Design Review - Interactive LED Staircase Modules

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Team #38

ECE 445

Interactive LED Staircase Modules – Mike Udelhofen

Introduction:

I have selected this project as a means to motivate pedestrians to engage in more physically active transit while reducing energy normally used in electronic devices. Additionally, the result will serve as a visually and sonically pleasing installation that can be placed in otherwise less attractive areas. I am excited to be employing Electrical Engineering skills and concepts in a way that will benefit human health, energy conservation, and the arts.

Objectives:

The project will serve to motivate pedestrians to use staircases instead of escalators and elevators in an initiative to conserve energy and promote a more active lifestyle, all the while making the place of installation more pleasant. It will consist of semi-transparent panels that can be easily installed onto a staircase. The interactive nature of the panels, with a series of LEDs and sensors that will respond with different illuminative patterns when stepped on, will attract passerby to use the stairs on which they are installed. Multiple modules can be connected together and will interact with each other to create ripple effects, create color gradients, and more. Additionally, ambient sounds are hoped to be incorporated in the response, with effects such as playing a different note for each stair step, thus creating an ascending musical scale as the user travels upward.

Benefits:

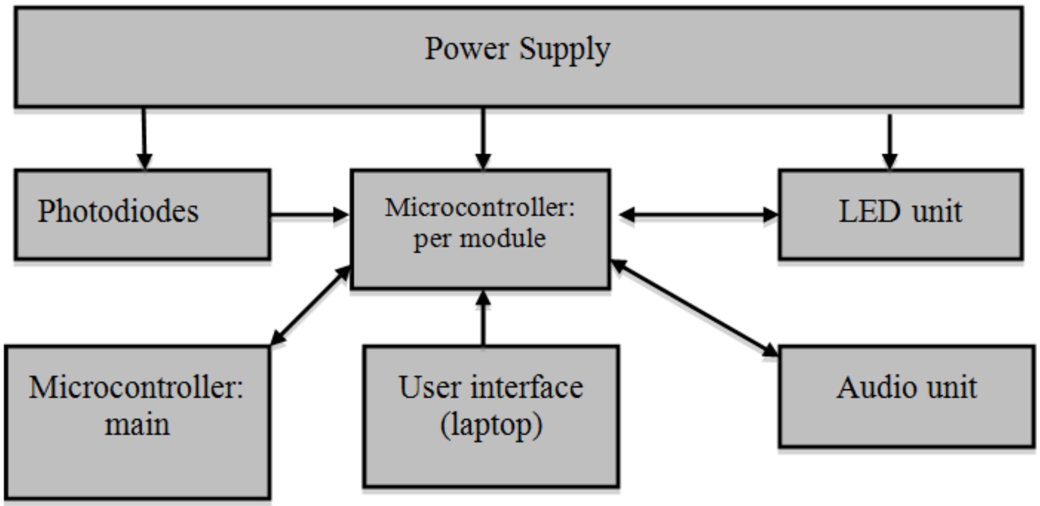
- Promotes pedestrian fitness
- Saves energy by diverting traffic from motorized lift systems
- Serves as a visually and sonically pleasing experience

Features:

- Multicolor LED array
- Pulsewidth-modulated photodetector array to relay step signal in sync with LED operation

- Modular – multiple panels can be connected together easily and will interact
- Speaker to play ambient sound responses

Design:



Block Description:

Photodetectors: These will detect changes in light over points on the staircase panel to determine where the user is stepping and, thus, which LEDs will light up. There will be one photodiode per pixel used as a detector, so 12 photodiodes per module in a 2 x 6 array. It will "watch" the underside of the plexiglass to check for changes in light as compared to a base value, which will be detected upon calibration. Its signal is sent to the Microcontroller.

It is important to note that the photodetectors will run synchronously with the pulsewidth modulation of the LEDs. In other words, they will only read data when LEDs are "off" as to avoid interference with the LEDs.

