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DIGITAL HEIGHT MEASUREMENT SENSOR DEVICE

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

ENGINEERING

Thesis Advisor and Department Chair Date

Jessica Kuczenski signed electronically 9-June-2020

DIGITAL HEIGHT-MEASUREMENT DEVICE

By

Valerie Woo

SENIOR DESIGN PROJECT REPORT

Submitted to

the Department of General Engineering

of

SANTA CLARA UNIVERSITY

in Partial Fulfillment of the Requirements

for the degree of

Bachelor of Science in Engineering

Santa Clara, California

Spring 2020

DIGITAL HEIGHT-MEASUREMENT DEVICE

Submitted By:

Valerie Woo

Abstract

A digital height-measurement device (stadiometer) was developed in partnership with the Pediatric Wellness Group (PWG) clinic to improve the speed and accuracy of the height measurement process and address the discomfort and inefficiency issues of traditional physical height-measurement devices currently used in hospitals and clinics. The digital stadiometer uses sensor components to quickly and efficiently measure a patient's height. One key need for accurate height measurements from this device is to ensure the device is level to the ground. Therefore, this project incorporated an accelerometer along with a "bubble level game" feature, which allowed the user to 'self-level' the device in two axes by moving a black circle into a ring as viewed by the LCD screen. The device was prototyped and tested, then mounted onto a helmet for final testing and analysis. The aim is for the helmet-mounted device to be incorporated into the Pediatric Wellness Group clinic's routine physical measurements that they perform for each patient. Unfortunately, due to the COVID-19 lockdown, prototype testing was unable to be completed in the clinic setting with patients. However, limited testing proved that the device took quick height measurements, with height displayed in about 6 seconds, and was relatively accurate, though it did not meet the ¼" accuracy desired by the customer. Future revisions to the device will strive to improve accuracy of the device through implementation of a temperature sensor and more thorough testing.

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1. Background

Height measurement is an important metric for pediatricians and their patients because a person's height changes so rapidly throughout childhood and can indicate health concerns if height deviates from growth curves. The purpose of this project was to develop a digital version of the traditional physical height-measurement devices (a.k.a stadiometers) currently used in hospitals and clinics. This device would have improved portability, while striving to stay within the accuracy and speed of the current devices. The device was in partnership with the Pediatric Wellness Group (PWG) clinic in Redwood City, CA. This report was created to document the design process for creating this device from researching the current height-measuring process and brainstorming possible solutions to the final testing and analysis of the device. This introduction section of the following report consists of information on the traditional stadiometer, the need for accurate height measurement, the need for quick height measurement, existing competitors, the digital height-measurement device, and project goals.

1.1. The Traditional Stadiometer

It is routine practice in pediatric hospitals and clinics to gather data on the patient's physical measurements before meeting with the doctor for any specific needs. One of these measurements is the height of the patient. A pediatrician will find the collection of height measurement data helpful so they can track the growth pattern of their patients. Most pediatricians will want to be able to have the most accurate data for their patients to ensure quality health care. Height is a critical indicator because it tracks how the patient is growing over time, comparing their growth to that of a healthy rate.

Traditional height measuring methods used in hospitals and clinics today consist of measuring the patient against a wall using a retractable ruler system called a stadiometer, shown in Figure 1. To measure the patient height accurately, the patient must stand up straight against the wall to be measured by the nurse. The nurse then places the ruler on top of the patient's head and records the measurement reading marked on the ruler.

Fig. 1: Traditional Stadiometer

Height data is input manually by the nurse into the patient's file records in the medical database of the hospital or clinic. The height measurements are recorded at each visit, and over time, these data measurements create a trendline of the patient's growth pattern. The patient's growth pattern can be compared with average growth patterns of patients with similar heights and weights to ensure that the patient is following the typical trend.

1.1.1 Need for Accurate Height Measurements

Accuracy of height readings helps detect abnormalities in a child's growth patterns, which can be used to diagnose them for any diseases. For example, Figure 2 shows a chart featured in the article, “Clinical Dilemmas in Evaluating the Short Child”[1] by Melissa D. Garganta, MD and Andrew A. Bremer, MD, PhD shows the growth pattern of a male patient with acquired hypothyroidism as compared to the average male.

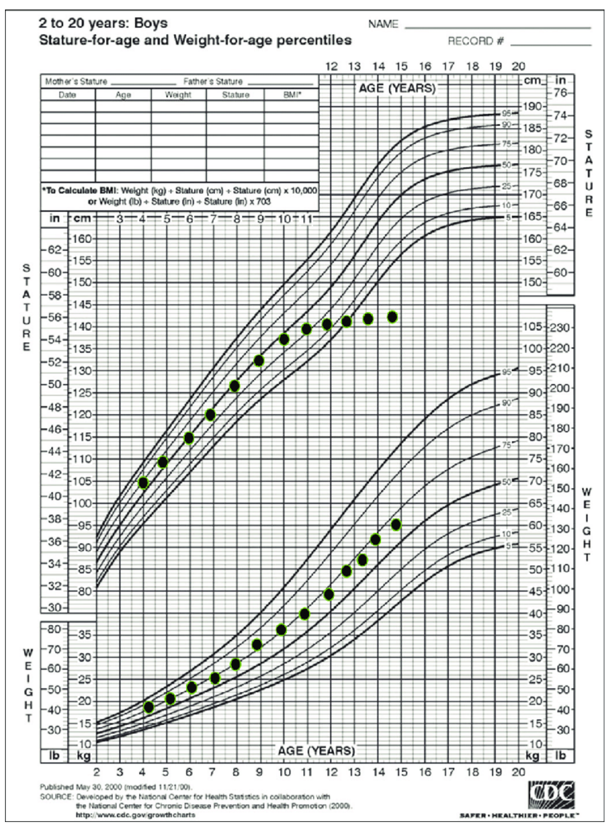

Fig. 2: The Growth Pattern Over Time for a Patient with Acquired Hypothyroidism [1]

Figure 2 shows the growth pattern of the patient with hypothyroidism indicated by the green dot trendline, and compared to the typical growth trendline of the average male. The patient's trendline of height over the years is flattening out much faster than expected for his age. When measurements are accurate to the patient's height, and if it is clear that their growth pattern does not match what is the typical trend, they can be examined for any ailments that may be causing the atypical pattern.

1.1.2 Need for Quick Height Measurements

The need for a quick height measurement is to increase the time efficiency of the patient's visit. According to the statistic chart, "Time U.S. physicians spent with each patient 2018"[2] published by John Elflein, 33% of doctors spend between 17-24 minutes with their patient.

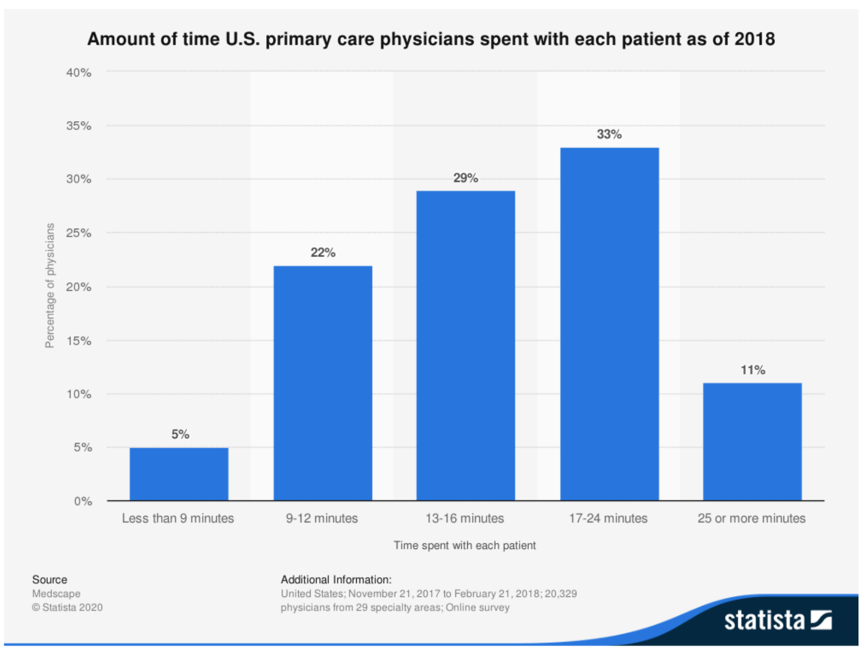

Fig. 3: Time U.S. physicians spent with each patient 2018 [2]

Since the patient only is allotted a certain amount of time during their visit, a faster height measurement system is important in order to allow for the most time to be spent addressing specific needs for the patient. When the physical is fast, the doctor can spend more time with the patient. As discussed in the article “15-Minute Visits Take A Toll On The Doctor-Patient Relationship” [3] by Roni Caryn Rabin, there is an issue when doctor-patient meetings are too short. The more time spent between doctor and patient, the more that the patient will be actively involved with discussing their health. This discussion will help ensure the doctor understands the patient’s condition to better assess their health.

1.1.3 Traditional Stadiometer Accuracy and Speed Statistics

Although traditional stadiometers are the standard device used by hospitals and clinics, they can sometimes result in inaccuracies. As stated in the article “Clinical height measurements are unreliable: a call for improvement” by A. L. Mikula, S. J. Hetzel, N. Binkley & P. A. Anderson [4], “When performing direct measurements on stadiometers, the mean difference from a gold standard length was 0.24 cm (SD 0.80). Nine percent of stadiometers examined had an error of >1.5 cm.” (A. L. Mikula, S. J. Hetzel, N. Binkley & P. A. Anderson) [4] The article states that, when testing traditional stadiometers, there are some errors in the height measurements. These errors, while relatively small, still negatively impact the assessment of the patient’s health, especially when a patient has an ailment such as osteoporosis in which even a small change of a few centimeters in a patient’s height is a crucial indicator used to assess their condition. [4]

An interview in Appendix A1 with Dr. Niki Saxena, a pediatric doctor at the Pediatric Wellness Group (a.k.a PWG) clinic has revealed that the average time of a total appointment is 30 minutes. Out of this time, the physical examination with the nurse can take as little as 2 minutes, to as long as 20 minutes. Since the patients can be as young as toddlers, some may not cooperate because they are scared or upset. The average time of a physical is 5-7 minutes. The height measurement process specifically, given there are no distractions, takes about 10 seconds. Section 1.2 further explains the important roles that Dr. Niki Saxena and the PWG have on this project, as well as the customer needs that set the parameters for the success of the digital stadiometer.

1.2 Partnership with the Pediatric Wellness Group Clinic

This project was created in partnership with the Pediatric Wellness Group (PWG) clinic. The PWG clinic is a small pediatrician clinic located in Redwood City, CA. This project was developed with the help of Dr. Niki Saxena, a pediatric doctor at PWG. Her knowledge was instrumental to understanding the scope and requirements for a product that would improve the pediatric height-measuring system.

The clinic was visited in order to see the current height measuring process firsthand and to interview the doctors and nurses. During interviews with Dr. Saxena and in observation of nurse practices, as seen in Appendix A1, the specific customer values required for a new device were set. These requirements are to ensure that the height measurement takes 10 seconds or less, and the measurement must be accurate to ¼". The device must cost under $100 since it must be affordable so that the clinic can buy multiple devices, or replace devices that are broken. It also must be portable since the current area where they measure patients is crowded, and they would prefer to move the device to other areas as needed. The new height-measuring device must be able to measure patients aged from toddlers to late teens or early twenties. A good range for the typical heights to be measured would be between three feet and six feet. These requirements of height accuracy, measurement speed, height measurement range, and cost are summarized below in Table 1.

Table 1: Customer Needs as Represented by Quantifiable Results

Customer Need:	**Metric:**	**Unit:**	**Value:**
Height Accuracy	distance	inches	<0.25
Measurement Speed	time	seconds	<10
Height Measurement Range	distance	inches	36-72
Cost	price	US Dollars	<100

Additionally, visiting the clinic reaffirmed the issues of the height measurement process. I watched the nurses take physicals of the patients, and noticed that some of the patients were visibly uncomfortable, which caused them to move around. Dr. Saxena also described that a common issue is the difficult situation where a nurse is shorter than the patient, which makes it harder for the nurse to reach the top of the patient’s head to measure height.

Fig. 4: This figure shows a nurse measuring a taller patient against a stadiometer. [5]

Figure 4 shows how difficult it can be for a nurse to measure a taller patient, as the nurse has to stretch their body to place the top of the ruler on the patient's head. These struggles can result in more time being spent during the physical, leaving less time for the doctor to spend directly with the patient.

1.3 Existing Competitors

There are a few digital stadiometers currently on the market which could be used to measure height in a clinic setting: the Inbody's PUSH Stadiometer [6], and the Detecto SONARIS Digital Sonar Stadiometer [7]. Images of both devices are shown in Appendix B and their features summarized in Table 2. The Inbody's PUSH Stadiometer is very similar to this project because it is a handheld portable device. The PUSH Stadiometer [6] is placed on the patient's head and uses an ultrasonic sensor to take a measurement. It costs around $150, and is connected to an accompanying app that measures the growth pattern of a patient. The exact accuracy is not shown on the device website. The measuring range of the device is from 0' to 9'.

The Detecto SONARIS Digital Sonar Stadiometer [7] is a digital device that can be mounted to the wall or placed on a surface. It costs around $300. However, the device is "touchless" which means that all the patient must do is stand under it in order for the reading to be taken. It also uses ultrasonic technology to triangulate the measurement. The accuracy is within 0.2", and the measuring range is from 1'8" to 6'7".

Table 2 compares these stadiometer products to the goals of this project's ideal stadiometer, as set by the customer needs values from Table 1.

Table 2: Competitor Stadiometer Products in Comparison to the Ideal Stadiometer

Product	**Features**	**Accuracy**	**Measuring Range**	**Cost**
PUSH [6]	Handheld device with smartphone compatibility	Not Included on Website	0'-9'	$149.99
Sonaris [7]	Wall mounted or placed on surface	Within 0.2"	1'8" - 6'7"	~$300
Ideal Stadiometer	Handheld device	Within 0.25"	3-6"	<$100

1.4 The Digital Height Measurement Device

Now that the background information on the state of the current height measurement process and the tools that are used has been given, a solution can be explored. The scope of the project is framed to address the particular issues encountered by the Pediatric Wellness Group clinic, as previously shown in Table 1.

Traditional stadiometers can be improved by transitioning from manual, physical rulers, to a digital height sensor device. A portable, handheld device will combat the issue of requiring a patient to stand against the wall. This can be more comfortable for patients, which can help ensure the process will be fast. It will also allow the nurse to move the device to a different room in case the usual operating area is crowded. The digital height-measuring sensor device (a.k.a stadiometer) is intended to accurately and efficiently measure the height of a patient within the parameters stated in the customer needs. It is intended to replace the manual ruler height-measuring systems in current hospitals and pediatric clinics.

1.4.1 Project Goals

The Digital Height-Measuring Sensor Device (a.k.a Stadiometer) is a device used to accurately and efficiently measure the height of a patient. It is intended to replace the manual ruler height-measuring systems in current hospitals and pediatric clinics.

My goal is to create a device that fulfils the needs that were set in place by Dr. Saxena (Table 1). To accomplish this goal, the system design of the device must be created with the quantitative requirements of the customer needs in mind. Both the hardware and software components of the device must be chosen within the parameters of the project scope to ensure the fulfilment of the customer needs.

The device system must allow a practitioner to successfully turn on the device, autonomously run the code on the device to take a height measurement, display the completed height measurement, and store the data long enough for the practitioner to manually input it into the medical database. When fully implemented into the PWG clinic's standard height measuring routine, this device has potential to make the routine faster and have increased height data accuracy.

2. Initial Development Phase

In order to produce a finalized product, there must first be multiple iterations inside of the engineering design process in order to determine which ideas will be successfully implemented. This section overviews the two initial iterations that the device underwent: the initial brainstorming phase from which a general idea of the device was generated, and the introduction of implementing an interactive "bubble level game" as a key feature of the device.

2.1 Initial Design Ideas

The main function of the device is to measure heights using the height sensor, display the data, and store it so that the practitioner can record it to the medical database. Therefore, some key components of this device include a distance sensor, an accelerometer, a button to initiate measurements, and an LCD screen. The distance sensor component is used to detect the distance between two objects, which in this case are the top of the patient's head and the floor. In addition to this, there must be an accelerometer component that detects when the device is parallel to the floor to ensure an accurate height reading. There must also be some way of displaying the information to the nurses, such as the height data results being printed onto a screen for them to read. This can be done by using an LCD screen. In order to connect each component together through code, a microcontroller must be used, such as an Arduino or Raspberry Pi brand device.

