3-D Localisation using Ultra-wideband

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Contents

Acronyms

GPS Global Positioning System. 3, 7

SPI Serial Peripheral Interface. 10

ToA Time of Arrival. 3

UWB Ultra wideband. 2–4, 9, 10

1 Introduction

1.1 Background

Localisation of objects has been of importance for the society for a long time. Today Global Positioning System (GPS) can take us within metres of certainty [1]. When locating the position of a building, this level of accuracy is acceptable. However, when it comes to localisation of objects indoors, when there is need to know where inside of a building something is situated, it is not sufficient. The location of an object in 3-D could for example be useful in large warehouses or in emergency situations.

Several studies have proposed an Indoor Positioning System (IPS) that utilises Received Signal Strength Indication (RSSI) for 3-D localisation of indoor objects [2, 3, 4]. RSSI is a measurement of the power present in a received radio signal and is used to estimate the distance between the transmitter and the target. The distance is needed to calculate the approximated location of the target, by applying three-dimensional trilateration. While RSSI based IPS's have been shown to successfully approximate the location in 3-D, the average accuracy ranges from 1 to 2 metres [4, 5]. Taken into account that the ceiling height in houses are circa 2.4 metres, an accuracy of 2 metres is not sufficient for localisation of the targets vertical position in the room.

Bharadwaj proposes an IPS using UWB technology for sensor communication [6], which allows high-resolution positioning by high-precision ranging based on Time of Arrival (ToA). ToA is the travel time of a radio signal from a transmitter to a receiver. As radio signals travel with known velocity, ToA can be used to calculate the distance between the sensors. Once the distance is calculated, trilateration can be used in the same way as the RSSI-based IPS. A working example that uses ToA, and works similarly to Bharadwaj's proposed IPS, is GPS. A difference with GPS is that it has to take the Special and General theories of Relativity [7] into account, since the transmitters (satellites) are constantly moving [8] as opposed to Bharadwaj's proposed IPS. UWB based IPS's have shown significantly improved accuracy compared to RSSI based IPS's, reaching centimetre[6] and even millimetre[9] precision.

This report investigates the UWB based IPS further, by confirming previous work and expanding the test environment to a full-sized furnished room. It further evaluates the system's practical use and robustness regarding interference from other objects.

1.2 Aim

The general aim of this project was to investigate if UWB based positioning systems are suitable for 3-D localisation of objects in furnished rooms. To answer this, the following questions were asked:

- How accurately can a UWB based positioning system localise an object in 3-D?

- How sensitive is a UWB based positioning system to interference?

2 Theory

2.1 Trilateration

Trilateration makes use of Equation 1 to calculate the distances between the transceivers.

$$Distance = Rate \times Time \tag{1}$$

Since radio signals travel with the speed of light, which is a known constant measured to exactly 299 792 458 metres per second [10, 11], the distance between a transmitter and a receiver can be calculated after measuring the ToA.

2.1.1 Application in 2-D

When localising an object in 2-D, knowing only the distance (D) between a transmitter (T) and a receiver, it is implied that the receiver is situated somewhere on the perimeter of the circle illustrated in Figure 1.

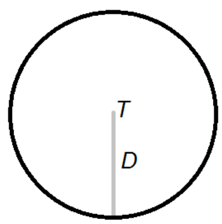

Figure 1: An illustration of the circle with the radius given by the distance D and the transmitter T at its center.

By measuring the distance from the receiver to another transmitter an additional circle can be calculated. Since the receiver must be situated on the perimeters of both circles it has to be located either at A or B as shown in Figure 2.

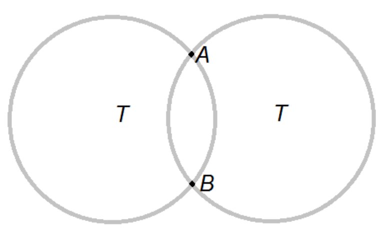

Figure 2: An illustration of two transmitters and their corresponding circles with intersections at A and B highlighted.

Repeating the previous step of measuring the distance to yet another transmitter it can be determined at which of the possible locations the receiver is situated since the three yielded circles all intersect in exactly one point as shown in Figure 3.

