Final Report

ASYNC

Automatically Synchronizing Crowd Interaction Device

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Executive Summary

Concerts are a mainstay of the American lifestyle, bringing people and their bands together in an entertainment experience on the scale of a sports game where everyone wins. Making an individual's concert experience better, both to attract more people to concerts and to improve the brand of a band, is a very profitable endeavour. Our Audience Interaction Device, or ASync, aims to achieve this goal by providing a brand new way for individuals, bands and other concert groups to interact with their audiences.

ASync provides value by allowing programmable interactions not just between the audience and the concert music, but also between audience members themselves. It achieves this by flashing multicolored lights within a handheld device based on pre-programmed instructions. For instance, when the user holds the device up, the movement of the device will cause it to change color. When they move it in beat with the music, the lights continue to react, changing color in time to the movement. This encourages audience participation, helping them to experience the music in a new way. Furthermore, when the device moves at the same time as devices around it, that group of devices will synchronize to create a group where all the devices are flashing the same colors at the same time. This additional functionality allows some group displays to be synchronized, like moving all devices in time to a beat or performing 'the wave' with other crowd members.

Other devices exist which seek to provide similar value to concert-goers. The most prominent of these devices was used by the band Coldplay in a concert series. This wrist-based device flashed in time to the music, but it was controlled centrally by AV specialists. Our device decentralizes control of the flashing lights by allowing individuals and groups of people to synchronize their devices' LED displays without the participation of any central party, and is handheld instead of being worn on the wrist.

To achieve our product specifications, our device utilizes a bank of LEDs to flash colors, an accelerometer to track movement, infrared communication capabilities to communicate with other devices, and a microcontroller to control all of the inputs. These device pieces are wrapped into a compact package that a user can hold in one hand and which is durable enough to survive

a drop. These pieces of hardware allow us to achieve all of the design goals that we need while allowing only communication with nearby devices.

Having laid out our plans for display hardware, communication hardware and software, we created our device. Our final design achieved all of the design goals we set out from an electrical and software standpoint. To verify our device was functioning properly, we first tested each device by itself to see if its lights flashed as expected. We then used the devices in small groups of two to five to verify that the multi-device interactions worked. To improve upon this device further, more of the bugs with the communication software should be worked out to allow for more group audience interaction. Also, a large scale test should be run with hundreds instead of tens of devices to fully test our product and verify that group interactions like ‘the wave’ propagate correctly. Finally, the device would benefit from an update to its hardware design to make mass manufacturing easier.

Problem Definition

Introduction

Audience interaction in large concerts and events adds another dimension to the experience of an individual attending the event. Audience interaction has always been present in most events, including dancing, singing, chants, apparel, or synchronized actions like the "wave." In more recent events, the advent of smartphones in the new digital age have contributed to these interactions. Concertgoers use their cellphones to record or use the light on their phone and wave it in synchronization to add to the general environment of the concert.

Although most people own a smartphone today, the level of synchronized interaction is limited to each individual's participation. Attempts have been made to increase synchronization with special applications using a central communication unit and the color-capable smartphone screens. These can be difficult to implement since they're not always easy and intuitive to use. A different solution to synchronizing interaction is needed, one that is simpler and doesn't require multiple steps to start participating.

This document proposes a design to a low-cost device that could be handed out for free at events. The device includes an accelerometer to detect the participant's movements, a multi-colored light to create a display, and a form of communication to interact with hundreds or thousands of other similar devices. The device automatically synchronizes (A-SYNC) with nearby devices, combining their own detected movement and the detected movements in nearby devices to create an overall effect in a large group.

Problem Statement

The goal of this project is to create a system of devices that can interact wirelessly and automatically with each other. The communication between the devices will require no active user inputs—the synchronization of the devices is based on the passive motion of the users. The purpose of the device is to enhance the experience of users who attend large events as it will allow them to interact with others around them. The design must meet requirements in communication, display, range, power, and cost. The system should be able to communicate using only sensors; there cannot and will not be any manual inputs. The devices should show synchronization in the form of a light and the light of each device should synchronize with respect to the activity of the users. The range of a device must be 2-3 meters, so that it can communicate with other nearby devices in a crowd. Each device also needs to have a power source that can last for at least six hours. Finally, in large-scale production, each device should cost approximately $5.

Client Needs

The following table lists the customer's needs for this project.