My initial design for the digital height-measurement sensor device consisted of a small, drawer-like container to house the components as shown in Figures 5 and 6.

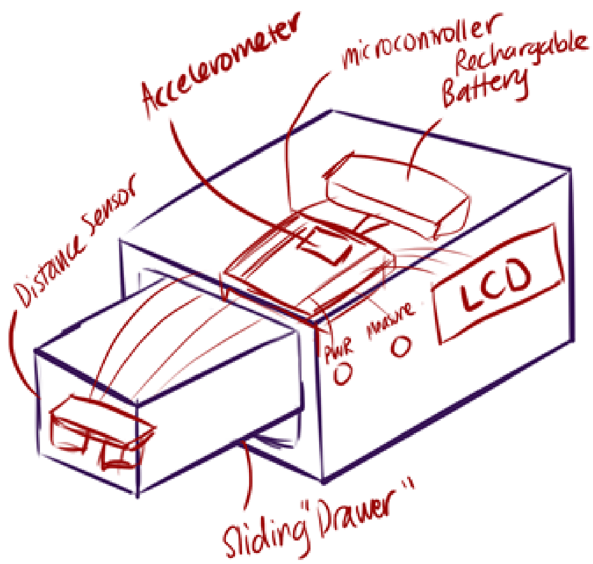

Fig. 5: Isometric View of Initial Concept Design. Drawn by Valerie Woo.

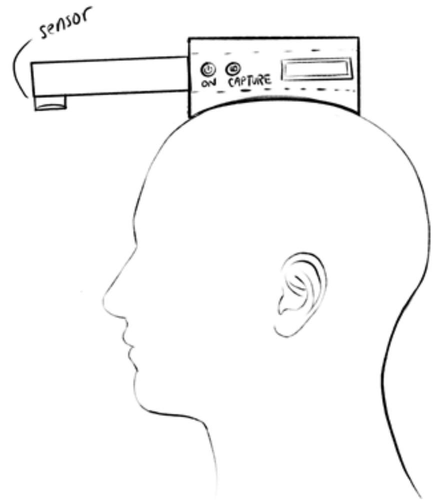

Fig. 6 : Side View of Initial Concept Design. Drawn by Valerie Woo.

Most of the components, such as the microcontroller, resistors, and wires would be inside of the main body of the drawer. However, the sensor would be on the extending part of the drawer so that the sensor has enough clearance to successfully take a reading to the ground, without any parts of the patient's body obscuring it. The device would be powered on and off through a button on the side of the device. Height-measurement data will also be activated using a side button. The LCD screen on the side of the device would then display the final height-measurement value.

2.2 The Gamified Design

From my initial design, one key issue identified was how to level the device for an accurate height reading. In order to achieve accurate height measurements, there must be some indication that the accelerometer on the device has reached a position that is parallel to the ground. Therefore, design elements that could both improve the accuracy of the device and encourage interactivity in its operation were brainstormed.

One primary idea was to turn the device into an interactive game for the user, while also being functional and effective as a height-measurement device. A digital game was developed to mimic a physical bubble level tool. With research, the "Arduino Micro Electronic Bubble Level" created by Kevin Palivec [8] was incorporated for the patient to self-level the device.

The bubble level game utilizes an LCD and an accelerometer to move a black circle to be aligned within the ring on the screen, as shown in Figure 7. This process is similar to how a physical bubble level works by letting the air bubble inside of the liquid to rise to the top and between the lines drawn on the tool. When the accelerometer is moved, this corresponds to a point on the LCD as indicated by the black circle. The device is parallel to the ground when the black circle fits within the inside of the ring centered on the origin of the X & Y grid on the LCD.

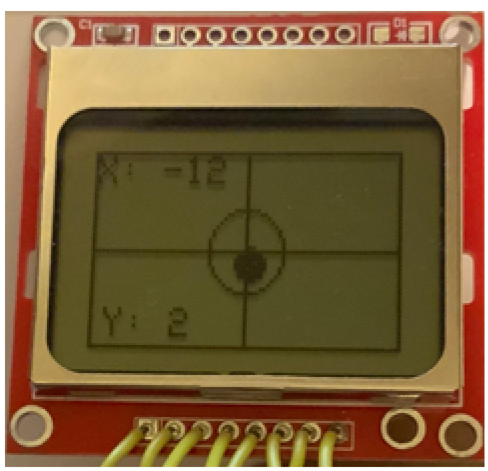

Fig. 7: The LCD Bubble Level Game

This gamified version of the device would solve the dilemma of how the device would indicate being parallel to the ground and being ready to take a reading. Not only would this be a practical way to ensure the device is parallel, but it would also provide entertainment for the patient. Entertaining the patient can be a good way to have the patient cooperate when having their measurements taken, and also can help distract them from any discomfort or awkwardness they may feel while standing up straight in an unnatural pose. A screen was thus added to the device where the patient could use it to level the device interactively, as shown in Fig. 8 and 9. This would be mounted in a similar fashion to a side-view mirror on a bike, easily visible and hands free, leaving the patient able to use their hands to adjust the helmet and level the device.

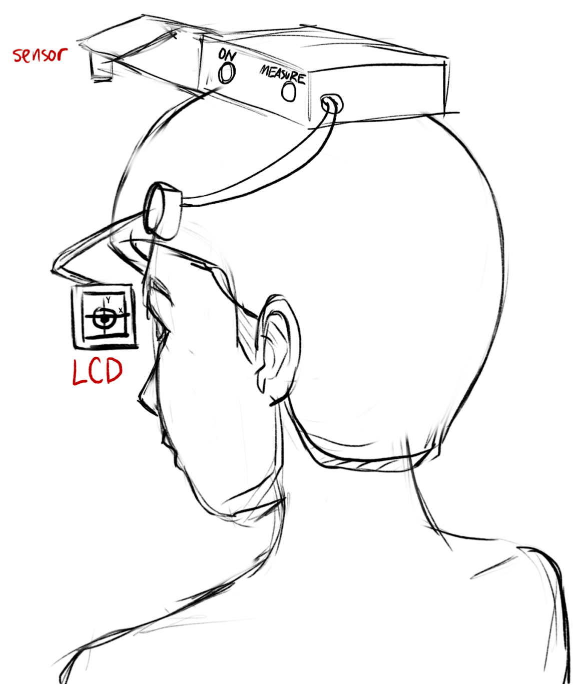

Fig. 8 : Sketch of LCD View on Patient's Head. Drawn by Valerie Woo.

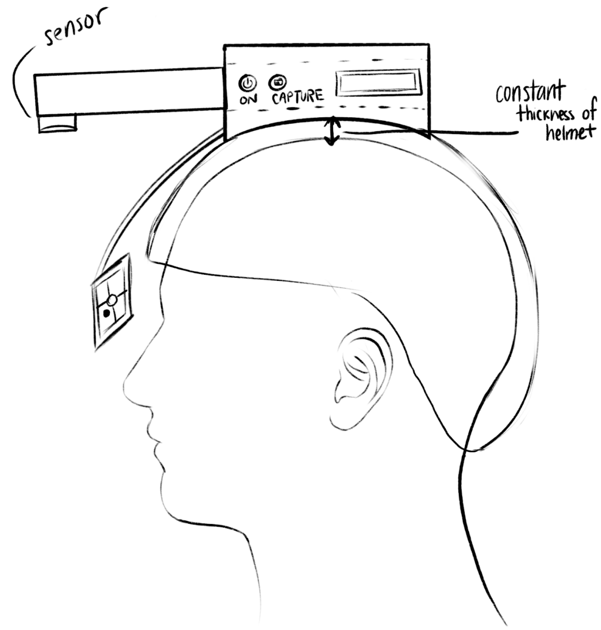

Fig. 9: Side View of Gamified Design. Drawn by Valerie Woo.

3. System Overviews

Now that some initial design ideas were considered in Section 2, the next phase in the design process is to understand and select device components and place these in the device system. This section will give an overview of how the key components were assembled for the prototype stadiometer testing devices through two iterative prototypes: Initial and Final.The sections are organized by the hardware and software.

3.1 Hardware

The device's hardware consists of all physical parts of the device. The hardware section is split into the Initial Rig and Final Rig subsections. Hardware details are available in Appendix C.

3.1.1 Initial Rig

The main components of the gamified device system are the Arduino Nano Microcontroller, the HC-SR04 Ultrasonic Ping Sensor, the Nokia 5110 LCD Screen, and the Memsic 2125 Accelerometer. Exact pricing for each component can be found in section 6.1.4 Bill of Materials.

The Arduino Nano Microcontroller was chosen due to its small size. Generally, the components of the device were chosen to be small because the small size would improve portability of the device and reduce the weight, which can be more comfortable for the patient when it rests on top of their head. Although small, it is still able to contain all of the input/output pins necessary to control each component of the device.

The HC-SR04 Ultrasonic Ping Sensor was chosen because it was cost effective, had only four pins to connect to the Arduino, and because it is advertised to successfully measure from 2 cm to 400 cm (0.787” to 157.48”). [10] This height range covers much more than the target height range of three to six feet. The sensor must be inexpensive in order to fit within the customer’s budget of the entire device costing less than $100, while still being accurate to ¼”. The price for this sensor was $4.95. Other sensor types such as LED, LIDAR, or VCSEL were considered, but the ultrasonic sensor was the most cost effective. [9]

The Nokia 5110 LCD screen was chosen based on its small, rectangular size of 1.94"x1.66"x0.25". This square-like LCD was chosen instead of a narrower screen so that it would be ideal for creating a grid for which to play the bubble level game. It is lightweight at 0.01 ounces, which is ideal for hanging it from the side of the helmet. The price for this LCD was $12.95.

The Memsic 2125 Accelerometer was chosen because of its small size and ability to detect two axes of rotation necessary to level the device to be parallel to the ground. Although it cost $24.99, which is more expensive than a MPU6050 Accelerometer, the Memsic 2125 device does not require soldering and also has 6 pins compared to the MPU6050's 8. This simplicity and smaller design were worth extra cost in order to produce a smaller overall device.

Functional features of the device were the activation, the bubble level game, and the height-measurement collection and result output on the Arduino Serial Monitor. For the initial rig, I assembled all of the components of the device onto a 4" x 5" cardboard rectangle plank as shown in Figures 10 and 11. The cardboard allowed for the device to be consolidated so that the components would not dangle from their wires while being tested. The cardboard also allowed for the initial rig to be easily carried and held against the wall for testing. Two holes were cut into the cardboard plank to hold the height sensor in place and to ensure that the ultrasonic waves could reach the floor.

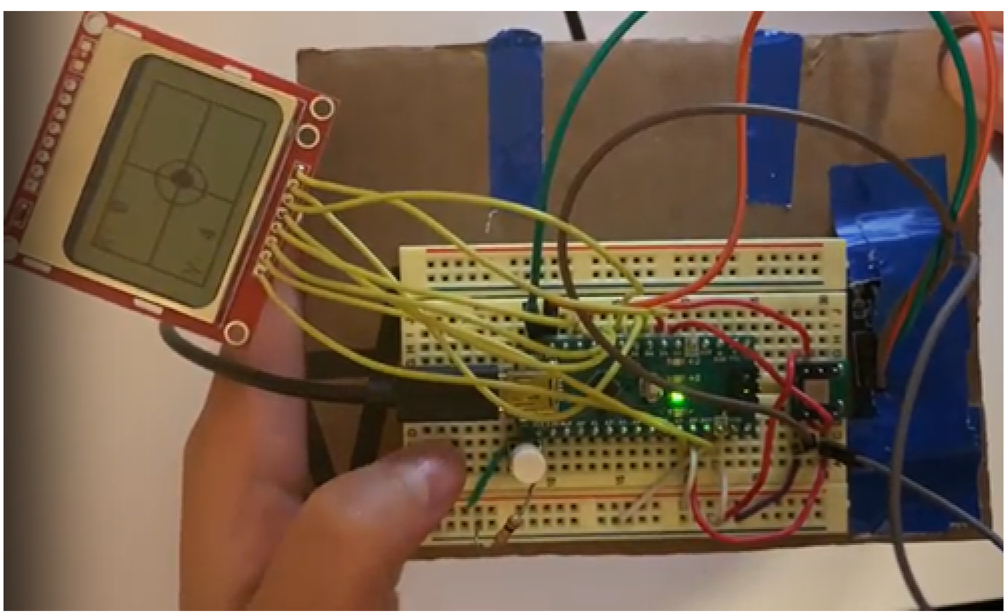

Fig. 10 : Top View of the Initial Device Rig

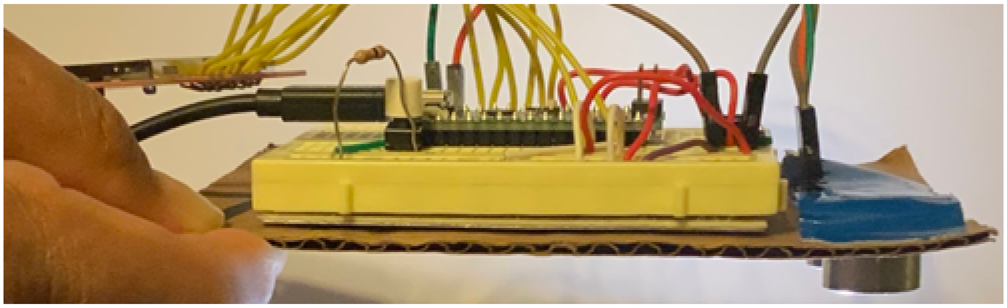

Fig. 11 : Side View of the Initial Device Rig

During this phase of the project, the device still must be tethered to the computer with a USB cord because it requires power and access to the Arduino software serial monitor, where the recorded height measurement is printed.

3.1.2 Final Rig

The final rig was created to reflect the actual usage of the device while measuring a real patient in the clinic. In order to test the device as it was intended to be if it were used in a hospital or clinic, it would need to be mounted onto a helmet or other head piece in order for it to be stable on top of the patient's head. If the device were simply placed on the patient's head without them holding it, the device might fall down when the patient moves. The helmet also helps the device stay parallel to the ground since it is at a fixed position on the patient's head.

In the final rig, the initial rig assembly was taped onto a 4" x 17" acrylic plank, which was then taped to a bicycle helmet, as shown in Figures 12 and 13. A bicycle helmet was chosen particularly because of the hard plastic casing and shape, which could be easily grabbed without losing its shape to adjust it.

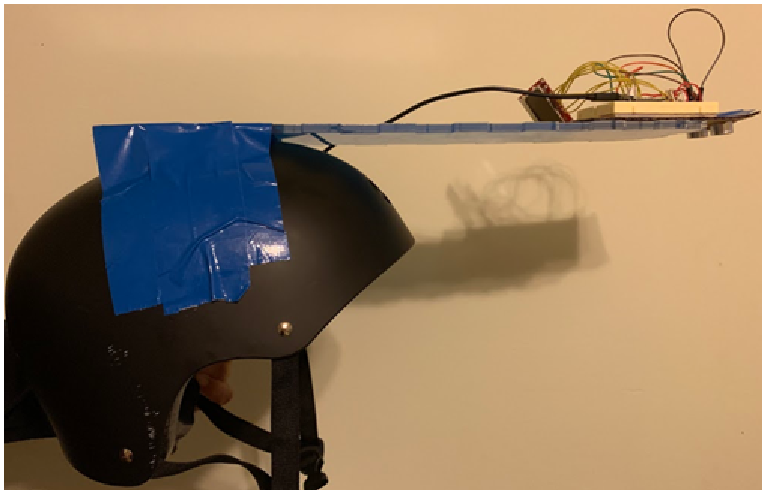

Fig. 12. : Side View of the Final Rig

The LCD screen on the final rig is intended to be visible by the patient and the practitioner administering the height measurement. The patient would be able to move their eyes upward towards the top of the device to see the screen, while the nurse could stand to the side of them to also see the screen. Although the LCD screen would be more ideal if it were closer to the user's face to improve visibility, the wires of the LCD were not long enough. Due to time constraints, the wires were not resoldered to be longer.