Microcontrollers: Receive all inputs from the photodetector array and other microprocessors to determine where LEDs should activate. They will also process data regarding which patterns and responses to execute within the LED arrays. Each module (or stair) will contain its own microcontroller to handle its own individual module functionality. There will be a "base" microcontroller to allow each module to communicate with the rest. For example, one module's

microcontroller will activate and control its own ripple effect response while simultaneously signaling to the base microcontroller where it has detected a step and other modules will continue the ripple effect.
Another will also control the data sent to the audio driver, again as a function of photodetector signal, to produce stored sounds.

User interface: The user interface will connect to the microprocessor via USB. It will be allowed to change and upload code to the microprocessor to change the functionality of the system or select between different display modes, but will not be required to stay connected during operation.

LED Driver: Converts signals from the microcontroller into usable signals to activate the designated LEDs within the array since the microcontroller lacks the ability to supply full current to LEDs. Each LED driver is 24-bit and includes PWM functionality, so two shall be used per module. The PWM will allow photodiodes to sample the lighting environment each cycle while LEDs are "off".

LED Array: Each module is defined by "pixels" and will be controlled as such. Each module will be 2 pixels x 6 pixels. Each pixel contains 4 RGB LEDs in a square pattern. Thus, the array is a total of 4 x 2 x 6 LEDs for a total of 48 RGB LEDs per module. For the scope of this project, 144 will be ordered to implement 3 panels. LEDs will be addressed in a row x column manner. No multiplexing is planned because the LED drivers will support enough bits for direct addressing.

Audio Driver: Receives a signal from the microprocessor and turns it into a usable audio output which is heard at the speaker. Also controls speaker volume.

Speaker: Receives audio input from the Audio Driver.

Power supply: Includes a standard 120V wall plug, transformer to 5V, linear adjustable voltage regulators, and ceramic decoupling capacitors in order to properly power each microcontroller and LED driver, which all operate on 5V. For the scope of the design project (i.e. implementing 3 modules), the hardware will require 3 power supplies at 4A each (one per module) or one large power supply at 12A with daisy chain abilities.