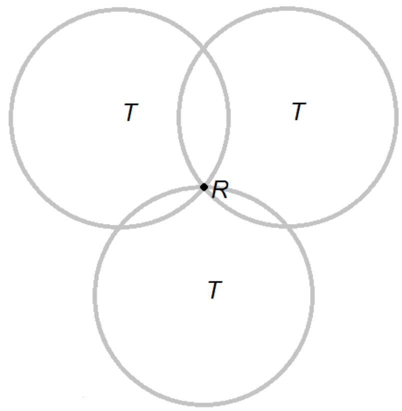

Figure 3: An illustration of three transmitters and the receiver shown in their intersection

2.1.2 Application in 3-D

Expanding the application the a 3-D environment increases the complexity as knowing only the distance between the receiver and one transmitter yields possible locations for the receiver on the peripheral of a sphere as shown in Figure 4.

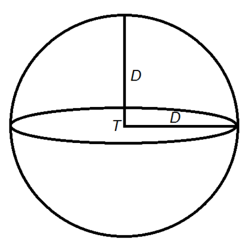

Figure 4: An illustration of the sphere with the radius given by the distance D and the transmitter T at its center.

By measuring the distance from the receiver to another transmitter an additional sphere can be calculated. Since the receiver must be situated on the peripheral of both spheres it has to be located somewhere on peripheral of the circle formed by the intersection of the two spheres as shown in Figure 5.

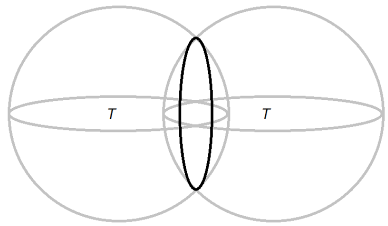

Figure 5: An illustration of the two spheres and their intersection highlighted as a black circle.

Having limited the possible locations of the receiver down to a circle, measuring the distance between the receiver and additional transmitters will decrease the possible locations in the same way as described in the 2-D environment at Section 2.1.1. That is, using a third transmitter limits the possible location of the receiver to two points. Sometimes it is enough to narrow it down to two possible locations as the positioning system may be designed in a way that only one of these points are valid. This is the case with GPS where one of the points will lie in space and the other one will lie on the surface of Earth.

2.2 Two-way ranging

As mentioned earlier trilateration depends on ToA in order to calculate the distance between a transmitter and the receiver.

$$T = T_R - T_T \tag{2}$$

Calculating the ToA can be done using Equation 2 as described above where T denotes the ToA, T_T denotes the time when the transmitter sent the signal and T_R denotes the time when the receiver received the signal. However, this method requires the transmitter and receiver to have very well-synchronised clocks since even a relatively small difference in time would result in quite a big difference in distance since it is multiplied with the speed of light.

Another method of calculating the ToA called Two-Way Ranging (TWR), which eliminates the need of synchronisation, uses two transceivers, that is devices that serves both as transmitters and receivers allowing them to both send and receive signals. The device initiating the communication is called the leader and the other is called the follower.

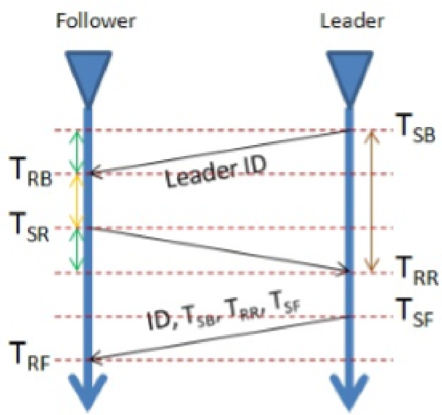

Figure 6: Illustration of TWR

Figure 6 shows the scheme for TWR where T_{SB}, T_{RR} and T_{SF} denotes the leaders send-time, receive-time and future send-time while T_{RB}, T_{SR} and T_{RF} denotes the followers receive-time, send-time and future receive-time respectively. By subtracting the followers turn-around time from the leaders round trip time as shown in Equation 3, the time it takes for a signal to travel from the leader to the follower and back is calculated giving twice the transmission time T_T, which is the same as the ToA.

$$2T_T = (T_{RR} - T_{SB}) - (T_{SR} - T_{RB}) \tag{3}$$

After the leader receives the response from the follower it responds with another signal enabling an additional calculation of the ToA using Equation 4.

$$2T_T = (T_{RF} - T_{SR}) - (T_{SF} - T_{RR}) \tag{4}$$

By taking the average of the two ToA calculations, resulting in Equation 5, the final value of the ToA is calculated.

$$T_T = \frac{T_{RF} - T_{SF} + 2(T_{RR} - T_{SR}) + T_{RB} - T_{SB}}{4} \tag{5}$$

3 Method

3.1 Hardware

3.1.1 UWB transceiver module — DWM1000

Figure 7: One of the DWM1000 UWB modules from Decawave used in the project.

