The front page is supposed to lie at this place, use of the bruface template required.

Abstract

This is the abstract blablabla...
Keywords: Ultrawide Band, ...

Acknowledgements

I thank ...

Contents

Chapter 1

Introduction

But du mémoire -> Etudier réponse impulsionnelle avec une seule ancre et voir ce que ça donne. Voir si on sait retrouver sa position ou non.

Blablabla... [12]

Chapter 2

State of the art

This sections has the purpose to explain the state of the art.

2.1 Ultra-Wideband Technology

Ultra-Wideand (UWB) is a communication technology using, as the name states, a large bandwidth. This is not a new technology as it is the one used by Guglielmo Marconi for the first transatlantic communication using radio waves [14]. As define by the International Telecommunication Union Radiocommunication Sector (ITU-R) to be considered as UWB, the bandwidth of communication must be at least 20 % of the arithmetic center frequency [15].

One interesting feature of UWB is the possible coexistence with other radio waves already present in the environment such as Wireless Fidelity (Wi-Fi). As it can be seen on Fig. 2.1, the extension of the UWB in the spectral domain is quite huge.

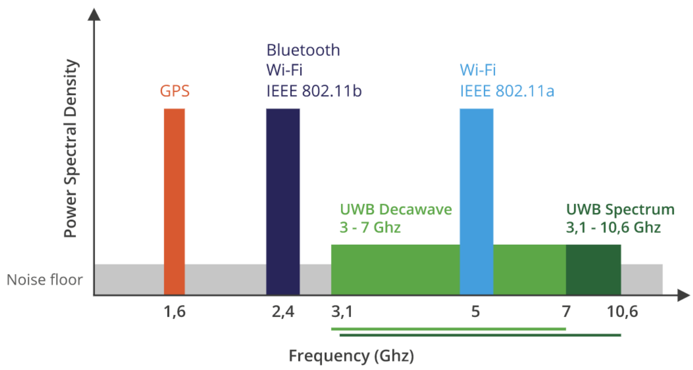

Figure 2.1: UWB spectrum compared to Wi-Fi and other wireless technology. Taken from [15]

Knowing this and based on the time-frequency duality reminded in eq. 2.1, one can see that the extension in the time domain will be quite small.

$$x(at) \longleftrightarrow \frac{1}{|a|} * X(\frac{f}{a}) \tag{2.1}$$

HERE - ADD THE IMAGE FOR TIME EXTENSION OF UWB
The Fig. 2.2 shows the theoretical duration of an impulse of the UWB.

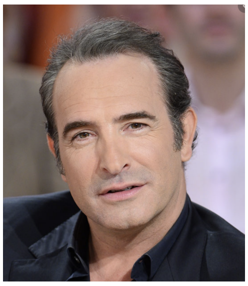

Figure 2.2: Theoritical duration of an UWB pulse

An advantage of the UWB is its robustness in regard of the Multipath Channels (MPC). This can be understood by looking at Fig. 2.3, where several peaks can be distinguished, each corresponding either to a different path travelled by the wave. Indeed, the probability to have a collision depends on the size of the pulse sent. From this, the interest of the UWB in confined area appears as a lot of MPC are present due to the reflections to all the wall of a room.

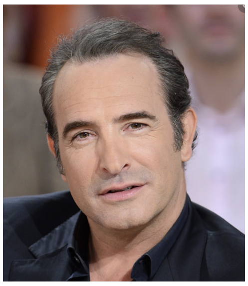

Figure 2.3: Example of an MPC

2.2 Real Time Locating Systems

Real-time locating systems (RTLS) are systems used to track and identify the location of objects in real time. This is a rather vague definition since nothing is specified concerning the means employed to achieve the localization. The RTLS that will be presented in this section will all have in common the use of wireless communications, between devices being called in this paper "anchor" and "tag". The tag being associated with the object to locate while the anchor is at a fixed and known location.