#	Need	Importance (5 is high)
1	Device shall contain sensors and process information related to device movement, hereafter referred to as 'movement sensors'.	5
2	Device shall be able to communicate the information gathered by its 'movement sensors' to its neighbors	4
3	Device shall have a display.	5
4	Device shall be able to communicate wirelessly with its neighbors at a distance of up to 2-3 meters without the aid of an intermediate device, such as a smartphone.	5
5	Device shall be able to power itself for at least six hours	5
6	Device should cost less than 5 dollars if it were mass produced	3
7	Device shall be able to synchronize its light with its neighbors in some sort of 'cluster' when the 'cluster' member's 'movement sensors' detect movement at the same frequency	4
8	Device synchronization must be tolerant of the imprecise behavior of nearby devices, including at least a few that may	3

	not be moving at all	
9	Device shall have a name other than ‘Device’	5

Table 1. Customer Needs

Product Design Specification

The following table lists lists specific design metrics and which customer needs are met by those metrics.

#	Need #s	Metric	Units	Ideal Value	Acceptable Range	Importance (5 is high)
1	1,7,9,10	Directional Sensing	Axes	3	3+	5
2	6	Cost	Dollars	5	4 to 20	3
3	4	Range	Feet	9	6-12	5
4	2,4,7,8	Connection Capacity	Clients	8	4-10	5
5	5	Battery Life	Hours	6	5+	4
6	3	Display Range in Dark	Feet	1000	800-1200	4
7	7,8	Synchronization/ Reaction Time	Milliseconds	250	100-400	5

Table 2. Design Specifications

Design Description

Overview

This device design is composed of two subsystems: hardware and software. The hardware subsystem connects the sensors and outputs to a microcontroller. The software subsystem enables the device to react to external stimuli in a deterministic way. The hardware device includes a microcontroller, one Adafruit neopixel RGB LED, one LIS3DHTR accelerometer, seven TSOP38338 infrared receivers, seven OED-EL-1L2 infrared transmitters, a nine volt battery, and a 3D printed case seen in Figure 1. These components are all purchased off the shelf, so the hardware design is primarily concerned with part selection and layout. To accomplish our software goals we wrote software to run an an ATMega328 microcontroller. This allowed us to use the Arduino development environment to quickly integrate our external sensors with our control software. The control software itself is a state machine which responds to a set of external stimuli in a set way. Our exact hardware choices are laid out in the 'Budget' section of this document. These devices were chosen to both meet the required sensing requirements as seen in the Product Design Specification 'Customer Needs' section.

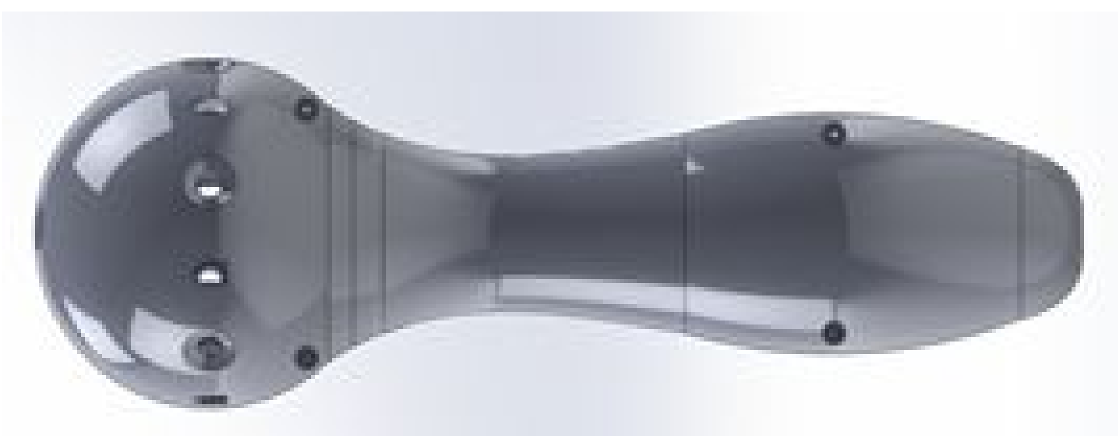


Figure 1. CAD rendering of hand-held interaction device.

Hardware

Six infrared (IR) LEDs are configured in a horizontal hexagon around the device with an additional LED facing upwards. Each LED is paired with a receiver when placed in the case. Since each LED has a 60-degree beam angle, the device will be able to communicate to any device around it using these six IR LEDs. The top LED will also help add to the general area the device can communicate to. The 60-degree angle was chosen to reduce the possibility of multiple transmissions colliding on one receiver.

The TSOP38338 receivers were chosen because of their ability to filter out ambient light noise. Most events will have significant amounts of different light, so filtering will be needed to avoid losing transmissions from other devices. Because of their filtering ability, the TSOP38338 receives transmissions in short bursts. This will help with our design since the devices are hand-held and the line of sight communication with other devices can be very brief. The TSOP receiver also has a 60-degree viewing angle, up to 20 meters. Since this is much farther than our required range, the TSOP receiver is an ideal match for the LED configuration that will be used.

