A waterproof plastic enclosure

2.1.3 Cutaway Side View 2

The view seen in Figure 5 below has been taken at the center of a row of touchless button recesses is shown, and details the touchless button recesses and how they interact with the sensing grid. See Table 3 for component definitions. In Figure 5 the cross hatched area is solid and the area to the right of it is open space. Wires, laser connections, photoresistors, and LEDs will be run through this open area to the control unit. The area to the left of the cross hatched section is the front panel; its width is given by dimension 17.

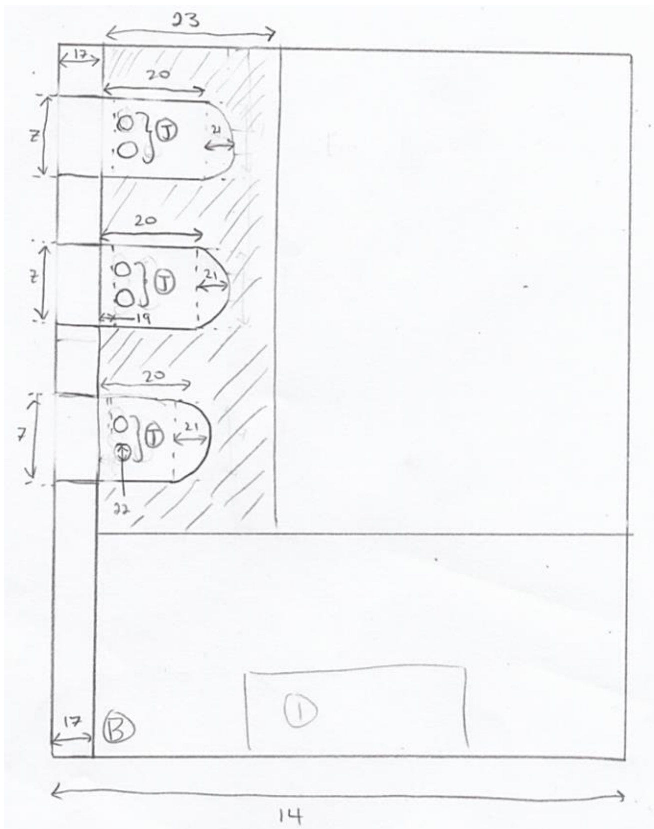

Figure 5: Cutaway side view 2 of the CleanLift panel, showing button recesses

Table 3: Cutaway side view 2 components

Letter	Component	Details
"J"	Holes for optical beams to pass through	Small holes in the touchless button recesses that pass from one side of the panel to the other

2.1.4 Rear View

The back of the panel shall have an antireflective surface to ensure that the optical beams do not reflect within the box. The lasers and photocells are attached to a modular frame, as shown at the bottom of Figure 6, to allow for precise alignment prior to attachment to the back of the front panel. See Table 4 for component definitions.

Not shown in Figure 6: vertical lasers and photocells. For more detailed diagrams of the optical sensing grid refer to Section 4. Also note that although the touchless button recesses designated by component C are shown in Figure 6 below, they are not actually visible from the back as they are recessed into a solid block.

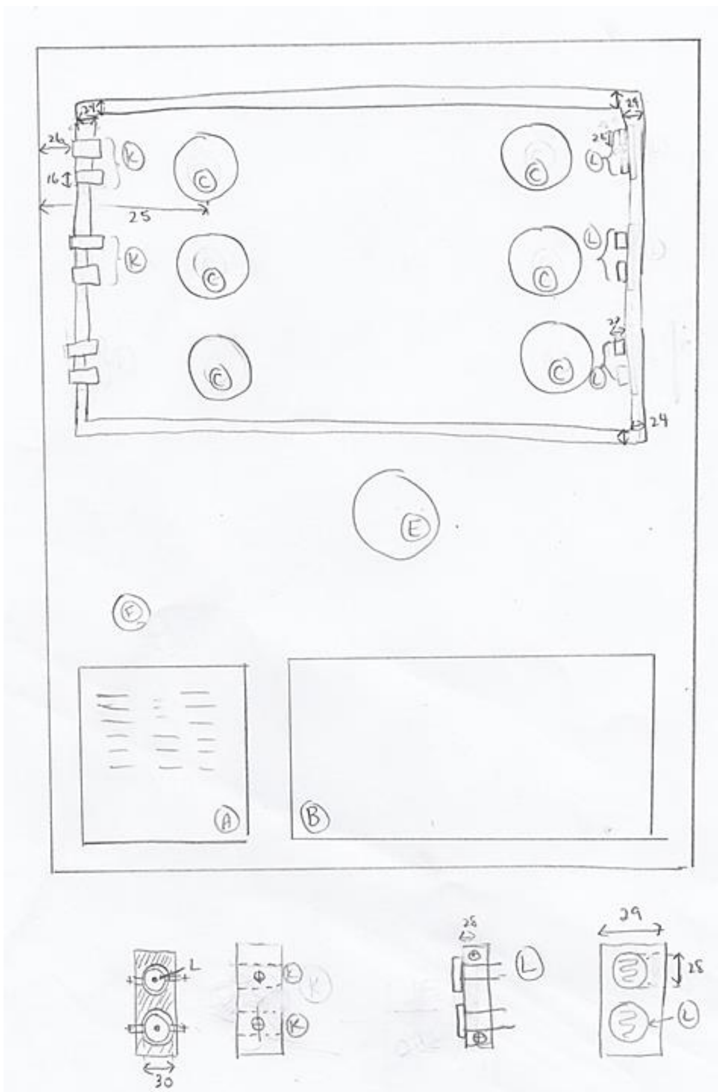

Figure 6: Rear view of the CleanLift panel

Table 4: Rear view components

Letter	Component	Details
"A"	Voice control enclosure	Rear view
"B"	Locked maintenance panel	Rear view

"C"	Touchless button locations	Rear view
"K"	Horizontal lasers	Signal for the sensing grid, as described in Section 4. Lasers shall be aligned by adjustable screws at the tops and bottoms of mounting holes
"L"	Horizontal photoresistors	Sensor for the sensing grid, as described in Section 4. Small holes will be drilled in the mounting block for the photoresistor leads; leads will be bent to anchor the photoresistor

2.1.5 Dimensions

Dimensions for Figure 3 – 6 are presented in Table 5 below along with the tolerance associated. These dimensions were determined either through empirical data obtained from the initial prototype or from existing standards, as discussed in later sections.