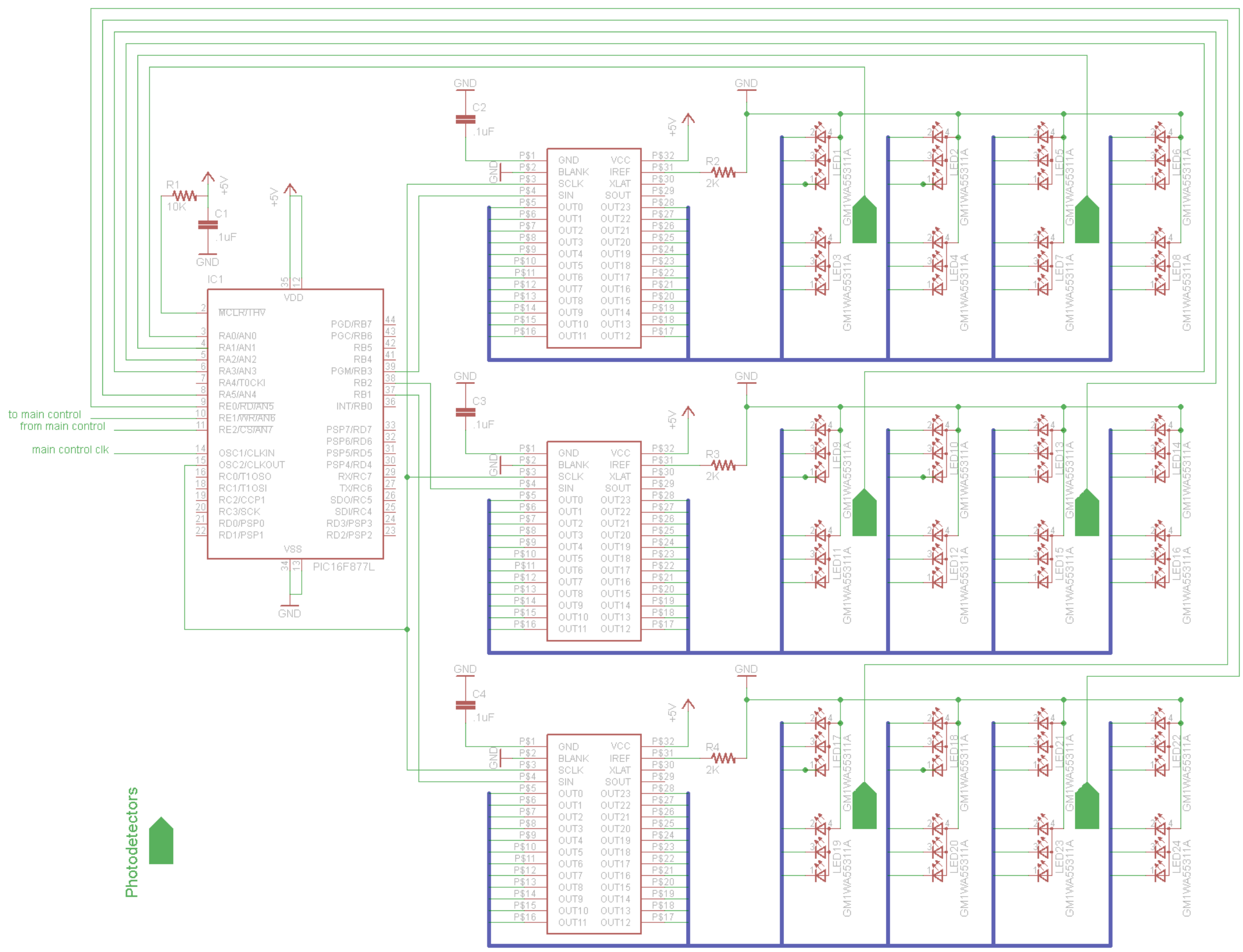
Physical Design

The LED array will be mounted on a perfboard. 4 LEDs compromise one pixel, and thus will be laid out in a square fasion. In the center of each pixel, in the center of the LED square, is the photodiode that controls each pixel. The perfboard will consist of two 18" x 12" sections per each module. Each module is 6 pixels wide x 2 pixels long.

