Swim Pacer Unit

Final Report

Mark Alikpala, George Garcia, Miao Lu
Team #3
TA: Alex Suchko

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Table of Contents

1.0 Introduction

1.1 History and Motivation

The Swim Pacer Unit proposed by Coach Howard Schein is a swimmer's training tool. Swimmers usually are unaware of how fast they are moving while swimming. We want to be able to create a tool that can provide visual representation of a set pace which will guide the swimmers at various speeds preprogramed by their coach.

We chose this project because it is ambitious, interesting, marketable, and it can potentially improve the performance of many athletes. Swimming is a very competitive sport that the world enjoys. But the hi-tech training tools are often overlooked. This project will revolutionize swimmer's training and create an impact to the electronic training equipment for swimmers.

1.2 Objectives

We will design and build a visual indicator for swimmers through the use of LED sequential lights. A controller with a digital interface will be designed to adjust the speed of the lights moving along the length of the pool. Pace profiles can be preprogramed into the control device. Swimmers can follow these lights to guide them in swimming at speeds that are set at predetermined settings. This device can also be operated on deck by the coach while an athlete is swimming. The pace can be set from the deck as the swimmer begins each length. Different profiles can be preprogramed and can be varied by the coach. The pace ranges from 8 to 30 seconds per length in 0.5 second intervals.

Benefits

- It can help improve the performance of swimmers
- The swimmer and the coach can now see how fast the swimmer is compared to the set pace
- Allows the swimmer to chase a visual cue

Features

- Programmable Pace Profiles and Pace controls
- Profiles can be saved and modified
- User friendly control interface and visual display
- Safe and reliable
- Works with all standard pools
- Waterproof LED sequential light indicator
- LCD monitor display

*Please refer to Appendix C for Terms and Keywords

2.0 Design

2.1 Concept Diagram

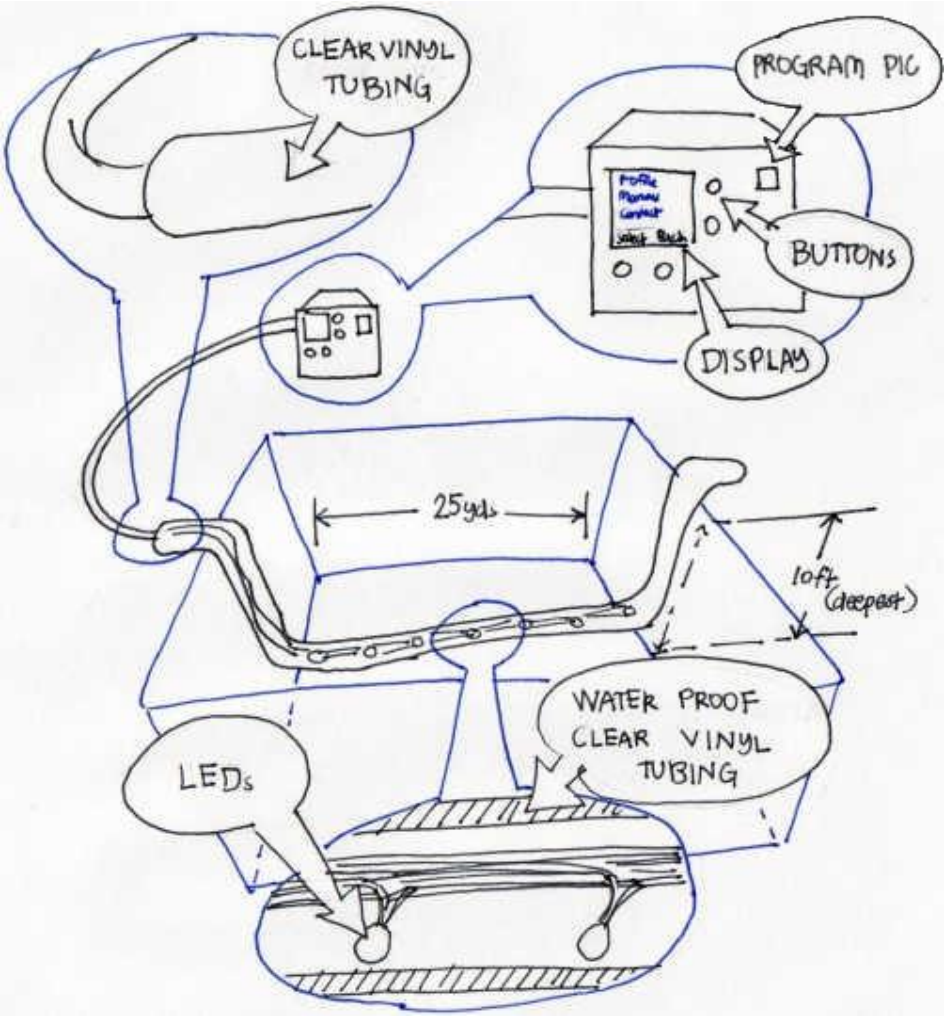


Figure 3a: Swim Pacer Unit Concept Diagram

The swim pacer unit is designed to have a control panel that has several buttons and an LCD display for the user to set the pace of the sequential light indicator. The Sequential Light Indicator will be protected by clear/transparent vinyl tubing, the same material used with aquariums. Since there are several integrated circuits to control the LEDs in the sequential light indicator, a special hard protective case must be prepared for these ICs.

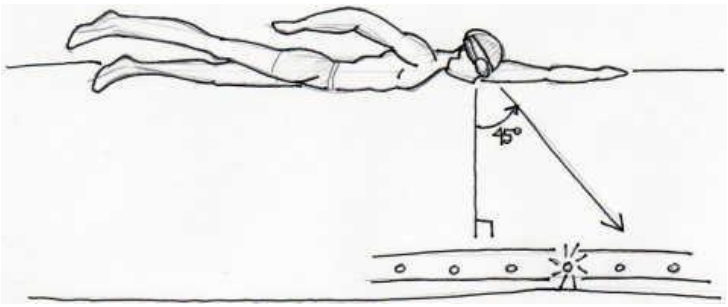


Figure 3b: Swimmer

A typical swimmer is able to see at a 45° angle below the surface of the water. From his perspective and peripheral vision, the swimmer will be able to see the sequential LEDs which would give him an idea of his pace relative to the pace of the LEDs. For instance, if the swimmer does not see the light then he knows that he is swimming faster than the pace. If the swimmer sees the light then he will know that he is slower than the set pace.

2.2 Detailed Block Diagram

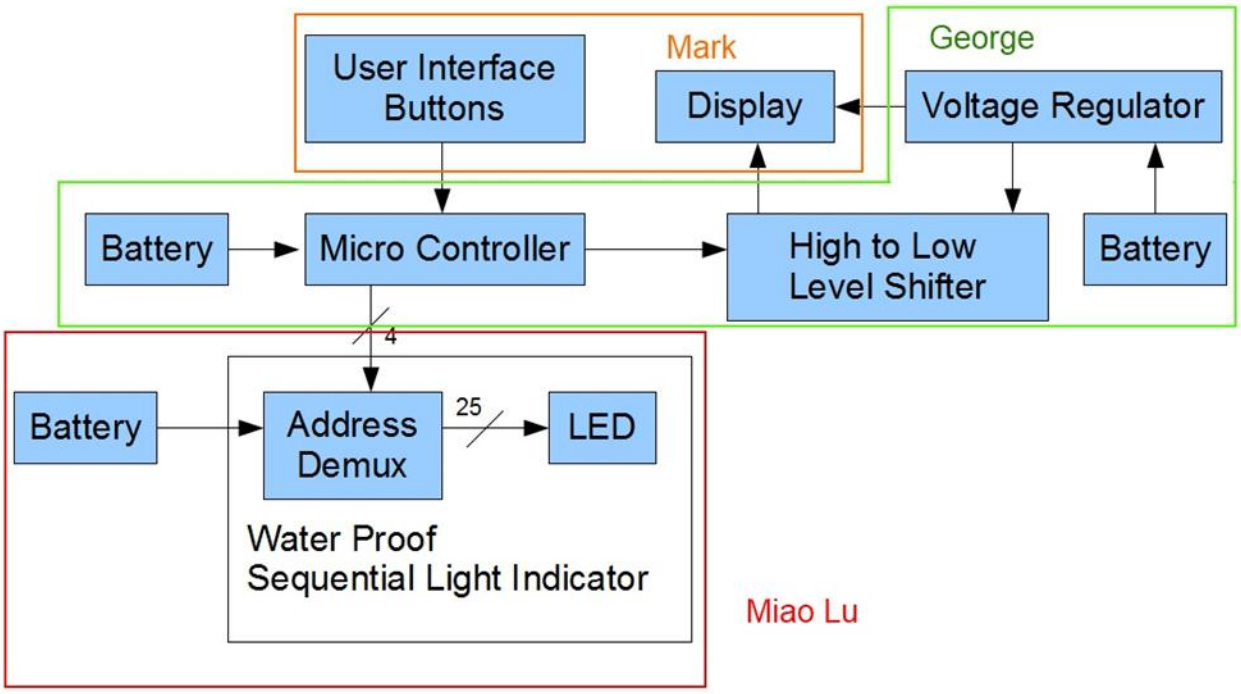


Figure 3c: Detailed Block Diagram

2.3 Block Descriptions

Microcontroller – This is the brain of the Swim Pacer Unit. This will receive user commands in the form of analog input coming from the User Interface block. The Microcontroller will be able to save current settings and profile information then output data to the Monitor Display. The Microcontroller also stores different swimmer pace settings and profiles as programs. Depending on the program called for using the User Interface Buttons, the Microcontroller controls the signals it sends to the Sequential Light Indicator. The Microcontroller also contains Profile information – set of user-defined customizable instructions that determine the output to the Sequential Light Indicator.

Water Proof Sequential Light Indicator – This strip of LED will run across the pool and will be visible to the swimmer. Each LED on this strip has a unique address that is accessed by the Microcontroller. The frequency of each light turning on depends on the settings. This block contains the Demultiplexers and the LEDs. The program saved on the PIC determines what signals to send to the Demultiplexers.

Address Demultiplexers – These demultiplexers are used to address each LED individually and are input only. The microcontroller communicates to these by supplying signals depending on which LED to turn on.

LED – These lights are used as indicators that swimmers should be able to see. These LEDs turn on sequentially as they receive signals from the demultiplexers. The pace of the lights as they turn on per length is controlled by the microcontroller.

High to Low Level Shifter – this IC converts the output from the Microcontroller to be usable by the Display monitor. The output of the PIC's Digital I/O is 5V but the LCD display requires 2V.

Display Monitor – This display shows the current settings that the sequential light indicator will be running. It will display current speed/pace and current profile being used. User Input will also be displayed. The data to display will come from the Level Shifter.