Table 5: Panel Dimensions

Dimension Number	Size (cm)	Tolerance (cm)
1	30	± 3
2	60	± 6
3	5	± 0.5
4	5	± 0.5
5	20	± 2
6	10	± 1
7	3.5	± 0.35
8	5	± 0.5
9	3	± 0.3
10	1.5	± 0.15
11	1.5	± 0.15
12	0.5	± 0.1
13	1.5	± 0.15
14	2.5	± 0.25
15	3	± 0.3
16	0.7	± 0.1
17	0.8	± 0.1
18	15	± 1.5
19	0.3	± 0.1
20	2	± 0.2
21	1	± 0.1
22	0.5	± 0.1
23	4	± 0.4
24	1	± 0.1
25	2	± 0.2
26	3	± 0.3
27	0.2	± 0.2
28	1	± 0.1
29	2.5	± 0.25
30	0.8	± 0.1

2.2 Prototypes

Several Prototype iterations will be used to improve the CleanLift design cycle, as described below.

2.2.1 Initial Prototype

The initial prototype is made of repurposed wood and only has a front panel; there is no enclosure. Repurposed wood reduced the environmental impact as well as the prototype cost. Having holes behind the touchless buttons instead of recesses into a solid block, as shown in Figure 5 above, simplified the construction of the initial prototype and allowed for a shorter build time, thereby increasing available test time.

Another difference between this prototype and our final design is that the LEDs do not light up the touchless button but are instead shown to the left of each button. Voice recognition/emergency calls, audio feedback, alarm buttons, maintenance panel, and system diagnostics are not included in this prototype. A simple initial prototype allows for a demonstrable version to be ready quickly for initial user testing.

2.2.2 Final Prototype

For a more accurate implementation, 3D printing shall be used for the front panel and button recesses. This allows for rapid prototyping that is also able to accurately represent the final design dimensions and layout.

The final prototype will also include voice recognition, audio feedback, alarm buttons, a maintenance panel and system diagnostics. Emergency call functionality will not be included.

2.2.3 Production Model

The production model of the system will include voice recognition/emergency calls, audio feedback, alarm buttons, maintenance panel, and system diagnostics. It will be made primarily of aluminium, as discussed further in Section 3. The production version will be customizable in various sizes so that current elevators can easily transition to CleanLift touchless elevator panels.

3 Physical Panel

The design of the physical panel of CleanLift relies on two major constraints: the design must facilitate an intuitive user experience, while also being safe, reliable, and sustainable. Designing with these considerations in mind means that CleanLift has an intuitive user experience and is safe for the environment and users.

3.1 Design Considerations and Approach

To ensure intuitive use by first time users of CleanLift, the physical appearance of the panel will be based off existing elevator standards and conventions as outlined in the Functional Specifications documentation. Upholding familiarity for users will ensure the system is used correctly and quickly by nearly all users, regardless of their familiarity with the product.

The panel is designed to integrate with existing elevators and end meet current elevator panel standards, to allow retrofitting existing elevators with new CleanLift systems. CleanLift elevator panels, just like regular panels, will include emergency stop and call/alarm buttons. These buttons will remain as mechanical buttons as they are infrequently used and are an established safety feature with excellent reliability. Dimensions, such as button size, are influenced by the standards and accessibility requirements (outlined in the Functional Specifications documentation) and will be discussed in the Accessibility Section below. See Table 5: Panel Dimensions in Section 2 for detailed dimensions.

The initial prototype, shown in Figure 7 below, is constructed with repurposed plywood for an environmentally friendly and flexible design. Both laser-sensor alignment and wire placement were issues encountered when constructing and debugging the initial prototype. 3D printing our final prototype ensures high precision, accurate representation, and durable demo prototype.

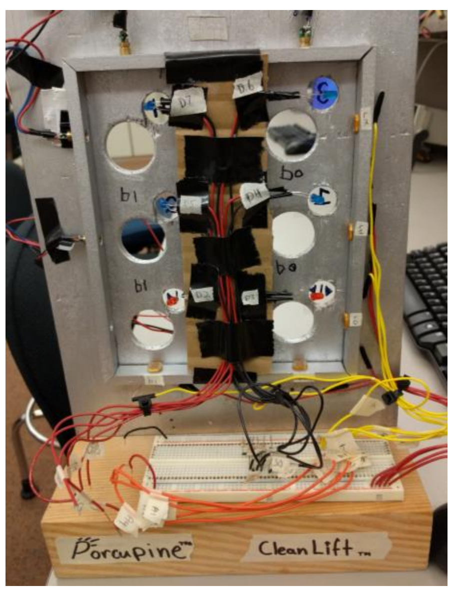

Figure 7: Initial wooden prototype

For our final production model, the panel material choice must take into account several considerations, including safety, durability, cost, hygiene, and aesthetics. As such, aluminum alloy will be used. It is non-magnetic, which prevents objects from being attracted to the panel or interfering with personal devices, as per FS - [PP-3.4.7-P]. It has a tensile strength greater than 430 MPa, which ensures that the panel will be tamper resistant, as per FS - [PP-3.5.3 -P]. It is easily constructed and inexpensive, as per FS - [GS-2.3.3-I]. Lastly, it is versatile enough for varied aesthetic modifications and allows for easy application of various coatings that are readily available.

