Indoor 3-D Localisation using Ultra-wideband

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Contents

1 Introduction

1.1 Background

Localisation has been of importance for a long time and Global Positioning System (GPS) has taken us within meters of certainty today [1]. When locating the position of a building that kind of accuracy is acceptable but it is not sufficient when it comes to localising objects indoors, when there is need to know where inside of a building something is situated. Knowledge of the location of an object in 3-D and indoors could be useful, for example, in large warehouses or in emergency situations.

Several papers proposes an Indoor Positioning System (IPS) utilising Received Signal Strength Indication (RSSI) [2, 3, 4], a measurement of the power present in a received radio signal. RSSI is used to estimate the distance between the communicating objects, which is needed to calculate the approximated location of the subject by applying three-dimensional trilateration. While RSSI based IPS's has 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 will not be sufficient to be able to localise at which height the subject resides.

Bharadwaj proposes an IPS using Ultra-wideband (UWB) technology for communication [6] which offers potential applications in high-resolution positioning by high-precision ranging based on time-of-arrival (ToA). ToA is the travel time of a radio signal from the transmitter to the receiver and this could be used to calculate the distance since radio signals travel with known velocity. 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 proposal is GPS. One 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] which is not the case in Bharadwaj's proposal. UWB based IPS's has shown much better 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 in order to investigate its practical use and its robustness regarding interference.

1.2 Research questions

This report aims to answer the following main and subsidiary questions:

- Is a UWB-based positioning system suitable for localising a subject in a furnished room in 3-D?
  - How accurate can a UWB-based positioning system localise a subject 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 at exactly 299 792 458 metres per second [10, 11], the distance between a transmitter and a receiver can be calculated after measuring the time it takes for a radio signal to arrive at the receiver, called Time of Arrival (ToA).

2.1.1 Application in 2-D

In order to more easily grasp how trilateration works in theory, the application is first described for a 2-D environment.

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.

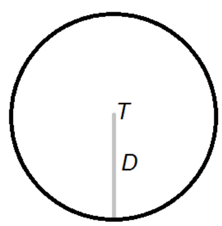

Figure 1: An illustration of the circle with the radius given by the distance D and the transmitter T at its center.

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.

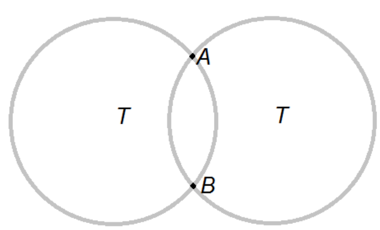

Figure 2: An illustration of two transmitters and their corresponding circles with intersections at A and B highlighted.

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.

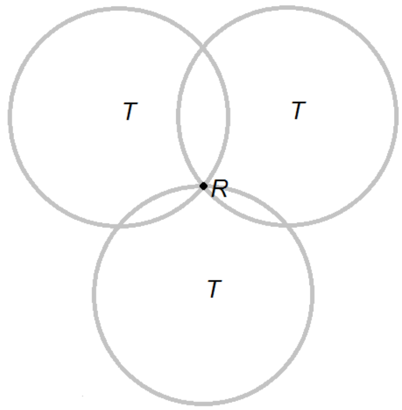

Figure 3: An illustration of three transmitters and the receiver shown in their intersection

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.

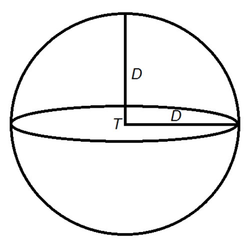

Figure 4: An illustration of the sphere with the radius given by the distance D and the transmitter T at its center.

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.

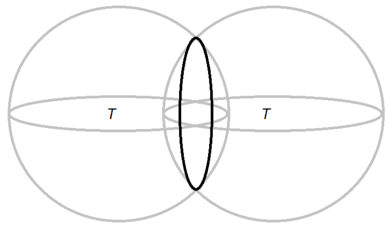

Figure 5: An illustration of the two spheres and their intersection highlighted as a black circle.

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 have two possible locations as the design of the positioning system may allow to rule out one of the points, that is the case with GPS where one of the points will lie in space and one will lie on the surface of Earth which has known location.

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 could be done simply 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-synchronized 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) eliminates the need of synchronization 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.

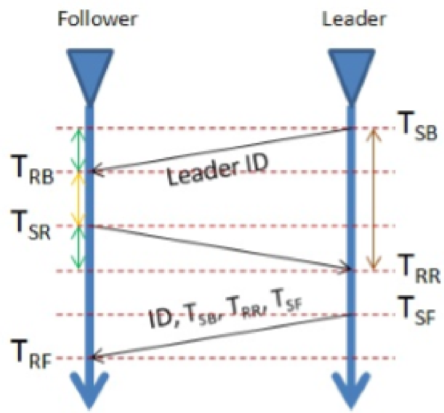

Figure 6: Illustration of TWR

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.

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

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