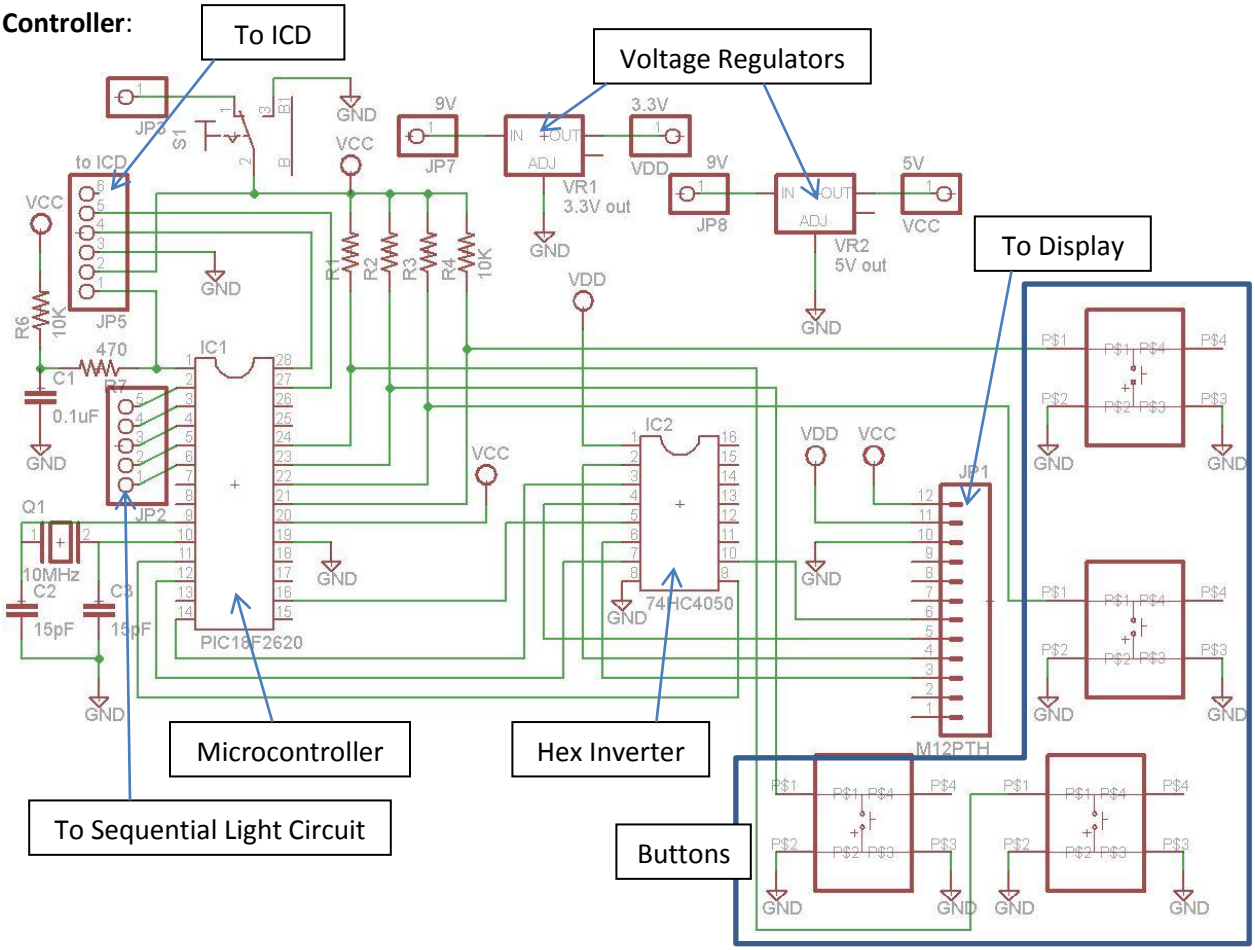
User Interface – This is the analog control that allows the user to give commands to the Microcontroller. Buttons will be available to customize profiles and change the current pace.

Batteries – These are used as power supply to the Swim Pacer Unit's components. Batteries are used instead of power supplied from an outlet to limit the current produced resulting in a safer product for users.

Voltage Regulators – These convert voltage supplied from the batteries into the required voltage for the level shifter and Monitor Display.

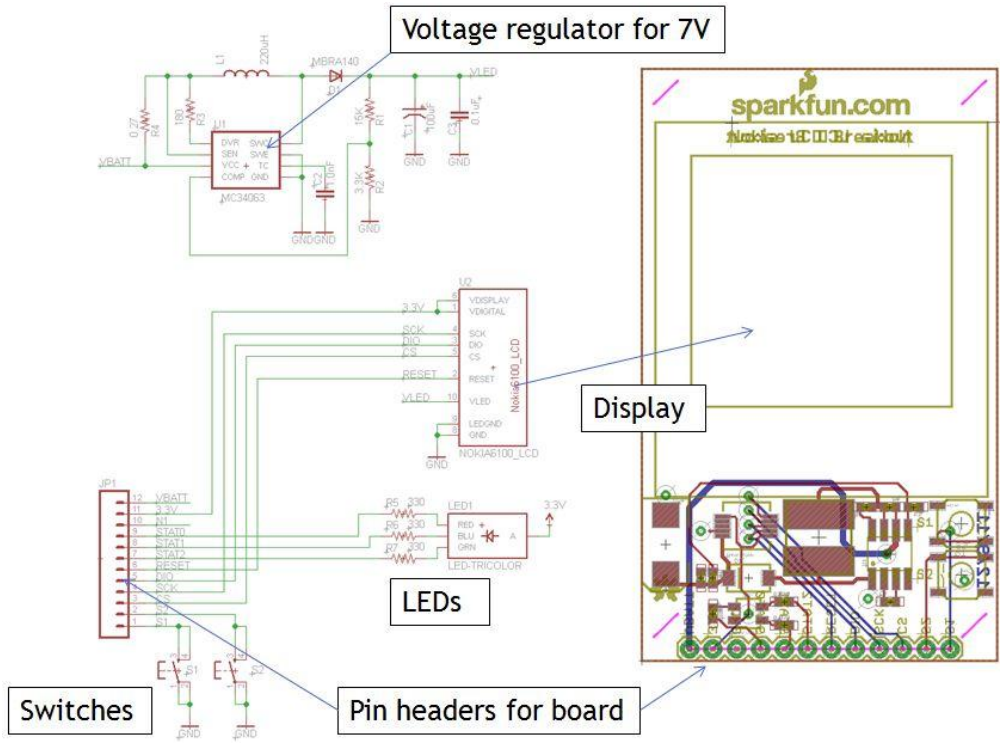
2.4 Schematics and Board placement

Controller:

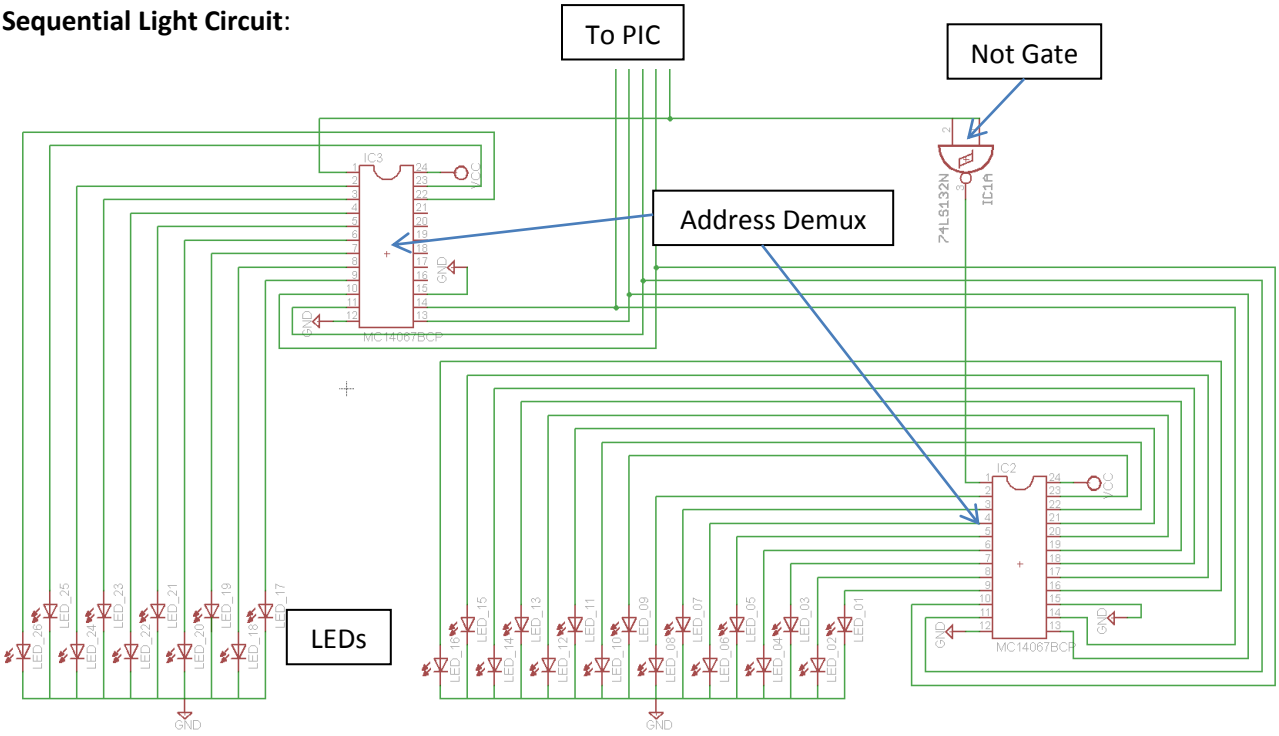


*Please refer to Appendix D for Eagle Schematics and Board

Display:



Sequential Light Circuit:



2.5 Schematic Descriptions

This part talks about the detailed explanation of the components used in the schematics. Implementing this circuit will exhibit proof of concept. Certain practical concerns, such as wire resistance, durability, transportation, etc. will be taken into consideration in applying the project to operational use.

PIC18F2620 – This PIC is the Microcontroller that serves as the brain of the Swim Pacer Unit. Input comes from the switches and sends display output signals to the Level Shifter and simple digital output signals to the demultiplexers. This PIC is powered by a 5V battery. From the data sheet, this PIC is a 28-Pin Enhanced Flash Microcontroller with 10-Bit A/D and nanoWatt Technology.

74HC4050 – This IC is a Hex High-to-Low Level Shifter. It is meant to lower the digital output signals from the pic to voltages usable by the LCD.

EPSON S1D155G10/Philips PCF8833 – This is the LCD where all the User Interface output will be visible. The part is ordered from Sparkfun and it is not sure which model will be received but both should work similarly. This component will be powered using the output from voltage regulators. These requirements are detailed in the Data Sheets.

74238N – These demultiplexers are used as addressing bits to address each LED. These take input signals from the PIC and turns on corresponding LEDs.

