Three-Dimensional Scanner (December 2012)

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***Abstract*— The goal of this project is to design and prototype a three-dimensional (3D) scanner that has the capability to recreate and display the inner contour of an object. 3D scanning is used to identify and analyze imperfections and damages of large objects after manufacture. The proposed non-contact technology based 3D scanner (3D EleMnt) is used to swiftly inspect the contours and quickly detect issues such as deformity, imperfections, cracks, and overall scale issues.**

The 3D EleMnt three-dimensional scanner has the capability to recreate models of a contour by mapping coordinates with analog infrared sensors positioned to sweep along the (zy-axis) and the linear actuator along the (x-axis). 3D scanning is used in combination with mapping and statistical analysis software to evaluate and visualize quality in manufacturing processes.

I. INTRODUCTION

Three-dimensional (3D) scanning is a method that obtains an objects 3D physical form and converts it into digital data to be displayed via an electronic data processor of some sort. 3D scanners are devices that analyze the "as-built" conditions of objects by collecting data points corresponding to the position and shape of the object. Collected 3D data has many useful applications including material processing and production, construction industry, and quality assurance and industrial technology to list a few. Most 3D scanners already produced have the capability to scan industrially large objects, moving objects, and the outer contour of objects. However, our design incorporates a non-contact active scanner which uses infrared sensors to scan the inner contour of objects. Ultimately, with proper design improvements and modifications, this 3D scanner can be used extensively to aid in the customization of shoes, early detection of warping in pipes and much more.

Various different technologies can be used to build 3D scanning devices and each technology comes with its own limitations, advantages and costs. In particular, the 3D EleMnt 3D scanner is designed to use a non-contact active analog and digital infrared sensor, an ArduIMU microcontroller, and Wixel wireless communicator. The scanner has an extending mechanism that moves outward at certain distances to scan as much surface of the object as possible. Once the surface is completely scanned, a three dimensional mapping of the object will be extracted onto a software program where a recreated model will be displayed onto a monitor by use of a 3D mapping software.

The objective of our design is to produce a prototype of the 3D scanner. The 3D scanner has the capabiltiies to measure, translate and display the inner contour of the object scanned. With further implementation to the design, it will also have the capability to provide details of any deformities present on the inner surface of the object.

II. PRIMARY SYSTEM COMPONENTS

A. *Component Requirements and Budget Allocations*

i. 12VDC 5A Regulated Power Supply

This 12VDC power supply is used to power our entire system. It is made to plug into a wall outlet which inputs 100-240V/1.6A (U.S. standard). From the internal regulator within the power supply, the power supply outputs 12V/5A from which is inputted into the step-down voltage regulator. The 12V is then stepped down to 5V in order to provide the proper amount of voltage to our system [1].

Figure 1: 12VDC 5A Regulated Power Supply

ii. DIYDrones ArduIME+V3

The ArduIMU+ V3 is the latest and greatest version of DIYDrones' smart IMU. This time they've made it smaller and faster by incorporating the new Invensense MPU-6000 3-axis gyro and accelerometer as well the 3-axis I2C magnetometer HMC-5883L. Specifically for this project, we disabled the accelerometer, gyro and GPS libraries [2].

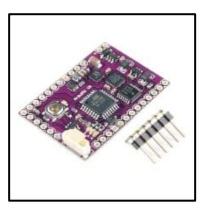


Figure 2: ArduIMU+V3 Microcontroller

iii. Concentric LACT 12P-12V-20 Linear Actuator with Feedback

This 12 V linear actuator can be used in a variety of heavy-duty applications. This version has a 12-inch stroke and a built-in potentiometer for position feedback. The motor has a ratio of 20:1 reduction gearbox that gives the actuator a dynamic load rating of 110 lbs. (50 kg) and a maximum speed of 0.5 in/s (1.3 cm/s). This particular linear actuator is rated to withstand up to 500 lbs. when not moving. Limit switches at each end making the actuator easy to control over its full range of motion, and the worm drive ensures that the shaft will hold its position even when unpowered [3].

Figure 3: Concentric LACT12P-12V-20 Linear Actuator with Feedback

iv. GWS S125 1/2T 2BB Sail Winch Servo

The GWS S125 1/2T 2BB Sail Winch Servo is a unique servo that has a wider rotation range than typical hobby servos. It rotates one full revolution (360°) over the standard 1-2 millisecond servo pulse range output by many RC receivers, and it is capable of approximately three full turns when used with a wider pulse range. This component is used as the base of our beamer module[4].