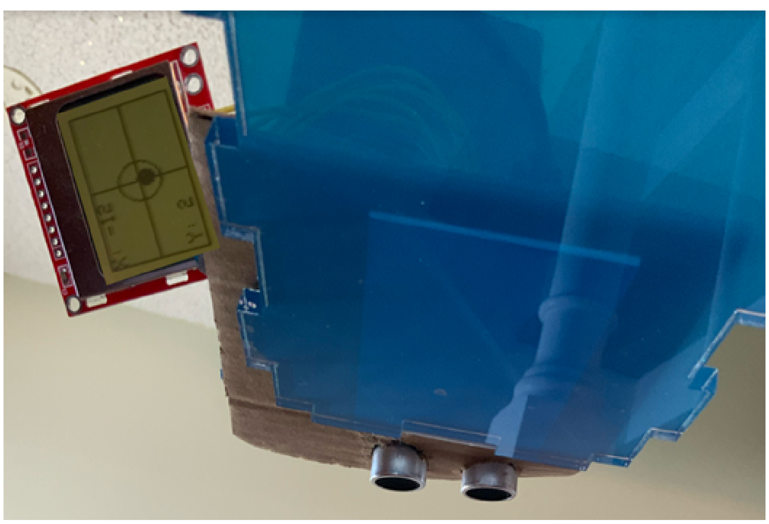

Fig. 13: Edited Patient's View of the Final Rig

3.3 Software

Code was written for the Arduino microcontroller and is available in Appendix D. The flowchart shown in Figure 14 illustrates the main code functions. The device's code consists of the main code loop and two subroutines: *bubblegame* and *pingsensor*.

The main loop prompts the user to press the "Measure" button to activate the device. The *bubblegame* subroutine is then initialized, the patient self-levels the device and when the bubble is within the target area, the *pingsensor* subroutine runs and takes height measurements.

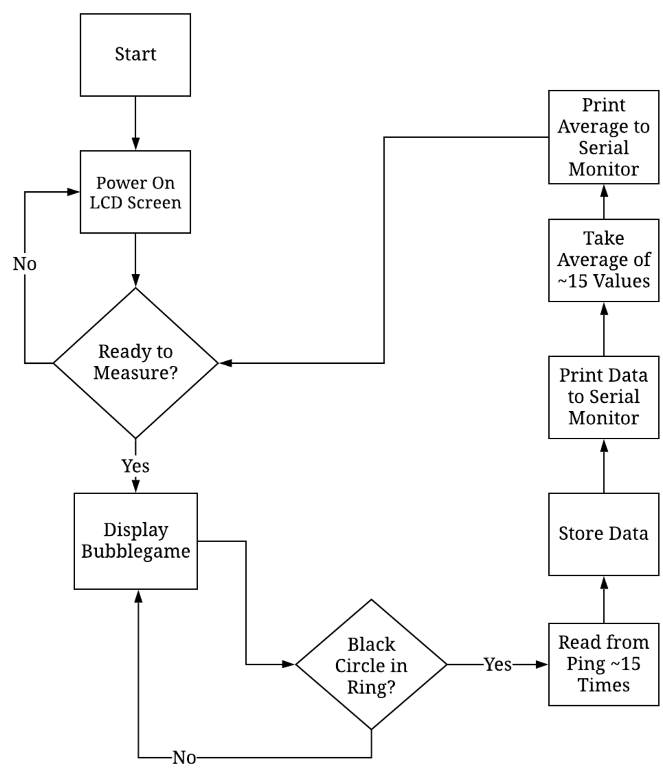

Fig. 14: The Software Flowchart

The *bubblegame* subroutine draws an X and Y coordinate grid on the LCD screen and a ring at the origin point in the center of the screen. The X & Y coordinate grid corresponds to the position on the LCD screen. The code creates a moving black circle that corresponds to the physical position of the accelerometer. Whenever the black circle stays within the center ring (see Figure 13), the ping sensor is told to take a height measurement. This is done by programming a threshold that detects when the black circle is within certain X & Y coordinates or not. In this code, the threshold is set so that the device takes measurements when the X & Y coordinates are both less than |10| on the on-screen grid.

The *pingsensor* subroutine activates the HC-SR04 Ultrasonic Ping Sensor, which bounces sound waves from the sensor to the floor and back, and stores the height data as a variable. The height data is then converted to inches, since the current stadiometers at the PWG clinic measure the patient in inches. The ping sensor activation was programmed to loop so that about 15 measurements were taken. About 15 measurements were chosen because this amount would be sufficient to account for too high or too low values, while only taking about 6 seconds. The program then calculates the average value of multiple ping sensor readings, and records the data on to print on the Arduino serial monitor.

4. Testing and Results

In order to determine how successful the device was in order to meet the customer's needs, it was tested to determine its capabilities and limitations. This section contains testing and analysis of both the initial and final rigs. It also addresses the issues encountered with the ultrasonic sensor.

4.1 Initial Rig Testing and Results

The initial rig was tested in order to use the data to calibrate the rig for height measurement accuracy and determine the time needed for measurement. Testing procedures and results are available in the following subsections.

4.1.1 Initial Rig Testing

In order to test the initial cardboard rig, a tape measure was used to mark out height at 3', 3'6", 4', 4'6", 5', 5'6", and 6' indicated by masking tape onto a white wall in my house's hallway, as shown in Figure 15. The floor was hardwood flooring. At each height, I held the device against the wall and ran the program. When the bubble game indicator was within the specified range of <|10| within the LCD grid, the device took about 15 measurements, from which it then took an average. This process was continued until the device took measurements at each of the different heights on the wall.

Fig. 15 : Height Measurements Taken on Initial Rig

4.1.2 Initial Results

Multiple trials of data were taken at each height, each with about 15 height measurements, and took the average height measurement value of each. The averaged data was used to calculate a calibration curve in order to improve device accuracy. The process of averaging was implemented in order to account for data readings that were slightly too high or low. It is important to note that the bubble game was set to run for about 6 seconds before stopping, which is under the customer requirement of the measurement being less than 10 seconds. Raw data is available in Appendix E.

In order to calibrate the data for increased accuracy, I created a scatter plot that compared the expected height data with the physically measured data from the device. I created a line of best fit for the scatter plot and used the slope of this line of best fit in order to calibrate the data in my code. A linear fit equation with a zero intercept revealed the slope of the line as 0.9822.

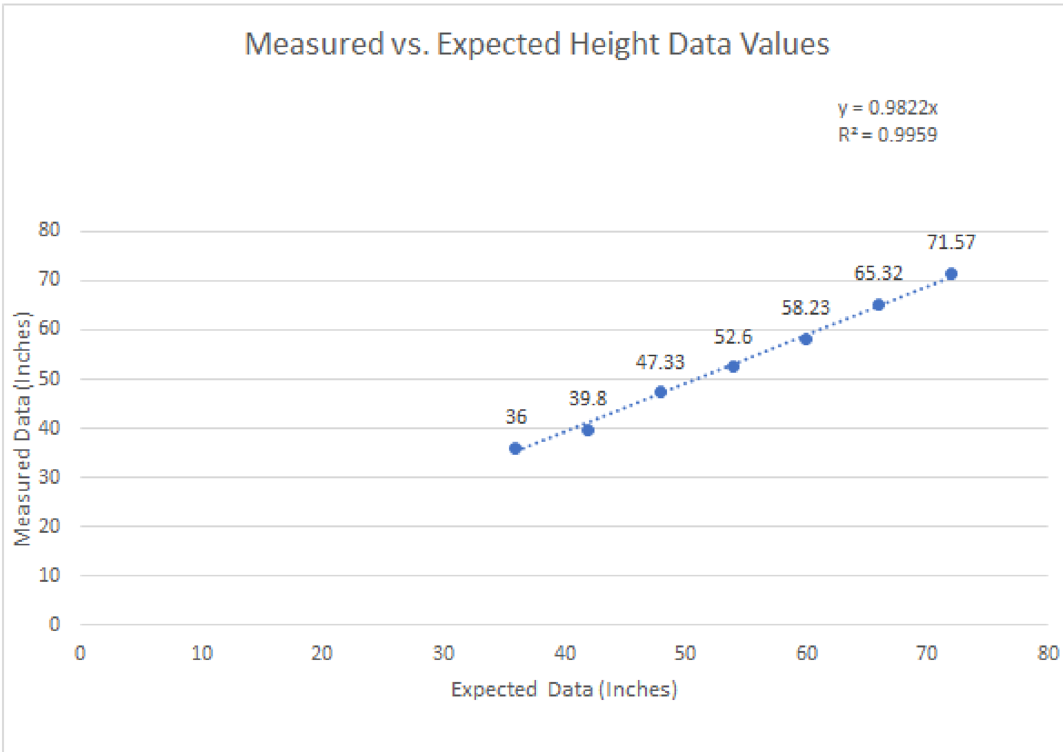

Fig. 16 : Scatter Plot of Measured Vs. Expected Values for Sensor Calibration

This linear trendline displayed an R^2 value of 0.9959. Since this value is very close to one, this is an indication that the data points follow the line of best fit very closely and are a good representation of linear data that passes through the expected origin. The slope of the device was recorded and implemented into the device's program in order to calibrate the device.

The initial measured values were generally lower than expected. This calibration was successful because once the raw data was multiplied by the inverse of the slope value of the y = mx + b equation, the values were increased slightly and became closer to the expected values.

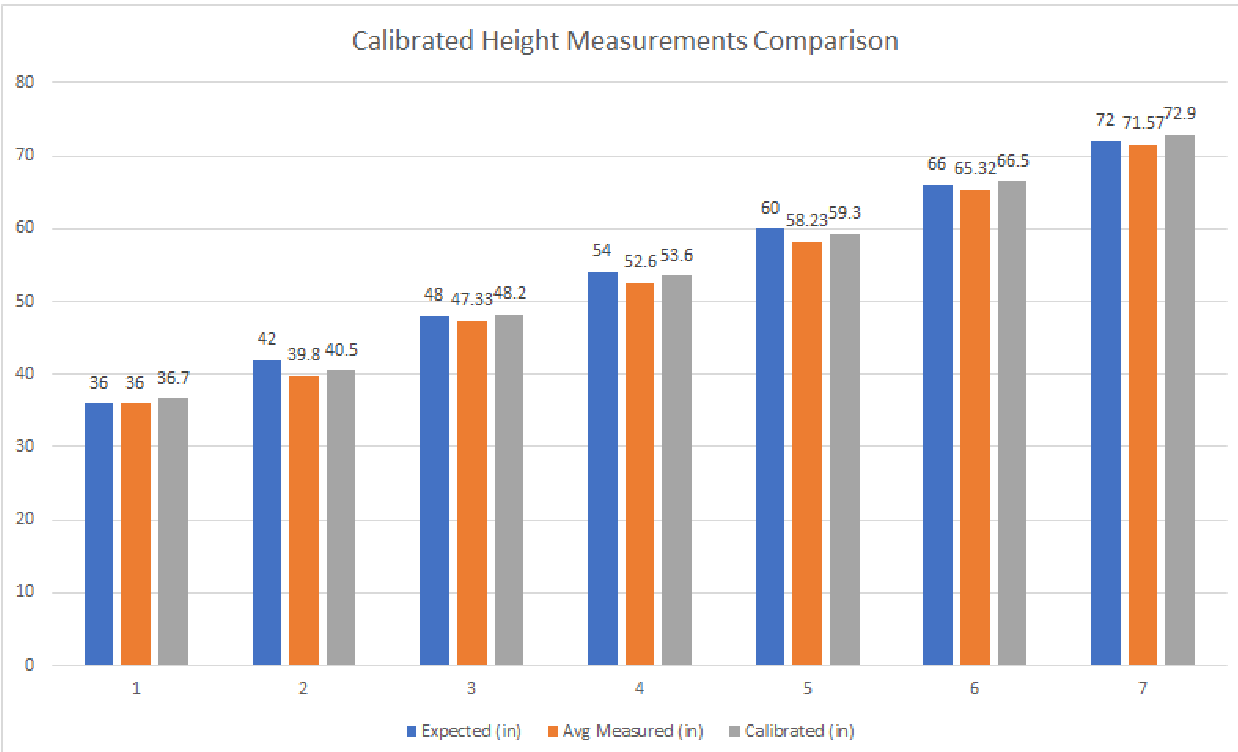

Fig. 17 : Height Measurements Comparison Before and After Calibration

Fig. 17 shows the comparison between the expected values, and the measured values before and after multiplying by the calibration factor. The calibrated values, as shown in the chart as the grey bar, are closer in value to the expected values by a factor of (1/0.9822).

4.2 Final Rig Testing and Results

Once the initial rig was calibrated and confirmed to be free of defects or any previously unseen problems, it was time to move on to the final rig testing. The final rig testing would determine the success of the project as a whole since the final rig is the closest to how the device would be used in the hospital or clinic.

4.2.1 Final Rig Testing

The final device tested height-measuring capabilities on people in order to reflect the actual usage while measuring a real patient in the clinic. The device was tested on myself at 61", my father at 65.5", and myself kneeling at 46.6" in order to mimic the height of someone who is shorter than I am. In a similar process to the initial rig testing, the wall was marked with measuring tape and masking tape according to the expected measurements.

Fig. 18 (a,b,c) : Testing Final Rig at a) 61",b) 65.5", and c) 46.6"

The testing process for the final rig consisted of wearing the helmet, pressing the height measurement button on the top of the device, and playing the bubble game by looking up at the LCD screen. It is notably difficult to know where the button is from the patient's point of view, since it is above their head, the location of the LCD will need to be altered once clinical testing is possible. I had edited the program to multiply the height measurement average data by the inverse of the slope found in the trendline of the initial testing results in order to calibrate it. Additionally, thickness of the helmet (1.5”) was subtracted from the height measurements.

However, the visibility of the LCD screen is dependent on the light source, and in poor lighting, the screen may be hard to decipher by its viewers. This problem makes it additionally difficult to photograph the LCD screen in some lighting, which drives the necessity for an edited picture. Figure 13 illustrates the process of playing the game from the patient's perspective.

4.2.2 Final Results

The final program ran in 8 different trials, resulting in 8 sets of about 15 height measurements; data is available in the Appendix. An average value was calculated from the 15 height measurements, similar to the testing in the initial rig. Using this recorded data, the difference and percent error between the expected and measured heights was calculated. The data is plotted in Figure 19. The Figure shows the expected height in comparison with the measured height as the total average value per each expected height level (61”, 65.5”, and 46.6”), which resulted in the total average measurements of (61.60”, 64.99”, and 45.41”). The error bar indicated on the average measured height indicates the absolute value of the difference between the measured height and the expected height.

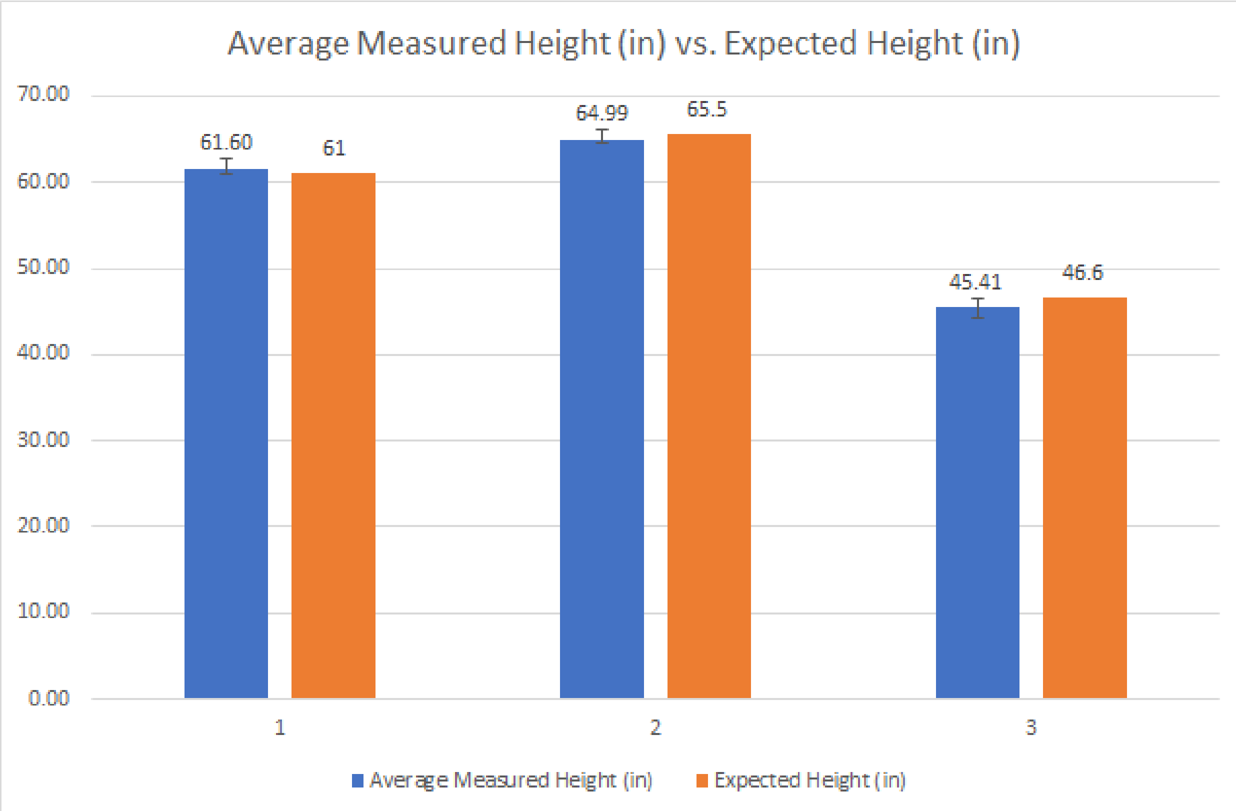

Fig. 19: Average Measured Height (in) vs. Expected Height (in)

Overall, the height measurement data looks very close to the expected values, and the percent error (from -0.9795% to 3.176%) is a good sign for the accuracy to be high. However, although small, the measured versus expected difference between measurements are shown to range from 0.5138" to 1.188", which is higher than the customer need for the sensor to have an accuracy within 0.25". Raw data for the Final Rig can be found in Appendix F.