Those RTLS can be separated in two categories : "Relative localization" and "Absolute localization". The relative localization algorithm presented in 2.2.1 is the Time of Flight (ToF) method that is used in this project to compute the distance between an anchor and a tag. This choice has been made and explained in [8], [11] alongside a presentation of several approach to determine the relative position of a tag relatively to an anchor.

2.2.1 Symmetric double sided two-way ranging

Symmetric double-sided two-way ranging (SDS-TWR) consists in an exchange of three messages between two devices, respectively $RDEV_1$ initiating the communication and '$RDEV_2$. Each device need to save the Time of Emission (ToE) or Time of Arrival (ToA) of every message. Those time being respectively t_0, t_1 for the first message, t_2, t_3 for the second message and t_4, t_5 for the last message.

Each message contains the different timestamps previously computed, meaning that at the end of this exchange $RDEV_2$ possess all the informations about the timestamps, while $RDEV_1$ misses the last one. If one wants $RDEV_1$ to be able to compute the ToF then a last message with that t_5 in it should be exchanged.

A schematic of the exchanges between $RDEV_1$ and $RDEV_2$ that occurs in SDS-TWR is shown on Fig. 2.4.

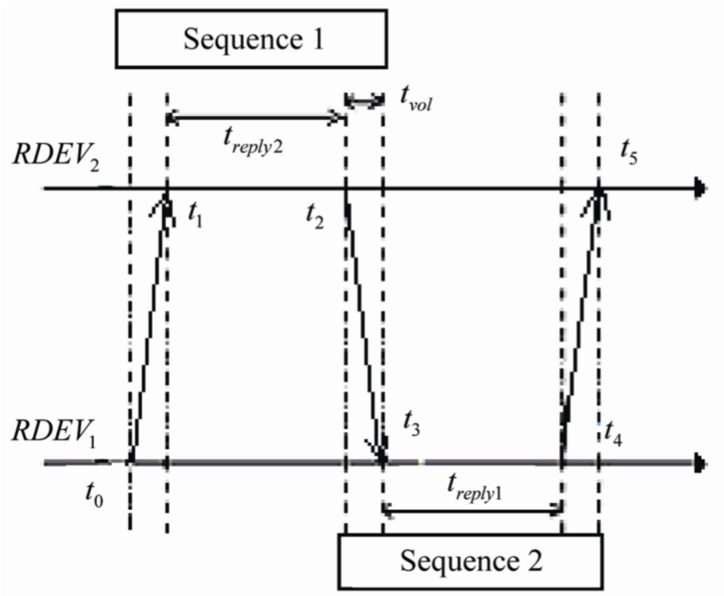

Figure 2.4: Symmetric double-sided two-way ranging. Taken from [3]

Based on those timestamps, the computation of the ToF can be observed in eq. 2.2.

$$t_{est} = \frac{((t_3 - t_0) - (t_2 - t_1)) + ((t_5 - t_2) - (t_4 - t_3))}{4} \tag{2.2}$$

Since that ToF computed remains an estimation, it is important to know the magnitude of the error as well as its evolution in parallel of the true value of the ToF.

$$t_{true} - t_{est} = \frac{1}{4} * (t_{reply2} - t_{reply_1}) * (e_1 - e_2) \tag{2.3}$$

The term $e_1 - e_2$ being the difference between the internal clocks of both devices. [3]

2.2.2 Trilateration

Based on the relative localization performed using SDS-TWR, a ToF can be computed. If the relative distance between a tag and three different anchors is known, it is possible to compute the intersection of three circle having as center the position of the anchor and radius the ToF associated to this anchor. A scheme displaying that solution can be seen on Fig. 2.5.