The accelerometer, LIS3DHTR, was chosen because the device needed to sense movement. This accelerometer has the ability to sense velocity and acceleration. This unit is also produced in a through hole package, which was useful in testing and easier to place on the printed circuit board.

The display was implemented with one NeoPixel RGB LEDs placed inside the top ball in the case. We wanted this display of brightly colored light to make each device clearly visible in a crowd, however brightness ultimately depended on where the LED was placed in the case. Using bright LEDs does make it easily apparent that the devices are synchronized with one another just by observing how they change color and brightness in unison. These LEDs have integrated driver chips, are serially addressable, and can be chained together. The full hardware diagram can be seen in Figure 2.

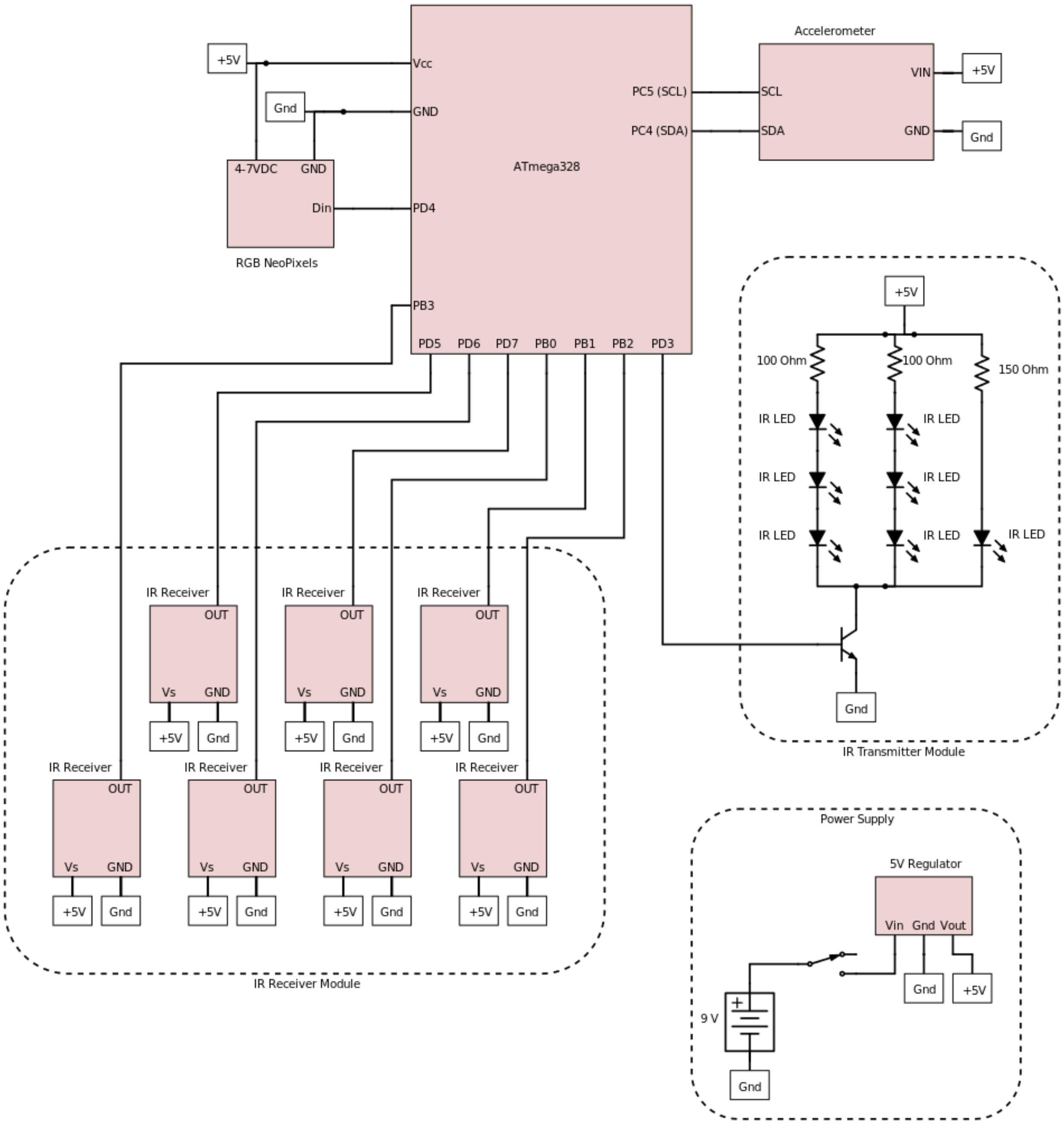


Figure 2. Schematic diagram for hardware design.

