Smart and Healthy Buildings Assignment 3 Report

iBeacon Based Ranging

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Ranging:

To come up with the ranging equation, we implemented an algorithm that scanned for a specific control beacon at known distances. The way it functions is that with each button press, the RSSI, Tx Power, and the distance to the beacon (which is pre-determined) are stored in lists.

We took two approaches to come up with the ranging equation. First, we performed the ranging experiment inside the link lab with the beacon being incrementally distanced from the receiver by 0.5m. However, this did not yield good results, as seen in Fig. 1.

```
ASCII   HEX   Decimal  Binary
tx_power list is [6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6]<CR><LF>
rssi list is [-47, -62, -62, -64, -65, -69, -63, -73, -70, -70, -73, -69, -73, -63, -74, -73]<CR><LF>
End of scan<CR><LF>
<CR><LF>

10/28/2022 16:14:25.866 [RX] - Button A Pressed! Scanning...<CR><LF>
<CR><LF>
distances list is [0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0]<CR><LF>
tx_power list is [6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6]<CR><LF>
rssi list is [-47, -62, -62, -64, -65, -69, -63, -73, -70, -70, -73, -69, -73, -63, -74, -73]<CR><LF>
0<CR><LF>
'c2:00:7d:00:03:e2'<CR><LF>
distances list is [0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5]<CR><LF>
tx_power list is [6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6]<CR><LF>
rssi list is [-47, -62, -62, -64, -65, -69, -63, -73, -70, -70, -73, -69, -73, -63, -74, -73, -73]<CR><LF>
End of scan<CR><LF>
<CR><LF>

10/28/2022 16:14:45.379 [RX] - Button A Pressed! Scanning...<CR><LF>
<CR><LF>
distances list is [0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5]<CR><LF>
tx_power list is [6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6]<CR><LF>
rssi list is [-47, -62, -62, -64, -65, -69, -63, -73, -70, -70, -73, -69, -73, -63, -74, -73, -73]<CR><LF>

10/28/2022 16:14:52.268 [RX] - 0<CR><LF>
'c2:00:7d:00:03:e2'<CR><LF>
distances list is [0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0]<CR><LF>
tx_power list is [6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6]<CR><LF>
rssi list is [-47, -62, -62, -64, -65, -69, -63, -73, -70, -70, -73, -69, -73, -63, -74, -73, -73, -65]<CR><LF>
End of scan<CR><LF>
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10/28/2022 16:15:00.128 [RX] - Button A Pressed! Scanning...<CR><LF>
<CR><LF>|

10/28/2022 16:15:05.846 [RX] - 0<CR><LF>
'c2:00:7d:00:03:e2'<CR><LF>
distances list is [0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5]<CR><LF>
tx_power list is [6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6]<CR><LF>
rssi list is [-47, -62, -62, -64, -65, -69, -63, -73, -70, -70, -73, -69, -73, -63, -74, -73, -73, -65, -64]<CR><LF>
End of scan<CR><LF>
<CR><LF>

10/28/2022 16:15:14.459 [RX] - Button A Pressed! Scanning...<CR><LF>
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0<CR><LF>
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distances list is [0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.0]<CR><LF>
tx_power list is [6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6]<CR><LF>
rssi list is [-47, -62, -62, -64, -65, -69, -63, -73, -70, -70, -73, -69, -73, -63, -74, -73, -73, -65, -64, -69]<CR><LF>
End of scan<CR><LF>
<CR><LF>
```