4.3 Ultrasonic Sensor Issues

The inaccuracies in the height measurements could be due to multiple factors: human error and experimental error. Experimental error could be due to: Obscurance of Conical Ultrasonic Waves, Temperature of the Air, and Floor Reflectivity.

4.3.1 Human Errors

Human error is a potential factor that led to inaccuracies between the measured and expected height measurement values. It could also have occurred because of discomfort. The helmet was too small for my father, which made the helmet too tight and uncomfortable. Additionally, when kneeling, I was uncomfortable holding the unnatural position during testing. This caused me to squirm and readjust my stance. Although these factors made the data less accurate, discomfort is an important limitation to consider in future iterations of the device.

4.3.2 Obscurance of Conical Ultrasonic Waves

Occasionally during the testing phase of the initial rig, large errors could sometimes occur in the height measurement. When I stood too close to a wall while testing the initial rig, I found the sensor readings were inaccurate because the wall obstructed the ultrasonic waves from reaching the floor. Since the ultrasonic sensor uses sound waves to bounce between two objects to take a reading, any unwanted objects in the way will influence the data negatively. This issue is most noticeable at the higher height measurements of 5’6” and 6’. The issue is most prominent at higher heights because the sound waves propagate in a wider conical pattern the farther they travel from the device, as shown in Figure 20.

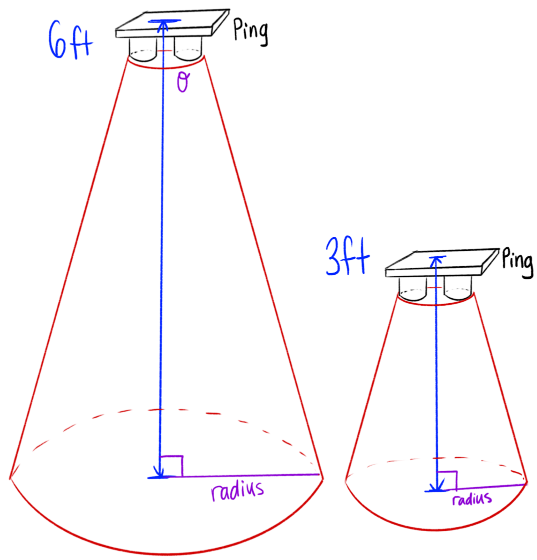

Fig. 20: Ping Sensor Sound Wave Spread at 6ft and 3ft. Drawn by Valerie Woo.

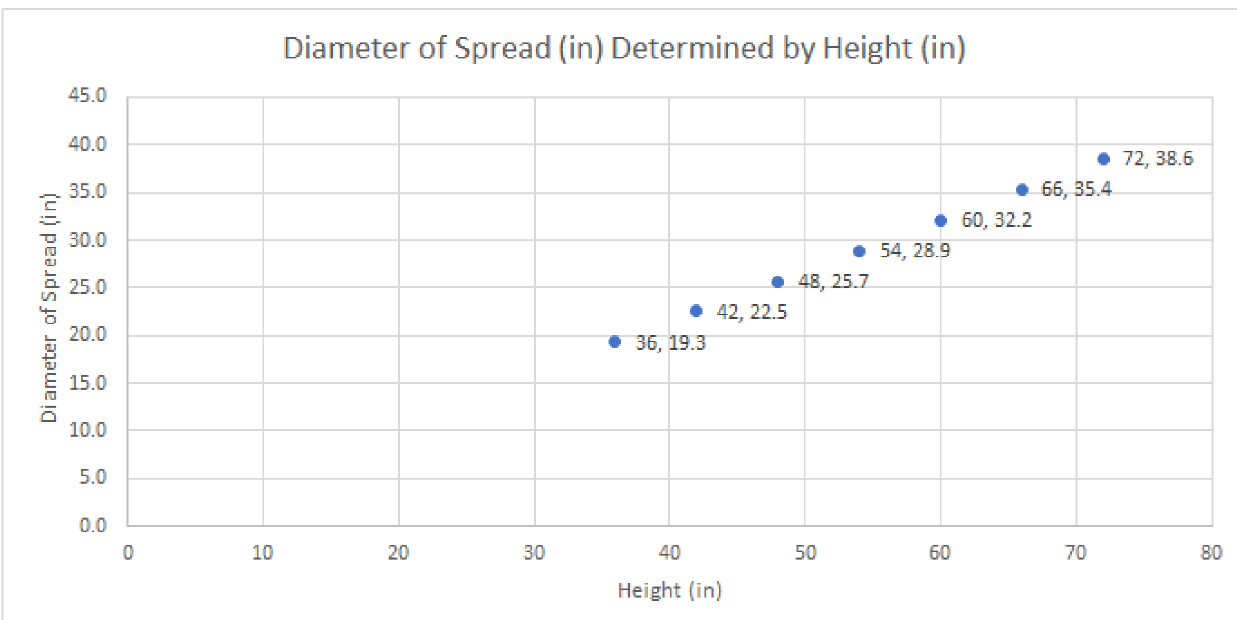

Fig. 21: The Direct Relationship between Diameter (in) of Spread as determined by Height (in).

The diameter of ultrasonic wave spread was calculated with trigonometry and listed in Appendix G. The measurement angle is 15° as according to the HC-SR04 datasheet. [10] There is a direct relationship between the height from the ground and the diameter of spread. When the device takes a measurement at 36", the spread was 19.3", compared to a spread of 38.6" at 72". This is a large difference of 19.3", or over an additional foot and a half larger diameter from which objects must be kept away from to avoid obscurance of the sensor.

This problem was easily fixed by making sure that nothing was in the way of the sensors when taking measurements. It is also worth testing if the ultrasonic sensor can be placed within a plastic tube like a PVC pipe in order to concentrate the sound waves towards the ground instead of a conical shape.

4.3.3 Temperature of the Air

According to the study referenced in "Effects of environment on accuracy of ultrasonic sensor operates in millimetre range" by Kirtan Gopal Panda, Deepak Agrawal, Arcade Nshimiyimana, and Ashraf Hossain, temperature and humidity in the environment can affect the accuracy of an ultrasonic sensor. [13] The device was tested at approximately 70 degrees Fahrenheit and 60% humidity. However, varying temperatures and humidities of different hospitals and clinics can cause an effect on the device's height measurements. If the hardware included temperature and humidity sensors and software was programmed to account for the temperature, the discrepancies caused by these factors could be lessened.

4.3.4 Floor Reflectivity

As stated in "ULTRASONIC SENSOR TARGET TYPES" by Sheri Sedgwick [12], the ideal target for an ultrasonic sensor is one that is hard, flat, and smooth. In the case of this device, the target is the hardwood floor surface the device was tested on. The hardwood floor was a relatively good surface to test on because it was hard, flat, and smooth. However, when the device is tested in the hospital or clinic, the floor types can vary. For a surface such as carpet, the sensors may not be as accurate as if they were on hardwood, since carpet is soft, textured, and uneven.

5. Challenges and Analysis

The Challenges and Analysis section of the report deals with the issues that arose during the product creation process, and how they may be addressed in future iterations of the device.

5.1 Self-Isolation due to COVID-19

I planned to visit the clinic after the final design was created and ready for testing, so I could show the prototype to Dr. Saxena and get real product feedback. With her permission, I could have patients try to measure themselves with the helmet-mounted final rig. However, due to the shelter in place COVID-19 restrictions, it was not possible for me to visit the clinic. It would be beneficial to apply the human centered design principles by getting feedback from real users. In future iterations of the device, I would like to ideally test the device on pediatric patients in order to discover how the device works during its intended use.

5.2 LCD Issues

During the final rig testing, I observed that the LCD screen had poor visibility. The screen was too small and too dark which made it possible, but difficult to play the bubble game. I tried to position the LCD in a place with better lighting, but the current device's requirement of needing specific lighting did not make for a viable product. In future iterations of the project, I may consider other models of LCD screens to ensure I use one that has sufficient internal lighting so that the screen can have increased visibility. Or provide longer leads to put the LCD screen in a more visible location.

Another issue encountered in the initial testing phase was the durability of the components. At some point during the process, the initial rig fell off of a table and onto the hardwood floor. The fall damaged leads to the LCD screen which needed to be repaired. It is important to take note of the lack of durability of the device because in a clinical setting, it must be durable enough to survive damage caused by regular use.

5.3 The Problem with Uniform Helmet Sizing

Since the final rig was attached to a specific helmet, it could not account for multiple people's different head sizes. As one of design goals was to complete the measurement within 10 seconds, there is no time to adjust settings. In order to combat this issue, a future device could be detachable from the helmet so that it can be reattached onto different helmets regardless of size. Alternatively, an adjustable helmet or other type of cleanable headwear could be implemented in order to fit many head sizes.

6. BOM, Budget Analysis, and Business Plan

The Bill of Materials (BOM), Budget Analysis, and Business Plan are all important aspects to consider while developing a product. In order for the product to be created, each part and process used to create it must be assessed financially. The business plan is a hypothetical exercise used to explore the device as if it were created for a business.

6.1 BOM and Cost Analysis

The BOM financially tracks the cost of every component that was used in the creation of the device. It is important to know how much money is spent during this project because it is important to know how the sponsorship money is allocated. It is also important because one of the customer needs for this project is to ensure the product costs less than $100, and so the cost of materials must be accounted for.

6.1.1 Introduction

My budget for the digital height-measurement sensor device was $500, sponsored by the Frugal Innovation Hub and EPICS in IEEE, and also the Santa Clara University School of Engineering. However, my expectations for how I would spend my budget did not match the reality, largely due to lockdown from COVID-19.

6.1.2 Budget Utilization

During the very beginning of the project, money was allotted out of the project budget in order to buy multiple types of sensors (LED, LIDAR, Ultrasonic, and VCSEL). However, three HC-SR04 ultrasonic ping sensors were purchased instead. Budget was allotted for multiple types of microcontrollers, before settling on the Arduino Nano only. A bluetooth module was considered in order to allow the device to communicate wirelessly with a computer for the practitioner to easily input height measurement data into the medical database. However, upon interviewing Dr. Saxena and the staff at PWG, it was discovered that they wanted to input the height measurement data manually into the medical database to avoid errors. Therefore, the bluetooth module was not purchased for the project.

Table 3: Estimated Project Budget

Item:	**Maximum Cost:**
Distance Sensors (Infrared, Ultrasonic, LED, etc.)	$130
Microcontroller (Arduino, Raspberry Pi)	$50
Bluetooth Module	$50
Breadboards, Wiring, Insulation, Cable organizers, etc.	$30
Casing	$40
Total:	$300

6.1.3 Additional Costs

In order to manufacture one Final Rig unit, several tools or additions to the main electrical circuit of the device had to be purchased. Firstly, due to COVID-19, a soldering kit had to be purchased in order to solder the wires onto the LCD screen during the Initial Rig process. Secondly, a helmet and helmet mirror were purchased so that the Initial Rig can be mounted onto the helmet so that it could produce the Final Rig. The helmet mirror was intended to be attached to the helmet and LCD screen, but was unused in the final design because the positioning of the device on the helmet did not allow it. Emphasis on affordability was placed for a small clinic, but additional money was requested to run various tests and replace broken parts. Additional costs due to extra components and tools are available in Appendix H.

6.1.4 Bill of Materials

The following table illustrates the expected cost of production for the device. The final rig did not have any bluetooth modules or a casing, which reduces the total cost significantly.

Table 4 : Bill of Materials

Category	Item	Description	Quantity	Unit Cost	Cost
Components					
	Distance Sensor		1	$4.95	$4.95
	Microcontroller		1	$19.88	$ 19.88
	Accelerometer		1	$24.99	$24.99
	LCD screen		1	$12.95	$12.95
Switches					
	Switches (toggle, push buttons, etc).		1	$3.00	$ 3.00
Wiring					
	Breadboards, Wiring, Insulation, Cable organizers, etc.		1	$7.00	$ 7.00
Total					$ 72.77

One unit of the height measurement device meets the customer requirement that the device must be under $100, met by the device total given in Table 8.

6.2 Business Plan

The following business plan is a hypothetical exercise that contemplates the process and information necessary to transform the digital height-measurement sensor device into a profitable business. Imagining this device as used as a product for a business is an important consideration in order to apply this product to the real world to make it a viable endeavor financially.

6.2.1 Target Market

The target market of the digital height-measurement sensor device is pediatric hospitals and clinics. This product is desirable by pediatricians in hospitals and clinics so that they can use it professionally in their medical practice.

However, this device also has potential to be marketed to families as a household device. In a household setting, families can use this device to measure a growing child's height over time. In contrast to the professional use of the product by pediatricians in hospitals, the family desires the device for personal use in order to track the growth of a child.

This could be useful if the child has a certain illness that affects height growth and needs to be tracked carefully, such as the patient with acquired hypothyroidism in Fig. 2. Additionally, the device could also be desirable by people with growing children, those who are interested in the concept of the device or enjoy technology and gadgets.

6.2.2 Customer Segments

There are customer segments within the target market. Firstly, the size of the hospitals must be considered because a small clinic would require different needs or pricing compared to the hospital. Additionally, the device must also be appealing to parents and guardians who want to use it as a personal device in their home for their family. For example, a small clinic would want an affordable device that fits their budget. A large hospital may have the budget to purchase a more expensive device. For use in a professional, medical setting, the pediatricians and nurses will be most interested in the practicality of the device, and how quickly and accurately the device can measure height.

When it comes to personal use, various buyers have different budgets that they would be willing to spend for this device. The device can measure the heights of patients from a wide range of ages where growth is typically most noticable: from 3-23 years old. On account of this large age range, different designs of the device must be considered. The design must not be too “childish” for the older patients, but it must also be user-friendly enough for a younger patient to understand and enjoy. The bubble game that is played to steady the ping sensor is an entertaining way to appeal to the user of the device. The device must also appeal design-wise to the parents and guardians who are purchasing the device. Though they may not be using this device on themselves, they must be satisfied with the device’s design and process enough to purchase it.

6.2.3 Customer Relationships

The customers of the product are doctors, nurses, patients, parents or guardians of patients. The customers would be able to purchase the product directly from the manufacturer, or from a general medical supply store. Customer service would be typically limited to purchasing the device from the store or manufacturer. An operations manual would be included with the device so that the user can start immediately after receiving the device. However there also must be a customer support system in case the device is defective.

6.2.4 Marketing

My emphasis in marketing the product will be on the importance of caring for the wellbeing and health of the users. Most customers are interested in this product because they care about the health of the person whose height they are measuring. A pediatrician will be interested in the care of the patient to ensure their good health in a professional perspective, while a parent or guardian will be interested in the care of the user of the device from a personal perspective. When marketing the product to potential buyers, I will emphasize how the purpose of the device is to help track the health of the device user. This is because my company cares about the wellbeing of every person who uses the device, and therefore provides quick and accurate height measurements to better track their growth over time.

I plan to advertise the device in settings where the target market will likely frequent. The device will be advertised in medical supply stores, drugstores, in healthcare and lifestyle magazines and websites, and in parenting magazines and websites. I expect the customers to notice the advertisements while buying products from medical supply or drugstores, while waiting in a hospital lobby, or while the customer is surfing the internet or browsing magazines.

6.2.5 Sales Channels

The channels for which the device would be sold are primarily the direct sales to the pediatricians and families, and the sales to the general medical supply stores. A website store could be created in order for individual customers to buy the product, and the device would then be delivered by mail. Alternatively, the device could be sold in bulk to general medical supply stores. Customers of the medical supply store can then purchase individual devices.

In the initial phases of the business, the devices would all be assembled by the designers through inside manufacturing. This is because there may not be many units of the device being sold, so it is manageable for the device to be manufactured internally. However, as the business grows, the number of units that are in demand increases, and external manufacturing resources are needed in order to keep up with the demand. Manufacturers will need to be hired to assemble the products in order to deliver them to customers in a timely manner.