Figure 4: GWS S125 1T 2BB Sail Winch Servo

v. Jrk 21v3 USB Motor Controller with Feedback

The jrk 21v3 motor controller is a highly configurable brushed DC motor controller that supports four interface modes: USB, logic-level serial, analog voltage, and hobby radio control (RC). The controller can be used with feedback for closed-loop speed or position control, or it can be used without feedback as an open-loop speed control. The continuous output current is approximately 3 A in the recommended operating range of 8–28 V, with derated performance down to 5 V and transient protection to 40 V [5].

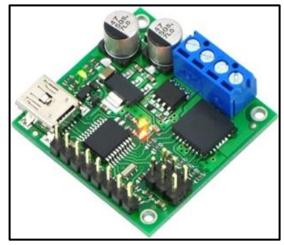


Figure 5: USB Motor Controller with Feedback

vi. Infrared Proximity Sensor Short Range Sharp GP2D120XJ00F

The GP2D120 features a detection range of 1.5" to 12". The shorter range gives you higher resolution measurements, and the lower minimum detection distance makes this sensor great for detecting very close objects. The distance is indicated by an analog voltage, making this sensor very easy to use [6].

Figure 6: Sharp 2D120X Analog IR Sensor

vii. Wixel Programmable USB Wireless Module

The Pololu Wixel is a general-purpose programmable module featuring a 2.4 GHz radio and USB. You can write your own software or load precompiled, open-source apps onto the TI CC2511F32 microcontroller at the heart of the Wixel, turning it into a wireless serial link, data logger, or whatever you need for your current project. With 29 KB of available flash and 4 KB of RAM, the Wixel is even suitable as the main controller for a robot or other system. This version ships with 0.1" male header pins installed as shown [7].

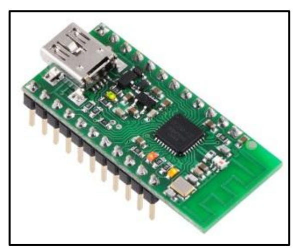


Figure 7: Wixel Programmable USB Wireless Module

viii. Pololu Step-Down Voltage Regulator D15V70F5S3

The compact (1.9"×0.6") D15V70F5S3 switching step-down (or buck) voltage regulator takes an input voltage between 4.5 and 24 V and efficiently reduces it to a lower, user-selectable voltage. The selectable output voltages are 5 and 3.3 V, and it can deliver 7 A continuous in typical applications [8].

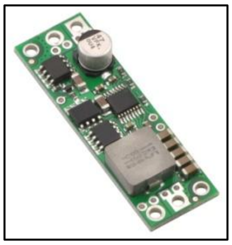


Figure 8: Step-Down Voltage Regulator

The cost breakdown for the each component used to build the 3D scanner is as follows:

Table 1: Budget breakdown

Component/Part		Qty	Price/Unit	Price
12VDC 5A Regulated Power Supply	x	1	$ 16.45	$ 16.45
Arduino Mini 05	x	1	$ 33.95	$ 33.95
Concentric LACT12P-12V-20 Linear Actuator with Feedback	x	1	$ 118.86	$ 118.86
Jrk 21v3 USB Motor Controller with Feedback	x	1	$ 51.95	$ 51.95
Pololu Step-Down Voltage Regulator D15V70F5S3	x	1	$ 24.95	$ 24.95
Printed Circuit Board	x	1	$ 50.00	$ 50.00
Infrared Proximity Sensor Short Range - Sharp GP2D120XJ00F	x	2	$ 13.95	$ 27.90
Wixel Programmable USB Wireless Module	x	2	$ 20.95	$ 41.90
	Total:			**$ 365.96**

B. *Alternatives*

During the process of our design, we were able to explore possible improvements that can be made to the design, sensor range and overall accuracy to further develop a product that has the capability to perform extensive scans. Three specific sensors that are compatible with our design and that are readily available in the market include:

Table 2: Alternative sensors

Type of Sensor	Advantages
Ultrasonic Sensor  $30/unit	• Longer range/ Better minimum limit (2cm-3cm) • More consistent readings • Controlled Pulse Width Module (PWM) • Uses high frequency sound pulses/more accurate readings
Laser Sensor QS186LEQ8  $70/unit	• Longer range (0.2m-5cm) • Compact structure • Uses laser diodes
Multi-Array Sensor - Kinect  $110/unit	• Practical range (1.2m-3.5m) • Extended range (0.7,-6m) • Highest accuracy • Open source software platform

