

ISPS-2

(Improved Spatial Positioning System)

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Acknowledgements

- Drs. Adrienne and Jeff LaFavre
- Julie Patterson and Rob Morgan (Parents)
- Grant Congdon (Partner from last year)

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Abstract

The purpose of this project was to continue to explore whether it was possible to create a GPS-like device on a small scale that was both inexpensive and accurate. This project uses the same idea as GPS, called trilateration, where the location of an unknown point can be determined through that unknown point's distance from a series of known points. This project is a continuation of a project that I worked on last year, with my goals this year being getting the system to work on a larger scale, and to experiment with other methods of measuring distance than were used last year. To accomplish this project, I used the previously stated idea of trilateration (the equations of which were solved through a program I wrote), along with a laser rangefinder and a 50'x50' testing area. In addition to this large scale testing, I also experimented with using sound as a measuring device instead of sound by researching and soldering a circuit board that was able to use speakers and receivers to find distance. I was able to achieve a high level of accuracy, with an error of about 4 inches in a 50 by 50 foot area. This project has many potential applications, including abilities that even the most expensive GPS receivers have. This includes the ability to track location while indoors, much more easily get location relative to nearby objects, and get an object's location with much greater accuracy at a lower price.

Research

The main article that I used for my project this year was:

<https://math.stackexchange.com/questions/884807/find-x-location-using-3-known-x-y-location-using-trilateration>. It is a question asked on an online math forum that has detailed equations that are used to solve for trilateration.

Drs. Adrienne and Jeffery LaFavre both helped me greatly with this project, and were my advisors for this project. Mr. LaFavre helped me with checking and understanding the ultrasonic distance sensor.

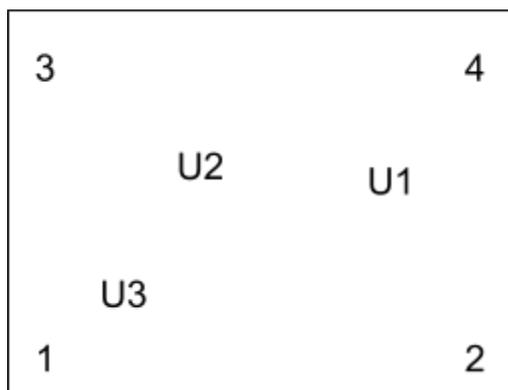
Materials

- 1x SF11-C Laser Rangefinder (<https://www.parallax.com/product/28054>)
- 50' Mason's String (Non Stretch)
- 1x Lufkin 100' Reel Tape
- 7x Orange Flag
- 1x Rebar Post
- 1x Screwdriver
- 1x Dell Laptop
- 1x Black and Decker Laser Level
- 1x Poster Board
- Electronics Supplies (<https://bit.ly/2R0juoM>)
- 1x Breadboard
- Soldering Station
- Python 3.8
- Notebook and Pen
- Table and stool
- 6"x6" piece of tile

Procedure

Setting Up The Testing Area

1. Gather your materials for this section of the project, which includes 7 flags, a rebar pole, a hammer, a screwdriver, measuring reel, and 50 foot mason's string (with loops)
2. Find a large flat area with no obstacles and put a rebar pole in one corner of the area.
3. Put the screwdriver through the end of the measuring reel and stick it in the ground at the pole and walk 50 feet forwards(\uparrow), preferably parallel to the boundary of the area.
4. Stretch the reel tight and plant a flag at 50 feet exactly.
5. Attach the string to the flag and leave the end of the reel attached to the original pole.
6. Walk left (\leftarrow) until the string is tight and the reel is at 70.71' ($50^2+50^2=70.71^2$) and plant a flag at the intersection of the string and reel.
7. Keep the reel attached to the original point and attach the string to the flag you just put in.
8. Walk down (\downarrow) until the string is tight and the reel reads 50' and plant a flag there
9. To check your work, attach the reel to the flag you just planted and walk to the second flag. The distance should be 70.71 feet if you have done everything correctly.
10. Take the 3 extra flags and plant them anywhere in the testing area, it doesn't matter where. When I was testing, I put one much closer to a corner than the others to measure the impact of that. The 3 flags you just planted are the 3 unknown points.