Figure 1: Ranging equation data collection test performed indoors

Our assumption is that this is due to the multipath effect of signals interference, which gives us RSSI values which may be incorrect. To remedy this, we performed the same experiment outside the link lab, and we obtained much better results, as shown in figure 2:

```
ASCII    HEX    Decimal  Binary
<CR><LF>
Button A Pressed! Scanning...<CR><LF>
<CR><LF>

10/28/2022 16:33:43.382 [RX] - 0<CR><LF>
'c2:00:7d:00:03:e2'<CR><LF>
distances list is [0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0]<CR><LF>
tx_power list is [6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6]<CR><LF>
rssi list is [-55, -59, -65, -61, -65, -70, -78, -73, -72, -77, -68, -76, -70, -79]<CR><LF>
End of scan<CR><LF>
<CR><LF>
Button A Pressed! Scanning...<CR><LF>
<CR><LF>
0<CR><LF>
'c2:00:7d:00:03:e2'<CR><LF>
distances list is [0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5]<CR><LF>
tx_power list is [6, 6, 6, 6, 6, 6, 6, 6, 6, 6,
10/28/2022 16:33:48.382 [RX] - 6, 6, 6, 6, 6]<CR><LF>
rssi list is [-55, -59, -65, -61, -65, -70, -78, -73, -72, -77, -68, -76, -70, -79, -79]<CR><LF>
End of scan<CR><LF>
<CR><LF>
Button A Pressed! Scanning...<CR><LF>
<CR><LF>

10/28/2022 16:33:56.073 [RX] - 0<CR><LF>
'c2:00:7d:00:03:e2'<CR><LF>
distances list is [0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0]<CR><LF>
tx_power list is [6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6]<CR><LF>
rssi list is [-55, -59, -65, -61, -65, -70, -78, -73, -72, -77, -68, -76, -70, -79, -79, -70]<CR><LF>
End of scan<CR><LF>
<CR><LF>

10/28/2022 16:34:02.193 [RX] - Button A Pressed! Scanning...<CR><LF>
<CR><LF>
0<CR><LF>
'c2:00:7d:00:03:e2'<CR><LF>
distances list is [0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5]<CR><LF>
tx_power list is [6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6]<CR><LF>
rssi list is [-55, -59, -65, -61, -65, -70, -78, -73, -72, -77, -68, -76, -70, -79, -79, -70, -80]<CR><LF>
End of scan<CR><LF>
<CR><LF>
```

Figure 2: Ranging equation data collection test performed outdoors

We decided to stop the testing at 8.5m because the default setting for the minimum_rssi in the BLERadio.start_scan() function is set to -80 and we thought that would be a good place to stop.

These data points were then fed to a graphing tool to try and approximate the distance-rssi-tx_power equation. The graphing tool is shown below in figure 3. We came up with three different range functions based on some theories we found here and the short paper from the assignment. The first function we tried was

$$distance = 0.055 * 10^{\left(\frac{RSSI - Power_{Tx}}{-10*3.8}\right) - 0.21}$$

$$distance = 0.02 * e^{-0.00675(RSSI - Power_{Tx})}$$

$$distance = 0.01 * 10^{-0.21\left(\frac{RSSI}{Power_{Tx}}\right)}$$

We tried all three equations because they generally follow the data points about as close as each other. However, since equation 3 is matching the datapoints we have the closest, we decided to use that for the final measurement. This is not fixed however the user can change a single definition in the code called EQN from 0 to 2 to choose any of these three equations with their constants for their ranging function.
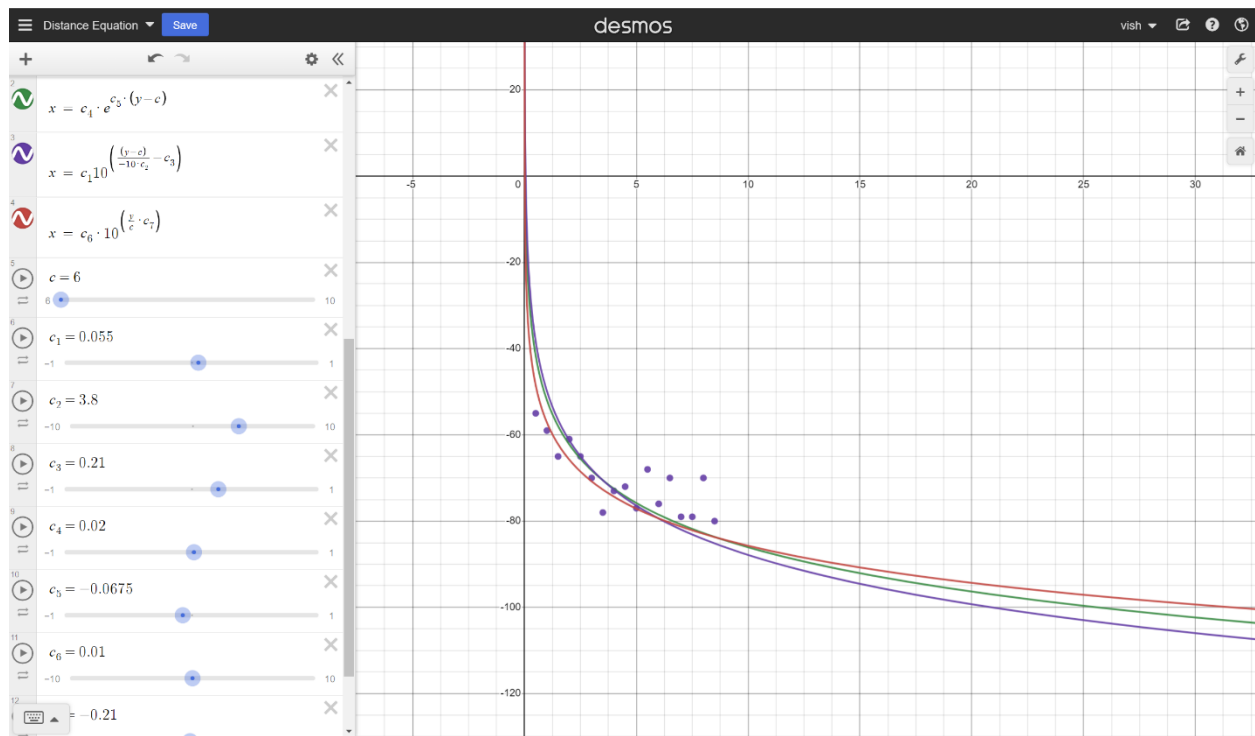
$x = c_4 \cdot e^{c_5 \cdot (y-c)}$