6.2.6 Revenue Streams

Revenue will be generated from the customer purchases, whether they be direct to the users through individual sales, or in bulk sales to a general medical supply store. At first, the business will be small, so the reach of the product may not be far yet as it is ideal to start small so that the business can keep up with its growth. In the beginning, the product will start out by selling to hospitals, clinics, and individuals in the San Francisco Bay Area. Through the website, the product can be shipped nation-wide. As the business steadily grows, sales to hospitals, clinics, and individuals can increase to the region of Northern California, then statewide, west coast, nationwide, and worldwide.

Since the product will cost $72 to produce, the device will be sold to customers at $90 to provide a profit while staying under $100. This would mean that the profit margin is about 20%. I suspect that the projection of sales for the device will follow a slow exponential trend because of how the device’s sales range increases its radius over time. I arbitrarily chose the exponential value to be 1.2, but since this is just a projection, there is no sure value.

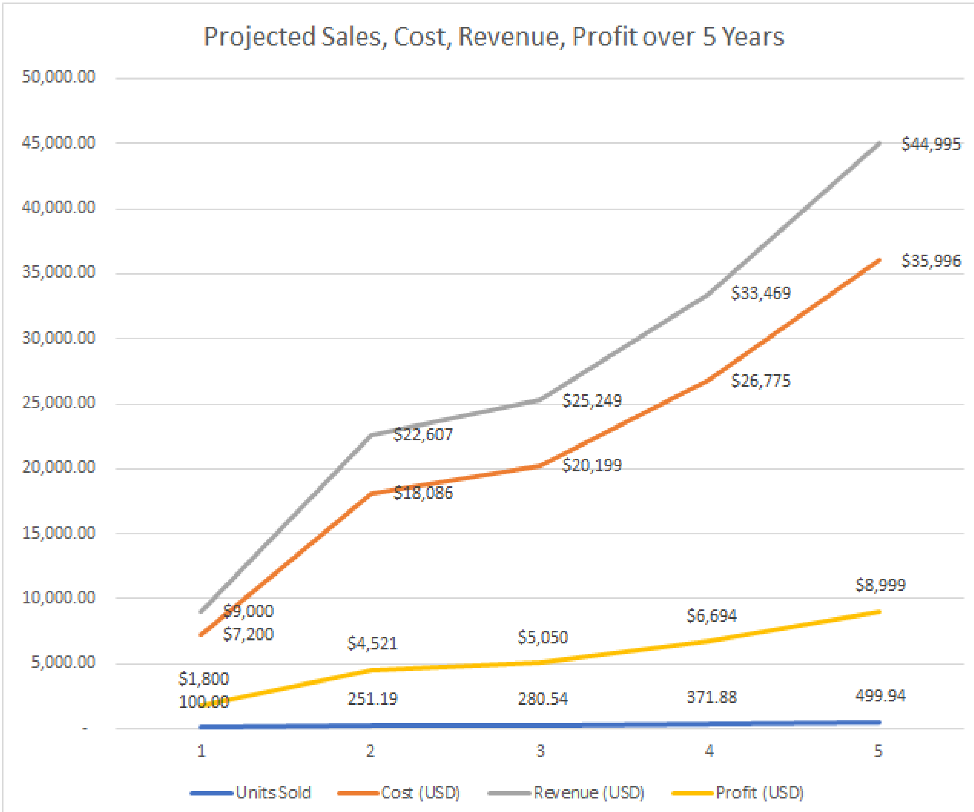

Fig. 22: Exponential Trend of the Projected Sales, Cost, Revenue, and Profit

As indicated by Figure 22, the business is projected to have a profit of $8,999 USD by the end of five years.

7. Professional Issues and Constraints

In this section of the report, the Digital Height-Measurement Sensor Device is examined as if it were a commercial product. The device would have a plastic chassis and its software and components would be custom-made and manufactured for the device. The project is assessed through the topics of Science, Technology and Society, Manufacturability, Economics, Usability, and Ethics.

7.1 Science, Technology, and Society

Science, technology, and society are all interconnected as science is used to develop the technology, which is then implemented to impact society. This device uses science in the development and use of electrical components and programs to make the stadiometer technology, which will benefit society, especially those in the medical field. This digital stadiometer is intended to provide extra portability and efficiency during the height-measurement process in hospitals and clinics, easing some discomforts and increasing the time doctors have to spend with their patients. When patients' discomfort is eased and doctors spend more time assessing their health, people may be less fearful and more aware of their health. When the height measurement process as a whole is more efficient, then peoples' health could be better assessed, leading to people more aware of their health and how to ensure good health and how to assess ailments.

7.2 Manufacturability

This device can be manufactured efficiently, reliably, and within acceptable costs. Currently, this device only required some simple soldering and planned to construct a chassis with 3D printing technology. If this device was manufactured at a larger scale, there are multiple methods for printing circuit boards and integrating electronic components. Similarly, the chassis could be developed for injection molding, making its manufacturability more affordable and available for mass production. The software of the device could be printed onto a chip instead of being programmed onto an Arduino Nano.

7.3 Economics

Because this device was created with a budget of <$100 envisioned, as stated in Sect. 6, the impact that this device can have is larger. This cost point is affordable for the small clinics to purchase several, meaning that more patients can be positively impacted in these clinical settings. This product was created with the affordability for a small clinic to purchase it, however, on a larger scale, the product could be sold to larger hospitals, or even places such as developing countries.

7.4 Usability

As a designer, I want to ensure that this device satisfies the engineering standard of usability. Throughout designing and prototyping the device, I wanted to create a user-friendly, enjoyable, and intuitive experience for the users of the device. The bubble level game was designed for the practicality of leveling the accelerometer parallel towards the ground, and as an interactive and fun experience for the patient to focus on while their height is being measured. The game is simple enough to be intuitive, as the objective is to keep the black circle in the ring on the screen. The LCD screen and button activation were meant to be a user-friendly way to interact with the game in order to initialize it. It is also critical that this device is safe to use. In a hypothetical commercial version of this product, it would be designed to ensure safety. This device would have an enclosed plastic chassis to cover the exposed wires. The chassis would be durable, impact-resistant, and with rounded edges so that there are no sharp corners that can cause injury.

7.5 Ethics

It is crucial to assess this project through the significance of ethics in order to strive for an ethically conscious project. This can be done by examining ethics through the categories of: ethical justification through compassion, upholding positive engineering characteristics, and acknowledging ethical pitfalls.

7.5.1 Ethical Justification through Compassion

This project was developed from the ethics perspective of compassion. Ultimately, this project is intended to make the healthcare process more efficient, which in turn benefits the health of patients. This project was created with the idea that all people deserve empathy and compassion, and so this device was developed so it can ultimately better assess people's health and ease their ailments and pain. Since this device is used to inspect patients for ailments that are a result of an abnormal growth pattern, it can be used to diagnose people sooner and reduce their suffering from the progression of disease. The affordability aspect of this device can help to ensure it is accessible to a wider range of people, since compassion and empathy should not discriminate between the rich and poor.

7.5.2 Upholding Positive Engineering Characteristics

In order to uphold positive engineering characteristics, the project must be examined through the lens of techno-social sensitivity, respect for nature, commitment to the common good, and courage and perseverance of the engineer despite obstacles.

This project brings awareness of how the evolution of technology affects society. The digital stadiometer uses sensor technology to allow for a more portable and compact device compared to the traditional stadiometer. The introduction of sensor technology to the height measurement process in hospitals and clinics helps to increase efficiency for the nurse by automating the ruler measuring. Due to the user-friendliness built into the device's technology, a beginner nurse will only have to place the device on the patient's head, press the button, instruct the patient to stand straight and still while they navigate the black circle into the ring on the LCD screen, and record the measurement. In comparison, a beginner nurse using a traditional stadiometer will need to learn how to properly extend or adjust the stadiometer for a very tall or very short patient. The use of technology intends to allow for a shorter training time and smaller learning curve for the nurses.

In a hypothetical commercial version of the device, this product would emphasize value of the natural world by ensuring that the manufacturing process is sustainable and environmentally friendly. The devices would be designed to be small, not only for more comfort for the patient, but also to use less plastic materials. The volume of the device is much smaller than the traditional stadiometer, which means that less material is required to manufacture one unit. The plastic chassis of the device would be injection molded or 3D printed, which would help reduce waste, compared to machining the product by cutting it out from plastic sheets.

This product aims to benefit the common good because of the wider range of people positively affected by the device due to its low cost. With more people able to purchase the device, the device assists the public since it can allow for people regardless of financial status to use the device to assess their health.

My efforts in this project were a feat of courage as I was the sole team member. At times, completing this project felt overwhelming since there were no other students to distribute the workload. For example, if I was busy or feeling unwell, progress in the project was slowed or halted until I could work on it again. If I were in a team, progress could be evenly distributed amongst all the teammates so that there could be steady progress. However, despite the lack of teammates, I persevered in my endeavors to complete this project to the best of my ability. I was determined to finish this project despite any obstacles in the way. This was especially hard after the COVID-19 outbreak, since I could not access the university Maker Lab to solder the electrical components.

7.5.3 Ethical Pitfalls

It is important to examine the safety and risk pitfalls that occurred during the project because it is vital to acknowledge these issues in order to ensure the safety of the customers and people around them. The Final Rig prototype of this device had exposed wires since it lacked a chassis due to time running out at the end of the school quarter. The exposed wires could pose the risk of electrocution or catching fire if they are damaged. Additionally, the final rig had sharp plastic edges that would need to be rounded for if this product became commercially available to ensure that no one gets injured.

8. Conclusion

The success of this device is dependent on the three most important customer needs: accuracy, speed of measurement, and budget. The requirements of the device are to ensure that the height-measurement takes 10 seconds or less to take a measurement, the measurement must be accurate to ¼", and it must be under $100 to purchase.

The final rig produced the following results for three sample heights expected at 61", 65.5", and 46.6". At 61", the average difference between the measured and expected values was 0.5975", the average percent error was -0.9795%, At 65.5", these values were 0.5138" and 0.2748%, respectively. At 46.6", these values were 1.1888" and 3.176%, respectively. The device took about 6 seconds in order to take a measurement. As stated in the financial section of this report, the cost to manufacture one device is about $72 USD. In the business plan section of the report, it is shown that a market price of $90 USD is profitable. This is less than the competitors, the PUSH and Sonaris digital height-measuring devices.

Two of the three customer needs were met: a price that is under $100, and a height measurement taken in less than ten seconds. Although the average difference and average percent error between measured values vs. expected were small, the average difference between expected and measured height values from all the heights tested was 0.7667". This did not satisfy the average difference as specified in the customer needs to be 0.25". With future iterations of this device, reducing the difference in measurements will be the priority so that it successfully meets all of the customer needs.

9. References

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10. Appendix

Appendix A: Customer Interviews

A1: Interview with Dr. Saxena at the Pediatric Wellness Group Clinic

Questions for Dr. Saxena:

Pains/Gains of current procedure: what would you wish?

-Measuring people taller than administrator of procedure
-accuracy between diff stadiometers in office
-Measuring people must be still
-Cost
-More portable options so no bottlenecks in hallway
-Cost, Speed, Accuracy, internal QA
- Consistency between devices and measurements(within device itself and with other devices, make sure devices are calibrated)

Asking about motivations:
-Growth trajectory of a child
helps detect medical conditions
Measuring patients ages 2+ as old as 23/24
-Height range 3-6ft
-Accurate Reading In 10 Seconds
-Current Readings are about 10 Seconds
-Faster and maximize the time for the doctors in the office, minimize time for the general procedure and more time for doctor to spend with patient

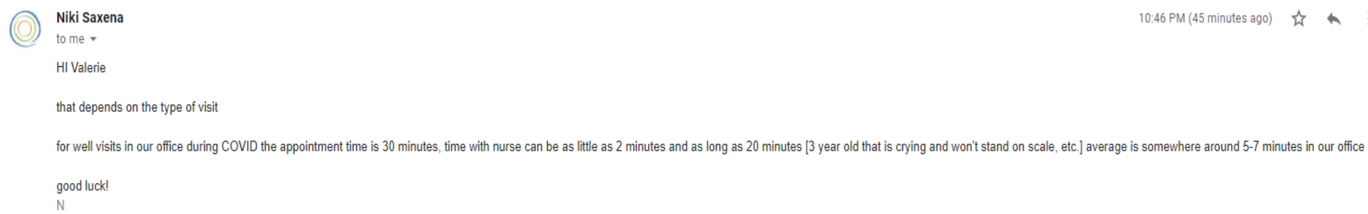
MOST IMPORTANT: speed and accuracy
Next: Cost and Portability
Must be durable enough to be dropped
Must be able to be dropped without worry about cost of replacing

Cost ideally: <$100

Would Be Nice(not necessary)

Bluetooth that connects from device to the database
APP

A2: Email Interview


Niki Saxena
to me
10:46 PM (45 minutes ago)

HI Valerie

that depends on the type of visit

for well visits in our office during COVID the appointment time is 30 minutes, time with nurse can be as little as 2 minutes and as long as 20 minutes [3 year old that is crying and won't stand on scale, etc.] average is somewhere around 5-7 minutes in our office

good luck!
N

“HI Valerie

that depends on the type of visit

for well visits in our office during COVID the appointment time is 30 minutes, time with nurse can be as little as 2 minutes and as long as 20 minutes [3 year old that is crying and won't stand on scale, etc.] average is somewhere around 5-7 minutes in our office

good luck!” -Dr. Niki Saxena

Appendix B: Competitor Stadiometer Devices

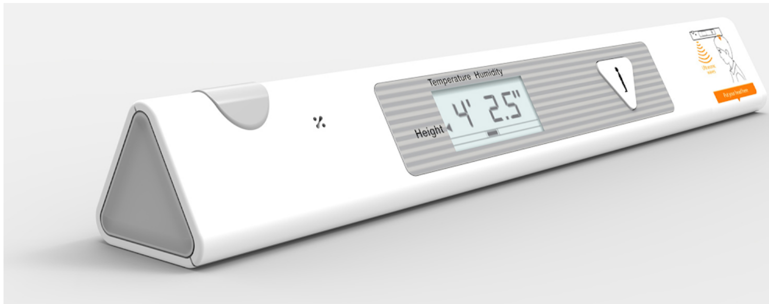


Fig. B1: PUSH Stadiometer [6]
PUSH Stadiometer. (2019, August 6). Retrieved June 7, 2020, from https://inbodyusa.com/products/push/

Fig. B2: Sonaris Stadiometer [7]
SONARIS Touchless Sonar Stadiometer. (n.d.). Retrieved June 7, 2020, from https://www.detecto.com/product/product-overview/Stadiometers/SONARIS-Touchless-Sonar-Stadiometer

Appendix C : Hardware Information

Fig. C1: HC-SR04 Ultrasonic Ping Sensor [10]
Marian, P. (2020, March 27). HC-SR04 Datasheet. Retrieved June 7, 2020, from https://www.electroschematics.com/hc-sr04-datasheet/

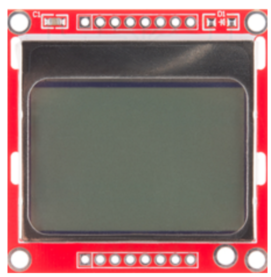


Fig. C2: Nokia 5110 LCD [11]
Sparkfun. (n.d.). Distance Sensing Overview. Retrieved June 7, 2020, from https://www.sparkfun.com/

Fig. C3: Arduino Nano [11]
Sparkfun. (n.d.). Distance Sensing Overview. Retrieved June 7, 2020, from https://www.sparkfun.com/

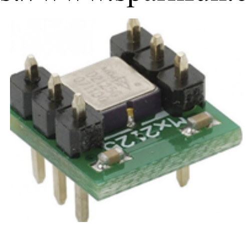


Fig. C4: Memsic 2125 Accelerometer [11]
Sparkfun. (n.d.). Distance Sensing Overview. Retrieved June 7, 2020, from https://www.sparkfun.com/