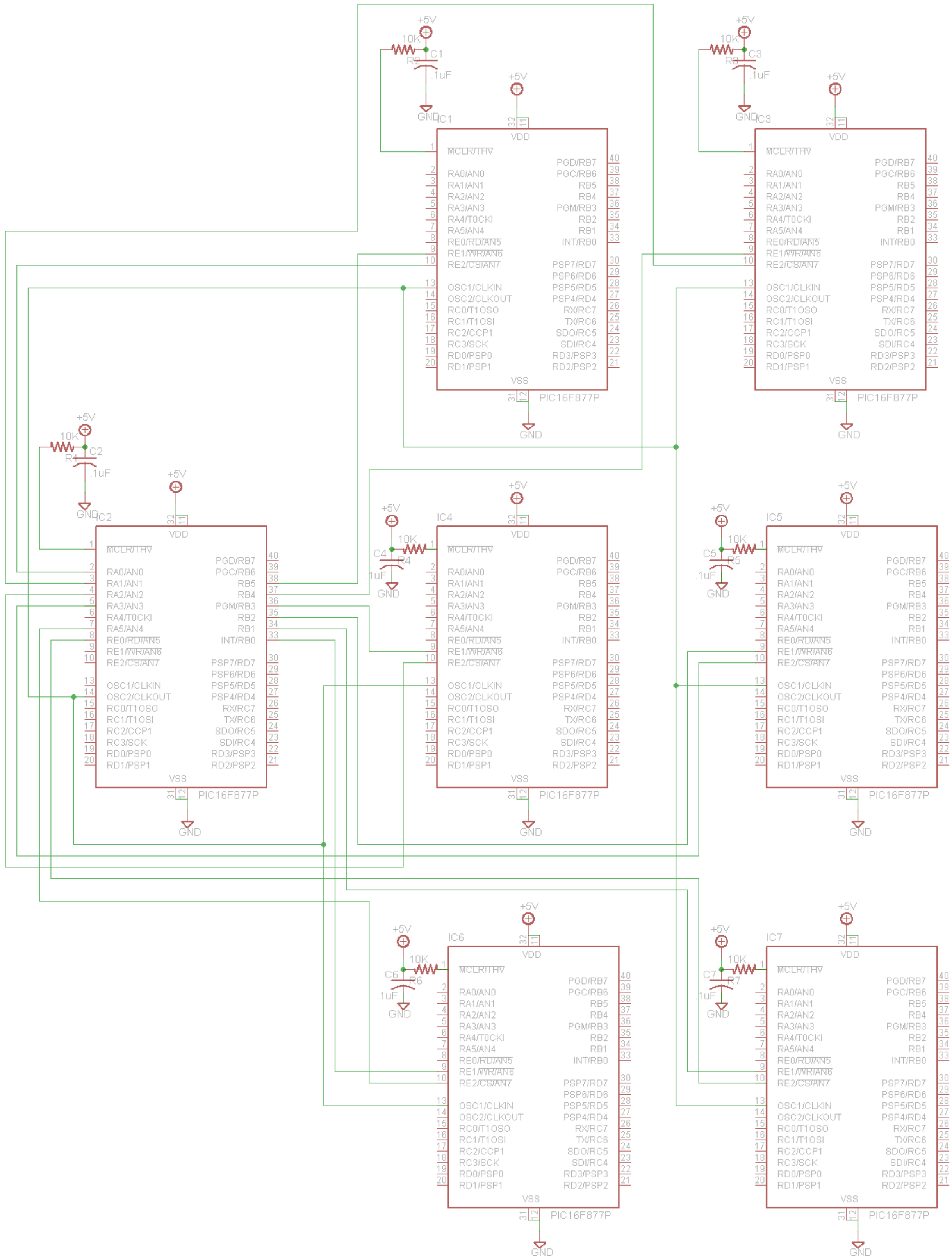
RGB LEDs and photodetectors will be connected with copper wire to LED drivers or microprocessors. The LED drivers and microprocessors will be mounted on separate PCBs located underneath the perfboard. Thus, each module is 36" wide by 12" long and contains 12 pixels with a total of 12 photodetectors and 48 RGB LEDs. Each module will be enclosed in a wood, metal, or plexiglass base enclosure with a matte plexigloss lid. Additional supports will likely be required to the inner area of the lid to prevent cracking under stress.

Schematics:

Module level - 1/2 Module or 6 Pixels



Main Level - 3 Modules



Schematic Descriptions:

Photodiodes: Output currents are in the detectable range for the microprocessor and thus do not need to be amplified. They are connected directly to analog inputs of the microprocessors. Current is low (2-15 nA) when dark and high (~70-90 μA) under bright conditions.

RGB LEDs: contain three terminals each, as well as a common ground. Terminals take 0 - 25mA of current each to create colors via blending. Thus, each RGB LED uses up to 75mA of current instantaneously.

PIC16F877: The main control units of the device. In the ½ module view, each microcontroller controls 6 pixels. It receives input from the photodiodes, as well as the main control unit, to determine when the LEDs for which it is responsible will activate. It communicates with the main control unit to alert it when a photodetector threshold voltage is passed and a step has been detected.