Finding Unknown Points Locations

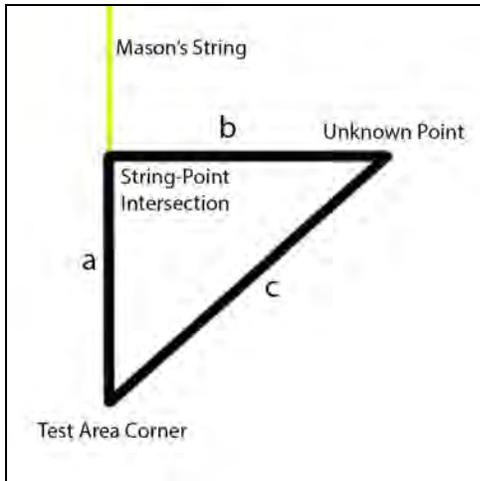
Before you start to use trilateration to find the locations of the points, you must first find the true locations of the unknown points, relative to the testing area.

1. Gather the materials needed for this section of the project: Measuring Reel, Screwdriver, Mason's String, and Notebook w/Pen. (When using the reel, always attach it at the pole with the screwdriver)
2. Estimate which corner is nearest to each of the unknown points and go to one of those corners.
3. Take the measuring reel and stretch it from the unknown point to the nearest corner and record the distance.
4. Stretch the mason's line from the corner to an adjacent corner.
5. Measure from the unknown point to the mason's line and record the distance. To make sure that you are getting the shortest possible distance between the flag and line, swing the reel while watching a point on the reel just outside where the line is. It will change distance from the line, where it is farthest from the line is where you should record from.



6. At the intersection of the reel and string, put the screwdriver.

7. Measure from the screwdriver to the original corner that you were using to measure from and record that measurement.



8. Do some relatively simple math:
 - $(a^2+b^2=c^2)$ To test that your measurements are correct
 - Determine the distance from the x and y axis in feet from point 1 (bottom left) of the testing area. (ex: 15,44)
 - 9. Repeat this for each of the three unknown points, and record the coordinates.

Installing Rangefinder Software

1. Go to: <https://lightware.co.za/pages/software-downloads>
2. Click on “Lightware Terminal” and then click “Run” on the pop-up.
3. If a popup asks if you want to let the software “Make changes to your device”, click yes.
4. Follow the instructions on the installer.
5. Open “Lightware Terminal” and plug in the SF11-C
6. Click connect in the upper left corner and readings should start to be displayed.

Finding Distances for Trilateration

1. Gather materials for this part of the project: SF11-C Rangefinder, laser level, laptop, table, stool, and tile.
2. Before you start to measure, estimate which 3 corners each unknown flag is closest to. Whichever corner is the closest to the highest number of unknown points is where you should start.
3. Attach the laser rangefinder and laser level to the piece of tile in my case.
4. Open the “Lightware Terminal” and plug in and connect the rangefinder.
5. Line the two up to the best of your ability and then point them at the poster board from ≈ 10 meters away.
6. Point the laser level at the poster board and with the computer, read the distance given by the rangefinder. Have someone move the poster board back and forth and see when the reading changes vs when the laser moves off the poster. Adjust the laser or rangefinder until the two events happen at the same time.
7. Go outside to the starting point and set up the table, stool, and computer.
8. Place the tile with rangefinder and level on the stool and have the rangefinder on top of or next to the corner point.
9. Have someone hold the poster board up at the unknown point of your choice and measure the distance by getting the laser point from the level on the flag and then getting the stool level and averaging the distances displayed on the screen.