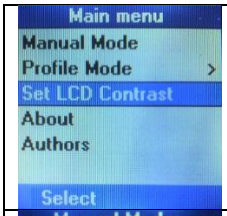
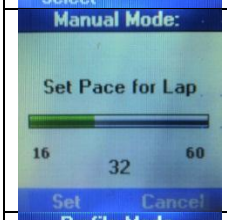
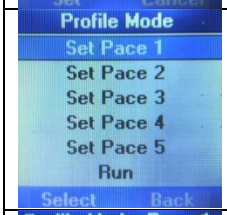
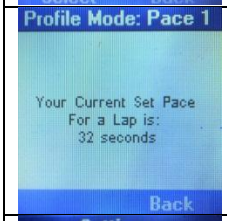
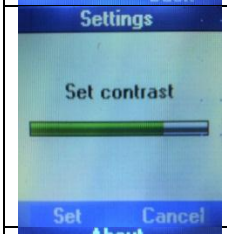
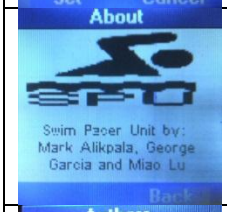
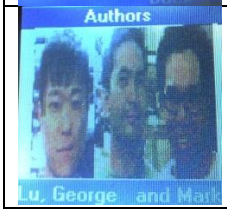
LM1117 – These parts are Voltage Regulators. 9V are input and these voltage regulators are configured to output 3.3V and 7V which is usable for the Level shifter and LCD.

Switches – Although these switches in the schematic are not the actual buttons that will be used for the final product, it can still do the same desired function. These switches provide useful interactive user interface to issue commands to the PIC.

Batteries – These supply 5V and 9V for the PIC and voltage regulators respectively. Several batteries could be connected in series in order to produce the desired voltage.

2.6 User Interface Display

*Please refer to Appendix E to flowcharts implementing the menu below

	This is the Main Menu. User may select from 5 different sub-menus: Manual Mode, Profile Mode, Set LCD Contrast, About, and Authors
	This is the display shown to users when they are setting a pace for a lap of a pool. The title bar on the top indicates what pace is being set. The image on the right shows that the pace for 'Manual Mode' is being set. If the user is in 'Profile Mode', it will dictate what Lap number of the Profile Mode is being currently set.
	In profile mode, a user may pre-set 5 continuous lap paces. The sequential light circuit would not run in Profile Mode until the 'Run' option is chosen.
	When the sequential light circuit is running, it will show the current set pace per lap, as well as what mode the user is in. The image on the right shows that the user is using 'Profile Mode' and is currently on 'Pace 1' with a lap pace of 32 seconds. If the user is in Manual Mode, he or she can press the up or down button to change the pace instantaneously.
	Set LCD Contrast allows the user to set the brightness of the LCD screen to his or her own preference.
	The about screen shows the Swim Pacer Unit logo, as well as its creators, Mark Alikpala, George Garcia, and Miao Lu.
	The 'Authors' page shows the picture of the creators of the Swim Pacer Unit.

3.0 Simulations and Calculations

3.1 Simulation Description

Using NI MultiSim, we produced a simulation that emulates the output to the sequential LED indicator for 1 lap (2 lengths). The PIC we are using cannot be simulated using NI MultiSim; hence, we are emulating its effect using a counter and a function generator for the clock to produce the desired. However, we are still using demultiplexers and lights to emulate our sequential lights operation.

For the simulation, a 4-bit up/down counter was used to determine which light was supposed to turn on at a specific point in time. Using a function generator as clock, we were able to produce square waves with adjustable frequency, accurate up to 10^{-15} hertz (femtohertz, fHz). Each count coming out of the up/down counter corresponded to an LED. Using a two dual 2-line to 4-line decoder/demultiplexer (74LS1550), we were able to specifically indicate what LED to power up. The outputs of the 74LS1550 give low voltage instead of high upon decoding. Therefore, we placed an inverter on every output to get a high signal for LEDs to light up and low signal for LEDs to close.

3.2 Simulations

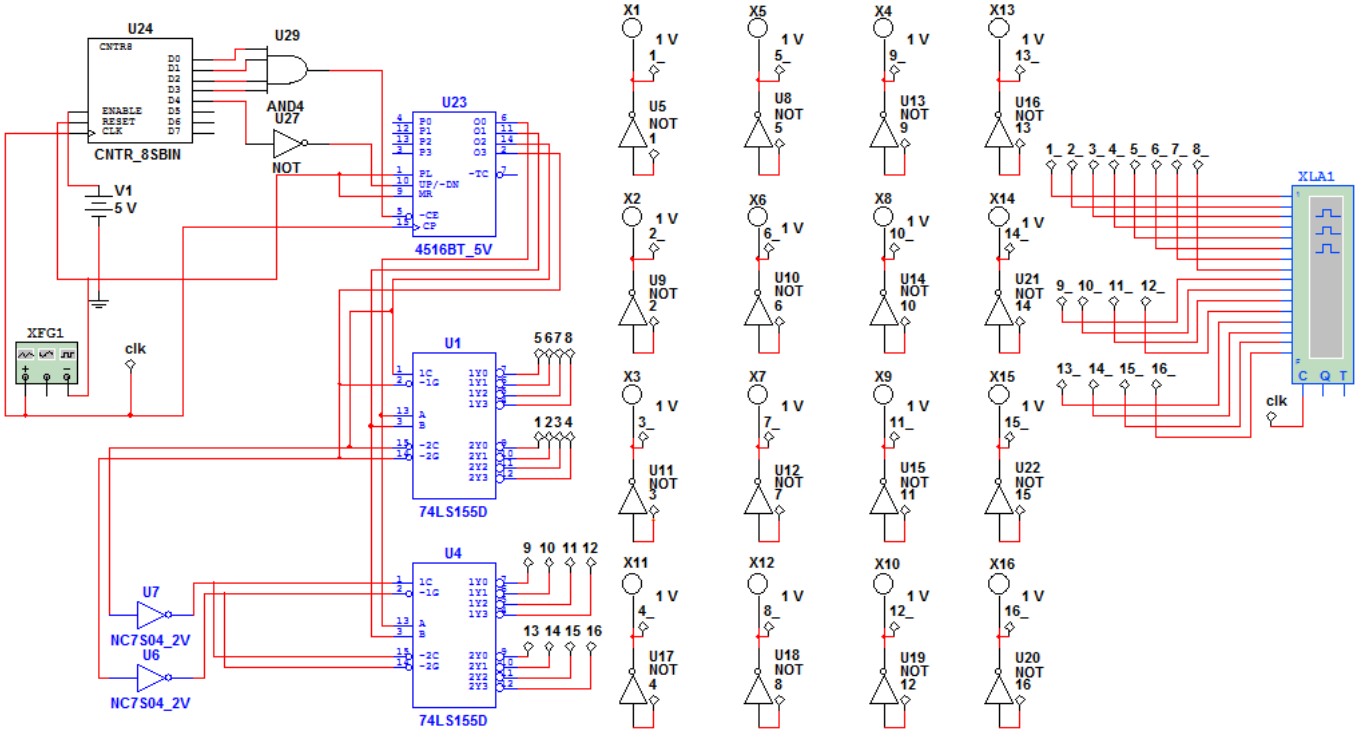


Figure 4a: NI Multisim Simulation

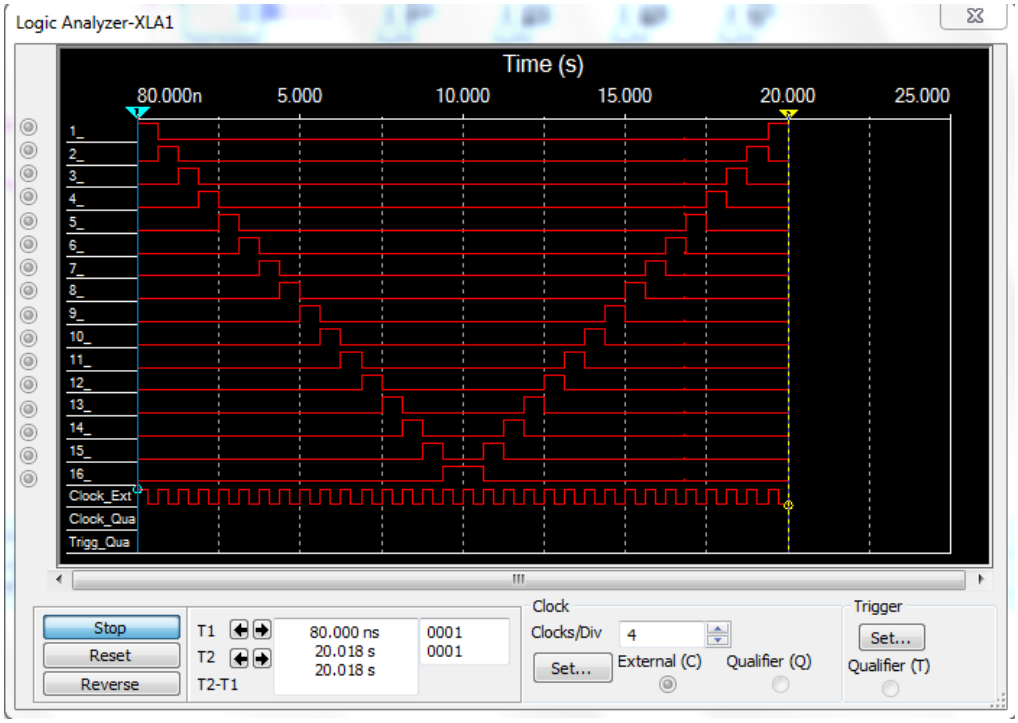


Figure 4b: Logic Analyzer output for 10 sec pace

In this simulation, we set the function generator to 1.6 Hz, which corresponds to a length pace of 10 seconds. As seen in this output, it took 10 seconds to light the LEDs from the first light (1_) until the last light (16_) for the length of the pool. Similarly, it took another ten seconds to for the last light (16_) until the first light (1_) to traverse back for another length.