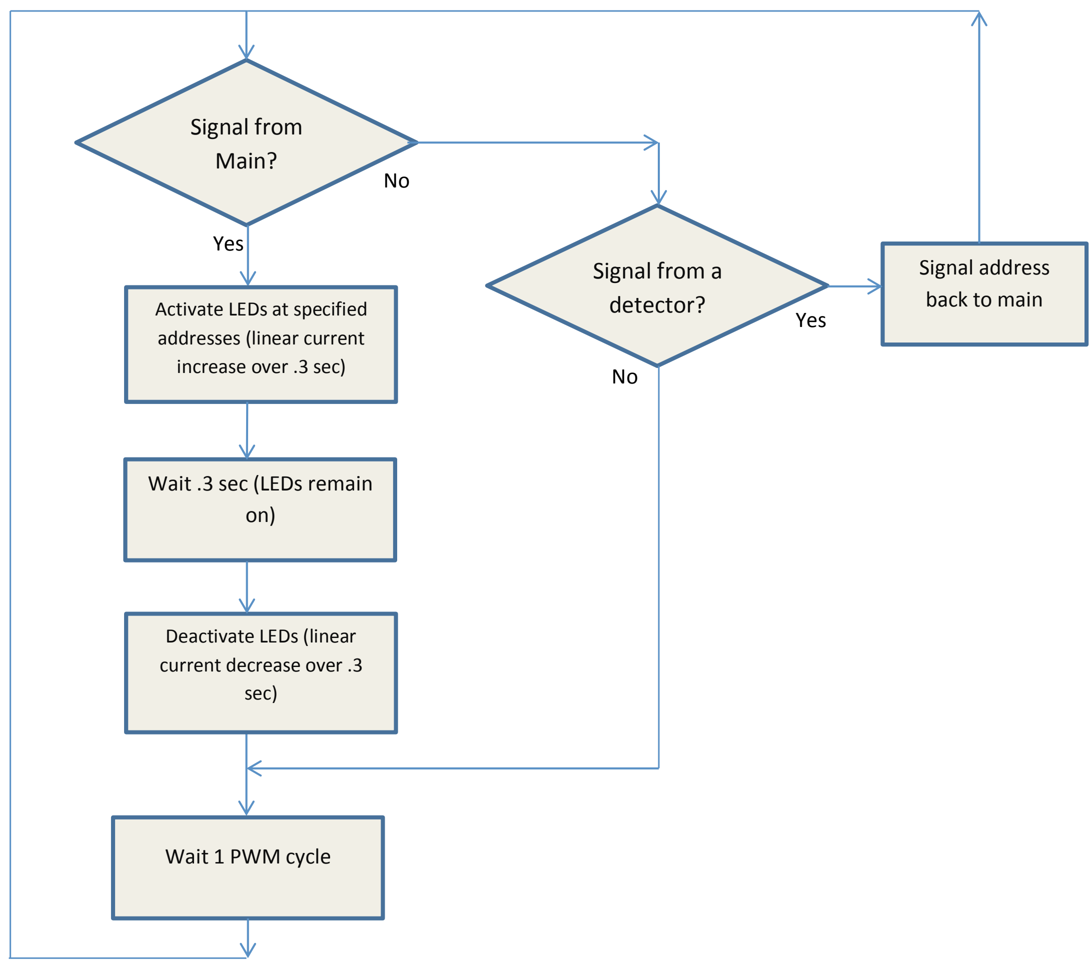
In the main control unit, one PIC16F877 chip is used to monitor and coordinate all other microcontrollers. It receives input from each and sends data out to each one serially regarding when to activate its LEDs. It also coordinates the different response patterns of the system, e.g. ripple effects or color changes.

TLC5947: This chip is the LED driver responsible for illuminating the LEDs. It receives a signal serially from the PIC microcontroller, decodes the signal, and outputs a maximum of 30mA per pin where necessary. Since each LED requires three inputs, pins are grouped into threes to determine which LED they will control. This is also the main pulsewidth modulation unit. A grey code counter determines the duty cycle and speed of the pulse. The LED driver also has a constant current sink; the current is controlled by a reference resistor set at 2kΩ to yield a maximum current of 30mA at each output pin.