3.1.1 Accessibility

CleanLift meets elevator panel accessibility regulations set by the United Nations [3] and adds extra features to ensure it is product that is accessible by all users. The panel is arranged to allow for the center buttons to be located 0.9 m – 1.4 m from the floor for height accessibility, as per FS - [PP-3.6.3-III]. Touchless button recess diameters will be 3.5 cm with a depth of 2 cm, to be large enough for most users but not large enough to allow damage to be done to the panel by foreign object, FS - [PP-3.4.5-III]. Having a recess rather than an open hole protects wires and sensors behind the panels and prevents unwanted items from being pushed into the internals of the panel. The measurements for the depth of the recesses and the hole diameters were determined through empirical analysis on the initial prototype. Also, CleanLift includes a voice recognition system to improve user experience for visually or physically impaired users who may not be able to use the button panel easily.

3.2 Feedback

In order to comply with current elevator standard practices, while providing exceptional user experience, the panel will feature visual and audio feedback on touchless button activation. The visual feedback will be the primary feedback method and is implemented using colored LEDs. Subtle audio feedback will be given as further confirmation of touchless button activation. These features are integral to ensuring CleanLift is intuitive and simple to use.

3.2.1 Visual

The final prototype and production models have LEDs embedded behind translucent number labels to indicate floor selection. There is also an LED strip in a circle surrounding the edge of the hole, as shown in Figure 8. This implementation ensures the light on the surface is visible to users and does not interfere with the optical grid.

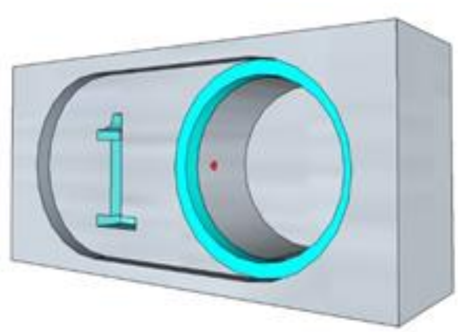

Figure 8: Touchless button with visual feedback

The simple LED driving circuit shown below in Figure 9 provides the proper amount of current flow to the LEDs, controlling their brightness. The LED circuit input voltage will be determined and powered by the microcontroller board. The current limiting resistor value of R = 220Ω was selected to ensure that LED's are above 100 lux, ensuring visibility under normal ambient light conditions (50-500 lux) as per FS - [SG-4.1.2-I].

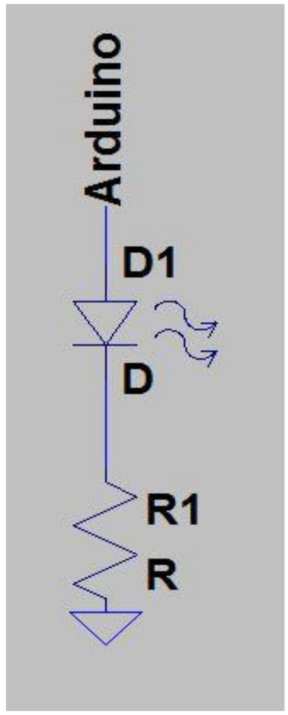

Figure 9: LED resistor circuit

3.2.2 Audio

Audio feedback is employed by CleanLift to give users a secondary indication of button selection, traditionally implemented through the implicit tactile feedback of mechanical buttons. This audio feedback is implemented by a simple buzzer, producing an tone of 659.26 Hz (known musically as E_5) at 60 dB. It also allows for easier use of the system by users who are visually impaired.

4 Sensing Grid

The sensing grid is what makes CleanLift a touchless system, and is at the heart of the functionality of the product as a whole. It has two main functions:

- Set up a matrix of virtual buttons
- Detect when a user has selected a button

In order to achieve these functionalities, the sensing grid is composed of two main components:

- Optical beams
- Optical sensors

The grid is composed of an array of optical beams positioned vertically and horizontally, which project light onto optical sensors on the opposing side of the grid, as seen in Figure 4. A button is defined as the intersection of a vertical and horizontal beam. When a user crosses the plane of both a vertical and horizontal beam, they select the button defined by the intersection of those beams as shown in Figure 10 below.