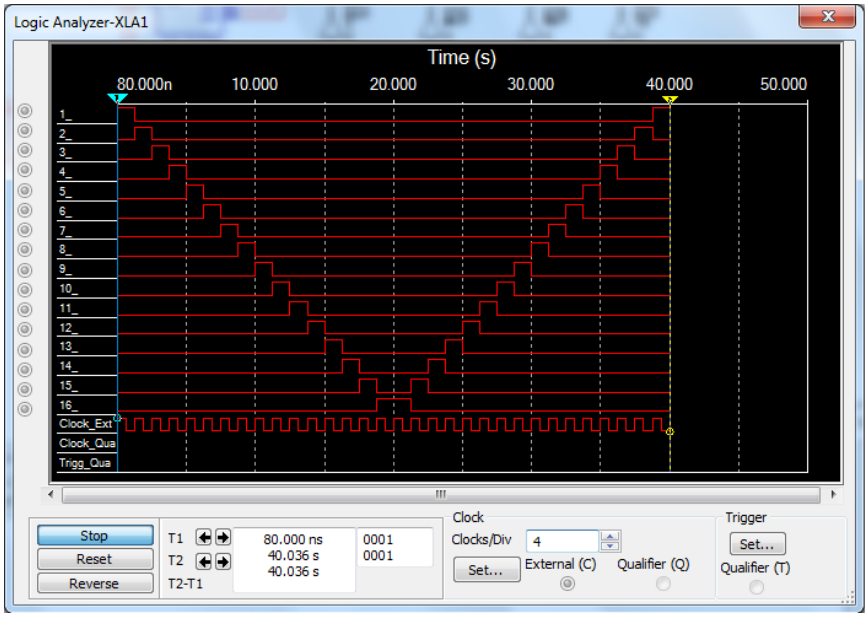


Figure 4c: Logic Analyzer output for 40 sec pace

In this simulation, we set the function generator to 0.8 Hz, which corresponds to a length pace of 40 seconds. As seen in this output, it took 20 seconds to light the LEDs from the first light (1_) until the last light (16_) for the length of the pool. Similarly, it took another 20 seconds to for the last light (16_) until the first light (1_) to traverse back for another length.

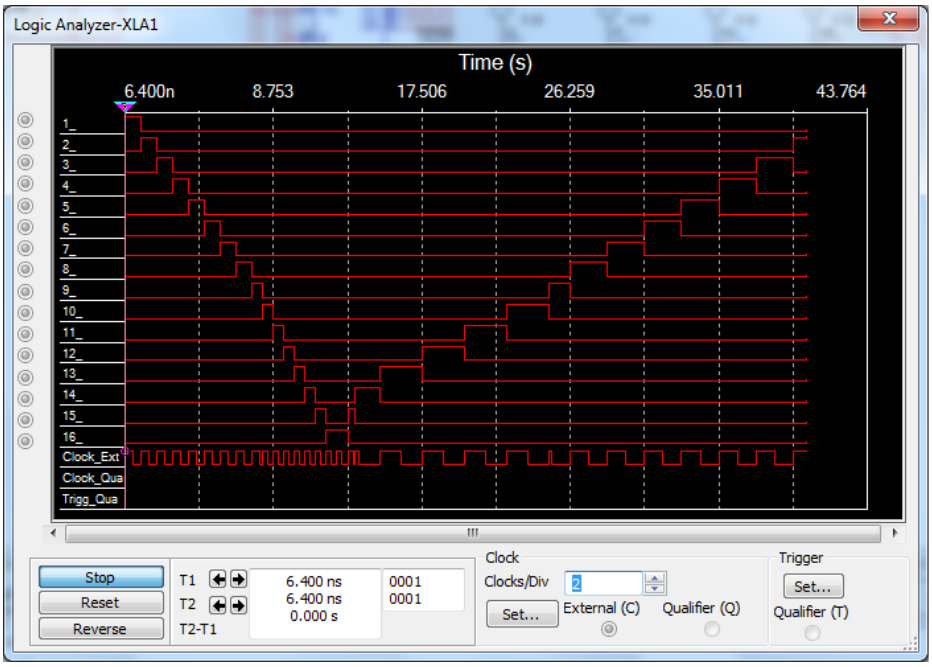


Figure 4d: Logic Analyzer output for 2 lengths with different paces

In this simulation, we set varying frequencies for the function generator. This, in turn, made the lights turn on slower or faster, depending on the function generator frequency. This plot shows that every time an input frequency is changed, it changed how fast each light turns on. This feature corresponds to the “OVERRIDE” feature in manual mode where the user could change the pace anytime within the length of the pool.

3.3 Calculations

*Please see Appendix A for Transition time from one light to next for 25 lights at different paces

According to our tolerance test, our timing should only be off by a maximum of 0.2 seconds per length.

For 25 lights, it is 0.008 seconds allowed error per light transition.

Formulas used:

$$\text{Frequency for lights} = \frac{\text{number of lights}}{\text{pace per length}}$$

$$\text{Transition time from one light to next} = \frac{\text{pace per length}}{\text{number of lights}} = \frac{1}{\text{Frequency for lights}}$$

$$\text{Allowed error} = \frac{\text{tolerance margin of error}}{\text{number of lights}}$$

4.0 Requirements

In order to ensure the functionality of the Swim Pacer Unit, rigorous testing fulfilling performance requirements and feature requirements were accomplished.

*Please refer to Appendix B for Performance and Feature Requirements.

5.0 Verification & Testing Procedures

*Please see Appendix B.0 for detailed Verification and Testing Procedures

Tolerance Analysis

To produce sufficient power to each LED, each LED should have a 200 mA current running through it when it is being lit up. We intend on allowing ±10% tolerance current running through an LED (± 20 mA). This could be measured using a current probe on the each line. We plan on placing a resistance on the LED power line. With a measured voltage, and known resistance, we will be able to have an accurate measurement of our current. Since our goal is to have an LED current of 300 mA and we plan on using a relatively high voltage input of around 5 volts, using the equation

$$R = \frac{V}{I} = \frac{5\ V}{200\ mA} = 25\Omega.$$

On 1% resistor tolerance:

$$I = \frac{V}{R} = \frac{5\ V}{25.25\ \Omega} = 198\ mA \text{ or } \frac{5\ V}{19.75\ \Omega} = 202\ mA$$

On 5% resistor tolerance:

$$I = \frac{V}{R} = \frac{5\ V}{26.125\ \Omega} = 191\ mA \text{ or } \frac{5\ V}{23.875\ \Omega} = 209\ mA$$

On 10% resistor tolerance:

$$I = \frac{V}{R} = \frac{5\ V}{27.5\ \Omega} = 182\ mA \text{ or } \frac{5\ V}{22.5\ \Omega} = 222\ mA$$

We can see from here that using a resistor with 10% tolerance, we can incur a current of 222 mA, which is 2 mA higher than our 10% tolerance level for current. Because of this, we are going to use a 5% resistor tolerance, which results in 191 mA and 209 mA are yielded from 26.125 Ω and 23.875 Ω respectively.

6.0 Cost and Schedule

6.1 Cost

Labor

Name	Rate	Hours	Total	Total x 2.5
George Garcia	$60/hour	275	$ 16,500	$ 41,250
Mark Alikpala	$22/hour	240	5,280	13,200
Miao Lu	$35/hour	257	8,995	22,488
			Grand Total	**$76,938**

Parts

Part	Quantity	Unit Cost	Total
Color LCD 128x128 Nokia Knock-Off with break out board	1	$ 34.95	$ 34.95
Clear Vinyl tubing 1" ID 100'	1	85.99	85.99
Microcontroller (PIC 18F2620)	1	4.59	4.59
Wires	1	30.01	30.01
LEDs	25	0.20	5.00
Resistors, Capacitors, diodes, inductors		15.00	15.00
IC's		20.00	20.00
Miscellaneous components		15.00	15.00
		Grand Total	**$210.54**

Total = 76,938 + 210.54 = $77148.54

6.2 Schedule

Week	George Garcia	Miao Lu	Mark Alikpala
1/23	Research programmable controller parts	Research interface sequential light control circuit parts	Research monitor display parts and high level design of sequential light circuit
1/30	Proposal: Design	Proposal: Introduction	Proposal: Verification & Requirements
2/6	Research programmable controller implementation	Research interface and sequential light control implementation	Research monitor display implementation
2/13	Complete block diagram, description, contents and simulations	Complete schematics, flow charts and calculations	Complete requirements & verification and tolerance & analysis
2/20 – DESIGN REVIEW	Update block diagram, description, contents and simulations with regards to design review critique	Update schematics, flow charts and calculations with regards to design review critique	Update requirements & verification and tolerance & analysis with regards to design review critique
2/27	-Prototype circuit implementation -Buy circuit parts	Create prototype of sequential light circuit through a protoboard	Circuit interface implementation
3/5	Program the controller	Interface controller with sequential light display	Interface controller with the monitor
3/12	Test interface and monitor display	Test every light turns on	Test light traverses at the set pace
3/19 – SPRING BREAK	Spring Break	Spring Break	Spring Break
3/26 – MOCK UP DEMOS	Add/Program “profile” feature to the swim pacer unit	Research on possible additional features for product enhancement	Test the product with Coach Howard Schein
4/2	Modify program profile feature’s efficiency	Test and implement the feasibility of the features for enhancement with Mark	Test and implement the feasibility of the features for enhancement with Lu
4/9	Test that each controller button works appropriately	Test that each light in the circuit works appropriately	Test that the monitor shows the appropriate displays
4/16	Troubleshoot any bugs regarding microcontroller	Troubleshoot any bugs regarding sequential light circuit	Troubleshoot any bugs regarding monitor display
4/23 – DEMOS	Construct final paper (Design portion)	Construct final paper (introduction, cost and misc.)	Construct Test and Verification
4/30 – FINALS PAPER DUE	Proofread Lu and Mark’s portion of the Final Paper. Work with Lu and Mark in combining the Final Paper together.	Proofread George and Mark’s portion of the Final Paper. Work with George and Mark in combining the Final Paper together.	Proofread George and Lu’s portion of the Final Paper. Work with George and Lu in combining the Final Paper together.

7.0 Conclusion

7.1 Accomplishments

Couple months ago for the design review, we have set up many goals to be accomplished for the final demo. All of those quests were fulfilled during our demo. Our pacing accuracy was well below our tolerance. The LCD display helped users navigating through different modes with ease. The user interface interacted with the sequential light circuit without issue. Both the manual mode and profile mode have been implemented, and work according to our original specifications.

*please refer to Appendix F for Lap Pace Accuracy

7.2 Uncertainties

Our device has been tested extensively, and has passed all of our tests and verification requirements but there are still some uncertainties that need to be addressed. To start, we have never tested the device underwater, so we are not sure whether it will really be waterproof or not. Once the device has been emerged into water, the visibility of the LEDs would create another uncertainty.

7.3 Future Work

During the fabrication stage of our project, we have noticed that it was rather difficult to transport our product from one place to another. We want to create a container for our project and to make the controller and the sequential light circuit detachable, so the user can transport our device from one place to another with ease. We also want to improve our casing for the controller. We were short on time for the final demonstration; as result, we have simply created a cardboard box as our casing. With the help of the people from the machine shop, a plastic casing will be created.

7.4 Alternatives

One thing we wanted to try was to replace our currently LEDs with the ultra-bright ones. This could potentially improve the visibility of our sequential light circuit for our users. We could also have used multiple LEDs instead of one per each yard.

7.5 Ethical Considerations

The major ethical issue for our project is underwater safety. Our goal is to ensure the safety of all potential users. To accomplish this, batteries will be used instead of using the power source of an outlet to reduce the current in order to avoid potential electrocution. Clear vinyl tubing will be used to provide insulation for the LED lights, cables, and microprocessors away from water. We will make sure that the swim pacer unit is safe to use, and that it will not cause potential harm to users.