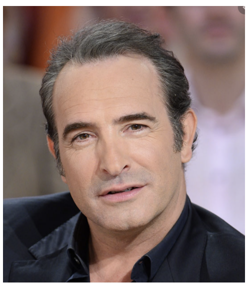

Figure 2.5: Triangulation -> Ajouter photo

As one can deduce, in a two dimensional plan, three anchors are need to have an intersection of only one point, removing the uncertainty. In a three dimensional plan, four anchors would be needed. This actually correspond to the following system of equations :

$$\begin{cases} (x_1 - x_0)^2 + (y_1 - y_0)^2 = d_1^2 \\ (x_2 - x_0)^2 + (y_2 - y_0)^2 = d_2^2 \\ (x_3 - x_0)^2 + (y_3 - y_0)^2 = d_3^2 \end{cases} \tag{2.4}$$

Where (x_i, y_i) corresponds to the position of the anchor i and d_i corresponds to the distance between this anchor and the tag, (x_0, y_0) being the position of the tag.

Uncertainties

Due to the inaccuracy of the computed distances, the system 2.4 can not be solved exactly. There is not a single point as an output. As it stands, the system probably does not have a solution, each equations solved two-by-two would likely gives different answers. To avoid this problem, the trilateration estimator developed in [16] has been used.

$$S(p_0) = \sum_{i}^{N} [(p_i - p_0)^T (p_i - p_0) - d_i^2]^2 \tag{2.5}$$

Where $p_k = (x_k, y_k) \forall x \in 0, ..., N$ in the two dimensional case. N being the number of anchor[1]. The objective of this estimator is to find the value of p_o minimizing the value of $S(p_0)$.

2.3 Implementation of a locating system

Using the technology briefly presented in sections 2.1 and 2.2 a locating system has been developed by Quentin Fesler and Cédric Hannotier in [8], [11]. This system is able to retrieve a localization with an error oscillating between twenty and fifty centimetres inside of a building [10].

This locating system is composed of fixed antennas[2] made using an ESP8266 as micro-controller and an UWB transceiver being the DWM1000 produced by Decawave[5]. The tag are built using an Android cellphone, a PSoC[3] and also a DWM1000 module.

2.3.1 DWM1000

The DWM1000 is the antenna chosen to operate the wireless communication part, it will be needed for the tag as well as for the different anchors. The configuration of these antenna and the Serial Protocol Interface (SPI) communication are both explained in this section.

[1] Which can be superior to 3, even in a 2D plan
[2] Called anchors
[3] The exact model is the : CY8C5888LTI-LP097 [10]

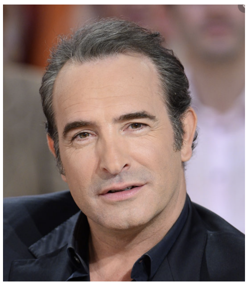

Figure 2.6: DWM1000 module

Configuration

Before using the DWM1000, tests have been conducted to choose the most suited configuration to have a low error rate, the best speed of the communication and the lowest power consumption possible. This leads to the following choices[4] :

- Channel number : 5
- Bitrate : 6.8 Mbits^{-1}
- Pulse Repetition Frequency (PRF) : 16MHz
- Preamble length : 128 bits

The chosen channel number is the number 5 partly due to the European Union (EU) regulations that are more strict in the frequencies bounds $(3.1; 4.8)$GHz than in the frequencies bounds $(6; 9)$GHz[4]. The other channel that is in those more boundaries in the 7^{th} one. The difference being a bandwidth being twice as large[5].

The choices of the bitrate are restricted between 110kbits^{-1}, 850kbits^{-1} or 6800kbits^{-1}. The reasons behind the choice of the bitrate at 6.8Mbits^{-1} are explained in [11].

The PRF can be chosen between 16MHz and 64MHz, an higher one increasing the operating range while consuming more power.

The preamble length is used for the channel estimation, the longer the more accurate. Unfortunately, a longer preamble means more power consumption unused to transmit "real" data and less time to transmit to "real" data. Recommended bitrate in function of the bitrate are proposed in [6].