$x = c_1 10^{\left(\frac{(y-c)}{-10 \cdot c_2} - c_3\right)}$

$x = c_6 \cdot 10^{\left(\frac{y}{c} \cdot c_7\right)}$

$c = 6$

$c_1 = 0.055$

$c_2 = 3.8$

$c_3 = 0.21$

$c_4 = 0.02$

$c_5 = -0.0675$

$c_6 = 0.01$

$= -0.21$

Figure 3: Graphing tool used to approximate the distance-rssi-tx_power relation. The x axis is distance in meters and the y axis is RSSI values.

x_1	y_1
0.5	−55
1	−59
1.5	−65
2	−61
2.5	−65
3	−70
3.5	−78
4	−73
4.5	−72
5	−77
5.5	−68
6	−76
6.5	−70
7	−79
7.5	−79
8	−70
8.5	−80

$x = c_4 \cdot e^{c_5 \cdot (y-c)}$

$x = c_1 10^{\left(\frac{(y-c)}{-10 \cdot c_2} - c_3\right)}$

$c_6 \cdot 10^{\left(\frac{y}{c} \cdot c_7\right)}$
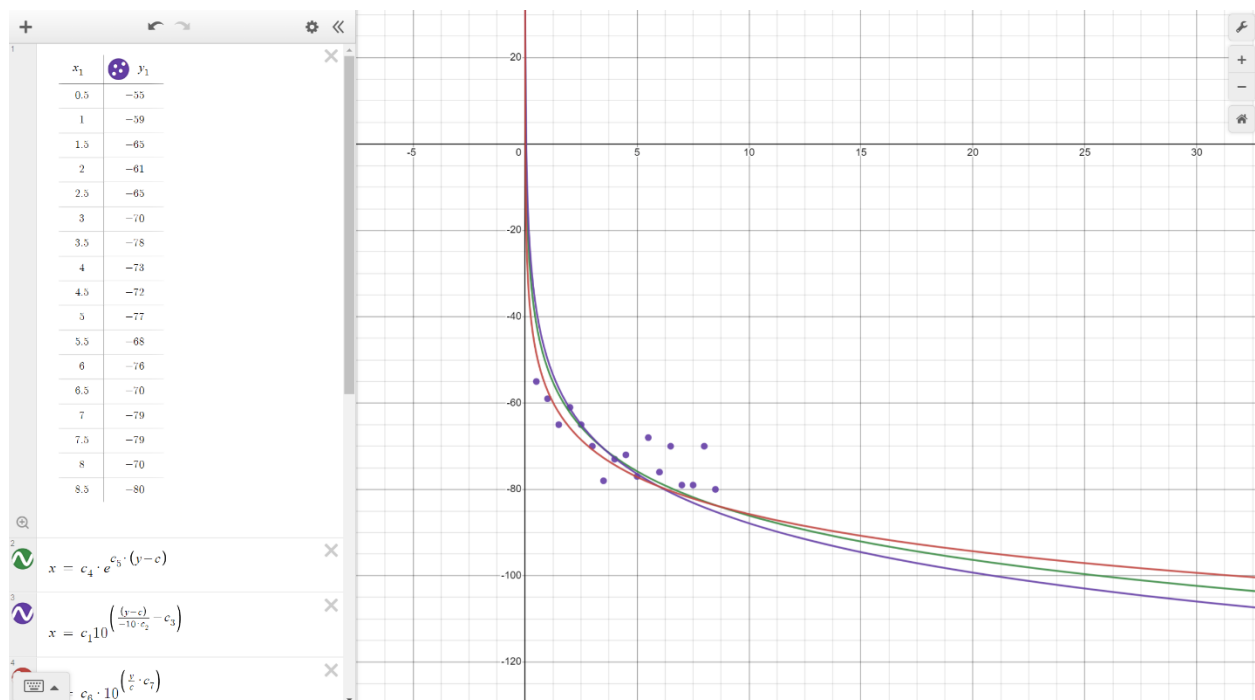
Figure 4: Data table. Full table is available in the excel sheet in the zipped folder.