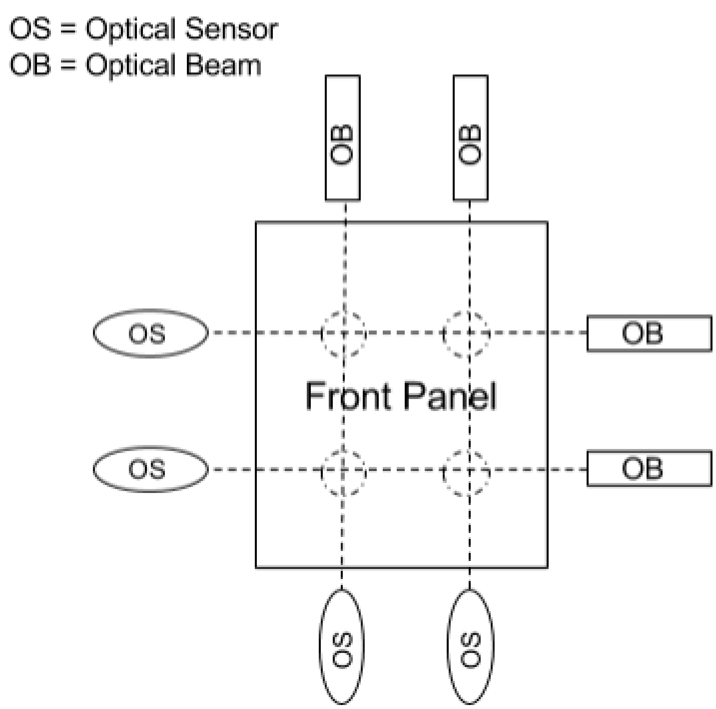

Figure 10: Sensing grid layout for a 2x2 touchless panel

4.1 Electronics

The optical beams selected for the prototype are visible light lasers (3mW red lasers), as they provide several advantages over other wavelengths of light such as infrared. Visible light lasers provide good range (greater than 1 m) (required by FS - [SG-4.1.5-P]), and thus scaling the size of our system for larger button panels will not be restricted by the range of the lasers. Using visible light lasers allows for the use of their visible nature as a feedback method when aligning the lasers. Users will also observe feedback from the reflection of the laser on their fingers when operating the system, which will give them additional feedback that they are using the system correctly. Additionally, visible light lasers are inexpensive, which will be important when scaling the system to accommodate a large number of buttons.

Photoresistors are the optical sensors being used for this iteration of the design, which employs visible light lasers as mentioned above. Photoresistors detect changes in light by varying their resistance at different light intensities [4]. By applying a visible light beam to a photoresistor, and observing the difference in voltage when the beam is not applied, we can detect when a user has crossed the plane of a beam path and thus triggered a button, as required by FS - [SG-4.1.1-I]. This change is with respect to the ambient light levels, and thus can be adjusted dynamically in software depending on the ambient light the sensors are exposed to (FS - [4.1.2-I]). As discussed earlier in Section 2.1.2, reducing ambient light increases accuracy in the processing of sensor measurements, thus proper enclosure design is of great importance.

Figure 11 shows a high level schematic of the sensing grid, and Figure 12 gives more detail on the power circuit used to power the lasers. Generic 3mW red lasers are used in the prototype design. The lasers selected require 3-5 V and 10 -14 mA, dependant on the desired beam intensity; using a common 9 V battery and the circuit shown in Figure 12 we supply the correct voltage and current to the lasers. The lasers have their own control circuit which is designed to keep the power constant for all input voltages between 3-5 V. By limiting the current we can dim the laser to the desired brightness, so a Howland current pump [5] will be used to supply a constant current of 10 mA to achieve the desired brightness.

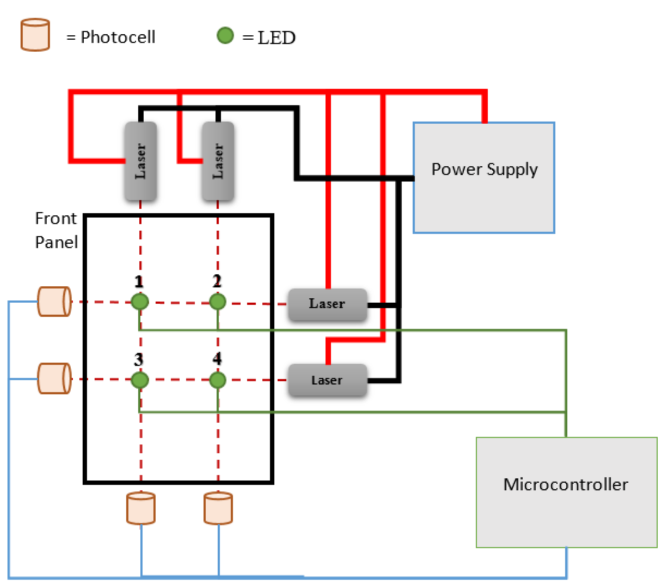

Figure 11: Schematic of system organization for a 4 button system

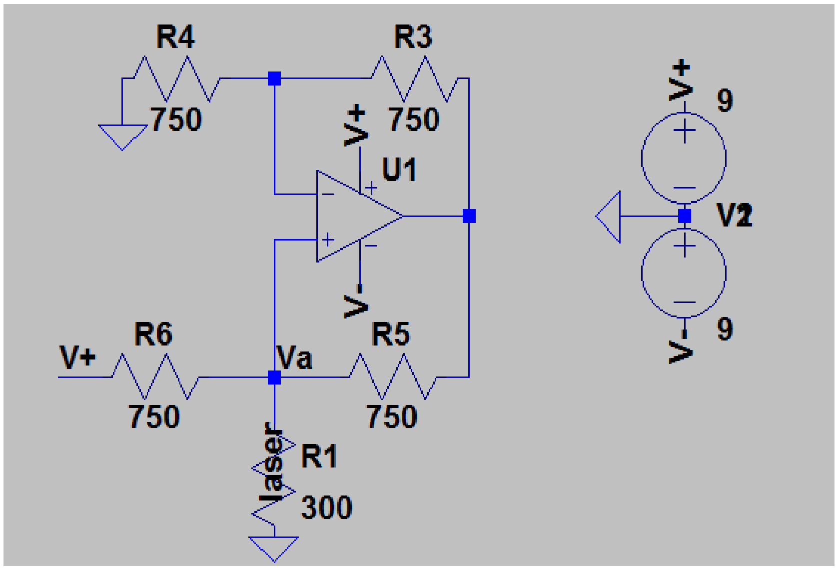

Figure 12: Laser powering circuit with a 9 V battery

Photoresistors are attached to 5 V supplies and the change in resistance is measured with the aid of a voltage divider, with the output of the voltage divider going to an analog pin of the control system microcontroller board, so signal processing can be done. The figure below shows this circuit with the photoresistor represented.