C. *Trade-Offs*

Due to the limited amount of space that the actual module holding the integrated chips has, smaller sized components were chosen for the design. As a result, the PCB designed to connect the components together was also required to be relatively small. The Wixel wireless communicator proved to be an excellent solution due to its long range, ease of use with its open source program, and its compact size. The analog sensor proved to be a little bulky due to its plastic case however this was dealt with by inserting special male headers to lift the sensor above the PCB.

The main tradeoff was a means to power the entire board which included a port for the servo motor which drained the most current in the system. Battery packs were investigated but did not yield the current and voltage needed to properly power each component. All the battery packs that meet the current and voltage criteria were too large and heavy for the servo to handle. To solve this problem, wires were fed from the beamer module and connected to a power supply unit created. This was a very crude method but it solved the problem of finding a small battery that needed to be constantly replaced or recharged.

D. *Analysis and Prototyping Results*

Initially, the beamer module was designed to be controlled by the ArduIMU microcontroller. After much testing, we discovered faults with its design and we decided to switch to a mini Arduino. This change in design would allow for more space to work with when it came to the PCB design as the mini is much smaller than the IMU and could accomplish all of the tasks required. A new PCB was designed but unfortunately, it would not have been ready by the competition day so we reverted back to our old design.

We were able to make the design work with the ArduIMU and created a case to properly hold everything together tightly while still keeping the wires out of the view of the infrared sensors.

E. *Detailed Design Descriptions*

A 3D Scanner will approximately measure up to one foot. The linear actuator (linear DC motor) with high resolution (~1mm) will be connected to the beamer module made up of the servo motor, microcontroller, gyro, accelerometer, analog sensors, and wixel wireless communicator. The linear actuator will carry the beamer module in the front. The servo motor will scan from 0 to 360 degrees at a resolution of one degree. The scan procedure will be to scan the objects' inner contour for every increment of the linear actuator using the beamer module. The average is taken for each increment scanned up to five scans.

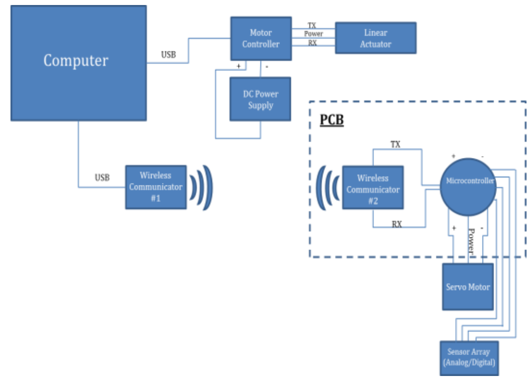
The infrared sensors (IRs) determine the motion path of the linear actuator with respect to the objects' inner contour. Sensors like accelerometers, gyros (3-axis) and tilt sensors will be used to determine the scan position and motion of the linear actuation and the beamer scan trajectory. These sensor values are important in mapping the collected coordinate data into a 3D perspective model. A reference sensor (gyro and IR sensor) will be placed outside the module to correlate the data collected to real world coordinate values.

The servo motor has a rail that holds a sensor module consisting of an analog IR sensor. Together the servo motor and linear actuator will be controlled by a motor controller connected to an Arduino microcontroller. The motor controller will control the step size of the linear actuator and ensure that the user knows the position of the piston.

Furthermore, the servo motor will receive the command to rotate a full cycle during which the sensor(s) will be activated and the data points collected will be recorded. After the cycle is complete the servo motor will reset back to the reference position of zero. Following the servo motor command, the microcontroller will process the data from the sensor and will be programmed to provide a file of values such that a three dimensional model will be constructed using any commercial program. The microcontroller can provide power to the servo motor and sensor array. An external power supply will power the linear actuator and motor controller.

The maximum length of the system is approximately 18in (linear actuator = 12in). The maximum width of the device will be approximately 2 to 3 inches. The servo motor with the beam module along with the sensors is of dimensions 40.5 x 20 x 42 mm.