Software

The software is written in Arduino C and makes use of several files and several libraries, including the Adafruit LIS3DH library, the Adafruit general sensor library, the Adafruit NeoPixel library, and the IRremote library by the user *sherriff*. The software is module, with communication between the modules occurring only via a set of global variables stored in a file called "stateGlobals.h". A parent module called "async" is used to initialize all other modules and run a loop which calls the accelerometer controller, IR receive controller, IR transmit controller, and LED controller. The IR transmit controller is also called when the LED controller determines that its state has changed. Some examination of the details of these files is warranted.

The accelerometer controller reads values in from the accelerometer and updates its corresponding global variable, AccelState. It does this by translating accelerations in the x, y, and z dimensions into a single velocity and instantaneous acceleration value. These values, and stored histories of these values and derivative values, are then used to set individual bits in the AccelState global variable. The bits in the AccelState correspond to a long pause in movement (as though the wave is about to start), an indicator which notes when we could be doing the wave but are not paused, an indicator saying there has been a very large acceleration, three bits indicating slow, medium (static), or large instantaneous accelerations, and a very large and long acceleration change. These bit settings can help to inform other modules of the state of movement of the device.

Two of the software modules are used as an IR receive controller and an IR transmit controller. These modules pull in or push out the known state of the device, which is itself an encoding of the LED state, the wheel position of the device (described later), and the device's unique ID. The ID is randomly generated using the Arduino 'random' function and seeded with a voltage level from a floating pin. It is highly likely to be unique due to its 16 bit length, but if another device has the same ID the effect will be that those devices will not interpret communications from each other.

The final module is the LED controller. This module uses global variables including AccelState, LEDState (which it sets itself), RxState (set by the receive controller), and wheelPos to determine what to display on the NeoPixel LEDs. The outputs it selects can include a wave output, where the device is white; a moving or static output, where the device's colors slowly rotate; or a beating output, where the color jumps by a primary step and the wheelPos variable is updated to continue slowly rotating through the color spectrum. The result of this module is a colorful display out of the RGB lights provided by the NeoPixel as seen in Figure 3.