Control

The DWM1000 is piloted via an SPI bus, this communication follows a master-slave scheme where the master, which is the micro-controller, controls the communication[2]. On Fig. 2.7, the four needed signals are displayed. Master Input, Slave Output (MISO) and Master Output, Slave Input (MOSI) are the connections used to transmit the data between the master and its slave. The Serial Clock (SCKL), generated by the master fixes the transmission speed happening on the MISO and MOSI. Since the SPI allows different slaves for only one master, the Slave Select (SS) is used by the master to select a specific slave to communicate with.

[4] A more detailed discussion on the choice of those parameters can be found in [11]

[5] The bandwidth of the 5^{th} one is 499.2MHz while the one from the 7^{th} is 1081.6MHz.

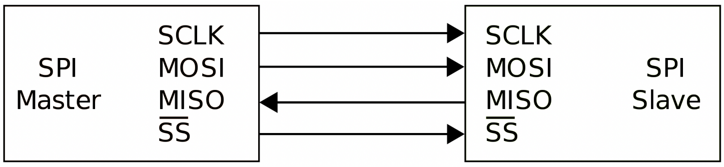

Figure 2.7: SPI Schematic

2.3.2 Anchor

The anchors are fixed antennas composed of a DWM1000 and an ESP8266 [7]. They are placed at known position in the room and are used to compute the ToF between the tag and the anchor using the SDS-TWR explained in section 2.2.1.

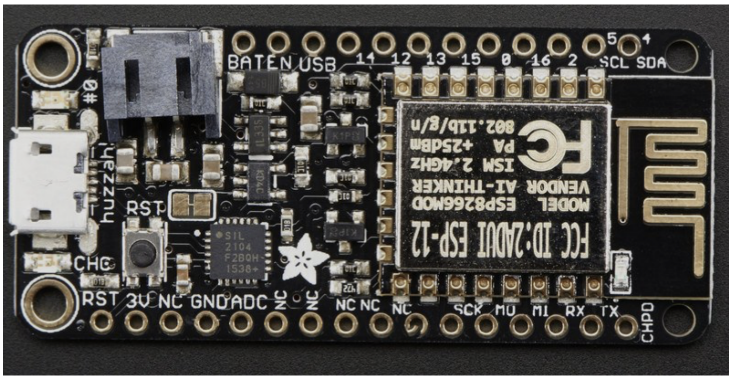

Figure 2.8: ESP8266 mounted on a Feather Huzzah board. Taken from [1]

The micro-controller has been combined with the development board Feather Huzzah from Adafruit [1], the Fig. 2.8 represents this module. This board can be flashed using an USB serie connection, allowing a easy deployment of the code, it also have the advantage to be light and small, an useful feature to deploy several anchors in a room without much cluttering.

2.3.3 Tag

The tag is the object we want to know the localization. It is composed of a DWM1000 antenna, a PSoC[6] and an Android application. The Fig. 2.9 shows the PSoC used as well as its custom board made by the electronic BEAMS service of the ULB.

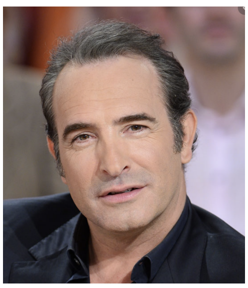

Figure 2.9: PSoC card

The communication between the DWM1000 an the PSoC is performed using a SPI bus as for the anchors, the PSoC being the master. As for the ESP8266, the PSoC

[6]The exact model is the : CY8C5888LTI-LP097 [10]

can flashed through an USB bus. The micro-controller receives instructions from the application on the cellphone and controls the communications of the DWM1000 with the different anchors. It then transmits the received data from the DWM1000 to the application through a USB bus. Verifier que c'est bien un USB bus .

2.3.4 Android Application

To control the PSoC, an android application has been developed. A screen-shot of the main window can be seen on Fig. 2.10. Four different buttons can be seen.