10. Repeat this until you have three readings from different points for each of the unknown points.

Using The Program to Determine Trilateration Coordinates

1. Download Python 3.8:
 - Go to: <https://www.python.org/downloads/>
 - Click the button under “Download the latest version for Windows”
 - Follow the instructions in the installer.
2. Press the Ctrl+N keys to open a new file
3. Open:
https://drive.google.com/file/d/1_khI71hIB4WfRD8r0fhYV4YNe7wUay7z/view?usp=sharing
4. Copy and Paste the code from the link to the Python IDE
5. Press: Fn+F5 or just F5 to save and run the file, name it whatever you want.
6. Follow the prompts in the shell and if all the information has been put in correctly, at the end a coordinate will be displayed.

```

Trilateration Program
Enter Known Points
X of First Point Used:0
Y of First Point Used:0
X of Second Point Used:50
Y of Second Point Used:0
X of Third Point Used:0
Y of Third Point Used:50
(0,0), (50,0), (0,50)
Which Points are Used?
First Point:1
Distance from 1 (meters):1.285
4.2158792714999995
Second Point:2
Distance from 2 (meters):14.975
49.1305775025
Third Point:3
Distance from 3 (meters):14.09
46.227034191
The location is: (1.0395999230270399,3.8083494793598036)
This window will close eventually

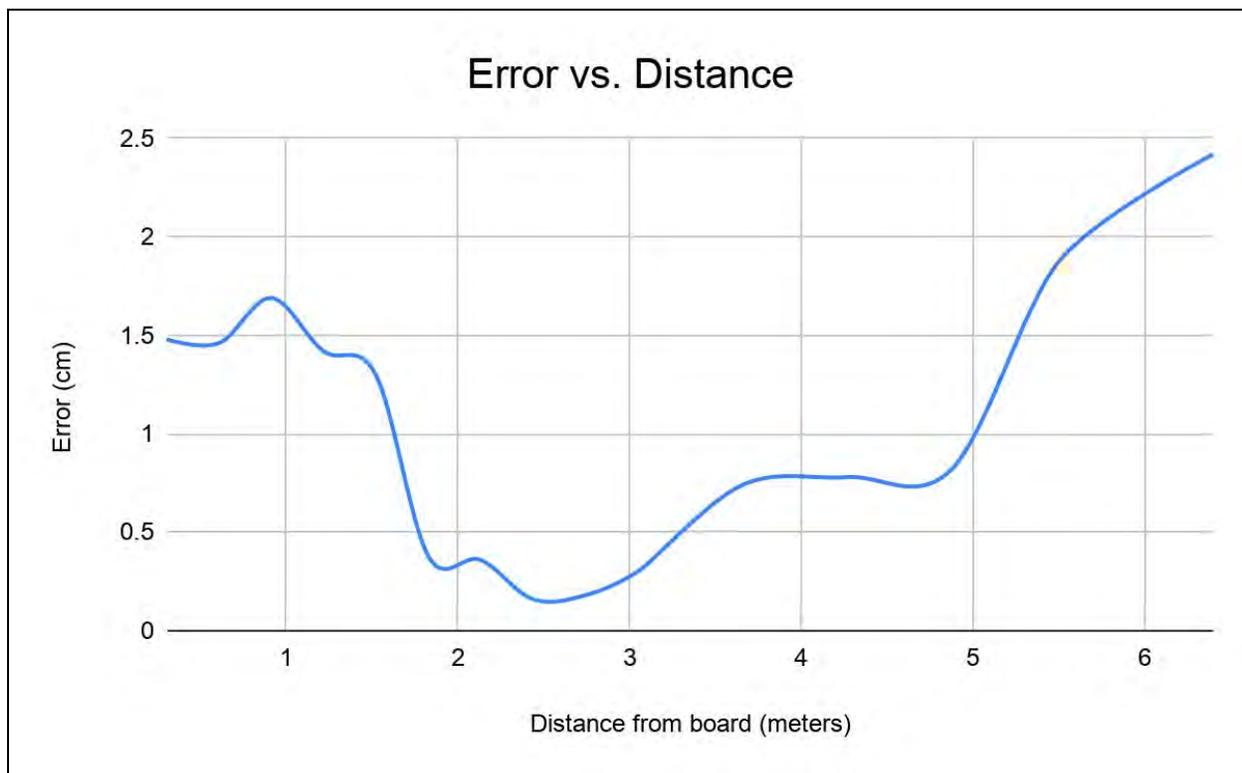
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7. Find the distance between the point you found in “Finding Unknown Points Locations” (I used: <https://www.easycalculation.com/analytical/distance.php>)
8. If all the steps were performed correctly, there should be an error less than 5 inches.

Observations and Results

I learned quite a bit about my project that I had not known before, including:

- How the trilateration equations actually work, instead of just taking them for what they were and hoping that they made sense
- How to more accurately measure distances using the laser rangefinder, by using a level and better targeting device.