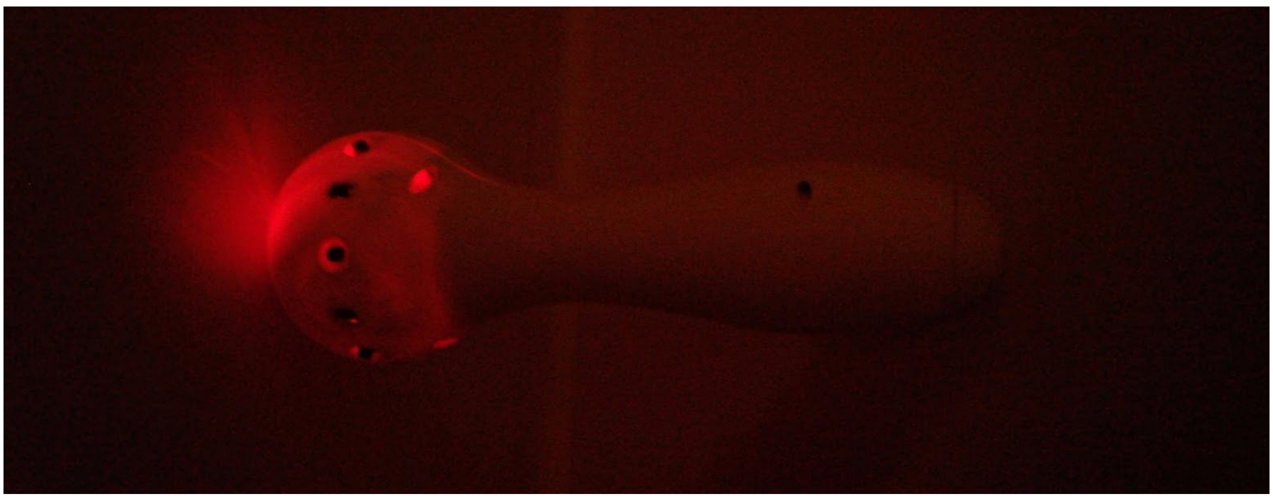


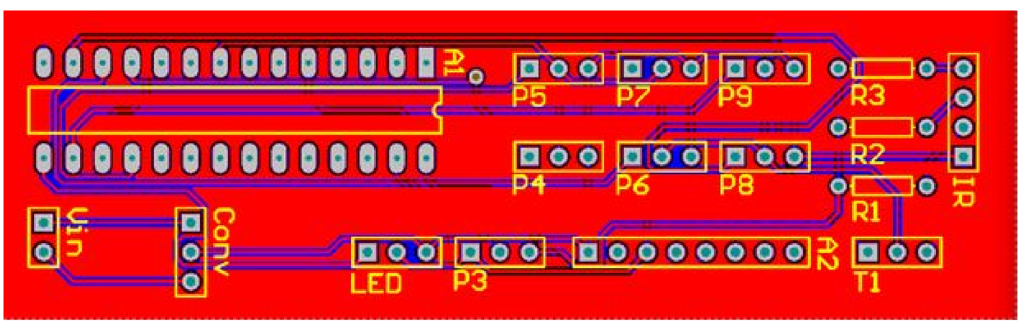
Figure 3. Color output from the Device

Design Evaluation

Evaluation by Prototyping

We prototyped our device in two stages. In the first prototyping stage, we used Arduino development boards to test the individual components chosen for the final device. We used simple library code available on various internet resources to test the IR receivers, IR transmission, and accelerometer actions. With these separate tests, we were able to determine that the accelerometer was capable of sensing three different axes of acceleration, which met design specification 1. The IR transmitters and receivers were capable of communicating at a range of more than 6 feet, meeting design specification 2. The accelerometer and IR components were also able to communicate very quickly (under 100 ms), meeting design specification 7.

After determining that the individual hardware components were capable of meeting the design specifications, we designed a circuit board to combine the components and test the overall



hardware design. We printed a single circuit board to verify the connections before producing the

Figure 5. Prototype PCB design sketch

ten prototype devices requested by the customer. Figure 5 shows the basic hardware layout of our PCB design. The processor connects to A1, the IR receivers to P3-P9, the accelerometer to A2, the voltage regulator to the Conv header, the RGB LEDs to the LED header, and the IR LED chains to the appropriate locations on the IR header, with appropriate resistors and transistor installed.While testing the initial PCB prototype, we discovered several connection errors. We also discovered that the Atmega328 processor needed to be connected to an external 16Mhz oscillator to avoid reprogramming several libraries needed for the hardware devices we were using. Our second PCB iteration corrected the connection issues and included the oscillator header with headers for some decoupling capacitors. With the results from our individual hardware testing, and the affirmation that our PCB worked properly, we moved on to evaluate the device by analysis.

Evaluation by Analysis

After assembling our second PCB, we proceeded to analyze our final prototype to produce the effects desired by the customer. We analyzed the three actions we decided to display; following a beat, synchronizing color, and following a wave in a crowd. We made several assumptions and simplifications for our analysis. Given the small number of prototype devices we used in comparison to the amount to be used in our planned applications, we had to assume that the actions seen in 5-10 devices would be similar to the actions seen overall in a large stadium. We also assumed that the devices would be stationary before a wave occured, since most people stop moving and watch the wave as it approaches them. The devices are programmed to communicate with at most 10 other devices, meeting specification 4. We were also able to determine that the device would last at least 5 hours on a 9V battery, meeting design specification 5. The devices are visible in the dark from 1,000 feet away, meeting specification 6.

When we tested the beat following, we discovered that the accelerometer responds better to slower defined movements than faster movements. The accelerometer movements had to be averaged enough to avoid large changes in accelerometer data causing the device's color to change twice on one beat. We also discovered that determining the difference between an up/down movement and side-to-side movement is essentially impossible without using a gyro with the accelerometer or IMU in place of the accelerometer. Thus, the up/down and side-to-side movements elicit the same reaction from the LED displayed on the device.

The color synchronization between the devices happens when devices receive communication from other devices. However, since the devices will usually be moving while communicating their color data to other devices, it is very possible that a device's color will change directly after it transmitted the previous color. A second device that may pick up this color will then be offset by a primary color from the first device. However, all of the devices will still continue to synchronize and continue to update their color to the majority color in the group. The end result is that the devices synchronize to the same three positions on the color wheel, and will all slowly change at the same rate on the color wheel, displaying a combination of the same three colors at all times.

Since we were not able to determine up/down directions from the accelerometer data, we had to use an alternative method to trigger a wave response from the device. We decided to make the assumption mentioned above; that the devices would be stationary before a wave occurred. The devices cannot enter the wave state and react appropriately with a white light unless they have remained period for a short time before moving up and down and also received a wave communication or “wave ready” from another device. All of the devices will transmit “wave ready” communications when they have remained stationary for a period of time. Because of this, a single device will never turn its light white unless it is communicating with another stationary device. We have successfully tested the wave action response with five devices, but the action is also affected by the same acceleration movement restrictions that the beat-following action is.

The successful testing of these three designed actions meets the customer’s need for the device to perform at least three distinct actions. Further actions could be implemented with more software development, and all of the actions could also be improved by implementing more advanced hardware, such as an IMU or gyro.