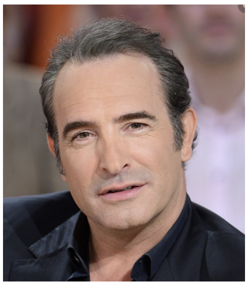

Figure 2.10: Main window of the android application

Navigation

The Navigation button opens a map of an environment[7] and an arrow is displayed at the estimated location of the tag, the orientation being the estimated orientation of the cellphone. The coordinates are also displayed, computed from the bottom left corner of the map. The used map is shown in Fig. 2.11.

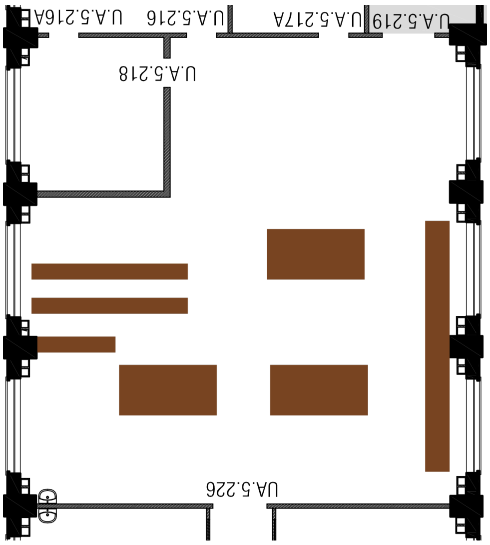

Figure 2.11: Map of the UA5.214

When this function runs, the application enters a loop that continuously request the PSoC to perform a SDS-TWR with each anchors. The data containing the different timestamps are transmitted towards the application for each anchor separately. From those data, the distance between each anchor and the tag is computed on the cellphone as well as the trilateration algorithm described in section 2.2.2, leading to a (x, y) estimated location.

[7]The room UA5.214 in this case, which is one of the electronic lab at the ULB.

A detailed state machine coming from [11] can be found in make a link to an annex an put the state machine in annex representing the state machine of an anchor and a tag. While the state machine of the anchor only perform one SDS-TWR at a time, the tag needs to keep an history of the anchors contacted to perform the trilateration afterwards.

Test USB connection, Test orientation

The "Test USB connection" allows to test that the USB communication bus used to communicate with the PSoC is fully operational. The test procedure consists of sending a 16 bits long messages to the PSoC, this message being : $0x0406$. If the PSoC is well connected, the application is supposed to receive a 32 bits long message being : $0x02034637$. This feature allows to quickly debug the USB communication.

The "Test orientation" has been designed to test the detection of the orientation the cellphone. The three angles necessary to characterize the orientation of the device, respectively the Azimuth, the Pitch and the Roll. The goal of this button was mainly to assess that the recuperation of the orientation of the cellphone was working.

Calibration

The "Calibration" has been designed to enhanced the precision on the timestamps. Indeed, there is a difference between the moment when the packet is received at the antenna of the DWM1000 and the moment of its detection which corresponds to the timestamp. The same phenomena appears when the UWB transceiver transmit a packet. Those errors on the timestamps are called the transmit/receive antenna delay and must be configured to match the actual antenna delay.

2.3.5 Precision obtained

The precision obtained with this locating system depends on several factors. It depends on the location of the anchors in the room, the distance of the tag to those anchors, the clutter of the room, etc...

Nonetheless, a statistical study has been conducted to assess the performances of the locating system. The tag has been placed at several location that can be observed in Fig. 2.12

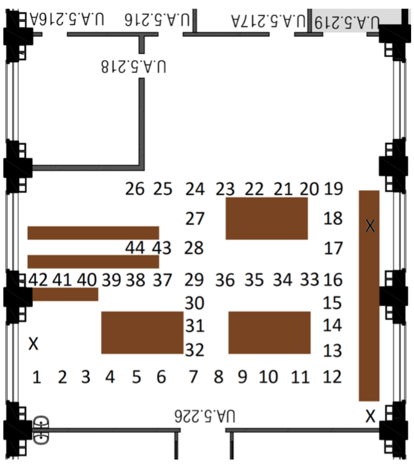

Figure 2.12: Locations corresponding to the measures represented in Fig. 2.13. Taken from [11]

For each location, the measurement was repeated hundred times. The error remains below 45 cm for 80% of the measurements but reaches up to 85 cm in the worse case. Such deviations can be explained by the geometry of the room, which is not trivial, the wall are not parallel, there is window in it, etc...[11].