Ultimately, the device will scan a cavity with dimensions consisting of 12"x 6" (lxw). For preliminary purposes, when the design and fabrication of a prototype is complete, we will start by testing uniform, smooth surfaces such as the contour of a bowl and box. Upon success, we will extend the test to scanning uniform, deformed, parabolic sheets and eventually surfaces with various deformities.



F. *Component-Level Testing/Verification*

Due to our design being modular by use of already prepackaged electronics testing could be done on the individual components so that they could be tested and verified to work. With systematically testing and verifying each component worked we can focus on components that were causing issues.

The ArduIMU was a good example of such a component. Through multiple modifications of the internal code it was determined that the manufacturer written libraries were interfering with the open source Arduino code. Libraries were using the same variable names and reference functions.

Coupled with poor documentation made testing and verification of the performance difficult. After much time, the issue with the conflicting libraries was solved but even then, the arduIMU was not performing in a reliable manner. As the IMU had built in sensors to constantly monitor, testing showed that adding more tasks for it to complete such as servo control and monitoring the infrared sensors proved to be too much for the IMU to handle. After loading code enabling all of its features, the controller would become unresponsive as the servo motor would randomly flair inaccurately and the serial communication became filled with jumbled strings.

It was at this point that we decided to completely disable the internal sensors and limited the duties of the controller to only those that were necessary such as reading the IR sensors and controlling the servo motor.

III. SYSTEM INTEGRATION AND TEST

A. *Integration Process*

i. *Code*

The integration process for our system depended heavily on programming the ArduIMU microcontroller to interact and communicate with each component (i.e. linear actuator, motor controller, servo motor, IR sensors, and wireless communicator). The code for our ArduIMU microcontroller is written in C language and utilizes Arduino libraries. The code starts by defining the necessary constants that are used later in the process. Then it initializes the serial communication with a BAUD rate of 115200 and goes on to initialize the servo motor onto a digital pin. The main loop of the code is made up of a 'for' loop that starts at 0 and ends at 360 (this calls a function to control the servo and move it to each specified degree to complete a full 360 degree sweep).

During the sweeping process, at each increment of the loop, the IR sensor is used to collect data and store it inside of an array. Once the 'for' loop is complete, the arduIMU then checks the value of the front digital sensor to see if the end of the object has been reached. The data is then formatted and sent to the wixel using the serial channel. The wixel sends the data wirelessly to another wixel connected to the computer via USB.

At this point, the data package arrives to the computer's COM port and has to be parsed and read. This is done through the use of a python script that checks the buffer for characters. Once the buffer is found to contain data, the script splits the chunk of data into separate values and stores the IR sensor readings into an array and stores the number of scans completed.

Now that the data is stored, it needs to be converted into the appropriate units. The raw voltage readings are converted into their equivalent values of centimeters. An algorithm is then used to smooth out the values to remove noise from the contour to be plotted.

Once all of the values are converted and calibrated, the Blender environment is then used to plot all of the individual points in the three dimensional environment. After all of the points are plotted for the set of data, faces for the mesh object are created and added to the data structure.

Using the number of sweeps completed, the script then calculates the next target distance for the linear actuator to travel to and sends a command through a different COM port to the motor controller. Thanks to the built-in feedback system, the motor controller is then able to accurately move the linear actuator to the desired location.

This process repeats for every 360 degree sweep until the actuator is fully extended or the front sensor indicates that the end of the object has been reached.

Once the scanning is over, the final mesh is linked to the Blender object, which is then linked to the Blender scene which is then redrawn to finally show the final model which can be saved and exported in many formats. This allows for the object model to be used in many applications.

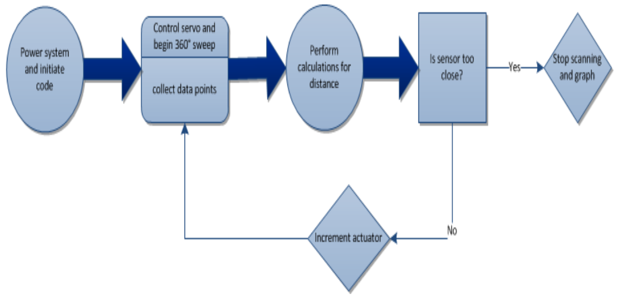


Figure 9: Flow chart for code algorithm

B. *System-Level Test Plans and Performance Results*

The first test run was done with a rectangular trash can. The dimensions of the trash can were right within our sensor range except for where the trash can had curved inwards towards the middle. The proximity of the sensor to the sides of the trash can was too close and went below the IR sensor's minimum operating range of 4cm.