Evaluation by Customer

Our internal customer was David Lilja, and our external customers are concert-goers, concert venues and bands. To evaluate our device, we asked all of these parties to examine the device’s aesthetics and sometimes operating function. It is assumed that the device’s functionality can be enhanced by creating additional actions to satisfy additional customer needs. Therefore the main criteria on which to evaluate our device has been its general goals, like multicolored lighting, multi-device synchronization, and its mechanical design. To have our customers evaluate this functionality, we listened to Dr. Lilja during our design presentation, surveyed concert-goers and talked to band members.

Dr. Lilija, who both created the initial design specifications and was involved in the design and prototyping process, was the first customer to evaluate our device. He primarily evaluated the device on the basis of whether or not the device met the product design specifications that he set forth when the project was initiated. Based on these criteria, we met his expectations. He also evaluated the device from the perspective of a concert-goer. With this perspective, he made the comment that it may be better to have the device strapped to the hand, or for small changes to be made to the patterns that the lights can create. Making such changes would enable a larger number of potential customers.

Our next set of customers we talked to were concert-goers. To evaluate the device from this perspective, we surveyed 10 potential customers not involved in the design process. These potential customers were between the ages of 20 and 23. The results of the 10 customer survey are shown below in Table 2. Based on this small survey, there does appear to be a market for this device. Most users indicated some interest in using the device, and said that such use would be worthwhile. However, most of the customers also said they were not interested in paying the amount of money we would charge, which indicates that the device may cost too much. Because the cost of a single device may be amortized over many uses if we rent each device, this may end up being the best business model. However, there was also a set of users who were interested in purchasing the device outright, and additional market information would be needed to verify that they are willing to pay significantly more for the device than it costs to manufacture. These customers also made some comments which are not apparent in the survey. These comments were similar to David Lilja's: they suggested adding a strap so the device didn’t fly off when moved quickly, and there were several comments about the design’s appearance, none of which were inherently negative.

Question	Yes / Good	No / Bad

A toy would be fun	7	3
Paying 10 dollars would be ok	4	6
Renting for 5 dollars would be fun	4	6
Design?	9	1

Table 3: Customer Survey

The final group of customers are bands. Some bands, like Coldplay, are known to be interested in using flashing lights or devices like this one. We asked one band member, Jackson Jaro, what he thought about having the device at one of his performances. He said, “It would be groovy.” However, he also commented that it would be okay only, “If they don’t throw it at you… although if they did, that would be our fault anyway….” This positive response reflects well on our device.

Conclusions and Recommendations

Meeting the Product Design Specifications

The goal of this project was to create a system of devices that can interact wirelessly and automatically with each other. The communication between the devices will require no active user inputs—the synchronization of the devices is based on the passive motion of the users. The final design met requirements in communication, display, range, power, and cost. The system is able to communicate using only sensors; requiring no manual inputs. The information is communicated using IR sensors and is provided by user movements, captured by an accelerometer. The devices show synchronization in the form of a light and the light of each device synchronize with respect to the activity of the users. By using IR sensors, the range of the device is controlled to communicate with other devices within 2 meters. Each device also contains a power source that can last for at least five hours. In the design specification, it was intended for the power source to last for at least six hours. However, the voltage converter that was available to us during the prototype stage needed a 9-volt battery. Finally, in large-scale production, each device should cost approximately \$5. In the final design, the cost for each device in a production scale of 10,000 would be \$8.62. Half of this cost is due to the accelerometer, which is priced at \$4. In mass production, the price of the components are expected to decrease and meet the \$5 goal.