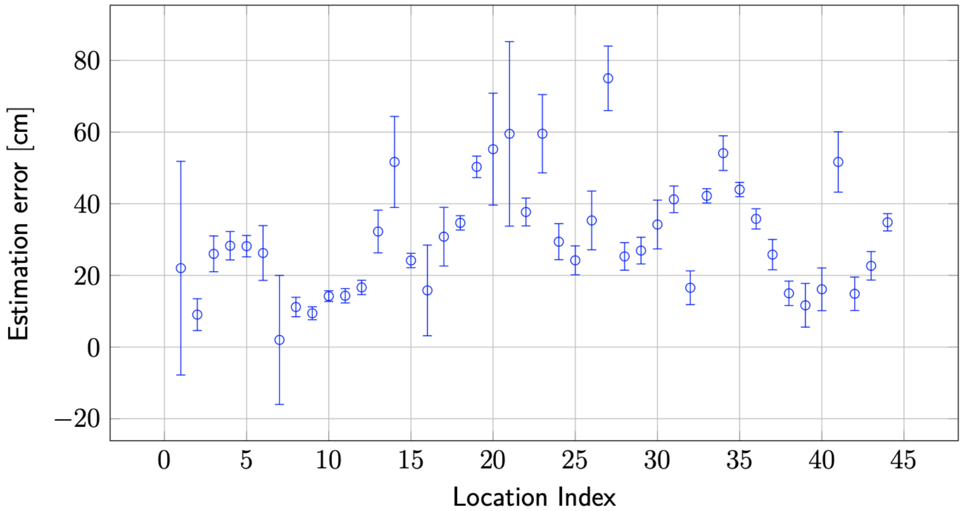

Figure 2.13: Error on the estimated location in function of the position of the tag. Taken from [11]

To achieve a better locating, anchors can be added, it has the advantage to add an equation to the system shown in eq. 2.5, which, if the new anchor gives some coherent measure, improves the estimation of the localization. The drawback is that it will slow done the actualization of the position, since it has to communicate with more anchor. Such algorithm dealing with four anchor is presented in [10].

2.4 Multi-path aided locating system

2.4.1 Channel Impulse Response

The Channel Impulse Response (CIR) has already been briefly introduced in the section 2.1. The CIR is not only used in telecommunications systems but also in control theory for example, to characterize the behaviour of a system[8] [9]. As the name states, the goal of this CIR is to characterize the reaction of a system to a stimulus in the form of a pulse.

An example is displayed on the Fig. 2.14. A ray tracing has been performed on the left image. The Line of Sight (LoS) rays and the way that have been reflected once can be observed. If a Dirac pulse is sent from the transmitter (TX) to the receiver (RX), since the propagation time will depend on the distance travelled, different peaks will appear, each corresponding to a different ray.

[8] In automatic, the transfer function which correspond to the step response is commonly used.

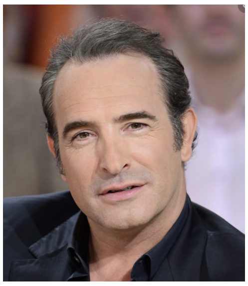

Figure 2.14: Double image -> Vient de la simulation ?

As one can see, those different arrival time for each ray correspond to the different peaks on the right figure of the Fig. 2.14. The height of the peak depend on the attenuation suffered by the emitted peak due to the reflections on the walls. The equations used to compute those attenuations are detailed in the section $ref\{SectionNotWrittenYet\}$.

2.4.2 Virtual Anchors

[13]

Explain the equation behind the simulation

Chapter 3

Conclusion

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