8.0 Citations

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[2]What is nanoWatt Technology. Microchip Technology Inc., USA. [Online]. Available:
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[7]Philips PCF8833 Data Sheet NXP ICs. [Online]. Available:
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[8]74238N Data Sheet. Texas Instruments Inc., Texas. [Online]. Available:
http://ciclope.fi.upm.es/display/docs/74238.pdf

Appendix A: Frequency and Transition

Frequency for 25 lights and Transition time from one light to next for 25 lights

Pace [sec]	Frequency for 25 lights [lights/sec]	Transition time from one light to next for 25 lights [sec/light]
8	3.1250	0.32
8.5	2.9412	0.34
9	2.7778	0.36
9.5	2.6316	0.38
10	2.5000	0.40
10.5	2.3810	0.42
11	2.2727	0.44
11.5	2.1739	0.46
12	2.0833	0.48
12.5	2.0000	0.50
13	1.9231	0.52
13.5	1.8519	0.54
14	1.7857	0.56
14.5	1.7241	0.58
15	1.6667	0.60
15.5	1.6129	0.62
16	1.5625	0.64
16.5	1.5152	0.66
17	1.4706	0.68
17.5	1.4286	0.70
18	1.3889	0.72
18.5	1.3514	0.74
19	1.3158	0.76
19.5	1.2821	0.78
20	1.2500	0.80
20.5	1.2195	0.82
21	1.1905	0.84
21.5	1.1628	0.86
22	1.1364	0.88
22.5	1.1111	0.90
23	1.0870	0.92
23.5	1.0638	0.94
24	1.0417	0.96
24.5	1.0204	0.98
25	1.0000	1.00
25.5	0.9804	1.02

26	0.9615	1.04
26.5	0.9434	1.06
27	0.9259	1.08
27.5	0.9091	1.10
28	0.8929	1.12
28.5	0.8772	1.14
29	0.8621	1.16
29.5	0.8475	1.18
30	0.8333	1.20

Appendix B: Performance and Feature Requirements

Performance Requirements

- User input reflects on the monitor display 100% of the time.
- LED Sequential Lights should be visible to the swimmer and the pace of each sequential light should have a margin of error of at most 0.4 seconds per lap pace.

Feature Requirements

Controller-to-Monitor Requirements (CTM)

CTM_1: A "Main Menu" page should be displayed when the system turns on. On the main menu, the user should be able to choose between 5 options: Main Menu, Profile Mode, Set LCD Contrast, About, and Authors.

CTM_2. The "manual pace" page should display the set pace (in seconds) for a lap of the pool. The default time is 32 seconds. It should have a minimum of 16 seconds and a maximum of 60 seconds. The user should be able to adjust the pace by 1 second intervals. The user should be able to activate the sequential light circuit or go back to the main menu from this page.

CTM_3: When the user activates the sequential light circuit from ‘Manual Mode’, then it should switch to a different display where it could indicate the set pace for a lap. A user should be able to change the pace from this display or go back to the main menu from this new display.

CTM_4: "Profile Mode" should consist of 5 different times for lap pace. Each pace for a lap should be editable. The user should be able to activate the sequential light circuit or go back to the main menu from this page.

CTM_5: When the user activates the sequential light circuit in the profile mode, then it should switch to a different display indicating the lap number and its corresponding set pace. Any button input aside from the ‘back’ button should have no effect on the display.

CTM_6: When the sequential light circuit has finished running while in profile mode, then it should return to the “Profile Mode” menu.

CTM_7: The ‘Set LCD Contrast’ page should be able to make the LCD brighter or dimmer by pressing the up or down button. If the “Select” button is pressed, it will save the last selected contrast value setting. If the ‘back’ button is pressed, the LCD contrast will be reverted back to what it was prior to entering ‘Set LCD Contrast’ menu.

CMT_8: The ‘About’ page should display the Swim Pacer Unit logo, as well as the name of its authors. Pressing the ‘back’ button will bring back the display to the main menu.

CMT_9: The ‘Authors’ page should display the pictures of the Authors, as well as their names on the bottom. Pressing the left or right (select or back) button will bring the display back to the main menu.

Controller-to-Lights Requirements (CTL)

CTL_1: When the unit is just turned on, no lights on the sequential light circuit should be on.
CTL_2: When a user presses "Back" from the "Manual Menu" or "Profile Menu" while the sequential light circuit is on, then the lights should turn off.

CTL_3: Selecting 'Run' from the 'Manual' menu or any 'Profile' menu would start the sequential light circuit from the start.
CTL_4: Pressing the up in ‘Manual Mode’ will make the lap pace go slower. Pressing the down button will make the lap pace go faster.
CTL_5: Pressing the up or down button in ‘Manual Mode’ will NOT affect the pace of the sequential lights circuit.

Sequential Light Circuits Requirement (SLC)

SLC_1: Only one light should be on at a time when the circuit is running
SLC_2: The lights should sequentially traverse across the pool
SLC_3: All LED’s should have the capability to turn on.

Tolerance Requirements (TOL)

TOL_1: The pace set can only be off by a maximum of 0.4 seconds.
TOL_2: The maximum time it takes the sequential light to travel through a lap of a pool should be 60 seconds.
TOL_3: The minimum time it takes the sequential light to travel across a lap of the pool should be 16 seconds.

Hardware Requirements (HRD)

HRD_1: Each LED should have 150 mA (±10 mA) flowing through it when it is on.
HRD_2: Each PIN from the PIC should output 5V when HIGH, 0 when LOW
HRD_3: When a button is pressed, it should give 0 V as an input to the PIC. When a button is not being pressed, it should constantly supply 5 V to the PIC.
HRD_4: The demultiplexer pins should output 5 V when HIGH, 0 when LOW
HRD_5: The voltage regulator should be able to drop the voltage from 9 V to 5 V.
HRD_6: The voltage regulator should be able to drop the voltage from 9 V to 3.3 V
HRD_7: The hex shifter output pins should have an output voltage of 3.3 V when HIGH, 0 when low.

Verification & Testing Procedures

B.1 Testing Procedures

Controller – to – Display tests

Purpose: The part of this test ensures that the communication between the controller and the monitor works as intended

Requirement	Test Steps	Expected Results	Results/Comments
CTM_1	1. Turn on the Swim Pacer Unit 2. Observe the screen. 3. Repeatedly press the down button. 4. Repeatedly press the up button.	1. The swim pacer unit turns on. 2. The display monitor should show the following options/selections: Manual Mode Profile Mode Set LCD Contrast About Authors "Manual Mode" should be initially highlighted. A header on the top should say “Main Menu”. There should be a Select button on the lower left. 3. One press of the down button will highlight the option below the current highlighted selection. Pressing the down button when the current selected option is the bottom-most (Authors) will not result in a change of the highlighted selection. 4. One press of the up button will highlight the option above	Everything Passed.

		the current highlighted selection. Pressing the up button when the current selected option is the top-most (Manual Mode) will not result in a change of the highlighted selection.	
CTM_2	Prerequisite: The Swim Pacer Display is turned on and is on the "Main Menu" 1. Highlight the 'Manual Mode' option and press 'Select'. 2. Press the up button repeatedly. 3. Press the down button repeatedly. 4. Press the 'Back Button' button. 5. Return to 'Manual Mode' and select 'Run' button	1. The display enters the 'Manual Mode' display. 2. The pace time will increase by 1 second every time the up button is pressed. At the same time, the pace bar will move to the right. When the current pace time displayed is 60 seconds when the up button was pressed, then the pace time should still remain at 30 seconds. 3. The pace time will decrease by 1 seconds every time the down button is pressed. At the same time, the pace bar will move to the left. When the current pace time displayed is 16 seconds when the down button was pressed, then the pace time should still remain at 16 seconds. 4. The display will exit the "Manual Mode" page and will go back to the "Main Menu" 5. The screen will show a new display which indicates your current pace time.	Everything Passed

CTM_3	Prerequisite: The Swim Pacer Unit is in 'Manual Mode'. The user has already adjusted the lap time to his desired pace. 1. Press the 'Run' button 2. Press the Up button repeatedly. 3. Press the Down button repeatedly. 4. Press back.	1. The screen will show a new display which indicates your current pace time. 2. The pace time will increase by 1 second every button press. When the time is equal to 60 seconds, it will stop increasing. 3. The pace time will decrease by 1 second every button press. When the time is equal to 16 seconds, it will stop decreasing. 4. The display will go back to the main menu.	Everything Passed
CTM_4	Prerequisite: The Swim Pacer Unit is turned on and is on the 'Main Menu' 1. Highlight 'Profile Mode' and press 'Select' 2. Highlight any Lap Pace and press 'Select' 3. Press the Up button repeatedly. 4. Press the Down up repeatedly. 5. Set a desired value for the lap pace. Record this value. 6. Press 'Select' 7. Highlight the Lap Pace in selected in step 2 and press 'Select' 8. Observe the lap pace time.	1. The display enters the 'Profile Mode' display. 2. The display enters the specific lap pace highlighted and enters a new display screen. 3. The pace time will increase by 1 second every time the up button is pressed. At the same time, the pace bar will move to the right. When the current pace time displayed is 60 seconds when the up button was pressed, then the pace time should still remain at 30 seconds. 4. The pace time will decrease by 1 seconds every time the down button is pressed. At the same time, the pace bar will move to the left. When the current pace time	Everything Passed

	9. Set a desired value for the lap pace. Record this value. 10. Press 'Back' 11. Highlight the Lap pace selected in step 2 and press 'Select' 12. Observe the lap pace time. 13. Repeat steps 2-12 for all the other 4 Lap Paces 14. Press 'Back' 15. Return to the 'Profile Mode' page, highlight 'Run' and press 'Select'	displayed is 16 seconds when the down button was pressed, then the pace time should still remain at 16 seconds. 5. Value has been set and recorded on a piece of paper. 6. The display will go back to 'Profile Mode' display page. 7. The display enters the specific lap pace highlighted and enters a new display screen. 8. The lap pace time displayed is equal to the value recorded in Step 6. 9. Value has been set and recorded on a piece of paper. 10. The display will go back to 'Profile Mode' display page. 11. The display enters the specific lap pace highlighted and enters a new display screen. 12. The lap pace time displayed is equal to the value recorded in Step 6 and NOT equal to the value recorded in Step 9. 13. Results should be similar from Expected Results 2-12. 14. The display goes back to the 'Main Menu' 15. The screen will show a new display which indicates your current pace time, as well as your lap number.	
CTM_5	Prerequisite: The Swim Pacer is in 'Profile	1. The screen will show a new	Everything Passed