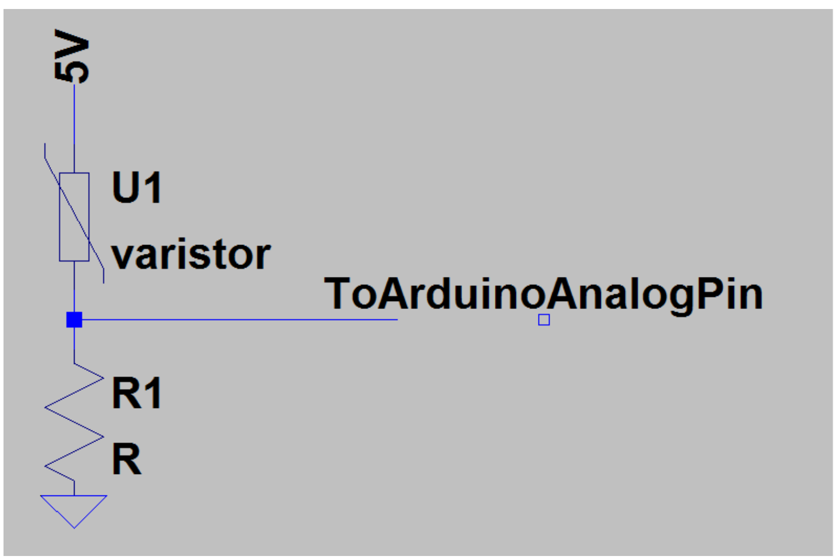

Figure 13: Voltage divider for photoresistors

Choosing a value close to the photoresistor means that the voltage measured by the Arduino will show more variance, this will help for signal processing. R = 3 kΩ will be used in the initial prototype. This value can be modified for the final prototype and production version to improve optical grid performance, as well as ambient light conditions. Initial testing shows the photoresistors to display a resistance of 4 kΩ at ambient light levels in a well-lit lab environment, and 2 kΩ when a laser is projected in addition to the ambient light.

4.2 Redundancy

Initial testing shows that the sensing grid with a single beam intersection for each button is sometimes difficult for users to trip considering the size of the hole compared to the area the user must place their finger. Thus, it makes sense to add more beam intersections at every button, and to implement logic such that any of the intersections being tripped will cause the button to be activated. For example, by placing two parallel laser-sensor pairs at each location previously occupied by a single pair (Figure 14), we can increase the number of beam intersections from 1 to 4. Using multiple components for each button also adds redundancy, as per FS - [SG-4.5.3-III], in the case of parts failing. If a laser or photoresistor stops working, there are still at least 2 beam crossings working at that button, and in the unfortunate case that two parts fail (combination of lasers and/or sensors), there is still one beam crossing functioning.

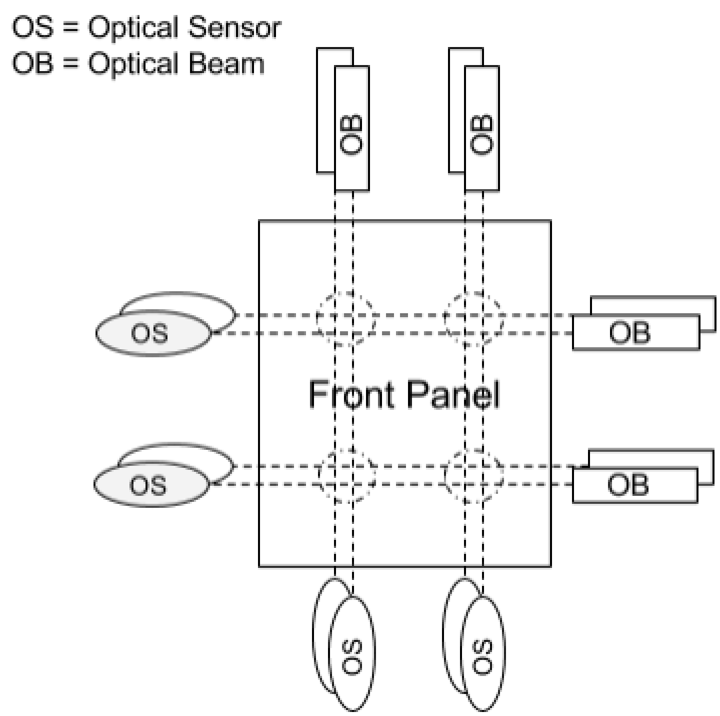

Figure 14: Multi-beam grid layout for a 2x2 touchless panel

5 Control System

The control system of CleanLift will provide functionality for three different categories:

- Ideal Usage
- Non-Ideal Usage
- Diagnostics

Ideal usage is defined as touchless, with the user triggering one button at a time, under normal elevator operating conditions (non-emergency situations with full power and user capabilities). Non-ideal usage is anything that falls outside of this definition of ideal usage, including situations where users accidentally trigger multiple buttons, trigger the same button multiple times in quick succession, place foreign objects into the sensing holes, attempt to tamper with the system, or keep buttons triggered for extended periods of time. During ideal usage, the control system will enable and disable feedback measures, such as visual and audio feedback, and will send floor selection information to the elevator's controller. The most basic form of what the control system's software will do is shown below in Figure 15. During incorrect usage, the control system shall deal with malfunctioning components, user error, and emergency situations. In the final prototype and production models, it will also provide diagnostic reports for maintenance, debugging, and monitoring purposes.