Appendix D: Software Information

The following code was created in part from [8] Palivec, K. (2017, October 4). Arduino Micro Electronic Bubble Level. Retrieved June 7, 2020, from https://www.instructables.com/id/Arduino-Micro-Electronic-Bubble-Level/

```
#include <SPI.h>

//arduino micro led visual level
#include <Adafruit_GFX.h>
#include <Adafruit_PCD8544.h>
Adafruit_PCD8544 display = Adafruit_PCD8544(5, 6, 7, 8, 9);
// pin 2 - Serial clock out (SCLK)     5
// pin 3 - Serial data out (DIN)      6
// pin 4 - Data/Command select (D/C)   7
// pin 12 - LCD chip select (CS)      8
// pin 11 - LCD reset (RST)   9

//Counter
int counter = 0;

  float height2=0;
  float subheight=0;
  float height_in=0;
  float heightavg;
  float Calheightavg;

//BUTTON

const int buttonPin = 13;

//PING
const int trigPin = 11;
const int echoPin = 12;
float duration, height;

//Array
int A [10];

//BUBBLE
const int X = 2; //X pin on m2125
const int Y = 3; //Y pin on m2125
int i=0;
int dist,inv=0;
boolean stan=0;

void setup() {
//BUTTON
pinMode (buttonPin, INPUT);

//PING
  pinMode(trigPin, OUTPUT);
 pinMode(echoPin, INPUT);


  //set up serial
  Serial.begin(9600);

pinMode(X, INPUT);
pinMode(Y, INPUT);
display.begin();
display.setContrast(50);
display.clearDisplay();

 }

void loop() {
//"Press "Measure if ready!"
display.clearDisplay();
display.println ("Press the 'Measure' button when READY!");
display.display();
delay(500);
display.clearDisplay();

  // button
int buttonState = 0;
buttonState = digitalRead(buttonPin);
//Serial.println (buttonState);


if (buttonState == HIGH) {
 // bubblegame();



 for (int i = 0; i <= 15; i++) {
    bubblegame();


}

  // Average the height values and display to the LCD

  heightavg = height2/counter;
  Calheightavg = (1/0.9822)*heightavg - 1.5;

Serial.println(Calheightavg);
```

```
}
counter = 0;
height2 = 0;
subheight = 0;
heightavg = 0;
}

void bubblegame(){

 //read in the pulse data
   int pulseX, pulseY;
   int angleX, angleY;
   int accelerationX,
accelerationY;


  pulseX = pulseIn(X,HIGH);
  pulseY = pulseIn(Y,HIGH);

   //map the data for the nokia
display
   accelerationX =
map(pulseX, 3740, 6286, 48,
0);
   accelerationY =
map(pulseY, 3740, 6370, 84,
0);
  // map data to crude angles
   angleX =
map(accelerationX,48,0,-90,9
0);
   angleY =
map(accelerationY,0,84,-90,9
0);

display.drawRect(0,0,84,48,B
LACK);
   display.drawLine( 42,  0,
42, 48, BLACK);
   display.drawLine( 0,  24,
84, 24, BLACK);

display.drawCircle(42,24,10,
BLACK);
   // display bubble

display.fillCircle(acceleration
Y,accelerationX,4,BLACK);
   display.setCursor(1,1);
   display.println("X: "+
String(angleX));
   display.setCursor(4,38);
   display.println("Y: "+
String(angleY));
   display.display();
   display.clearDisplay();

if (abs(angleX) <= 10 &&
abs(angleY) <=10) {

  subheight = height2;

  pingsensor();

  delay(250);
  height2 = subheight +
height_in;
  counter = counter + 1;
  Serial.print("Counter:  ");
Serial.print(counter);
Serial.print("  Height:
");Serial.print(height_in);Seri
al.print("  Subheight:
");Serial.print(subheight);Seri
al.print("  Height2:  ");
Serial.println(height2);

}

   // delay the data feed to we
dont overrun the serial
   delay(90);
//counter = 0;
//height = 0;
//subheight = 0;

 }

  void pingsensor()
 {
digitalWrite(trigPin, LOW);

delayMicroseconds(2);

digitalWrite(trigPin, HIGH);

delayMicroseconds(10);

digitalWrite(trigPin, LOW);

                              duration =
pulseIn(echoPin, HIGH);
                              //Convert
centimeter height to inches
                              height =
(duration*.0343)/2; //cm
                              height_in
= height/2.54; //in
                              //Array



 }
```

Appendix E: Initial Raw Data

Table E1: Initial Raw Data

Counter:	1	Height:	71.42	Subheight:	0	Height2:	71.42
Counter:	2	Height:	71.39	Subheight:	71.42	Height2:	142.8
Counter:	3	Height:	71.56	Subheight:	142.8	Height2:	214.36
Counter:	4	Height:	71.56	Subheight:	214.36	Height2:	285.92
Counter:	5	Height:	71.72	Subheight:	285.92	Height2:	357.64
Counter:	6	Height:	71.54	Subheight:	357.64	Height2:	429.18
Counter:	7	Height:	71.4	Subheight:	429.18	Height2:	500.58
Counter:	8	Height:	72.12	Subheight:	500.58	Height2:	572.7
Counter:	9	Height:	71.79	Subheight:	572.7	Height2:	644.49
Counter:	10	Height:	71.6	Subheight:	644.49	Height2:	716.09
Counter:	11	Height:	71.4	Subheight:	716.09	Height2:	787.49
Counter:	12	Height:	71.42	Subheight:	787.49	Height2:	858.91
Counter:	13	Height:	71.58	Subheight:	858.91	Height2:	930.49
Counter:	14	Height:	71.62	Subheight:	930.49	Height2:	1002.11
Counter:	15	Height:	71.58	Subheight:	1002.1	1 Height2	: 1073.70
Counter:	16	Height:	71.45	Subheight:	1073.7	0 Height2	: 1145.15
71.57							
Counter:	1	Height:	65.05	Subheight:	0	Height2:	65.05
Counter:	2	Height:	65.24	Subheight:	65.05	Height2:	130.29
Counter:	3	Height:	65.08	Subheight:	130.29	Height2:	195.37
Counter:	4	Height:	65.25	Subheight:	195.37	Height2:	260.63
Counter:	5	Height:	65.12	Subheight:	260.63	Height2:	325.74
Counter:	6	Height:	65.5	Subheight:	325.74	Height2:	391.24
Counter:	7	Height:	65.31	Subheight:	391.24	Height2:	456.55
Counter:	8	Height:	65.31	Subheight:	456.55	Height2:	521.87
Counter:	9	Height:	65.5	Subheight:	521.87	Height2:	587.37
Counter:	10	Height:	65.44	Subheight:	587.37	Height2:	652.81
Counter:	11	Height:	65.27	Subheight:	652.81	Height2:	718.08
Counter:	12	Height:	65.08	Subheight:	718.08	Height2:	783.16
Counter:	13	Height:	65.62	Subheight:	783.16	Height2:	848.78
Counter:	14	Height:	65.66	Subheight:	848.78	Height2:	914.45
Counter:	15	Height:	65.49	Subheight:	914.45	Height2:	979.93
Counter:	16	Height:	65.12	Subheight:	979.93	Height2:	1045.06
65.32							
Counter:	1	Height:	58.84	Subheight:	0	Height2:	58.84
Counter:	2	Height:	58.81	Subheight:	58.84	Height2:	117.65

Counter:	3	Height:	58.6	Subheight:	117.65	Height2:	176.25
Counter:	4	Height:	58.96	Subheight:	176.25	Height2:	235.2
Counter:	5	Height:	58.76	Subheight:	235.2	Height2:	293.97
Counter:	6	Height:	59.1	Subheight:	293.97	Height2:	353.07
Counter:	7	Height:	58.6	Subheight:	353.07	Height2:	411.67
Counter:	8	Height:	57.82	Subheight:	411.67	Height2:	469.49
Counter:	9	Height:	58.57	Subheight:	469.49	Height2:	528.06
Counter:	10	Height:	57.45	Subheight:	528.06	Height2:	585.52
Counter:	11	Height:	57.07	Subheight:	585.52	Height2:	642.59
Counter:	12	Height:	57.73	Subheight:	642.59	Height2:	700.32
Counter:	13	Height:	57.39	Subheight:	700.32	Height2:	757.71
Counter:	14	Height:	57.77	Subheight:	757.71	Height2:	815.48
Counter:	15	Height:	58.84	Subheight:	815.48	Height2:	874.33
Counter:	16	Height:	57.43	Subheight:	874.33	Height2:	931.75
58.23							
Counter:	1	Height:	51.92	Subheight:	0	Height2:	51.92
Counter:	2	Height:	52.05	Subheight:	51.92	Height2:	103.97
Counter:	3	Height:	53.16	Subheight:	103.97	Height2:	157.14
Counter:	4	Height:	51.59	Subheight:	157.14	Height2:	208.72
Counter:	5	Height:	52.1	Subheight:	208.72	Height2:	260.82
Counter:	6	Height:	51.75	Subheight:	260.82	Height2:	312.57
Counter:	7	Height:	53.37	Subheight:	312.57	Height2:	365.94
Counter:	8	Height:	51.75	Subheight:	365.94	Height2:	417.69
Counter:	9	Height:	53.33	Subheight:	417.69	Height2:	471.02
Counter:	10	Height:	53.15	Subheight:	471.02	Height2:	524.18
Counter:	11	Height:	52.06	Subheight:	524.18	Height2:	576.23
Counter:	12	Height:	53.34	Subheight:	576.23	Height2:	629.57
Counter:	13	Height:	53.31	Subheight:	629.57	Height2:	682.89
Counter:	14	Height:	53.12	Subheight:	682.89	Height2:	736.01
Counter:	15	Height:	52.19	Subheight:	736.01	Height2:	788.2
Counter:	16	Height:	53.33	Subheight:	788.2	Height2:	841.54
52.6							
Counter:	1	Height:	47.55	Subheight:	0	Height2:	47.55
Counter:	2	Height:	47.4	Subheight:	47.55	Height2:	94.95
Counter:	3	Height:	47.35	Subheight:	94.95	Height2:	142.3
Counter:	4	Height:	47.4	Subheight:	142.3	Height2:	189.7
Counter:	5	Height:	47.14	Subheight:	189.7	Height2:	236.84
Counter:	6	Height:	47.2	Subheight:	236.84	Height2:	284.04
Counter:	7	Height:	47.39	Subheight:	284.04	Height2:	331.43

Counter:	8	Height:	47.2	Subheight:	331.43	Height2:	378.62
Counter:	9	Height:	47.36	Subheight:	378.62	Height2:	425.98
Counter:	10	Height:	47.18	Subheight:	425.98	Height2:	473.16
Counter:	11	Height:	47.55	Subheight:	473.16	Height2:	520.72
Counter:	12	Height:	47.2	Subheight:	520.72	Height2:	567.91
Counter:	13	Height:	47.55	Subheight:	567.91	Height2:	615.46
Counter:	14	Height:	47.2	Subheight:	615.46	Height2:	662.66
Counter:	15	Height:	47.39	Subheight:	662.66	Height2:	710.05
Counter:	16	Height:	47.2	Subheight:	710.05	Height2:	757.25
47.33							
Counter:	1	Height:	40.19	Subheight:	0	Height2:	40.19
Counter:	2	Height:	40.17	Subheight:	40.19	Height2:	80.36
Counter:	3	Height:	39.36	Subheight:	80.36	Height2:	119.72
Counter:	4	Height:	39.68	Subheight:	119.72	Height2:	159.4
Counter:	5	Height:	40.98	Subheight:	159.4	Height2:	200.38
Counter:	6	Height:	39.95	Subheight:	200.38	Height2:	240.34
Counter:	7	Height:	40.1	Subheight:	240.34	Height2:	280.44
Counter:	8	Height:	39.42	Subheight:	280.44	Height2:	319.85
Counter:	9	Height:	39.07	Subheight:	319.85	Height2:	358.92
Counter:	10	Height:	39.41	Subheight:	358.92	Height2:	398.33
Counter:	11	Height:	39.3	Subheight:	398.33	Height2:	437.63
Counter:	12	Height:	39.46	Subheight:	437.63	Height2:	477.09
Counter:	13	Height:	39.8	Subheight:	477.09	Height2:	516.88
Counter:	14	Height:	39.4	Subheight:	516.88	Height2:	556.28
Counter:	15	Height:	39.75	Subheight:	556.28	Height2:	596.03
Counter:	16	Height:	40.73	Subheight:	596.03	Height2:	636.76
39.8							
Counter:	1	Height:	36.33	Subheight:	0	Height2:	36.33
Counter:	2	Height:	35.98	Subheight:	36.33	Height2:	72.31
Counter:	3	Height:	36.29	Subheight:	72.31	Height2:	108.6
Counter:	4	Height:	35.92	Subheight:	108.6	Height2:	144.52
Counter:	5	Height:	36.09	Subheight:	144.52	Height2:	180.61
Counter:	6	Height:	35.78	Subheight:	180.61	Height2:	216.39
Counter:	7	Height:	35.79	Subheight:	216.39	Height2:	252.17
Counter:	8	Height:	35.88	Subheight:	252.17	Height2:	288.05
Counter:	9	Height:	36.22	Subheight:	288.05	Height2:	324.28
Counter:	10	Height:	35.88	Subheight:	324.28	Height2:	360.16
Counter:	11	Height:	36.19	Subheight:	360.16	Height2:	396.35
Counter:	12	Height:	35.72	Subheight:	396.35	Height2:	432.07

Counter:	13	Height:	35.88	Subheight:	432.07	Height2:	467.95
Counter:	14	Height:	36.05	Subheight:	467.95	Height2:	503.99
Counter:	15	Height:	35.89	Subheight:	503.99	Height2:	539.88
Counter:	16	Height:	36.06	Subheight:	539.88	Height2:	575.94
36							

Expected (in)	Avg Measured (in)	Calibrated (in)
36	36	36.7
42	39.8	40.5
48	47.33	48.2
54	52.6	53.6
60	58.23	59.3
66	65.32	66.5
72	71.57	72.9

Appendix F: Final Raw Data

Table F1: Height Data at 61”

Counter: 1 Height: 61.79 Subheight: 0.00 Height2: 61.79
Counter: 2 Height: 62.15 Subheight: 61.79 Height2: 123.93
Counter: 3 Height: 62.34 Subheight: 123.93 Height2: 186.27
Counter: 4 Height: 62.27 Subheight: 186.27 Height2: 248.55
Counter: 5 Height: 62.35 Subheight: 248.55 Height2: 310.90
Counter: 6 Height: 62.52 Subheight: 310.90 Height2: 373.42
Counter: 7 Height: 62.48 Subheight: 373.42 Height2: 435.90
Counter: 8 Height: 62.23 Subheight: 435.90 Height2: 498.13
Counter: 9 Height: 62.37 Subheight: 498.13 Height2: 560.50
Counter: 10 Height: 62.09 Subheight: 560.50 Height2: 622.59
Counter: 11 Height: 62.63 Subheight: 622.59 Height2: 685.22
Counter: 12 Height: 62.31 Subheight: 685.22 Height2: 747.54
Counter: 13 Height: 62.10 Subheight: 747.54 Height2: 809.64
Counter: 14 Height: 62.40 Subheight: 809.64 Height2: 872.04
Counter: 15 Height: 62.42 Subheight: 872.04 Height2: 934.47
Counter: 16 Height: 62.51 Subheight: 934.47 Height2: 996.98
61.94
Counter: 1 Height: 62.23 Subheight: 0.00 Height2: 62.23
Counter: 2 Height: 62.44 Subheight: 62.23 Height2: 124.66
Counter: 3 Height: 62.50 Subheight: 124.66 Height2: 187.16
Counter: 4 Height: 62.53 Subheight: 187.16 Height2: 249.69
Counter: 5 Height: 63.08 Subheight: 249.69 Height2: 312.77
Counter: 6 Height: 62.07 Subheight: 312.77 Height2: 374.84
Counter: 7 Height: 62.81 Subheight: 374.84 Height2: 437.66
Counter: 8 Height: 62.44 Subheight: 437.66 Height2: 500.10
Counter: 9 Height: 62.46 Subheight: 500.10 Height2: 562.56
Counter: 10 Height: 62.71 Subheight: 562.56 Height2: 625.27
Counter: 11 Height: 62.20 Subheight: 625.27 Height2: 687.47
Counter: 12 Height: 62.68 Subheight: 687.47 Height2: 750.15
Counter: 13 Height: 62.01 Subheight: 750.15 Height2: 812.16
Counter: 14 Height: 62.17 Subheight: 812.16 Height2: 874.33
Counter: 15 Height: 62.50 Subheight: 874.33 Height2: 936.83
Counter: 16 Height: 62.35 Subheight: 936.83 Height2: 999.18
62.08
Counter: 1 Height: 61.95 Subheight: 0.00 Height2: 61.95