	Mode' and the lap paces have been pre-set to their desired values. 1. Highlight 'Run' and press 'Select' 2. Press the 'Up' button 3. Press the 'Down' button 4. Press the 'Back' button 5. Repeat Steps 1 to 4, but on all other 4 lap paces (Laps 2 to 5)	display which indicates your current pace time, as well as your lap number (Lap 1 as start) 2. Nothing happens. 3. Nothing happens. 4. The display goes back to 'Profile Mode' menu. 5. The results should be similar to 'Expected Results' 2 to 4.	
CTM_6	Prerequisite: The Swim Pacer Unit is running on Profile Mode. 1. Observe the monitor. 2. Observe the monitor after the sequential lights circuit does a complete lap 3. Wait until all 5 laps are finished. Observe the screen.	1. The monitor should display the current Lap number and its corresponding pre-set lap time. 2. The lap number increases by 1. The lap time changes to correspond with the new lap number. 3. The screen goes back to 'Profile Mode' after all 5 laps have finished	Everything Passed
CTM_7	Prerequisite: The Swim Pacer Unit is turned on and is on the 'Main Menu' 1. Highlight 'Set LCD contrast' and press 'Select' 2. Observe the monitor display and its contrast. 3. Press the Up botton repeatedly. 4. Press the Down Button repeatedly.	1. The display enters the 'Set LCD contrast' page. 2. There is a 'contrast bar' which identifies the intensity of the LCD contrast. 3. The 'contrast bar' will move to the right every button push. The LCD contrast will brighten every button push as well. When the 'contrast bar' is on the right-most, LCD contrast will not change	Everything Passed

	5. Adjust the LCD contrast to your desired contrast. 6. Press 'Select' 7. Highlight the 'Set LCD cotnrast' and press 'Select' 8. Adjust the LCD contrast to any value aside from the value in step 5. 9. Press 'Back'	anymore. 4. The 'contrast bar' will move to the left every button push. The LCD contrast will get dimmer every button push as well. When the 'contrast bar' is on the left-most, LCD contrast will not change anymore. 5. The LCD contrast has been adjusted to the desired. 6. The display goes back to the 'Main Menu'. The contrast does not change. 7. The display enters the 'Set LCD Contrast' display page. 8. LCD contrast has been adjusted. 9. The display goes back to the 'Main Menu'. The LCD contrast goes back to the value that was set in step 5.	
CMT_8	Prerequisite: The Swim Pacer Unit is turned on and is on the 'Main Menu' 1. Highlight 'About' and press 'Select' 2. Observe the Screen 3. Press the 'Back' button	1. The display enters the 'About' screen. 2. The display shows the Swim Pacer Unit logo, as well as the following text: "Swim Pacer Unit by: Mark Alikpala, George Garcia, and Miao Lu" 3. The display will go back to the Main Menu.	Everything Passed
CMT_9	Prerequisite: The Swim Pacer Unit is turned on and is on the 'Main Menu' 1. Highlight 'Authors'	1. The display enters the 'Authors' screen. 2. The display shows the pictures of the Authors, as	Everything Passed

	and press ‘Select’ 2. Observe the Screen 3. Press the left or the right button (Select or Back)	well as their names on the bottom: “Lu, George and Mark” 3. The display will go back to the Main Menu.	

B.2 Controller-to-lights test

Purpose: The part of this test ensures that the communication between the controller and the sequential lights circuit

Requirement	Test Steps	Expected Test Results	Results/Comments
CTL_1	1. Turn on the Swim Pacer Unit.	1. The display turns on. No lights on the sequential light circuits are turned on.	Everything Passed
CTL_2	Prerequisite: User should be in "Manual Mode" or "Profile Mode". The sequential light circuit must be already running. 1. Press the "Back" button	1. The sequential light circuit should turn off.	Everything Passed
CTL_3	Prerequisite: User should be in "Manual Mode" or "Profile Mode". The sequential light circuit should be off. 1. Press the 'Run' button if in Manual Mode or scroll down to the "Run" button in "Profile Mode" then press the "Select button.	1. The sequential light circuit should turn on from the start (LED closest to the controller)	Everything Passed

CTL_4	Prerequisite. User should be in "Manual Mode". The sequential light circuit must be running. 1. Press the Down button multiple times 2. Observe the sequential lights circuit as you decrease the time 3. Press the Up button multiple times. 4. Observe the sequential lights circuit as you increase the time.	1. The time displayed for "Lap Pace" decreased significantly. 2. The sequential light circuit traverses the pool faster. 3. The time displayed for “Lap Pace” increased significantly. 4. The sequential light circuit traverses the pool faster. *Note: We asked the users to decrease/increase the pace significantly because it is hard to observe the change in pace by 1 second intervals	Everything Passed

B.3 Sequential Lights Circuit Test

Requirements	Test Steps	Expected Test Results	Results/Comments
SLC_1	Prerequisite: User should be in "Manual Mode" or any of the three "Profiles". The sequential light circuit should be off. 1. Press the 'Run' button if in Manual Mode or scroll down to the "Run" button in "Profile Mode" then press the "Select button. 2. Observe the sequential light circuit	1. The sequential light circuit should turn on. 2. Only 1 light is on at a given point in time.	Everything Passed

SLC_2	Prerequisite: User should be in "Manual Mode" or any of the three "Profiles". The sequential light circuit should be off. 1. Press the 'Run' button if in Manual Mode or scroll down to the "Run" button in "Profile Mode" then press the "Select button. 2. Observe the sequential light circuit	1. The sequential light circuit should turn on. 2. The lights sequentially "traverse" from right to left or from left to right one by one.	Everything Passed
SLC_3	Prerequisite: User should be in "Manual Mode" or any of the three "Profiles". The sequential light circuit should be off. 1. Press the 'Run' button if in Manual Mode or scroll down to the "Run" button in "Profile Mode" then press the "Select button. 2. Observe the sequential light circuit	1. The sequential light circuit should turn on. 2. All lights should be able to turn on (one at a time).	Everything Passed

B.4 Tolerance Tests

Purpose: This test ensures that the sequential lights circuit is accurate up to 0.2 seconds

Requirements	Test Steps	Expected Test Results	Results/Comments
TOL_1	Prerequisite: User should be in "Manual Mode" or any of the three "Profiles". The sequential light circuit should be off. 1. Press the 'Run' button if in Manual Mode or scroll down to the "Run" button in "Profile Mode" then press the "Select button. 2. Using a digital stopwatch, record the time it takes for the sequential lights to traverse across a length of a pool. 3. Compare the time you measured with the time displayed on the screen.	1. The sequential light circuit should turn on. 2. The time is recorded in a digital stopwatch. 3. The time should only be off by a maximum of 0.2 seconds.	Everything Passed
TOL_2	Prerequisite: The user is in 'Manual' mode. The pace time displayed is set to 60 seconds. The sequential light circuit is not yet running. 1. Repeatedly press the up button. 2. Press Run. 3. Using a digital stopwatch, record the time it takes for the sequential lights to traverse across a lap of a pool.	1. The time displayed on the monitor should still be 60 seconds. 2. The time sequential light circuit turns on. 3. It should take 60 seconds (±0.2 s) for the sequential light circuit to traverse across a lap of a pool	Everything Passed
TOL_3	Prerequisite: The user is in 'Manual' mode. The pace time	1. The time displayed on the monitor	Everything Passed

	displayed is set to 16 seconds. The sequential light circuit is not yet running. 1. Repeatedly press the down button. 2. Press Run. 3. Using a digital stopwatch, record the time it takes for the sequential lights to traverse across a lap of a pool.	should still be 16 (±0.2 s) seconds. 2. The time sequential light circuit turns on. 3. It should take 16 seconds for the sequential light circuit to traverse across a lap of a pool	

B.5 Hardware Requirements Test

Requirements	Test Steps	Expected Test Results	Results/Comments
HRD_1	1. Disconnect the connection from the demultiplexer and an LED. 2. Connect the demultiplexer to an ammeter. Connect the output of the ammeter to an LED. 3. Verify that the measured current is between 140 mA to 160 mA when the LED is turned on. 4. Repeat steps 1-3 for all LEDs	1. Connection disconnected properly. 2. Connections are properly made 3. The measured current is between 140 mA to 160 mA. 4. Results to be the same as expected results 1-3	Not Tested
HRD_2	1. Using a voltmeter, measure the voltage coming out of the PIC pin when the output is supposed to be HIGH. 2. Using a voltmeter, measure the voltage coming out of the PIC when the output is supposed to be LOW. 3. Repeat steps 1 and 2 for all output pins of the PIC	1. The measured voltage is 5 V when the expected pin is supposed to be HIGH. 2. The measured voltage is 0 V when the expected pin is supposed to be LOW. 3. Results should be the same as expected results 1-2	Everything Passed
HRD_3	1. Press a button 2. Using a voltmeter, measure the voltage into the PIC that corresponds to the button pushed. 3. Depress the button. 4. Using a voltmeter, measure the voltage into the Pic that corresponds into the un-pushed button. 5. Repeat steps 1-3 to the other 3 buttons	1. The button is pressed successfully. 2. The measured voltage should be around 0 V. 3. The button has been depressed successfully. 4. The measured voltage should be around 5 V. 5. Results to be the same as expected results 1-4	Everything Passed
HRD_4	1. Using a voltmeter, measure the voltage coming out of the demultiplexer pin when the output is supposed to be HIGH. 2. Using a voltmeter, measure	1. The measured voltage is 5 V when the expected pin is supposed to be HIGH. 2. The measured	Everything Passed

	the voltage coming out of the demultiplexer pin when the output is supposed to be LOW. 3. Repeat for all utilized demultiplexer output pins.	voltage is 0 V when the expected pin is supposed to be LOW. 3. Results to be the same as expected results 1-2	
HRD_5	1. Using a voltmeter, measure the input voltage into the 5 voltage regulator. 2. Using a voltmeter, measure the output voltage out of the 5 voltage regulator	1. The measured input voltage is 9 V. 2. The measure output voltage is 5 V.	Everything Passed
HRD_6	1. Using a voltmeter, measure the input pin into the 3.3 voltage regulator. 2. Using a voltmeter, measure the output voltage out of the 3.3 voltage regulator	1. The measured input voltage is 9 V. 2. The measured output voltage is 3.3 V	Everything Passed
HRD_7	1. Using an oscilloscope, probe an output pin that is being utilized in the hex shifter when the output is supposed to be HIGH 2. Using an oscilloscope, probe an output pin that is being utilized in the hex shifter when the output is supposed to be LOW. 3. Repeat for all utilized hex shifter output pins. *Note: An oscilloscope is used because serial datas are being sent in a short span of time. It is clearer to see HIGH and LOW values using an oscilloscope.	1. The output pin has a voltage of 3.3 V when the expected pin is supposed to be HIGH. 2. The output pin has a voltage of 0 V when the expected pin output is supposed to be LOW 3. Results should be the same as expected results 1-2	Everything Passed

Appendix C: Terms and Keywords

Demux (DMUX) – Demultiplexer

IC – Integrated Circuit

I/O – Input/Output

LCD – Liquid Crystal Display

LED – Light Emitting Diode

MultiSim – National Instruments® (NI) Multi-purpose electronics Simulator

NI – National Instruments®

nanoWatt Technology – This is currently the industry's lowest power, widest operating voltage range, and most flexible power-managed technology available for embedded systems today.