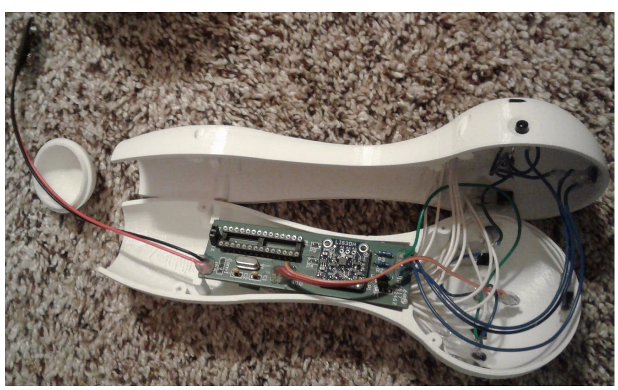


Figure 5. Exposed PCB in the device case

Recommendations for Improvement

We believe there are four primary ways to improve the product. First, we could achieve better synchronization between devices by improving the sending and receiving of communications. This functionality works, but it's possible to further improve our software to smooth out some inconsistencies in observed behavior. Second, we could improve the manufacturability of the device by changing its PCB layout. Right now our PCB, seen in Figure 4, has many wires soldered onto it that lead to the IR receivers, IR transmitters, and NeoPixel LEDs. This makes manufacturing unnecessarily difficult, so those wires should come off and be replaced by an irregularly shaped PCB that can be placed in the ball of the device with the electronics soldered directly on. Our third improvement is making more actions - both group and individual - for specific applications. The exact activities that would be added are unknown, but it is likely that any potential customer would want to add some (or many) such activities. Our fourth and final improvement would be improving gravity detection. Currently our device only contains an accelerometer and not a gyroscope, so we cannot determine which detection is down. By adding a gyroscope, our device would be able to smooth out many of its actions and create entirely new ones that are not possible without this additional sensor input.

Marketing Opportunities

We envision our device being used in three types of settings. The first and intended setting is in concerts. The ability of this device to change color when the audience is moving it and then to work together in groups represents a unique way for concert-goers to show that they love the music they're hearing, or that things aren't going so well. With this competitive advantage over cell phones or other devices, we could focus on marketing the device as the most advanced way to interact with an audience. Another potential market is large gatherings with a long wait time. These are events where audience members file into the location slowly and the organizers risk losing the interest of those audience members. If this device is viewed as a toy, it can help occupy the audience while it waits for the event in question to begin, and then use the device during the event as well. A final market is small demonstration groups, like flash mobs or small stage performances. This market would be more demanding, likely requiring that the device perform specific functions which it is not currently capable of doing. Therefore, serving this market would require some additional work on allowing an external party to modify the actions that the device can make based on its movement and received communications.

Appendix

Project Timeline

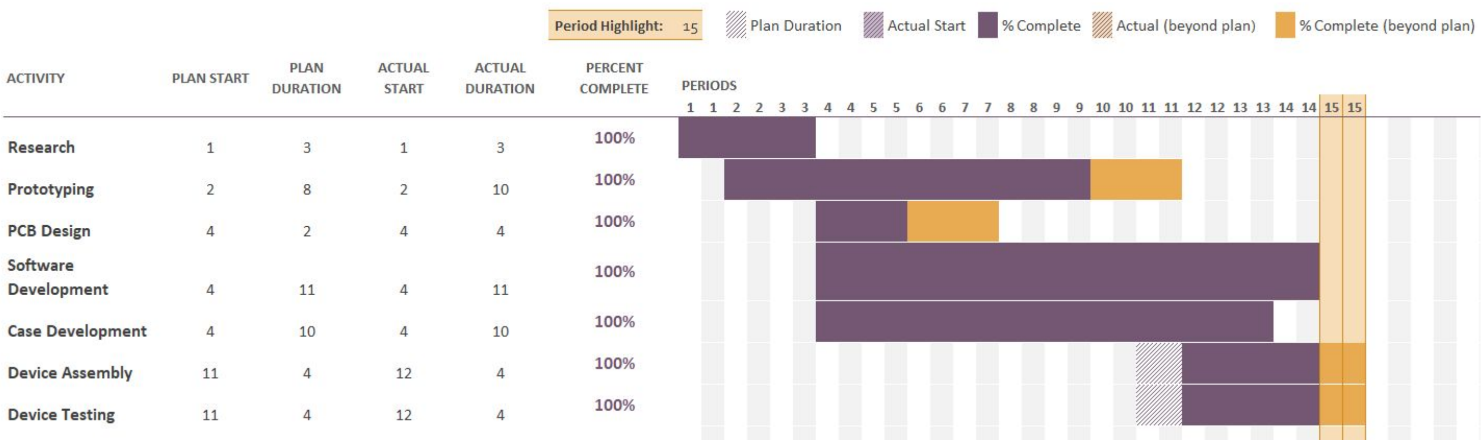


Figure 6. Gantt Chart of our Timeline

Budget

The budget was confined to three hundred dollars. We were required to construct ten devices for a demonstration under this budget. To accomplish this, we kept the cost of each prototype device under thirty dollars. There is an additional requirement to keep a mass-manufactured version of the device under five dollars. To demonstrate the cost of both prototyping and mass production, the following table lists all of the hardware with values in ‘Prototyping Cost’ and ‘Mass Quantity Cost’. ‘Prototyping Cost’ implies the cost for one A-SYNC device by the quantity of individual parts needed. The ‘Mass Quantity’ column assumes that 10,000 devices are being manufactured and reflects the resulting price break.