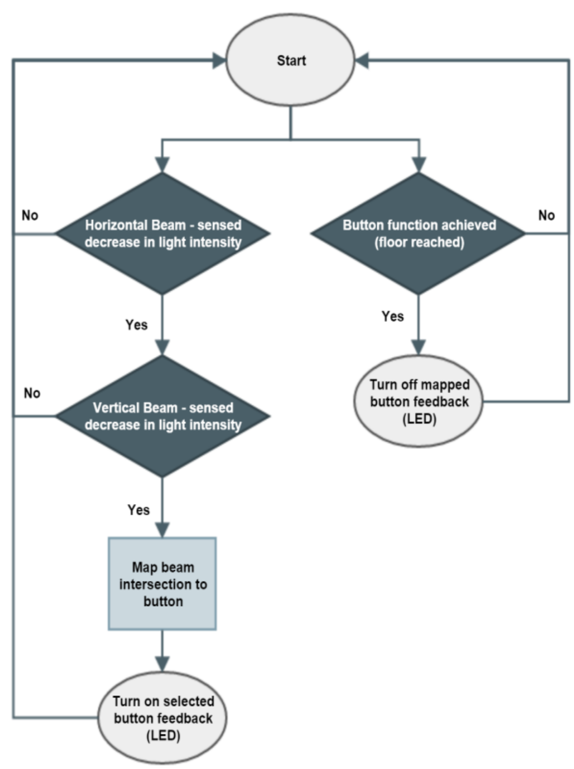

Figure 15: Control flowchart for button selection in basic use case

CleanLift's control system will be modular to allow for easy addition of new features and redundancy, as well as simple maintenance and repair.

5.1 Implementation

CleanLift's control system is implemented via an Arduino Uno for the prototyping phases, to allow for an easily modifiable system and a modular design. The Arduino Uno is an inexpensive, yet expansive microcontroller board based on the ATmega328P. With 14 digital input/output pins, 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button, it has everything that is needed for a 2x3 button prototype. A production model, however, will require more input and output pins for panels that interface with a greater number of floors. A similar, custom, microcontroller board will be designed for these production models, which will be able to incorporate a larger number of input and output pins, as well as removing any unneeded functionality.

The motivation for the final production boards is to provide the needed functionality while also being power conscious, to avoid unnecessary drain on an existing elevator's power system. As per Functional Specifications [CS-5.2.1-III] and [CS-5.2.2-III], the control system shall be configurable to communicate with most existing elevator systems, outputting a compatible serial signal.

5.2 Ideal and Non-Ideal Usage

Ideal usage shall be governed by the flowchart above, Figure 15.

Non-ideal usages detected and handled by the control system are characterized by the actions in Table 6, as per FS - [CS-5.3.1-I].

Table 6: Non-ideal use cases and appropriate control system response

Use Case Description	Control System Response
Elevator is empty for more than ten (10) minutes	The control system shall turn off power to laser grid (FS - [CS-5.1.8-P]) to conserve power
User slips and accidentally triggers a sensor	The control system shall ignore all signal changes that propagate for less than 200 ms (FS - [CS-5.3.2-I])
User quickly and consecutively triggers a single touchless button more than three (3) times	The control system will recognize the user distress and give short auditory instructions
User triggers more than three (3) touchless buttons at once	The control system will recognize the user distress and give short auditory instructions
User provides incorrect command to the voice control module	The voice control module repeats the instructions to the user
A laser is blocked (activating a button) for a period of more than 15 seconds	The button's LED will flash 3 times and an audio message will be played.
A laser is blocked for a period of more than 5 minutes	The laser will be flagged as needing repair or replacement

5.3 Feedback

A main focus of the control system is to provide feedback to the user. As per FS - [CS-5.1.1-I], feedback response time should be less than 500 ms, which constrains the design of the code to be quick and accurate.

Upon selection of button by a user, the control system shall trigger the correct pins and/or functionality required as per FS - [CS-5.1.3-I], [CS-5.1.4-I], and [CS-5.1.6-III], which pertain to visual, audio, and voice recognition feedback, respectively. As discussed in Section 3.2, visual feedback is triggered via output pins on the system's microcontroller. Audio feedback and voice recognition are implemented via a voice recognition module, described later in this section. Specifications of these feedback methods are listed in Table 7 below, a consisting of the components with which the control system interacts.

Table 7: Control System Component Interactions for a 2x3 model with optical grid redundancy of 2

Component	Multiplicity	I/O	Min V	Max V	Expected V
Photoresistors	10	Input	0V	5V	2V unobstructed 3V laser blocked
Laser Power Circuit	1	Output	0V	5V	0V lasers off 5V lasers on
Voice Recognition Module	1	I/O	0V	5V	0V idle 5V in use
LEDs	6	Output	0V	5V	0V off 5V on

Through the functionality of the voice recognition module, as per Functional Specification [CS-5.1.7-P], helpful audio feedback shall be given to the user if CleanLift is used incorrectly. This feedback will include short but concise messages such as, "Insert your finger into the touchless button to the right of your desired floor," intended to give the user unobtrusive information on how to use CleanLift in cases of non-ideal usage, as described above.

5.4 Voice Recognition Module

To implement the voice recognition aspects of the control system, and to control all audio feedback, CleanLift uses the EasyVR Shield 3.0 - Voice Recognition Shield. It is a simple shield to add on to an Arduino system (but also capable of interacting with non-Arduino systems) that includes built-in voice recognition processing functionality, as well as a DTMF tone generator and an 8 Ω speaker output.

This shield provides CleanLift with a robust and simple to use voice recognition module, and controls audio feedback (such as "beeps" when a floor is selected).