Counter: 2 Height: 61.96 Subheight: 61.95 Height2: 123.91
Counter: 3 Height: 61.93 Subheight: 123.91 Height2: 185.83
Counter: 4 Height: 61.92 Subheight: 185.83 Height2: 247.75
Counter: 5 Height: 62.07 Subheight: 247.75 Height2: 309.82
Counter: 6 Height: 61.93 Subheight: 309.82 Height2: 371.75
Counter: 7 Height: 61.73 Subheight: 371.75 Height2: 433.48
Counter: 8 Height: 61.71 Subheight: 433.48 Height2: 495.18
Counter: 9 Height: 61.87 Subheight: 495.18 Height2: 557.05
Counter: 10 Height: 61.72 Subheight: 557.05 Height2: 618.77
Counter: 11 Height: 61.97 Subheight: 618.77 Height2: 680.74
Counter: 12 Height: 62.16 Subheight: 680.74 Height2: 742.90
Counter: 13 Height: 62.34 Subheight: 742.90 Height2: 805.24
Counter: 14 Height: 62.18 Subheight: 805.24 Height2: 867.42
Counter: 15 Height: 62.34 Subheight: 867.42 Height2: 929.76
Counter: 16 Height: 61.97 Subheight: 929.76 Height2: 991.73
61.61
Counter: 1 Height: 61.63 Subheight: 0.00 Height2: 61.63
Counter: 2 Height: 61.45 Subheight: 61.63 Height2: 123.08
Counter: 3 Height: 61.46 Subheight: 123.08 Height2: 184.54
Counter: 4 Height: 62.38 Subheight: 184.54 Height2: 246.93
Counter: 5 Height: 61.58 Subheight: 246.93 Height2: 308.50
Counter: 6 Height: 61.40 Subheight: 308.50 Height2: 369.90
Counter: 7 Height: 61.36 Subheight: 369.90 Height2: 431.26
Counter: 8 Height: 61.38 Subheight: 431.26 Height2: 492.63
Counter: 9 Height: 61.77 Subheight: 492.63 Height2: 554.40
Counter: 10 Height: 61.95 Subheight: 554.40 Height2: 616.35
Counter: 11 Height: 61.60 Subheight: 616.35 Height2: 677.95
Counter: 12 Height: 61.60 Subheight: 677.95 Height2: 739.55
Counter: 13 Height: 61.75 Subheight: 739.55 Height2: 801.30
Counter: 14 Height: 61.79 Subheight: 801.30 Height2: 863.08
Counter: 15 Height: 61.79 Subheight: 863.08 Height2: 924.87
Counter: 16 Height: 61.83 Subheight: 924.87 Height2: 986.70
61.29
Counter: 1 Height: 61.67 Subheight: 0.00 Height2: 61.67
Counter: 2 Height: 61.69 Subheight: 61.67 Height2: 123.37
Counter: 3 Height: 61.54 Subheight: 123.37 Height2: 184.90
Counter: 4 Height: 61.73 Subheight: 184.90 Height2: 246.63
Counter: 5 Height: 61.62 Subheight: 246.63 Height2: 308.25
Counter: 6 Height: 61.79 Subheight: 308.25 Height2: 370.03

Counter: 7 Height: 62.32 Subheight: 370.03 Height2: 432.36
Counter: 8 Height: 62.50 Subheight: 432.36 Height2: 494.86
Counter: 9 Height: 62.14 Subheight: 494.86 Height2: 557.00
Counter: 10 Height: 62.50 Subheight: 557.00 Height2: 619.50
Counter: 11 Height: 61.85 Subheight: 619.50 Height2: 681.35
Counter: 12 Height: 62.20 Subheight: 681.35 Height2: 743.55
Counter: 13 Height: 61.97 Subheight: 743.55 Height2: 805.52
Counter: 14 Height: 62.20 Subheight: 805.52 Height2: 867.72
Counter: 15 Height: 61.81 Subheight: 867.72 Height2: 929.52
Counter: 16 Height: 61.79 Subheight: 929.52 Height2: 991.32
61.58
Counter: 1 Height: 61.77 Subheight: 0.00 Height2: 61.77
Counter: 2 Height: 62.12 Subheight: 61.77 Height2: 123.90
Counter: 3 Height: 61.77 Subheight: 123.90 Height2: 185.67
Counter: 4 Height: 62.29 Subheight: 185.67 Height2: 247.97
Counter: 5 Height: 62.08 Subheight: 247.97 Height2: 310.05
Counter: 6 Height: 61.80 Subheight: 310.05 Height2: 371.85
Counter: 7 Height: 61.78 Subheight: 371.85 Height2: 433.63
Counter: 8 Height: 61.75 Subheight: 433.63 Height2: 495.38
Counter: 9 Height: 62.08 Subheight: 495.38 Height2: 557.46
Counter: 10 Height: 61.86 Subheight: 557.46 Height2: 619.32
Counter: 11 Height: 62.20 Subheight: 619.32 Height2: 681.52
Counter: 12 Height: 62.19 Subheight: 681.52 Height2: 743.71
Counter: 13 Height: 62.01 Subheight: 743.71 Height2: 805.72
Counter: 14 Height: 62.03 Subheight: 805.72 Height2: 867.75
Counter: 15 Height: 61.99 Subheight: 867.75 Height2: 929.74
Counter: 16 Height: 61.83 Subheight: 929.74 Height2: 991.57
61.6
Counter: 1 Height: 61.69 Subheight: 0.00 Height2: 61.69
Counter: 2 Height: 61.96 Subheight: 61.69 Height2: 123.64
Counter: 3 Height: 61.46 Subheight: 123.64 Height2: 185.11
Counter: 4 Height: 61.69 Subheight: 185.11 Height2: 246.80
Counter: 5 Height: 61.72 Subheight: 246.80 Height2: 308.52
Counter: 6 Height: 61.56 Subheight: 308.52 Height2: 370.08
Counter: 7 Height: 61.91 Subheight: 370.08 Height2: 431.98
Counter: 8 Height: 61.54 Subheight: 431.98 Height2: 493.52
Counter: 9 Height: 62.08 Subheight: 493.52 Height2: 555.60
Counter: 10 Height: 61.95 Subheight: 555.60 Height2: 617.55
Counter: 11 Height: 62.14 Subheight: 617.55 Height2: 679.69

Counter: 12 Height: 62.14 Subheight: 679.69 Height2: 741.83
Counter: 13 Height: 61.74 Subheight: 741.83 Height2: 803.57
Counter: 14 Height: 62.05 Subheight: 803.57 Height2: 865.62
Counter: 15 Height: 61.52 Subheight: 865.62 Height2: 927.13
Counter: 16 Height: 62.02 Subheight: 927.13 Height2: 989.15
61.44
Counter: 1 Height: 61.58 Subheight: 0.00 Height2: 61.58
Counter: 2 Height: 61.24 Subheight: 61.58 Height2: 122.83
Counter: 3 Height: 61.76 Subheight: 122.83 Height2: 184.59
Counter: 4 Height: 61.43 Subheight: 184.59 Height2: 246.01
Counter: 5 Height: 61.44 Subheight: 246.01 Height2: 307.45
Counter: 6 Height: 61.43 Subheight: 307.45 Height2: 368.88
Counter: 7 Height: 61.76 Subheight: 368.88 Height2: 430.64
Counter: 8 Height: 61.63 Subheight: 430.64 Height2: 492.27
Counter: 9 Height: 61.99 Subheight: 492.27 Height2: 554.26
Counter: 10 Height: 61.68 Subheight: 554.26 Height2: 615.94
Counter: 11 Height: 61.86 Subheight: 615.94 Height2: 677.80
Counter: 12 Height: 61.66 Subheight: 677.80 Height2: 739.46
Counter: 13 Height: 61.64 Subheight: 739.46 Height2: 801.10
Counter: 14 Height: 61.81 Subheight: 801.10 Height2: 862.91
Counter: 15 Height: 61.25 Subheight: 862.91 Height2: 924.16
Counter: 16 Height: 61.88 Subheight: 924.16 Height2: 986.04
61.24

Table F2: Height Data at 65.5”

Counter: 14 Height: 65.53 Subheight: 851.40 Height2: 916.93
Counter: 15 Height: 65.33 Subheight: 916.93 Height2: 982.26
Counter: 16 Height: 65.35 Subheight: 982.26 Height2: 1047.62
65.16
Counter: 1 Height: 65.62 Subheight: 0.00 Height2: 65.62
Counter: 2 Height: 65.61 Subheight: 65.62 Height2: 131.22
Counter: 3 Height: 65.26 Subheight: 131.22 Height2: 196.48
Counter: 4 Height: 65.28 Subheight: 196.48 Height2: 261.76
Counter: 5 Height: 65.70 Subheight: 261.76 Height2: 327.46
Counter: 6 Height: 65.37 Subheight: 327.46 Height2: 392.82
Counter: 7 Height: 65.68 Subheight: 392.82 Height2: 458.50
Counter: 8 Height: 65.35 Subheight: 458.50 Height2: 523.84
Counter: 9 Height: 65.20 Subheight: 523.84 Height2: 589.04

Counter: 10 Height: 65.37 Subheight: 589.04 Height2: 654.41
Counter: 11 Height: 65.45 Subheight: 654.41 Height2: 719.86
Counter: 12 Height: 65.60 Subheight: 719.86 Height2: 785.46
Counter: 13 Height: 65.24 Subheight: 785.46 Height2: 850.70
Counter: 14 Height: 65.31 Subheight: 850.70 Height2: 916.01
Counter: 15 Height: 65.78 Subheight: 916.01 Height2: 981.79
Counter: 16 Height: 65.63 Subheight: 981.79 Height2: 1047.42
65.15
Counter: 1 Height: 65.87 Subheight: 0.00 Height2: 65.87
Counter: 2 Height: 65.43 Subheight: 65.87 Height2: 131.30
Counter: 3 Height: 65.70 Subheight: 131.30 Height2: 197.00
Counter: 4 Height: 65.37 Subheight: 197.00 Height2: 262.37
Counter: 5 Height: 65.26 Subheight: 262.37 Height2: 327.63
Counter: 6 Height: 65.39 Subheight: 327.63 Height2: 393.02
Counter: 7 Height: 65.67 Subheight: 393.02 Height2: 458.69
Counter: 8 Height: 65.49 Subheight: 458.69 Height2: 524.18
Counter: 9 Height: 65.65 Subheight: 524.18 Height2: 589.83
Counter: 10 Height: 65.57 Subheight: 589.83 Height2: 655.39
Counter: 11 Height: 65.69 Subheight: 655.39 Height2: 721.08
Counter: 12 Height: 65.75 Subheight: 721.08 Height2: 786.83
Counter: 13 Height: 65.57 Subheight: 786.83 Height2: 852.40
Counter: 14 Height: 65.57 Subheight: 852.40 Height2: 917.97
Counter: 15 Height: 65.55 Subheight: 917.97 Height2: 983.52
Counter: 16 Height: 65.78 Subheight: 983.52 Height2: 1049.30
65.27
Counter: 1 Height: 65.54 Subheight: 0.00 Height2: 65.54
Counter: 2 Height: 65.67 Subheight: 65.54 Height2: 131.21
Counter: 3 Height: 66.04 Subheight: 131.21 Height2: 197.25
Counter: 4 Height: 65.41 Subheight: 197.25 Height2: 262.66
Counter: 5 Height: 65.59 Subheight: 262.66 Height2: 328.25
Counter: 6 Height: 65.61 Subheight: 328.25 Height2: 393.86
Counter: 7 Height: 65.41 Subheight: 393.86 Height2: 459.26
Counter: 8 Height: 65.69 Subheight: 459.26 Height2: 524.95
Counter: 9 Height: 65.45 Subheight: 524.95 Height2: 590.40
Counter: 10 Height: 65.62 Subheight: 590.40 Height2: 656.01
Counter: 11 Height: 65.45 Subheight: 656.01 Height2: 721.46
Counter: 12 Height: 65.42 Subheight: 721.46 Height2: 786.88
Counter: 13 Height: 65.44 Subheight: 786.88 Height2: 852.32
Counter: 14 Height: 65.53 Subheight: 852.32 Height2: 917.85

Counter: 15 Height: 65.35 Subheight: 917.85 Height2: 983.19
Counter: 16 Height: 65.32 Subheight: 983.19 Height2: 1048.51
65.22
Counter: 1 Height: 65.23 Subheight: 0.00 Height2: 65.23
Counter: 2 Height: 65.74 Subheight: 65.23 Height2: 130.97
Counter: 3 Height: 65.12 Subheight: 130.97 Height2: 196.08
Counter: 4 Height: 65.25 Subheight: 196.08 Height2: 261.33
Counter: 5 Height: 65.10 Subheight: 261.33 Height2: 326.43
Counter: 6 Height: 65.07 Subheight: 326.43 Height2: 391.50
Counter: 7 Height: 64.95 Subheight: 391.50 Height2: 456.45
Counter: 8 Height: 64.87 Subheight: 456.45 Height2: 521.31
Counter: 9 Height: 65.11 Subheight: 521.31 Height2: 586.42
Counter: 10 Height: 65.01 Subheight: 586.42 Height2: 651.44
Counter: 11 Height: 65.03 Subheight: 651.44 Height2: 716.46
Counter: 12 Height: 65.03 Subheight: 716.46 Height2: 781.50
Counter: 13 Height: 65.22 Subheight: 781.50 Height2: 846.72
Counter: 14 Height: 65.10 Subheight: 846.72 Height2: 911.83
64.81
Counter: 1 Height: 65.10 Subheight: 0.00 Height2: 65.10
Counter: 2 Height: 64.97 Subheight: 65.10 Height2: 130.07
Counter: 3 Height: 64.72 Subheight: 130.07 Height2: 194.79
Counter: 4 Height: 64.72 Subheight: 194.79 Height2: 259.51
Counter: 5 Height: 64.75 Subheight: 259.51 Height2: 324.26
Counter: 6 Height: 64.70 Subheight: 324.26 Height2: 388.97
Counter: 7 Height: 64.74 Subheight: 388.97 Height2: 453.71
Counter: 8 Height: 64.72 Subheight: 453.71 Height2: 518.44
Counter: 9 Height: 65.06 Subheight: 518.44 Height2: 583.49
Counter: 10 Height: 64.89 Subheight: 583.49 Height2: 648.38
Counter: 11 Height: 65.01 Subheight: 648.38 Height2: 713.39
Counter: 12 Height: 65.09 Subheight: 713.39 Height2: 778.47
Counter: 13 Height: 64.74 Subheight: 778.47 Height2: 843.22
64.54
Counter: 1 Height: 64.70 Subheight: 0.00 Height2: 64.70
Counter: 2 Height: 64.66 Subheight: 64.70 Height2: 129.37
Counter: 3 Height: 64.85 Subheight: 129.37 Height2: 194.22
Counter: 4 Height: 64.77 Subheight: 194.22 Height2: 258.99
Counter: 5 Height: 64.77 Subheight: 258.99 Height2: 323.76
Counter: 6 Height: 64.83 Subheight: 323.76 Height2: 388.60
Counter: 7 Height: 64.81 Subheight: 388.60 Height2: 453.41

Counter: 8 Height: 64.78 Subheight: 453.41 Height2: 518.19
Counter: 9 Height: 64.83 Subheight: 518.19 Height2: 583.01
Counter: 10 Height: 64.76 Subheight: 583.01 Height2: 647.77
Counter: 11 Height: 64.61 Subheight: 647.77 Height2: 712.38
Counter: 12 Height: 64.58 Subheight: 712.38 Height2: 776.96
Counter: 13 Height: 64.80 Subheight: 776.96 Height2: 841.75
64.42
Counter: 1 Height: 64.87 Subheight: 0.00 Height2: 64.87
Counter: 2 Height: 64.91 Subheight: 64.87 Height2: 129.77
Counter: 3 Height: 64.68 Subheight: 129.77 Height2: 194.45
Counter: 4 Height: 64.99 Subheight: 194.45 Height2: 259.44
Counter: 5 Height: 65.01 Subheight: 259.44 Height2: 324.45
Counter: 6 Height: 64.70 Subheight: 324.45 Height2: 389.15
64.53
Counter: 1 Height: 64.57 Subheight: 0.00 Height2: 64.57
Counter: 2 Height: 64.49 Subheight: 64.57 Height2: 129.06
64.2
Counter: 1 Height: 66.91 Subheight: 0.00 Height2: 66.91
Counter: 2 Height: 66.54 Subheight: 66.91 Height2: 133.45
Counter: 3 Height: 66.92 Subheight: 133.45 Height2: 200.36
Counter: 4 Height: 66.63 Subheight: 200.36 Height2: 266.99
Counter: 5 Height: 66.55 Subheight: 266.99 Height2: 333.55
Counter: 6 Height: 66.53 Subheight: 333.55 Height2: 400.07
Counter: 7 Height: 67.01 Subheight: 400.07 Height2: 467.09
Counter: 8 Height: 66.42 Subheight: 467.09 Height2: 533.51
Counter: 9 Height: 66.55 Subheight: 533.51 Height2: 600.05
Counter: 10 Height: 66.20 Subheight: 600.05 Height2: 666.25
Counter: 11 Height: 66.47 Subheight: 666.25 Height2: 732.72
Counter: 12 Height: 66.18 Subheight: 732.72 Height2: 798.90
Counter: 13 Height: 66.78 Subheight: 798.90 Height2: 865.68
Counter: 14 Height: 66.47 Subheight: 865.68 Height2: 932.16
Counter: 15 Height: 66.43 Subheight: 932.16 Height2: 998.58
Counter: 16 Height: 66.57 Subheight: 998.58 Height2: 1065.15
66.28
Counter: 1 Height: 65.95 Subheight: 0.00 Height2: 65.95
Counter: 2 Height: 66.06 Subheight: 65.95 Height2: 132.01
Counter: 3 Height: 66.10 Subheight: 132.01 Height2: 198.10
Counter: 4 Height: 66.05 Subheight: 198.10 Height2: 264.16
Counter: 5 Height: 66.14 Subheight: 264.16 Height2: 330.30