- How to solder an ultrasonic distance finding circuit and the underlying concepts behind it.
- I better understand how the code behind the distance finder works and how to modify it for my own purposes.



Rangefinder Error Graph

| Distance from board (meters) | Rangefinder Distance | Error (meters) | Error (cm) | Error (cm) |
|------------------------------|----------------------|----------------|------------|------------|
| 6.4008 | 6.425 | 0.0242 | 2.42 | 2.42 |
| 5.4864 | 5.505 | 0.0186 | 1.86 | 1.86 |
| 4.8768 | 4.885 | 0.0082 | 0.82 | 0.82 |
| 4.2672 | 4.275 | 0.0078 | 0.78 | 0.78 |
| 3.6576 | 3.665 | 0.0074 | 0.74 | 0.74 |
| 3.048 | 3.045 | -0.003 | -0.3 | 0.3 |
| 2.7432 | 2.745 | 0.0018 | 0.18 | 0.18 |
| 2.4384 | 2.44 | 0.0016 | 0.16 | 0.16 |
| 2.1336 | 2.13 | -0.0036 | -0.36 | 0.36 |
| 1.8288 | 1.825 | -0.0038 | -0.38 | 0.38 |
| 1.524 | 1.511 | -0.013 | -1.3 | 1.3 |
| 1.2192 | 1.205 | -0.0142 | -1.42 | 1.42 |
| 0.9144 | 0.8975 | -0.0169 | -1.69 | 1.69 |
| 0.6096 | 0.595 | -0.0146 | -1.46 | 1.46 |
| 0.3048 | 0.29 | -0.0148 | -1.48 | 1.48 |

Rangefinder Error Data

| | Absolute X, Y (Feet) | Absolute X, Y (Meters) | Tested X, Y (Feet) | Tested X, Y (Meters) | Error (Inches) |
|--------------|-------------------------|---------------------------|-----------------------|-----------------------------|-------------------|
| Test Point 1 | (34.115, 24) | (10.398, 7.3152) | (34.462, 24.094) | (10.5040176, 7.3438512) | 3.84in |
| Test Point 2 | (8.415, 5.785) | (2.564, 4.8113) | (8.1387, 15.566) | (2.48067576, 4.7445168) | 4.228in |
| Test Point 3 | (1.37, 4) | (.4175, 1.2192) | (1.0396,3.8084) | (0.31687008, 1.16080032) | 4.584in |

Table of Unknown Point Locations

Use the distance equation. If your unknown point is (x, y) , your known points are (x_i, y_i) which are distances r_i from your unknown point, then you get three equations:

$$(x - x_1)^2 + (y - y_1)^2 = r_1^2$$

$$(x - x_2)^2 + (y - y_2)^2 = r_2^2$$

$$(x - x_3)^2 + (y - y_3)^2 = r_3^2$$