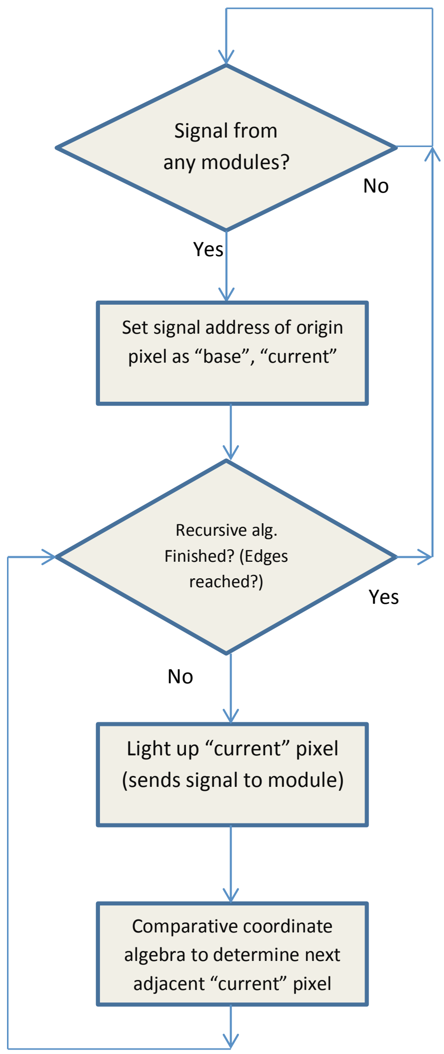
Power supply: transformed from wall voltage down to 5V using a standard two-prong adapter. This voltage is usable by all powered components.

Software Flowcharts:

½ Module or single microprocessor:



Main control unit:



Performance Requirements:

- Detects a footstep on 100% of instances
- Latency from detection to output within .3 seconds
- Consumes less power than an escalator (standardized per each stair)
- Each module withstands at least 250 pounds distributed over a 10 square inch area
- System will be modular up to 20 devices

Testing Procedures:

Power Supply Requirements	Verification
1.) All powered units receive adequate power a. Microprocessors receive 5V b. LED drivers receive 5V c. RGB LEDs receive no more than 3.2V	1.) a. A voltage between 4.5 and 5.5V is measured at V_{DD} pins. b. A voltage between 4.5 and 5.5V is measured at V_{DD} pins. c. A voltage between 2 and 3.2V is to be measured from each pin to ground.
2.) System's total power consumption is below that of average escalator power consumption	2.) Probe the voltage at the power supply to check the total power dissipation and compare to that of a standard escalator.
3.) Power supply ripple is less than .5V	3.) Probe power supply's output to first microcontroller with an oscilloscope

Photodiode Array Requirements	Verification
1.) Photodetector detects user input for 100% of trials a. Output current ranges within 30µA to 90µA for a distance of 0-2 inches.	1.) Current is measured through the photodiode for placing an object directly over the photodetector at a distance of 2 inches through matte plexiglass. Perform 20 trials. a. Measure current through the photodetector with oscilloscope with an object at a distance of 0-2 inches.
2.) Photodetector does not produce false positives a. Photodiode current is under 20µA for no stimulus b. Photodiode current is under 20µA for	2.) a. Connect an oscilloscope to the photodiode, monitor output current for non-stimulated photodiode under matte plexiglass, check that it is 0-20µA.

stimulus at greater distances than 6 inches.	b. Connect an oscilloscope to the photodiode, monitor output current for photodiode under matte plexiglass stimulated by objects 6 inches away and greater, check that it is 0-20μA.

Microcontroller Requirements	**Verification**
1.) Two pulse trains for photodetector trigger and LED PWM signal are driven out of step. a. Pulse trains have same frequency. b. Pulse trains' periods do not overlap.	1.) Attach each pulse from microcontroller to oscilloscope, a. Measure frequencies on side-by-side plot. b. Duty cycles are out of phase and do not overlap.
2.) Main microprocessor can handle the operation of three modules simultaneously. a. Latency of device is less than 300ms	2.) Simulate or monitor three assembled modules. a. Drive a 90μA, 10ms pulse into one module's photodetector analog input. Monitor output directly at the LED driver output of the corresponding pixel. Check time differential on oscilloscope.

LED Array Requirements	**Verification**
1.) Each pixel can be addressed individually	1.) Count up through addresses from the main microprocessor, enabling each with maximum current for 1 second.
2.) LEDs can display full spectrum of 256 colors	2.) Activate all outputs to LED driver from the microprocessor. Drive three current signals with periods of of 1sec, 2sec, and 4sec with amplitude varying from 0mA to 25mA. Assign

	each signal to a color. Visually inspect LED array as full color spectrum should be cycled.