After the first test run, we used a square cardboard box that was considerably larger than the trash can and had a dimension of approximately one foot around. The size of the box seemed perfect for our sensor's range but our system did not deal well with scanning and mapping out its corners properly.

At this point, we decided to reduce the reflection factor of the box by spray painting it black. This yielded much better results as the box scan became much more accurate as the shape of the mapped model resembled more of that of a square.

We then tried testing on a rounded object as opposed to one with sharp corners. For this, we created a half circle shape with cardboard and construction paper. With everything painted black and the half circle made slanted so that it now resembled a half heart, we scanned again. With this this shape, the results were most accurate. The mapped shape was almost exactly like that of the original object with minor differences.

IV. PROFESSIONAL CONTEXT

A. *Possible Marketing*

When the idea to create and build a 3D scanner made for scanning inner contours of objects was originally presented, the idea was being analyzed by the Zappos service company who is a retailer of shoes. They saw a meaningful application in scanning the inner contour of shoe to customize and improve the overall fitting. The final product would be a small scaled scanner that is approximately six inches in length and utilizes small, low power components.

With the proof of concept, the prototype can be scaled down to the desired size and implemented in the same manner. To run the smaller scaled may only require minor modifications to the code. With more testing and improvements of the current prototype through the use of better components along with a dedicated search of smaller low power components this project can become a very marketable product that will find various uses in the real world. For more possible uses please refer to the future work section.

V. SUMMARY AND CONCLUSION

A. *Summary of Project*

Overall, we were able to prove the concept of our design and demonstrated a working product. Although the components that we used in this specific design are not the highest performing or most accurate components, we have integrated our system to allow for reasonable upgrade and improvement. As mentioned above in the *Possible Marketing* section, the 3D scanner has the potential to be used for numerous applications. This is an innovation that will advance in the technological world and will contribute greatly to manufacturing processes of all sorts.

B. *Specific Contributions*

Specific contributions made to the implementation of the 3D scanner are as follows:

Morris Ben-Aouicha (Computer Engineering) – Mr. Ben-Aouicha was solely responsible for the implementation of the systems coding and algorithmic design which is highly significant to the integration of our system. Mr. Ben-Aouicha also contributed to the purchase of components and the write-up of this final report.

Chequala Fuller(Electrical Engineering) – Ms. Fuller was responsible for all documentation (i.e. final report, poster board, budget, schedules, and all power point presentations) throughout the duration of senior design I and II. Ms. Fuller also assisted in the designing of the linear actuator sleeve and case holders for the power supply and beamer module. In addition, Ms. Fuller contributed to the purchase of components and was responsible for the communication between the Howard R. Hughes College of Engineering and the 3D EleMnt senior design group.

Sung-Jae Oh (Computer Engineering) – Mr. Oh assisted with parts of the code used to integrate the system.

Christian Vega (Electrical Engineering) – Mr. Vega was in charge of researching components for our design and laying out the entire system setup. Mr. Vega also contributed to the purchase of components, assisted in the integration process and contributed to the final write-up of this final report.

C. *Lessons Learned*

Throughout the iterative design process the key lesson was organization. Ensuring that all parts and design ideas were kept in order helped eliminate any confusion when it came to physically building the 3D scanner. The lesson of organization also leads to effective communication amongst group members. This is one of the most important factors in staying on track with progress and design. Confusion can ensue if group members begin to make decisions on important issues without discussing the decision with other group members beforehand. The entire group must agree with a design idea and stick with it.

On a technical matter, we learned that by choosing to use electronic components designed with an open source platform allowed for us to easily integrate our system. Open source components and software generally have the best documentation and examples that are readily available online. Forums, wiki, and Google code pages provide additional resources that can be used. This was a deciding factor on choosing parts and saving time. Instead of spending time on figuring out how the product worked it was convenient to read through a detailed manual with step-by-step instructions.

Another factor worth mentioning is the use of modular design. Using components that are already prepackaged gave a significant benefit when testing. If there was an issue with a specific component, it was easy to test and locate which part was creating the issue. Pinpointing errors fast is very important when there are strict deadlines in place and by saving time quickly correcting errors, more time was able to be spent on building and testing.