Counter: 6 Height: 66.12 Subheight: 330.30 Height2: 396.42
Counter: 7 Height: 66.03 Subheight: 396.42 Height2: 462.46
Counter: 8 Height: 65.91 Subheight: 462.46 Height2: 528.36
Counter: 9 Height: 65.96 Subheight: 528.36 Height2: 594.32
Counter: 10 Height: 66.37 Subheight: 594.32 Height2: 660.69
Counter: 11 Height: 66.30 Subheight: 660.69 Height2: 726.99
Counter: 12 Height: 66.20 Subheight: 726.99 Height2: 793.19
Counter: 13 Height: 66.39 Subheight: 793.19 Height2: 859.57
Counter: 14 Height: 66.16 Subheight: 859.57 Height2: 925.74
Counter: 15 Height: 65.67 Subheight: 925.74 Height2: 991.40
Counter: 16 Height: 66.11 Subheight: 991.40 Height2: 1057.51
65.79
Counter: 1 Height: 65.80 Subheight: 0.00 Height2: 65.80
Counter: 2 Height: 65.80 Subheight: 65.80 Height2: 131.60
Counter: 3 Height: 65.70 Subheight: 131.60 Height2: 197.31
Counter: 4 Height: 65.70 Subheight: 197.31 Height2: 263.01
Counter: 5 Height: 65.68 Subheight: 263.01 Height2: 328.69
Counter: 6 Height: 66.16 Subheight: 328.69 Height2: 394.84
Counter: 7 Height: 65.55 Subheight: 394.84 Height2: 460.39
Counter: 8 Height: 65.79 Subheight: 460.39 Height2: 526.18
Counter: 9 Height: 65.45 Subheight: 526.18 Height2: 591.63
Counter: 10 Height: 65.77 Subheight: 591.63 Height2: 657.40
Counter: 11 Height: 65.57 Subheight: 657.40 Height2: 722.97
Counter: 12 Height: 65.58 Subheight: 722.97 Height2: 788.55
Counter: 13 Height: 65.56 Subheight: 788.55 Height2: 854.11
Counter: 14 Height: 65.80 Subheight: 854.11 Height2: 919.92
Counter: 15 Height: 65.77 Subheight: 919.92 Height2: 985.69
Counter: 16 Height: 65.81 Subheight: 985.69 Height2: 1051.50
65.41

Table F3: Height Data at 46.6”

Counter: 1 Height: 45.53 Subheight: 0.00 Height2: 45.53
Counter: 2 Height: 45.86 Subheight: 45.53 Height2: 91.39
Counter: 3 Height: 46.03 Subheight: 91.39 Height2: 137.42
Counter: 4 Height: 45.60 Subheight: 137.42 Height2: 183.01
Counter: 5 Height: 45.78 Subheight: 183.01 Height2: 228.79
Counter: 6 Height: 46.08 Subheight: 228.79 Height2: 274.87
Counter: 7 Height: 45.93 Subheight: 274.87 Height2: 320.80
Counter: 8 Height: 45.83 Subheight: 320.80 Height2: 366.63

Counter: 9 Height: 45.41 Subheight: 366.63 Height2: 412.04
Counter: 10 Height: 46.47 Subheight: 412.04 Height2: 458.51
Counter: 11 Height: 45.33 Subheight: 458.51 Height2: 503.83
Counter: 12 Height: 45.62 Subheight: 503.83 Height2: 549.45
Counter: 13 Height: 46.18 Subheight: 549.45 Height2: 595.63
Counter: 14 Height: 45.20 Subheight: 595.63 Height2: 640.84
Counter: 15 Height: 45.62 Subheight: 640.84 Height2: 686.45
Counter: 16 Height: 46.24 Subheight: 686.45 Height2: 732.69
45.12
Counter: 1 Height: 45.23 Subheight: 0.00 Height2: 45.23
Counter: 2 Height: 45.11 Subheight: 45.23 Height2: 90.34
Counter: 3 Height: 45.49 Subheight: 90.34 Height2: 135.84
Counter: 4 Height: 45.66 Subheight: 135.84 Height2: 181.49
Counter: 5 Height: 45.60 Subheight: 181.49 Height2: 227.10
Counter: 6 Height: 46.25 Subheight: 227.10 Height2: 273.35
Counter: 7 Height: 45.20 Subheight: 273.35 Height2: 318.55
Counter: 8 Height: 45.62 Subheight: 318.55 Height2: 364.17
Counter: 9 Height: 45.29 Subheight: 364.17 Height2: 409.45
Counter: 10 Height: 45.60 Subheight: 409.45 Height2: 455.05
Counter: 11 Height: 45.39 Subheight: 455.05 Height2: 500.44
Counter: 12 Height: 45.37 Subheight: 500.44 Height2: 545.81
Counter: 13 Height: 45.65 Subheight: 545.81 Height2: 591.46
Counter: 14 Height: 45.10 Subheight: 591.46 Height2: 636.56
Counter: 15 Height: 45.39 Subheight: 636.56 Height2: 681.96
Counter: 16 Height: 45.04 Subheight: 681.96 Height2: 727.00
44.76
Counter: 1 Height: 46.02 Subheight: 0.00 Height2: 46.02
Counter: 2 Height: 45.83 Subheight: 46.02 Height2: 91.85
Counter: 3 Height: 45.33 Subheight: 91.85 Height2: 137.17
Counter: 4 Height: 45.43 Subheight: 137.17 Height2: 182.60
Counter: 5 Height: 45.39 Subheight: 182.60 Height2: 227.99
Counter: 6 Height: 45.83 Subheight: 227.99 Height2: 273.81
Counter: 7 Height: 46.15 Subheight: 273.81 Height2: 319.96
Counter: 8 Height: 45.83 Subheight: 319.96 Height2: 365.79
Counter: 9 Height: 45.60 Subheight: 365.79 Height2: 411.38
Counter: 10 Height: 45.49 Subheight: 411.38 Height2: 456.87
Counter: 11 Height: 45.41 Subheight: 456.87 Height2: 502.28
Counter: 12 Height: 45.85 Subheight: 502.28 Height2: 548.12
Counter: 13 Height: 45.37 Subheight: 548.12 Height2: 593.49

Counter: 14 Height: 45.66 Subheight: 593.49 Height2: 639.15
Counter: 15 Height: 45.76 Subheight: 639.15 Height2: 684.91
Counter: 16 Height: 45.82 Subheight: 684.91 Height2: 730.73
45
Counter: 1 Height: 46.14 Subheight: 0.00 Height2: 46.14
Counter: 2 Height: 46.32 Subheight: 46.14 Height2: 92.46
Counter: 3 Height: 46.48 Subheight: 92.46 Height2: 138.94
Counter: 4 Height: 46.32 Subheight: 138.94 Height2: 185.26
Counter: 5 Height: 46.54 Subheight: 185.26 Height2: 231.80
Counter: 6 Height: 45.99 Subheight: 231.80 Height2: 277.79
Counter: 7 Height: 46.07 Subheight: 277.79 Height2: 323.86
Counter: 8 Height: 46.28 Subheight: 323.86 Height2: 370.14
Counter: 9 Height: 46.39 Subheight: 370.14 Height2: 416.52
Counter: 10 Height: 46.53 Subheight: 416.52 Height2: 463.05
Counter: 11 Height: 46.34 Subheight: 463.05 Height2: 509.39
Counter: 12 Height: 45.93 Subheight: 509.39 Height2: 555.32
Counter: 13 Height: 45.56 Subheight: 555.32 Height2: 600.87
Counter: 14 Height: 45.72 Subheight: 600.87 Height2: 646.60
Counter: 15 Height: 45.91 Subheight: 646.60 Height2: 692.50
Counter: 16 Height: 45.89 Subheight: 692.50 Height2: 738.39
45.49
Counter: 1 Height: 46.02 Subheight: 0.00 Height2: 46.02
Counter: 2 Height: 45.87 Subheight: 46.02 Height2: 91.89
Counter: 3 Height: 46.12 Subheight: 91.89 Height2: 138.00
Counter: 4 Height: 46.46 Subheight: 138.00 Height2: 184.46
Counter: 5 Height: 46.97 Subheight: 184.46 Height2: 231.44
Counter: 6 Height: 46.30 Subheight: 231.44 Height2: 277.74
Counter: 7 Height: 46.30 Subheight: 277.74 Height2: 324.03
Counter: 8 Height: 46.42 Subheight: 324.03 Height2: 370.45
Counter: 9 Height: 46.53 Subheight: 370.45 Height2: 416.99
Counter: 10 Height: 46.67 Subheight: 416.99 Height2: 463.66
Counter: 11 Height: 46.67 Subheight: 463.66 Height2: 510.33
Counter: 12 Height: 46.26 Subheight: 510.33 Height2: 556.59
Counter: 13 Height: 46.20 Subheight: 556.59 Height2: 602.78
Counter: 14 Height: 46.26 Subheight: 602.78 Height2: 649.04
Counter: 15 Height: 46.32 Subheight: 649.04 Height2: 695.36
Counter: 16 Height: 46.71 Subheight: 695.36 Height2: 742.07
45.72
Counter: 1 Height: 46.11 Subheight: 0.00 Height2: 46.11

Counter: 2 Height: 46.61 Subheight: 46.11 Height2: 92.72
Counter: 3 Height: 46.77 Subheight: 92.72 Height2: 139.49
Counter: 4 Height: 46.50 Subheight: 139.49 Height2: 185.99
Counter: 5 Height: 46.85 Subheight: 185.99 Height2: 232.84
Counter: 6 Height: 46.68 Subheight: 232.84 Height2: 279.52
Counter: 7 Height: 46.13 Subheight: 279.52 Height2: 325.65
Counter: 8 Height: 46.34 Subheight: 325.65 Height2: 371.99
Counter: 9 Height: 46.72 Subheight: 371.99 Height2: 418.72
Counter: 10 Height: 46.05 Subheight: 418.72 Height2: 464.77
Counter: 11 Height: 45.97 Subheight: 464.77 Height2: 510.73
Counter: 12 Height: 46.17 Subheight: 510.73 Height2: 556.90
Counter: 13 Height: 46.71 Subheight: 556.90 Height2: 603.61
Counter: 14 Height: 46.36 Subheight: 603.61 Height2: 649.97
Counter: 15 Height: 46.74 Subheight: 649.97 Height2: 696.71
Counter: 16 Height: 46.94 Subheight: 696.71 Height2: 743.65
45.82
Counter: 1 Height: 45.94 Subheight: 0.00 Height2: 45.94
Counter: 2 Height: 46.36 Subheight: 45.94 Height2: 92.30
Counter: 3 Height: 46.26 Subheight: 92.30 Height2: 138.56
Counter: 4 Height: 46.81 Subheight: 138.56 Height2: 185.37
Counter: 5 Height: 46.63 Subheight: 185.37 Height2: 232.00
Counter: 6 Height: 46.22 Subheight: 232.00 Height2: 278.21
Counter: 7 Height: 45.99 Subheight: 278.21 Height2: 324.21
Counter: 8 Height: 46.47 Subheight: 324.21 Height2: 370.68
Counter: 9 Height: 46.34 Subheight: 370.68 Height2: 417.02
Counter: 10 Height: 46.55 Subheight: 417.02 Height2: 463.56
Counter: 11 Height: 46.49 Subheight: 463.56 Height2: 510.05
Counter: 12 Height: 46.12 Subheight: 510.05 Height2: 556.17
Counter: 13 Height: 46.69 Subheight: 556.17 Height2: 602.86
Counter: 14 Height: 46.32 Subheight: 602.86 Height2: 649.17
Counter: 15 Height: 46.36 Subheight: 649.17 Height2: 695.53
Counter: 16 Height: 46.38 Subheight: 695.53 Height2: 741.91
45.71
Counter: 1 Height: 46.37 Subheight: 0.00 Height2: 46.37
Counter: 2 Height: 46.16 Subheight: 46.37 Height2: 92.53
Counter: 3 Height: 46.08 Subheight: 92.53 Height2: 138.60
Counter: 4 Height: 46.35 Subheight: 138.60 Height2: 184.95
Counter: 5 Height: 46.38 Subheight: 184.95 Height2: 231.33
Counter: 6 Height: 45.47 Subheight: 231.33 Height2: 276.80

Counter: 7 Height: 46.28 Subheight: 276.80 Height2: 323.08
Counter: 8 Height: 46.28 Subheight: 323.08 Height2: 369.36
Counter: 9 Height: 46.58 Subheight: 369.36 Height2: 415.94
Counter: 10 Height: 46.40 Subheight: 415.94 Height2: 462.34
Counter: 11 Height: 47.08 Subheight: 462.34 Height2: 509.42
Counter: 12 Height: 46.38 Subheight: 509.42 Height2: 555.80
Counter: 13 Height: 46.40 Subheight: 555.80 Height2: 602.20
Counter: 14 Height: 46.39 Subheight: 602.20 Height2: 648.59
Counter: 15 Height: 46.57 Subheight: 648.59 Height2: 695.16
Counter: 16 Height: 46.16 Subheight: 695.16 Height2: 741.31
45.67

Table F4: Average Height Data of All Trials vs. Expected Height

Trial	Average Measured Height (in)	Avg. Measured Height (in)	Avg. Measured Height (in)			Avg-Expected
1	61.94	65.32	45.12			0.5975
2	62.08	65.16	44.76			0.51375
3	61.61	65.15	45			1.18875
4	61.29	65.27	45.49			
5	61.58	65.22	45.72			
6	61.6	64.81	45.82			
7	61.44	64.54	45.71			
8	61.24	64.42	45.67			
Average Measured Height (in)	61.60	64.99	45.41			
Expected Height (in)	61	65.5	46.6			

Appendix G: Diameter of Ultrasonic Sensor Spread (in) vs. Height (in)

Table G1: Diameter of Ultrasonic Sensor Spread (in) vs. Height (in)

Height (in)	Diameter of Spread (in)
36	19.3
42	22.5
48	25.7
54	28.9
60	32.2
66	35.4
72	38.6

Equation 1:

$$Diameter = 2 \times tan(15) \times Height \quad (1)$$

Appendix H: Complete Budget Utilization

Table H1 : Complete Budget Utilization

Category	Item	Size/Description	Quantity	Unit Cost	Cost
Components					
	Distance Sensors (Ultrasound)	HC-SR04 Ultrasonic	3	$4.95	$ 14.85
	Microcontroller (Arduino Nano)	Arduino Nano	1	$19.88	$ 19.88
	Accelerometer	Memsic 2125	1	$24.99	$ 24.99
	LCD screen	Nokia 5110	2	$12.95	$ 25.90
	Temperature Sensors	TMP36	5	$1.76	$ 8.80
Switches					
	Switches (toggle, push buttons, etc).		1	$3.00	$ 3.00
Wiring			1		
	Breadboards, Wiring, Insulation, Cable organizers, etc.		1	$7.00	$ 7.00
Rigging					
	Acrylic Plank	Loaned from Dr. Kuczenski	1		
	Helmet		1	$25.98	$25.98
	Helmet Mirror		1	$14.95	$14.95
Tools					
	Soldering Iron Kit		1	$26.21	$26.21
Total					$ 171.56

Appendix I: Revenue Streams

Table I1: Revenue Streams

Years	Units Sold	Cost (USD)	Revenue (USD)	Profit (USD)
1	100.00	$ 7,200	$ 9,000	$ 1,800
2	251.19	$ 18,086	$ 22,607	$ 4,521
3	280.54	$ 20,199	$ 25,249	$ 5,050
4	371.88	$ 26,775	$ 33,469	$ 6,694
5	499.94	$ 35,996	$ 44,995	$ 8,999