Part 5:

SAHB1

X	Y	Beacon1	Beacon2	Beacon3
6.9133	14.9055	c2007d00008a	c2007d00009c	c2007d000052
10.1628	14.7398	c2007d000096	c2007d000392	c2007d000059
18.8372	23.189	c2007d000392	c2007d00005f	c2007d00038c
8.96172	12.7904	c2007d000059	c2007d00009b	c2007d00038a
19.1275	11.8885	c2007d000052	c2007d00008f	c2007d000098
10.851	15.0378	c2007d000096	c2007d000052	c2007d000392
Average values	**12.4755867**	**15.4251667**		

SAHB2

X	Y	Beacon1	Beacon2	Beacon3
45.2728	17.6302	c2007d00036e	c2007d000055a	c2007d000391
44.8645	15.6065	c2007d000076	c2007d000077	c2007d00009d
49.839	12.9224	c2007d000099	c2007d000391	c2007d00008d
44.5092	11.64	c2007d000064	c2007d00006d	c2007d00008d
59.6566	21.3454	c2007d00038e	c2007d000370	c2007d000059
50.3054	19.1249	c2007d00009d	c2007d000077	c2007d000072
Average values	**49.0745833**	**16.3782333**		

SAHB3

X	Y	Beacon1	Beacon2	Beacon3
22.4287	22.8474	c2007d00038a	c2007d000096	c2007d00008f
24.6335	14.7971	c2007d000095	c2007d00038a	c2007d000094
22.3092	21.4636	c2007d00038a	c2007d000094	c2007d00008e
22.7151	28.852	c2007d000095	c2007d00008f	c2007d000096
21.1164	20.5611	c2007d000096	c2007d00008e	c2007d000094
24.0433	15.5121	c2007d000095	c2007d000392	c2007d000094
Average values	**22.8743667**	**20.6722167**		

SAHB4

X	Y	Beacon1	Beacon2	Beacon3
44.5015	13.4122	c2007d00005a	c2007d000391	c2007d000099
42.7259	12.7718	c2007d000391	c2007d000064	c2007d000099
46.3467	11.3393	c2007d00008d	c2007d000064	c2007d000391
39.8778	17.9157	c2007d000098	c2007d00006d	c2007d000068
36.3992	13.4236	c2007d00036f	c2007d00005a	c2007d000064
55.3854	8.5216	c2007d00036f	c2007d000391	c2007d000068
Average values	**44.2060833**	**12.8973667**		

SAHB5

X	Y	Beacon1	Beacon2	Beacon3
42.4725	30.9988	c2007d00008f	c2007d00005a	c2007d000068
37.9231	10.4381	c2007d000099	c2007d00008d	c2007d00008e
38.235	20.0145	c2007d000370	c2007d00008d	c2007d00008e
24.8189	40.1769	c2007d00005a	c2007d00009b	c2007d000076
45.4631	23.2425	c2007d000370	c2007d000077	c2007d000076
41.8445	17.6304	c2007d00008f	c2007d000068	c2007d000077
Average values	**38.4595167**	**23.7502**		

Figure 5: We used a trilateration approach using 3 scanned beacons whose values for each test along with the coordinates are tabulated here. The actual sheet is present in the excel workbook in the zipped folder.

For SAHB1, the average coordinates we obtained were (12.476, 15.425)

For SAHB2, the average coordinates we obtained were (49.076, 16.378)

For SAHB3, the average coordinates we obtained were (22.874, 20.672)

For SAHB4, the average coordinates we obtained were (44.206, 12.897)

For SAHB5, the average coordinates we obtained were (38.459, 23.750)

However, while all other locations had some line-of-sight beacons, SAHB 5 did not have a single line-of-sight beacon, and we believe this shows its impact on the coordinates.

For all the testing rounds, the values were never quite agreeing with each other very accurately. We believe this is because of the tuning parameters we used for our range function, the hardware specs being different for the iBeacons and the microbit, in addition to environmental effects like multipath to some extent.