5.5 Diagnostics and Reliability

As per FS - [CS-5.5.3-III], [CS-5.5.4-III], and [CS-5.5.5-P], daily diagnostics files are created and kept in the system for at least 1 week and up to 4 weeks, depending on the available memory of the microcontroller board system. These files are saved as a CSV file, with the following headers: Time, Button, and Error. These headers outline the time, buttons presses, and/or any errors encountered during use. Figure 16 below shows a sample of what the file will look like.

	A	B	C	D
1	Time	Button	Error	
2	06/03/2016 11:34:16	1		
3	06/03/2016 11:34:30	4		
4	06/03/2016 11:42:12	3		
5	06/03/2016 11:42:09	5		
6	06/03/2016 11:52:09		Empty elevator	
7	06/03/2016 13:34:21	2		
8	06/03/2016 13:38:46	Open		
9	06/03/2016 13:42:02	1		
10	06/03/2016 13:45:06	3		
11	06/03/2016 13:45:30		Long press on 3	

Figure 16: Sample diagnostics file

6 Sustainability & Safety

Environmental concerns and safety are paramount to Porcupine Solutions and the creation of CleanLift. We believe in creating a cleaner and more sustainable world, and CleanLift's clean-oriented design would not be complete without applying a Cradle to Cradle philosophy, as well as having safety as a top priority.

6.1 Sustainability

We aim to accomplish our sustainability goals by following two main policies:

- Minimize waste
- Use sustainable materials

We followed these policies by using repurposed and biodegradable material for our initial prototype, creating it out of plywood and spare materials. We are also reusing as much of these materials as we can for our final prototype. This includes reusing lasers, sensors, microcontrollers, and wiring whenever possible, ensuring compliance with FS - [GS-5.4-I]. All electrical components of the prototypes are RoHS compliant (FS - [GS-5.3-I]), meaning they are free of the following hazardous and unethical materials: lead (Pb), mercury (Hg), cadmium (Cd), hexavalent chromium (CrVI), polybrominated biphenyls (PBB), polybrominated diphenyl ethers (PBDE), and four different phthalates (DEHP, BBP, BBP, DIBP) [6]. Not only are these hazardous materials dangerous for human health, they are often unsustainable and not recyclable. The modular design of CleanLift, as per FS - [GS-5.5-II], ensures that individual components can be easily repaired. Finally, as material recycling techniques and biodegradable plastics become more advanced, applications of ethical materials become more varied. As such, we will use recyclable, reusable, or biodegradable materials in our production models wherever possible, to minimize CleanLift's total environmental impact at both creation and end of life of the product.

6.2 Safety

One of CleanLift's major applications is in hospitals, where safety of the patients, visitors, and staff must be maximized. Also, a health conscious product that is not safe to use, manufacture, or maintain is not a truly clean product and does not fit into the model of Porcupine Solutions.

To ensure that the system does not present a safety hazard during installation or use (FS - [GS-0.2-I]), a few constraints have been put in place. Firstly, the panel complies with existing safety expectations, including smooth surfaces and mechanical emergency and call buttons (FS - [PP-3.4.1 -P] and [SG-4.3.5-III]), and having backup power sources for all main components (FS - [CS-5.4.5-P] and [SG-4.3.6-P]). Ensuring that the panel causes no harm to users through electrical issues, tampering, or damage to the system is also a primary concern. All components and relevant subsystems are and must be grounded to the common elevator ground and isolated from electrical interference (FS - [CS-5.4.1-I], [CS-5.4.2-III], [SG-4.3.7-P], and [PP-3.4.6-III]). The control system is also contained in a waterproof and tamperproof housing to avoid inadvertent or intentional damage (FS - [CS-5.4.3-P] and [CS-5.4.4-P]). This is easily done by containing the control system in a plastic enclosure that is only accessible through the locked maintenance panel.

Finally, the main hazard with the CleanLift system is the possibility of the lasers causing harm. We have taken great precautions to reduce the likelihood of this, as discussed in earlier sections and as dictated in the Functional Specifications document ([PP-3.4.1-II], [SG-4.3.2-I], [SG-4.3.3-III], [SG-4.3.4-III], and [GS-5.1-I]). By avoiding designs where the lasers are easily exposed to the user we minimize the possibility for damage to occur. In cases where this possibility can not be completely removed, other precautions have been taken to make the beams themselves as safe as possible. Limiting power to the lasers and using beams that fall well within the safety range as dictated by Figure 17 and described in Section 4 effectively reduces the probability of safety issues concerning lasers even further.

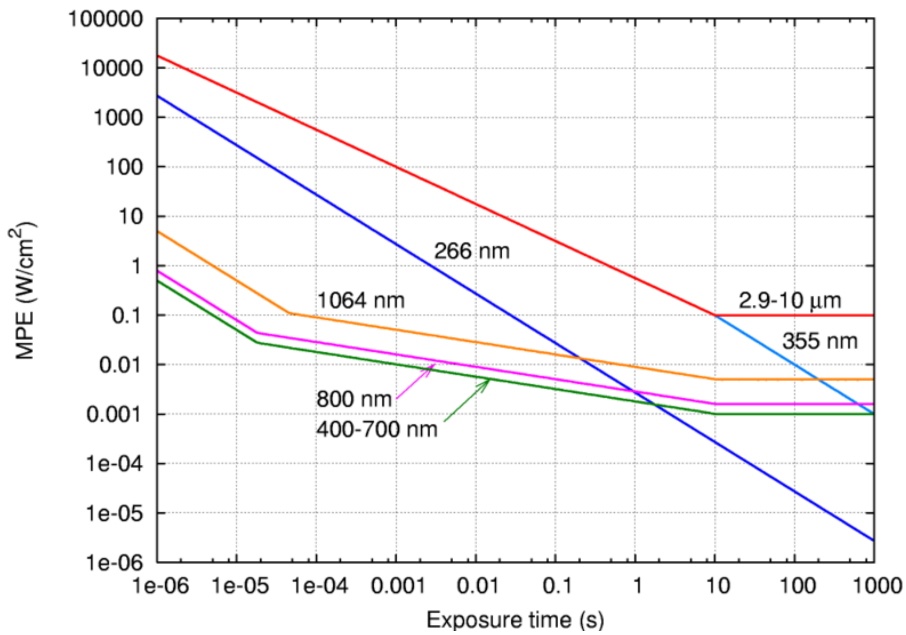

Figure 17: Maximum Permissible Exposure vs. Exposure time based on IEC 60825 MPE guidelines [7]