We can expand out the squares in each one:

$$x^2 - 2x_1x + x_1^2 + y^2 - 2y_1y + y_1^2 = r_1^2$$

$$x^2 - 2x_2x + x_2^2 + y^2 - 2y_2y + y_2^2 = r_2^2$$

$$x^2 - 2x_3x + x_3^2 + y^2 - 2y_3y + y_3^2 = r_3^2$$

If we subtract the second equation from the first, we get

$$(-2x_1 + 2x_2)x + (-2y_1 + 2y_2)y = r_1^2 - r_2^2 - x_1^2 + x_2^2 - y_1^2 + y_2^2.$$

Likewise, subtracting the third equation from the second,

$$(-2x_2 + 2x_3)x + (-2y_2 + 2y_3)y = r_2^2 - r_3^2 - x_2^2 + x_3^2 - y_2^2 + y_3^2.$$

This is a system of two equations in two unknowns:

$$Ax + By = C$$

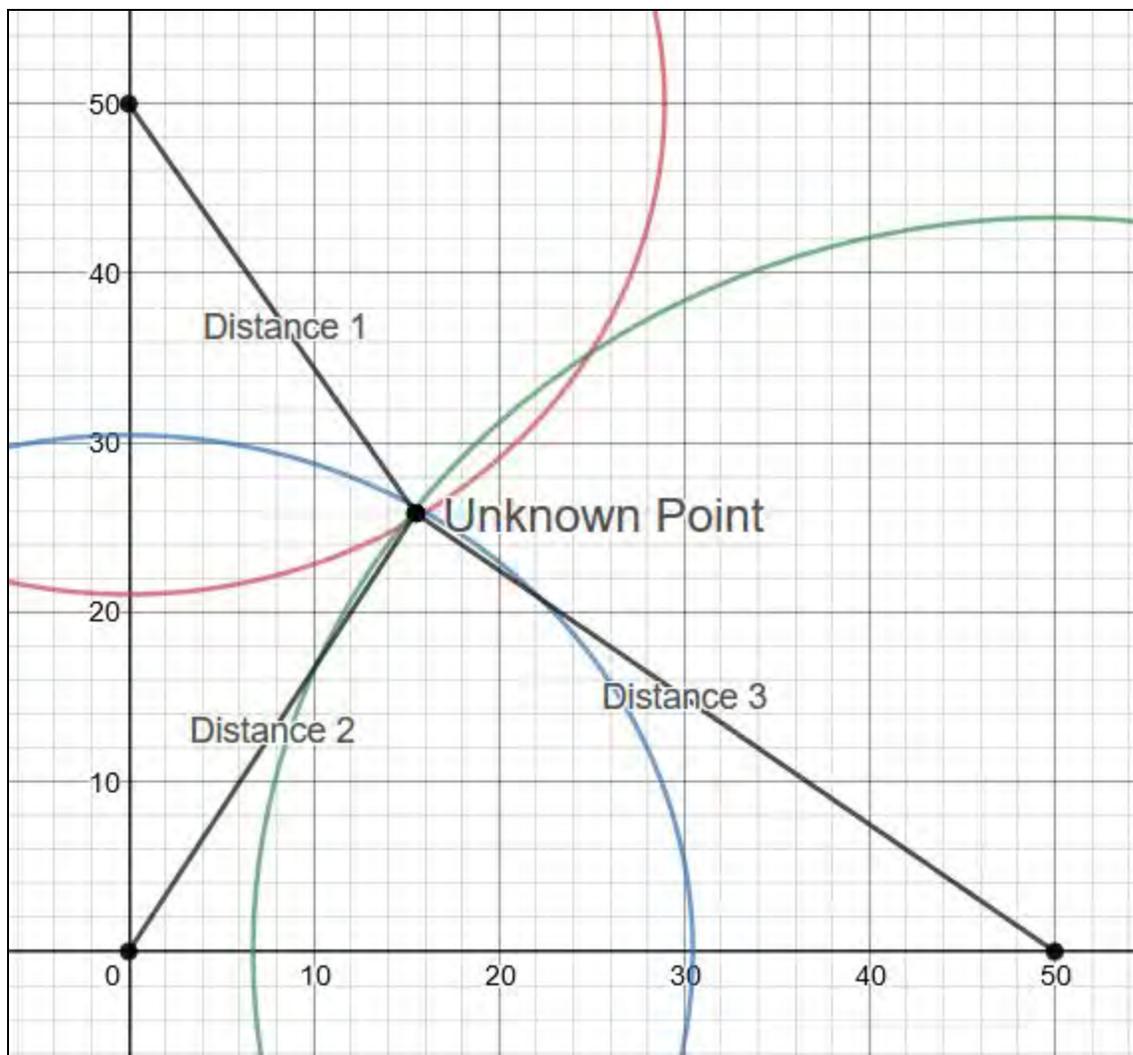
$$Dx + Ey = F$$

which has the solution:

$$x = \frac{CE - FB}{EA - BD}$$

$$y = \frac{CD - AF}{BD - AE}$$

Trilateration Equations



Trilateration Equation

Conclusion

In summary, this project turned out, in my opinion, very well. I can attribute this to the many hours that were put in this year by myself and my advisors to make sure that everything was being done as well as possible. I was able to accomplish everything that I had wanted to do in terms of large scale trilateration testing. I was also able to achieve a high level of accuracy for the area that I was testing in, most of the readings being only about 4½ inches off, a great improvement from last year. I was also able to make a lot of progress in using other methods to find distance, namely the ultrasonic distance finder that I constructed. I built the circuit from scratch and know exactly how it should work, but as of now, I am experiencing some code troubles which are stopping it from working completely. This whole project has been very interesting to me, I love to work with electronics, and has also been informative about how some systems that I take for granted work.

Reference Page

Find X location using 3 known (X,Y) location using trilateration, Retrieved 2014-8-1
from: <https://math.stackexchange.com/questions/884807/find-x-location-using-3-known-x-y-location-using-trilateration>