3.1.2 Wireless sensor module — Tmote Sky

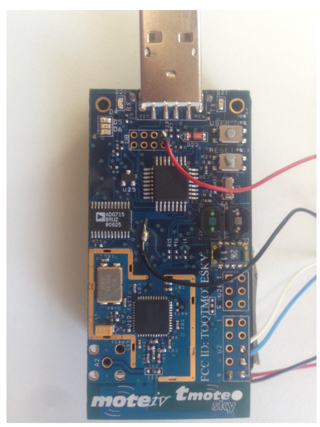

Figure 8: One of the Tmote Sky modules used in the project.

3.2 Implementation

3.2.1 Connecting the modules

The UWB modules used in this project have a Serial Peripheral Interface (SPI) that was used for communication with the Tmote Sky modules. Since the Tmote Sky does not have a dedicated SPI connection through extension pins it had to be connected in another way. In this project it was done as shown in Figure 10 where the SPI_MISO was connected to a point in the middle of the circuit board. This was achieved by carefully scraping the surface of the board to expose the copper and then cleaning the area with a flux pen before soldering.

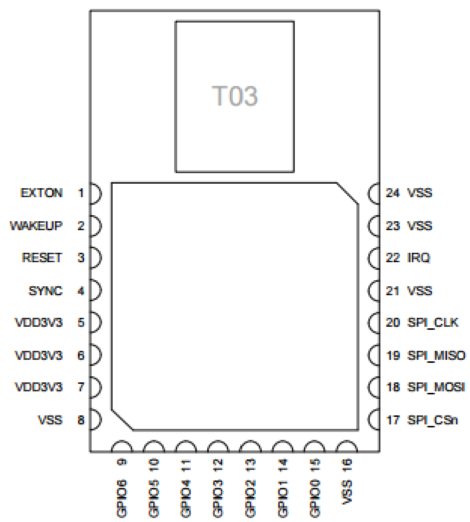

Figure 9: A diagram showing the pins for the DWM1000 UWB module.

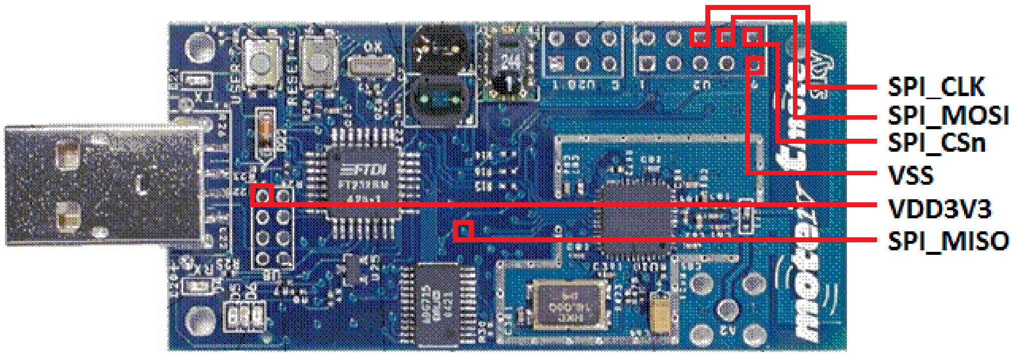

Figure 10: A figure showing how an UWB module is connected to a Tmote Sky.

Figure 11 shows the result after soldering the components according to Figure 9 and 10.

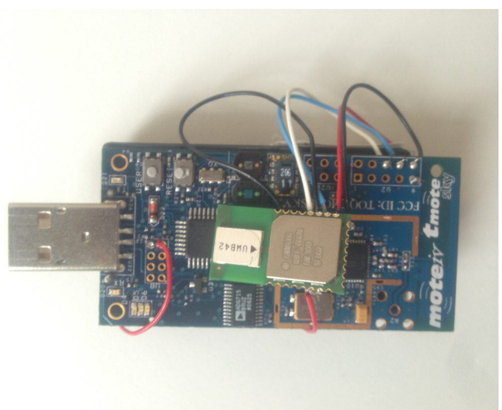

Figure 11: A figure showing a Tmote Sky connected to a UWB module.