D. *Future Work*

Our system design is a prototype for a small scaled 3D scanner (250mm x 25mm) which, ultimately, can be used for applications such as:

- Scanning the inner contour of a shoe to customize and/or improve fitting
- Inspecting the contour of pipes to detect deformities early
- Inspecting the inner contour of small objects to correct scale issues

In the future, with improvements to the design, sensor range and accuracy, the 3D scanner could have the capability to be used for applications such as:

- Aid in the evacuation of buildings
- Support National Security application (e.g. bomb searches)

VI. APPENDICES

A. *Detailed Design*

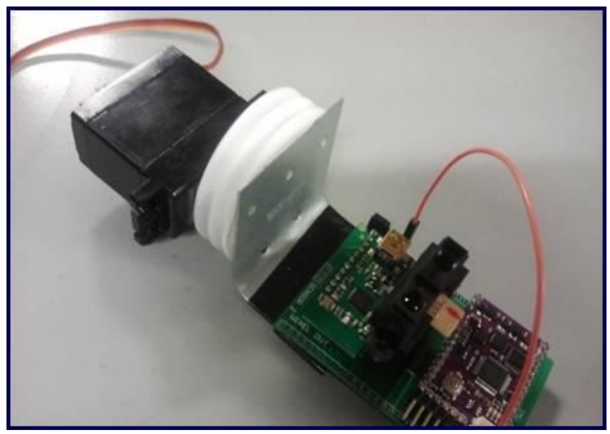


Figure 10: Beamer module consisted of the servo motor, microcontroller, sensors and wixel wireless communicator

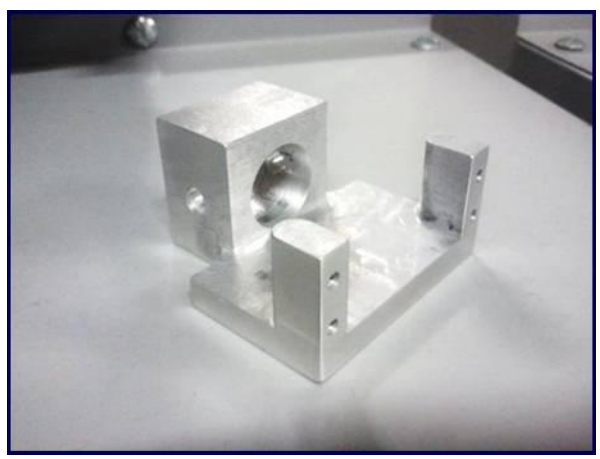


Figure 11: Linear actuator sleeve which secures the beamer module to the actuator