PIC – Programmable Integrated Circuit

UI – User Interface

Project Specific Acronyms:

CTL – Controller to Light

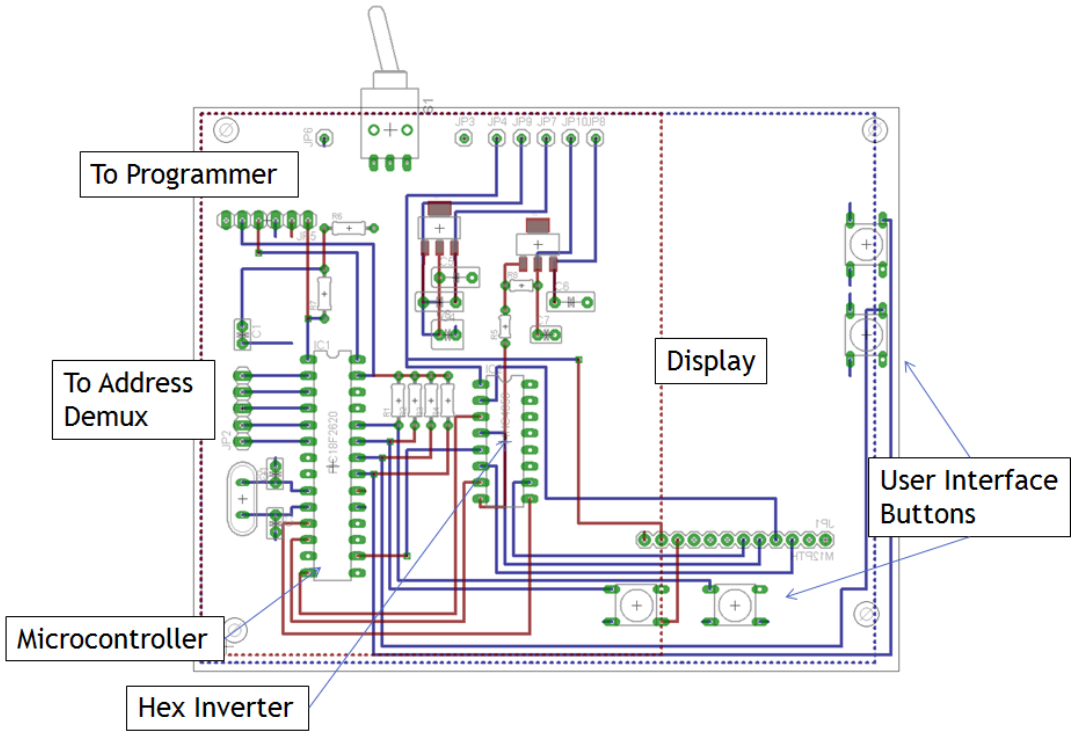
CTM – Controller to Monitor

SLC – Sequential Lights Circuit

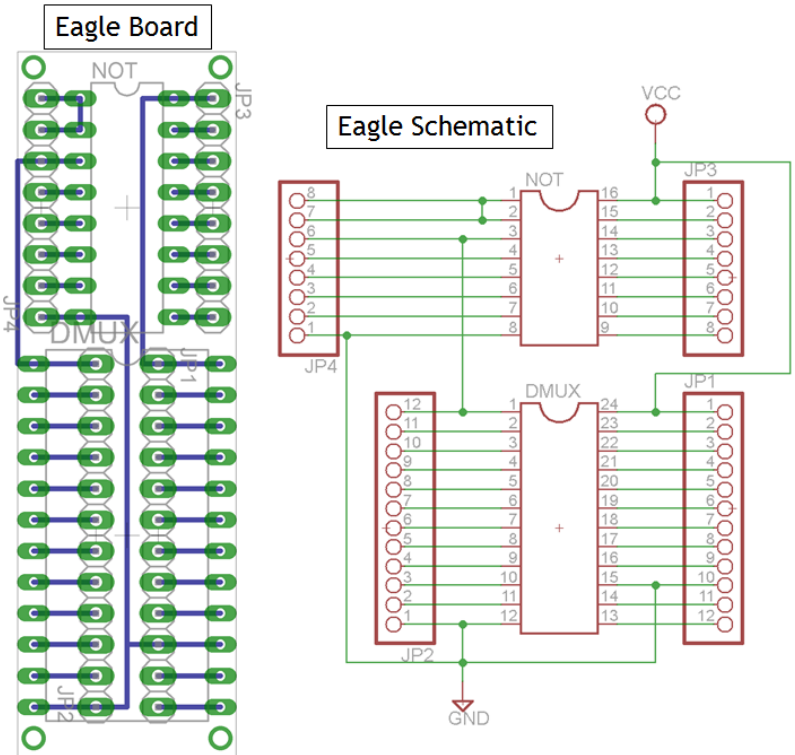
TOL – Tolerance

Appendix D: Eagle Schematics and Board

Controller:

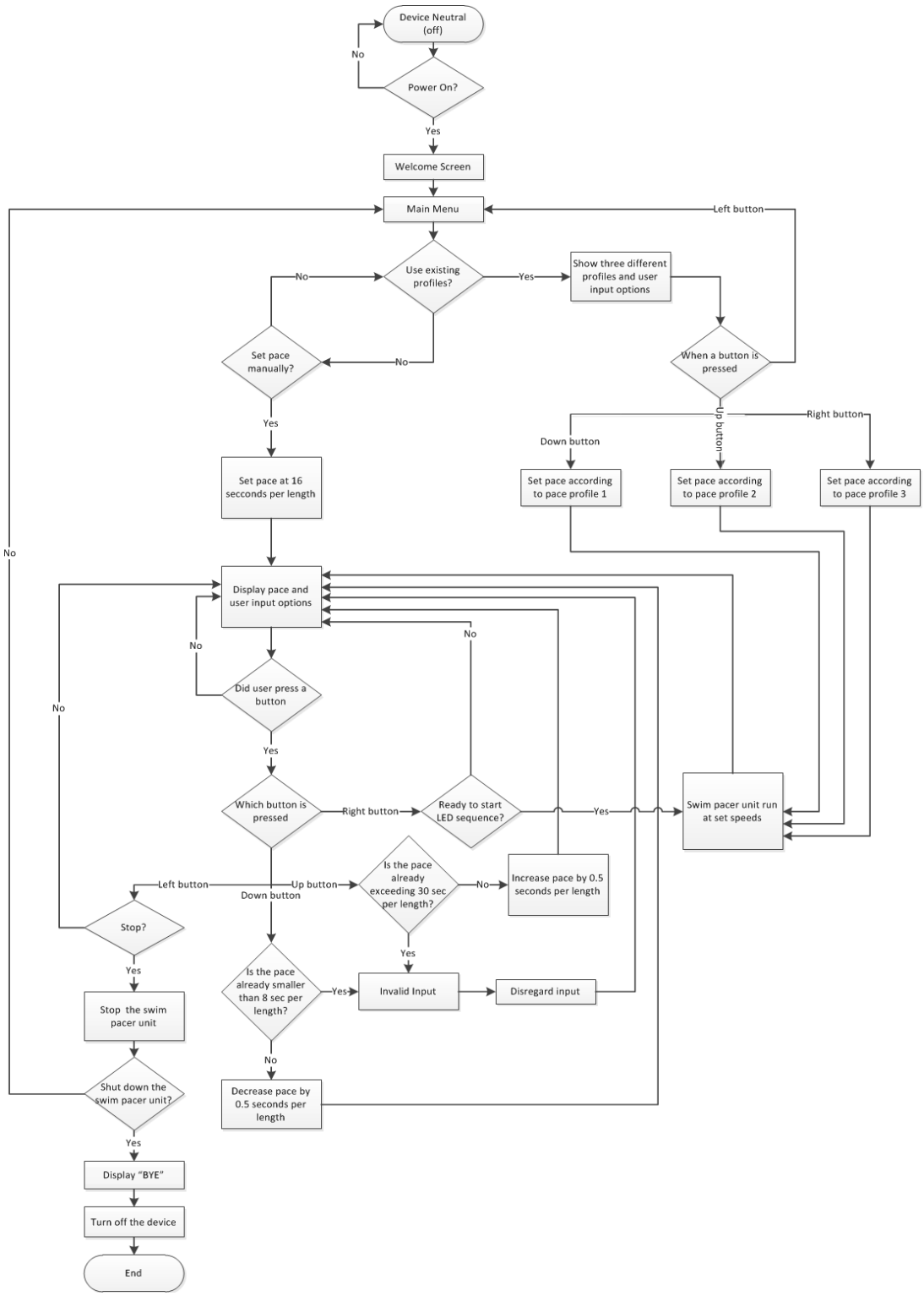


Address Demux:

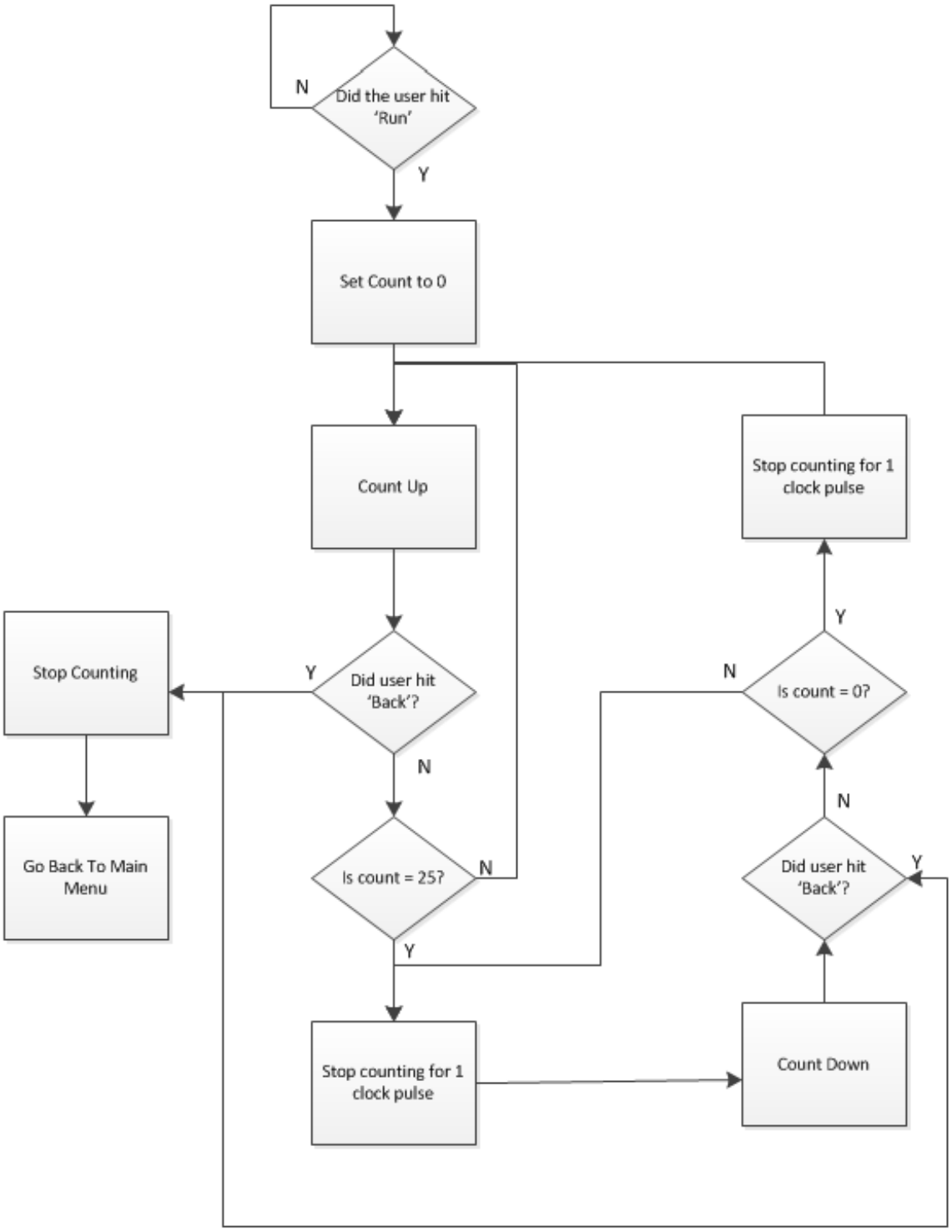


Appendix E: Flowcharts

Flowchart for user interface



Flowchart for counter (for 25 lights)



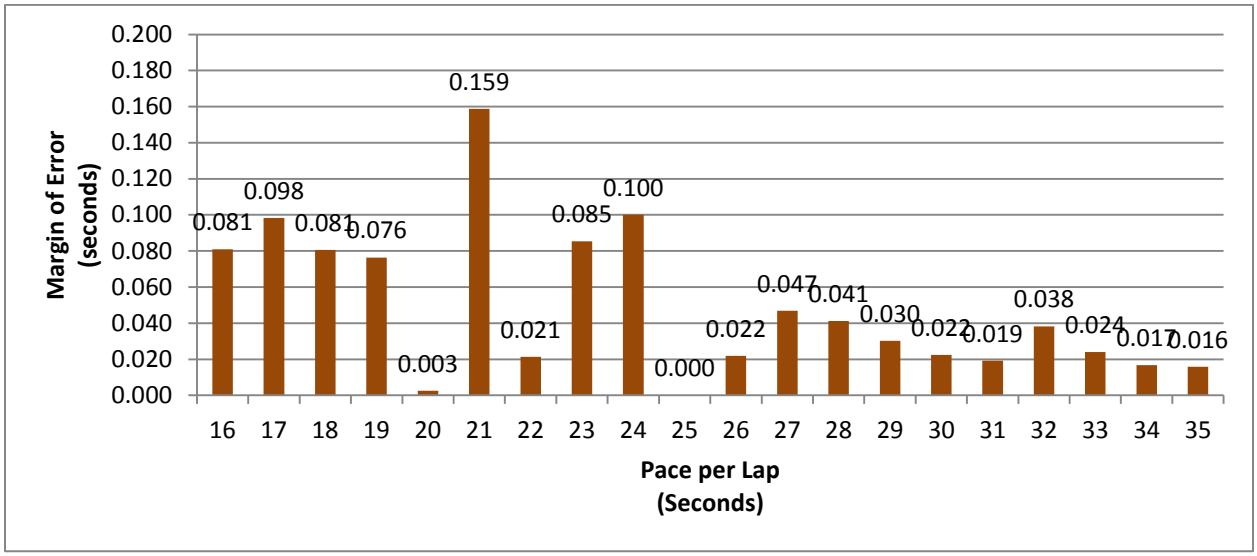
Appendix F: Lap Pace Accuracy

Test: Lap Pace Accuracy

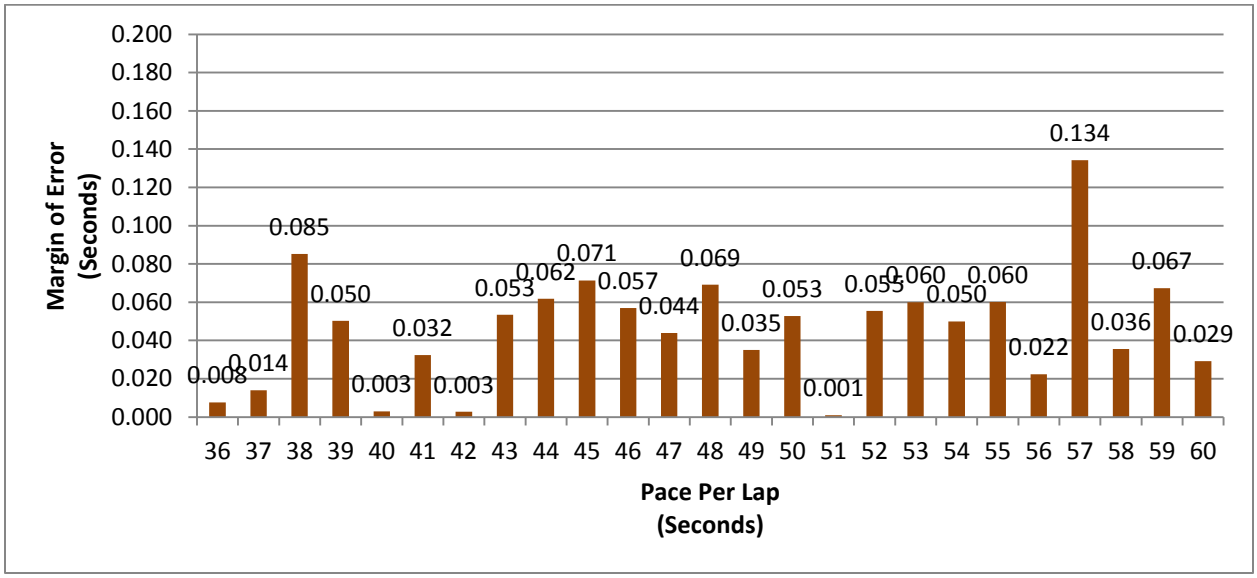
Lap Pace (seconds)	Try 1 (seconds)	Try 2 (seconds)	Try 3 (seconds)	Try 4 (seconds)	Try 5 (seconds)	Average (seconds)	Error (seconds)
16	15.993	16.207	15.935	16.213	16.057	16.081	0.081
17	16.906	16.967	16.933	16..833	16.801	16.902	0.098
18	18.136	18.167	18.033	18.000	18.067	18.081	0.081
19	19.191	18.800	19.397	19.020	18.974	19.076	0.076
20	19.999	19.998	19.874	19.973	20.143	19.997	0.003
21	21.300	21.340	21.287	21.034	21.233	21.239	0.239
22	22.106	22.000	22.000	22.000	22.001	22.021	0.021
23	23.400	22.600	23.000	23.250	23.177	23.085	0.085
24	24.230	23.890	24.070	24.100	24.210	24.100	0.100
25	25.174	25.000	24.835	24.972	25.019	25.000	0.000
26	26.232	25.897	26.015	26.022	25.943	26.022	0.022
27	27.023	27.010	27.028	27.170	27.003	27.047	0.047
28	27.909	27.963	27.808	28.023	28.091	27.959	0.041
29	29.005	28.920	28.999	28.805	29.120	28.970	0.030
30	29.800	29.965	30.199	29.900	30.024	29.978	0.022
31	30.982	30.924	31.156	30.922	30.920	30.981	0.019
32	31.997	31.834	31.909	32.129	31.940	31.962	0.038
33	32.990	33.103	32.924	32.838	32.025	32.776	0.224
34	34.087	34.008	34.024	34.000	33.965	34.017	0.017
35	34.861	35.148	34.829	34.945	35.138	34.984	0.016
36	36.049	35.953	36.000	36.159	35.877	36.008	0.008
37	37.042	36.804	36.959	37.131	37.134	37.014	0.014
38	38.197	38.169	38.071	38.088	37.901	38.085	0.085
39	39.085	38.917	38.852	39.179	39.218	39.050	0.050
40	40.181	39.835	40.191	39.801	40.007	40.003	0.003
41	41.196	40.988	41.079	40.929	40.970	41.032	0.032
42	42.080	41.954	42.041	42.128	41.783	41.997	0.003
43	43.093	43.196	42.925	43.177	42.876	43.053	0.053
44	44.158	44.064	43.882	44.112	44.093	44.062	0.062
45	45.000	45.118	45.155	44.905	45.179	45.071	0.071
46	45.943	46.053	46.063	46.139	46.087	46.057	0.057
47	47.198	47.051	47.068	46.994	46.909	47.044	0.044
48	47.836	48.024	48.152	48.128	48.206	48.069	0.069
49	49.063	48.998	49.114	49.081	48.919	49.035	0.035
50	49.994	50.088	50.209	50.081	49.892	50.053	0.053
51	51.157	50.841	51.039	50.920	51.038	50.999	0.001

52	52.207	52.160	52.003	51.927	51.980	52.055	0.055
53	53.047	52.864	53.144	52.800	52.845	52.940	0.060
54	54.193	53.794	53.863	53.812	54.088	53.950	0.050
55	54.964	54.918	54.854	55.006	54.957	54.940	0.060
56	55.789	56.162	55.826	55.908	56.203	55.978	0.022
57	57.180	57.143	57.118	57.056	57.174	57.134	0.134
58	58.103	57.997	58.029	57.973	58.076	58.036	0.036
59	58.867	59.155	58.801	58.927	58.913	58.933	0.067
60	59.916	60.185	59.833	60.093	60.119	60.029	0.029

Margin of Error 16 to 35 seconds per lap



Margin of Error 36 to 60 seconds per lap



Test: Voltage Regulators

Regulator Type	Input (V)	Output (V)
5 V Regulator	9	4.97
3.3 V Regulator	9	3.32

Test: PIC Pins output voltage

When Expected Output Signal is:	Pin Voltage (V)
HIGH	4.923
LOW	0.2

Test: Demux Pin Output Voltage

When Expected Output signal is:	Pin Voltage
HIGH	4.916
LOW	0.2

Test: Hex Shifter Pin Output Voltage

When Expected Output signal is:	Pin for:	Voltage (V)
HIGH	SCK	3.29
LOW		0
HIGH	DIO	3.28
LOW		0
HIGH	/CS	3.3
LOW		0
HIGH	RESET	3.28
LOW		0

Test: Buttons

Button #	Voltage when pressed (V)	Voltage when unpressed (V)
1	0.02	4.98
2	0.023	4.98
3	0.014	4.98
4	0.023	4.98