Tolerance Analysis:

The photodetector array is the most sensitive component of the design. In order for the system to function properly in terms of feedback, the sensor needs to be in proper working order. This means that it must detect a footstep with 100% accuracy and, when it does, the output voltage must be consistent and reliable. The results must also not produce any false positives, such as peaks in current when the user is not actually standing over one of the sensors. It will be important to test these output voltages from the sensors and ensure that they work properly with the matte plexiglass that is to be used. As the photodiodes produce currents from 2nA when dark and 90µA under lit conditions, a tolerance of +/- 20µA should be sufficient for photodetection. Any one of the photodiodes can be probed to check its response.

Cost Analysis:

Cost of Labor = $80/hour x 2.5 x 144 hours = $28,800

Cost of Parts:

Part #	Manufacturer	Part	Price	Quantity	Total Price
-	Local hardware store	Plexiglass panels	-	3 panels x 1ft x 3ft = 9 sq ft	$50
“5MMLEDRGBCOMMONANODE”	Niktronix	RGB LEDs	$0.35	3 x 48 = 144	$50.40
PDB-C156	Advanced Photonics	Photodiodes	$1.05	3 x 12 = 36	$37.80
16F887	Microchip	Microprocessor	FREE	5	$0.00
TLC5947	TI	LED driver	$6.72	18	$120.96*
DRV632PWR	TI	Audio driver	$1.60	1	$1.60*
AS09008PO-2-WR-R	PUI Audio	Speaker	$5.06	1	$5.06
STLQ50C50R	STM	Voltage Reg.	$0.17	11	$1.87
T1132-P5N-ND	CUI	Power Adapt.	$8.06	1	$8.06
-	-	PCB	FREE	7	$0
-	-	Miscellaneous	$20.00	-	$20.00
				TOTAL	**$295.75**

*Note plans to enter TI Design competition and receive free TI parts up to $200.

Total Cost = Cost of Labor + Cost of Parts = **$29,095.75**

Addendum:

The initial scope of the project, including large amounts of audio functionality, has been reevaluated. At this point, it is most important that the LED staircase modules respond to user input with different patterns of light generation sequences. Secondly, the LED modules must communicate in a modular fashion. Also note that both of these tasks greatly dependent on the software of the system. In short, functional emphasis is placed on the visual response of the system, while the audio side of the system will be implemented in as much detail as time permits. At the least, a step will produce a synthesized sound at some frequency, but the refinement of this ambient sound may not be too complicated. Time permitting, the audio processing can be done in a modular way such that each step plays its own note in the musical scale.

Schedule:

Week	Task
1/16-1/30	Choose project idea, search for partners, submit RFA.
2/6	Work on and submit project proposal, search for parts.
2/13	Research microcontrollers and their specifications, begin electronics design, search for parts.
2/20	Continue electronics design, further research microcontrollers
2/27	Finish electronics design, place parts orders
3/5	Assemble first module, ensure response of sensors and LED array.
3/12	Ensure operation of sensors, LED array, and audio in conjunction with microprocessor, begin writing code to control response behavior of first module.
3/19	SPRING BREAK
3/26	Finish assembly of first module, write code to control response behavior of first module, begin assembly of other two modules.
4/2	Assembly of other two modules.
4/9	Finish building other two modules, implement code for full system.
4/16	Finish writing and testing code on full system.
4/23	Final demo, presentation.
4/30	Finish final paper, presentation.

Citations:

Niktronix – RGB LED
http://www.niktronixonline.com/5mm_Super_Bright_RGB_Common_Anode_p/5mmledrgbcommonanode.htm

Seeed – RGB LED – common anode spec sheet
http://www.seeedstudio.com/depot/5mm-triple-output-led-rgb-common-anode-20-pcs-p-622.html?cPath=156_157

TI TLC5947 LED Driver
http://www.ti.com/product/tlc5947

PDB-C156 Photodiode
http://www.lasercomponents.com/de/?embedded=1&file=fileadmin/user_upload/home/Datasheets/api/si-pin/plastic-enc-leads/pdb-c156.pdf&no_cache=1

PIC16F877 datasheet
http://ww1.microchip.com/downloads/en/devicedoc/39582b.pdf