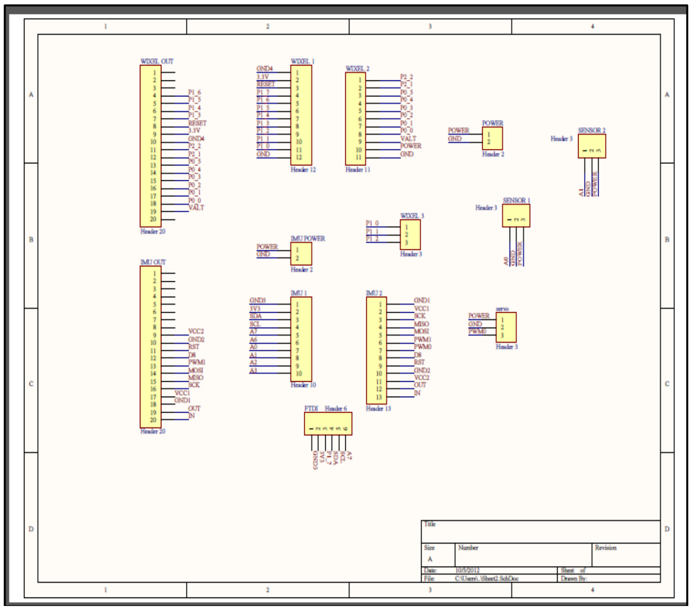


Figure 12: Altera schematic for the beamer module layout

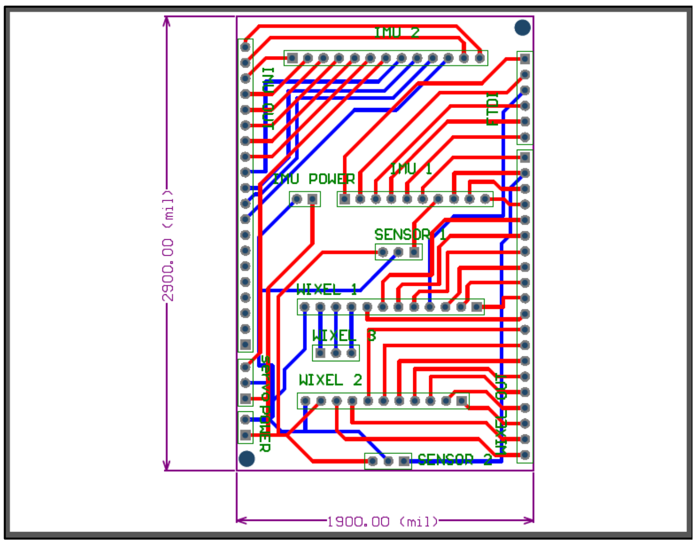


Figure 13: PCB layout for the beamer module

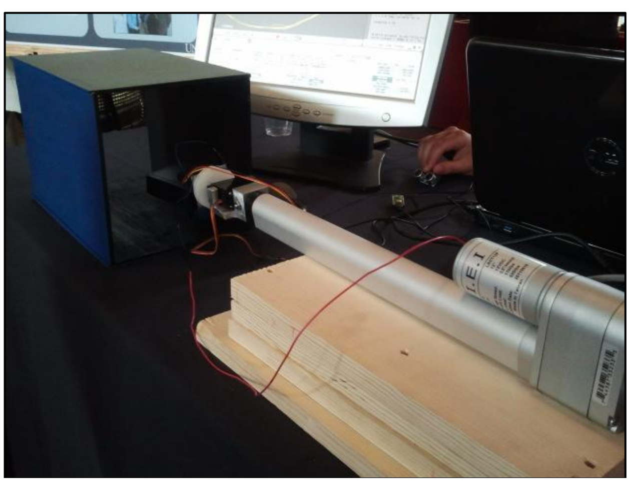


Figure 14: Final system design

B. Detailed Test Results

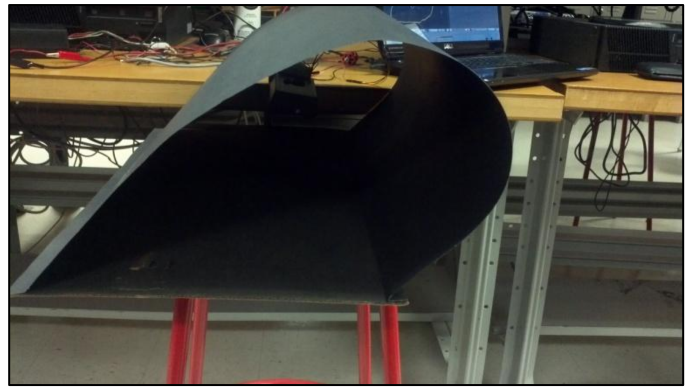


Figure 15: A slanted parabolic test object

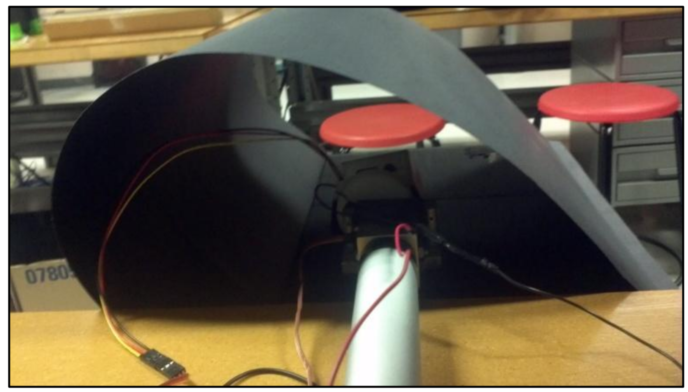


Figure 16: 3D scanner sweeping the inner contour of the slanted parabolic object