We are committed to creating a clean, easy to use CleanLift system that is also sustainable and safe, from design and prototyping to eventual production models.

7 Conclusion

Elevators are extensively used in the majority of public spaces, and are a breeding ground for bacteria [2]. Since harmful bacteria can be transmitted from user to user by touching the elevator buttons, having a touchless elevator panel, such as CleanLift, will greatly reduce disease transmission. Detailed in this document is the design required to ensure the CleanLift system is competitive in the elevator market, provides excellent user experience, and integrates with current elevator design, all while ensuring safety and sustainability.

CleanLift has be designed in such a way that it can be used correctly and quickly by most users new to the system and nearly all experienced users. It shall integrate with existing elevators, while also ensuring relevant standards are met. Also high on the list of priorities while designing and producing CleanLift is that it shall be safe during use or maintenance and shall be based on the sustainable Cradle to Cradle philosophy. The system shall be accessible for differently abled users, such as those who are visually impaired, or wheelchair users.

The optical sensing grid of CleanLift, as described in Section 4, has be designed to be reliable and robust, with redundancy and customized circuitry planned for the production models. The physical design of the grid has not only been designed with users in mind, as discussed in Section 3, it been designed to reduce any safety hazards to users and minimize opportunities for eye damage due to design fault or incorrect use.

The control system of CleanLift is what interprets input from the sensing grid, and it is designed to recognize use patterns that signify a frustrated user and to be able to diagnose optical sensors that are not working. It has the functionality of being able to determine when a button area is activated and shall initiate appropriate feedback as quickly as possible.

With the design described in the above document combined with the functional specifications document, the design and function of CleanLift is defined. It shall provide significant health benefits to users with a competitive, easy to integrate, reliable and safe, intuitive, and sustainable product.

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Appendix A: Test Plan

The test plan is split into 4 subsections, General system, Physical Panel, Optical Sensing Grid, and Control System.

A.1 General

Test Number	Test Name	Test Procedure	Expected results
GS - 1.1	User Experience - New User	1) A new user will be asked to trigger a floor and will be given no instructions	a) As per functional spec for demo prototype, 70% of users tested shall not touch the panel in any way
GS - 1.2	User Experience - Experienced User	1) Experienced users shall be asked to trigger a button quickly and casually	a) Users shall not inadvertently touch panel b) Users shall be able to trigger button within 3 seconds
GS - 1.3	Optical Beam Safety	1) Move an object to various locations around the front panel and observe whether the beam reflects on it 2) User shall insert a reflective object into a touchless button, and attempt to reflect beam outwards towards a target object	1.a) There shall not be a beam reflected on the object as this means that there is a possibility of beam exposure to the eyes of real users 2.a) Beam shall not be visible on target object for an extended period of time (greater than 5 seconds)

A.2 Physical Panel

Test Number	Test Name	Test Procedure	Expected results
PP - 2.1	Touchless button size and depth	1) User will attempt to activate a touchless button	a) User should not accidentally hit the sides of the recess b) User should be able to stop prior to hitting the bottom of the recess
PP - 2.2	LED feedback	1) User will activate each touchless button individually	a) The LED associated with the activated touchless button will illuminate b) LED will illuminate within 0.5 seconds of touchless button activation
PP - 2.3	Auditory Feedback	1) User will activate a touchless button	a) A small buzzer noise at 60 dB will sound
PP - 2.4	Aesthetics and Safety	1) User will look at system from all directions	a) No wires or components should be visible

A.3 Sensing Grid

Test Number	Test Name	Test Procedure	Expected results
SG - 3.1	Optical Sensor Alignment	1) Tester with access to control system will block each optical beam and check changes in optical sensor	a) Sensor values will change more than ± 20% when beam is blocked
SG - 3.2	Ambient Light	1) With system set up in a well lit room, User will attempt to activate all buttons 2) With system set up in a dim room, User will attempt to activate all buttons 3) With system set up in a dark room, User will attempt to activate all buttons 4) User will shine a bright light onto front panel and attempt to activate every touchless button	a) The panel will behave normally

A.4 Control System

Test Number	Test Name	Test Procedure	Expected results
CS - 4.1	User Errors	1) User will trigger a single touchless button three (3) times quickly 2) User will trigger more than three (3) touchless buttons at once	a) System will recognize the user distress and give short auditory instructions
CS - 4.2	Diagnostics	1) Tester with access to control system will disconnect a laser 2) Tester will run diagnostics	a) Diagnostics correctly identifies the laser that was disconnected
CS - 4.3	Voice control - Correct Usage	1) User will activate the voice control system by pressing the call button 2) User will attempt to activate a floor by saying "Floor 1" 3) Repeat step 2 for all floors	a) The correct floors are activated
CS - 4.4	Voice control - Error	1) User will activate the voice control system by pressing the call button 2) User will say nonsense	a) The voice control repeats the instructions to the user