Item	Part Number / Name	Quantity	Prototyping Cost	Mass Quantity Cost
PCB	N/A	1	0	0.16
Battery	9-volt alkaline battery	1	0.80	0.80

LEDs	1528-1196-ND (NeoPixel Mini PCB)	1	4.95	1.28
Case	Custom 3D Printed	1	0	0.10
Accelerometer	LIS3DHTR	1	4.01	0.68
Infrared Sensors	TSOP38338 (AGC3 38kHz Receiver)	7	3.92	2.80
Infrared Transmitters	OED-EL-1L2 (60° IR LED)	7	2.80	0.76
Microcontroller	ATmega328	1	2.00	1.28
Crystal Oscillator	16MHz	1	0.26	0.26
Miscellaneous	Various	1	1.00	.50
Total Costs for 10 devices	ASync		19.74	8.62

Table 4. Project Budget

Detailed Drawings

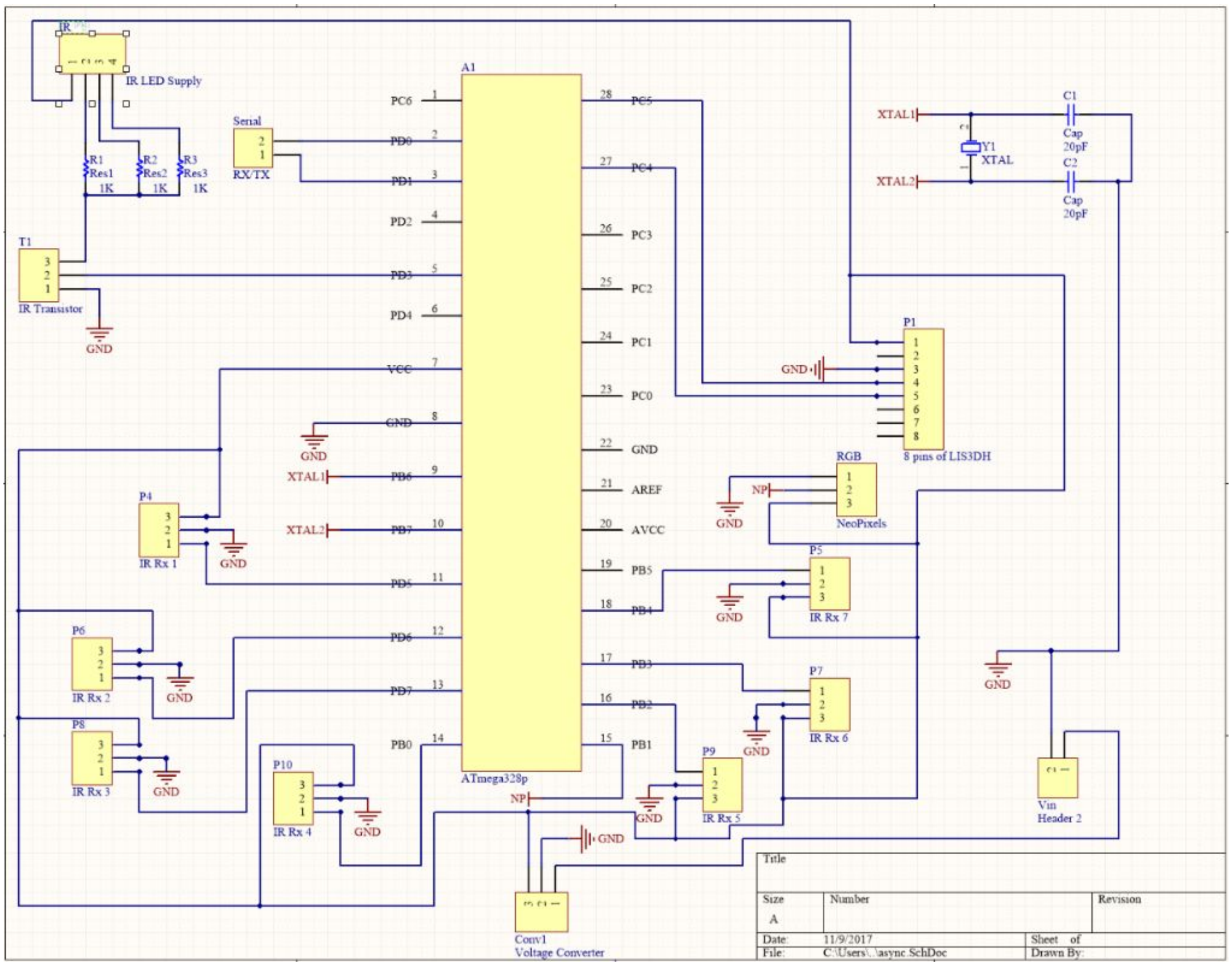


Figure 7. PCB Schematic Diagram

Relevant Datasheets

The ATmega328 datasheet can be found at: https://z.umn.edu/atmega. It was not included because of its length. See the next pages for relevant datasheets.