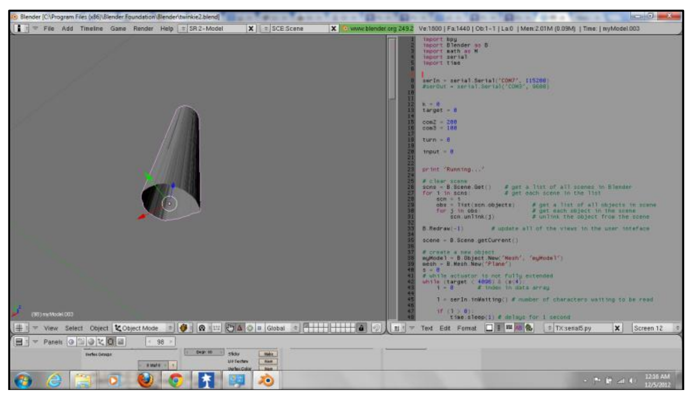


Figure 17: Final result of the slanted parabolic test object

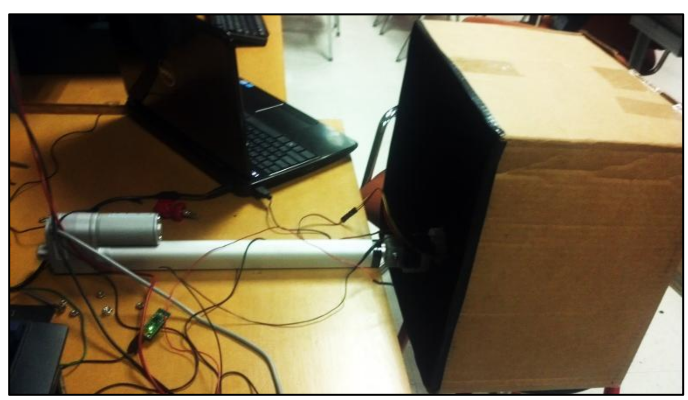


Figure 18: A square box test object

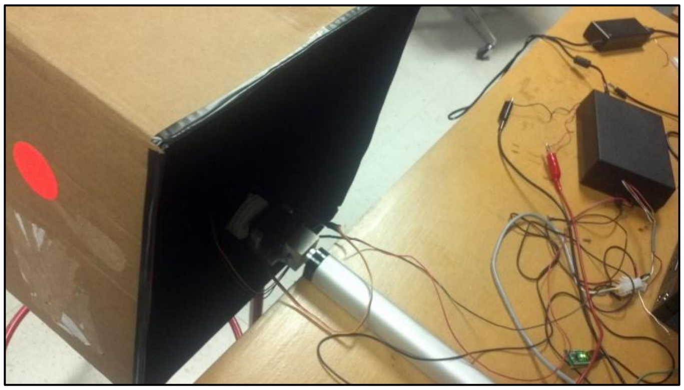


Figure 19: Square box test object

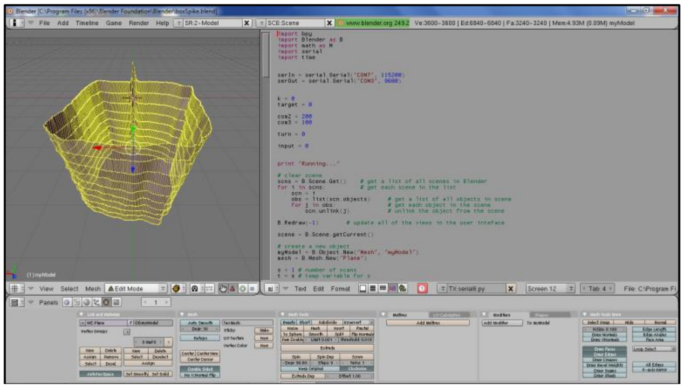


Figure 20: Final result of the square box contour

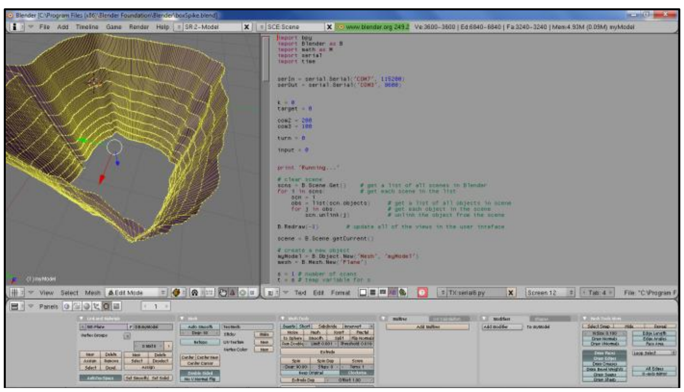


Figure 21: Final result of the box test object from another angle

References

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