3.2.2 Path loss formula

The model used to calculate the distance is derived from equation 6 described in [12] where $\overline{PL}$ denotes mean path loss, d_0 denotes a reference distance, d denotes the distance between the transmitter and the receiver and n denotes the path loss exponent.

$$\overline{PL}(d) = PL(d_0) + 10 * n * log_{10}(\frac{d}{d_0}) \tag{6}$$

Oguejiofor proposes a model where d_0 is one meter and utilizes equation 6 to derive equation 7 where n is the path loss exponent, $RSSI$ is the received signal strength and $PL(d_0)$ is the path loss at the reference distance of one meter away from the transmitter [13].

$$d = 10^{\frac{PL(d_0)-RSSI}{n*10}} \tag{7}$$

Equation 8 was used to determine the value of the path loss exponent, n, using M measurements as proposed by Oguejiofor [13].

$$n = \frac{\sum_{i=1}^{M}[PL(d_i) - PL(d_0)]}{\sum_{i=1}^{M}[10 * log_{10}(d_i)]} \tag{8}$$

3.2.3 Polynomial curve fitting

Using the path loss formula yielded no satisfying results and therefore another method using polynomial curve fitting was tested. The following measurements were made for applying polynomial curve fitting.

Table 1: Recorded RSSI values at different distances

Distance in metres	**RSSI loss in dB**
1	11
2	13
3	15
4	16
5	18
6	20
7	21
8	23
9	25
10	27

In order to find a polynomial function of degree 3 to approximate the distance between two nodes by using the RSSI loss values, the RSSI loss values was saved as X and the distances was saved as Y, the MATLAB function $polyfit$ was used as shown below.

```
polyfit(x,y,3)
```

The result of the call to $polyfit$ was used to define the approximative distance function given by equation 9, where x is the path loss expressed in dB.

$$Distance = -8.1446 * 10^{-4}x^3 + 4.4385 * 10^{-}2x^2 - 0.18979x - 1.2203 \tag{9}$$

The obtained approximative function looked promising when comparing it to the measured distances in the range of 1 to 10 metres as shown in Figure 12.

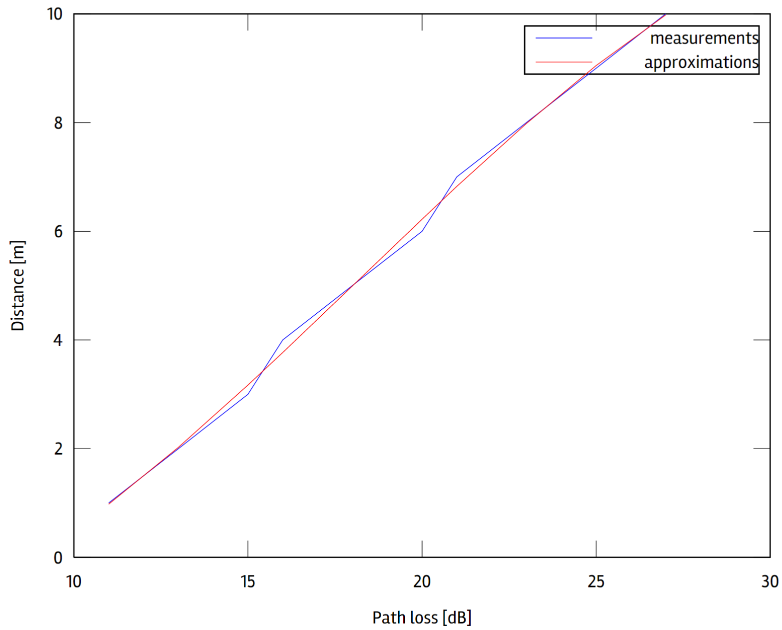

Figure 12: A plot visualizing the comparison of the measured distances and the results of the approximative function.

Rewrite this and maybe move it to theory! ...

3.2.4 API

3.2.5 Lab setup

4 Result

5 Related work

6 Conclusions and future work

7 Bibliography

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