1. Introduction

Outdoor positioning can be improved with the start-up of Galileo. So, the accuracy will usually be in the order of a few metres. With Galileo services, the users needs require the same performances in outdoor and indoor applications. This is more obviously true in the construction, hypermarket, museums, where location awareness can become a crucial parameter for value-added services, especially for Galileo-GPS services. Positioning in difficult environments, especially in indoor, represents a current limitation for localisation systems (GPS/Galileo). In fact, indoor positioning faces additional difficulties as compared to outdoor positioning. Attenuation and multipath reflections of the line-of-sight (LOS) signal (or direct path) by the walls, floors, and ceiling of a tunnel are the main factors preventing typical GPS receivers from functioning indoors. Most of the time, the sum of multipath signals is stronger than the direct path signal, thereby preventing the receiver from accurately calculating the time of arrival [1]. The multipath signal distorts the cross correlation function peak, as detected by a receiver. The scientific and industrial community, especially in transport applications, considers that it is important to provide a positioning function in indoor (tunnel, station...) with a good performance of about a few centimetre. So, in order to reach this performance level, different techniques are under development, such as Ultra Wide Band technology. The UWB promises to overcome the power consumption and accuracy limitations of both the GPS and WLAN, and is more suitable for indoor location-based applications. In fact, Ultra Wide Band (UWB) technology provides high accuracy positioning in the multipath and confined environments typically found inside buildings. Integration of UWB with GPS or Galileo can provide a seamless transition from outdoor to indoor position and vice-versa. The ranging accuracy expected from UWB systems should be better than 0.5m in severe multipath environments [2, 3]. This chapter focuses on the indoor positioning system using the Ultra Wide Band, especially for transport applications. The first section is dedicated to introducing the indoor positioning application [3]. After this introduction, we present a brief review of some relevant work [7–9]. In indoor positioning system especially for transport applications two scenarios are considered: the self localisation and server-based localisation.
In the self localisation, called the positioning system, the mobile receives signals from the bases station (the transmitter) and interprets the received-signals as ambient information for localising its position in a local coordinate system. The server-based localisation (fixed points) is based on the measure of the signals radiated from a mobile. Then, using the signals measured at distributed sensors, the server estimates the position of the mobile. In the second section of this chapter, we present two approaches for UWB positioning. The first one is based on the Direct Sequence Spread Spectrum UWB technique. The second one is based on the new waveforms, using the orthogonal waveforms, called the Modified Gegenbauer Functions. These functions allow specific waveforms for each transmitter with a good orthogonal propriety [3]. Theses approaches are studied and evaluated in terms of localisation errors for different multipath channels. The multipath channel effect in the UWB environment is introduced and analysed in this section for indoor positioning applications. In the third section, the test results using laboratory instruments are presented to validate the simulation and analytical results, given in the second section. In the fourth section, the first results concerning a new positioning approach for railway application, using UWB radio and Time Reversal techniques, are given. The last section of this chapter is dedicated to proposing conclusions and recommendations for future research.

2. Introduction of the indoor positioning system

In indoor positioning system two scenarios are considered: the self localisation and server-based localisation. In the self localisation, the mobile receives signals from the Base Stations BS (the transmitter) and interprets the received-signals as ambient information for localising its position in a local coordinate system. The block schema of this scenario is illustrated in figure 1. Each station (access point) sends the radio frequency signal and the processing, used to calculate of the mobile position, is realised in the mobile. The server-based localisation (fixed points) is based on the measure of the signals radiated from a mobile. Then, using the signals measured at distributed sensors, the server estimates the position of the mobile. The block schema of the second scenario is illustrated in figure 2.

Positioning techniques exploit one or more characteristics of radio signals to estimate the position of their source or the self position. Depending on accuracy requirements and constraints on transceiver design, various signal parameters can be employed. Commonly, a single parameter is estimated for each received signal. However, it is also possible to estimate multiple signal parameters in order to improve positioning accuracy. Some of the parameters that have been used for positioning are the Received Signal Strength Intensity (RSSI), the
Angle Of Arrival (AOA), the Time Of Arrival (TOA) and the Difference of Time Of Arrival (TDOA).

- Received Signal Strength Intensity (RSSI): provides information about the distance between two points. The main idea behind the RSS approach is that if the relation between distance and power loss is known, the RSS measurement at a point can be used to estimate the distance between that point and the transmitting point, assuming that the transmitted power is known.

- The Angle Of Arrival (AOA): this technique is based on determining the direction of the arrival signal. A stationary device measures the angle of arrival of the signal sent by a mobile device. Location can be estimated through triangulation if at least two stationary devices perform measurement. Measuring angles requires a specific antenna array. The angle information is obtained at an antenna array by measuring the difference in arrival times of an incoming signal at different antenna elements.

- Time Of Arrival (TOA): In TOA positioning, a mobile device sends a signal to a stationary device, which sends it back to the mobile device. The mobile device measures the round-trip time (RTT) of the signal. This leads to a circle, whose radius corresponds to half of the RTT and whose centre is on the location of the stationary device. Location of the mobile device can be approximated to be at the intersection of at least three measured circles. This technique requires accurate clocks because a 1μsec error in timing equals to a 300 m error in distance estimate. Thus, the accuracy is too low for TOA positioning.

- Time Difference Of Arrival (TDOA): TDOA positioning is developed to eliminate the tight synchronization requirement of TOA. In fact TOA range measurements require synchronisation among the mobile station (MS) and the Base Station BS (transmitter). However, TDOA measurement can be obtained even in the absence of synchronisation between MS and BS, if there is synchronisation among the base stations. In this case, the difference between the arrival time of two signals travelling between the MS and BS is estimated. This locates the MS on a hyperbola with foci at the BS.

Instead of performing a single measurement such as RSSI, AOA or TOA, a point can be estimated using a combination of position-related parameters. Such hybrid approaches can provide more accurate information about the position of the mobile than the approaches that estimate a single position parameter. Various combinations on measurement, such as TOA/AOA, TDOA/AOA and TOA/RSSI, are possible depending on accuracy requirement, complexity constraints, propagation environment and necessary processing delay [13, 18].
3. Indoor positioning application

Indoor localisation is the determination of the position of a device or a person in an indoor environment. While the localisation in outdoor environments can in most cases, efficiently and accurately use the GPS, or some more accurate variants like D-GPS, these systems are usually not efficient indoors. Typically, the transit satellite signal is highly damped when traversing the building and is not sufficient for a receiver to be detected. Satellite signals which are reflected by surrounding buildings may be detected through windows, but the path length for the satellites will be altered differently each from another and the position determination will be inaccurate to some 10..1000 meters. Therefore, the investigation of position detection technologies suitable for indoor environments is a current research and development topic.

3.1. Large public indoor positioning application

In recent years the applications for indoor localisation information have been developed and their use has increased. The new technologies continue to improve with better and more accurate positioning information. So, the new applications have been developed for the mass consumer markets. Different indoor location services and applications are offered in various domains. Location-based advertising has an application in a scenario in which the cell phone of a visitor to a mall can be located and used to display an advertisement of a shop very near to where its holder is located. Person and asset tracking applications in schools: surveillance of the children, criminals can be monitored using the positioning system, items can be tracked in warehouses, materials and equipment in manufacturing areas.

3.2. Indoor positioning application for transport applications

For transport applications, especially in subway transportation areas, it is very important to ensure the positioning service. In fact, the subway line is divided in parts called sections of about 500 m in length. When a train is in a section, it is declared to be engaged and no coach can go in until the train leaves it. This is the safety system adopted in most of the current networks. In this scope, only a few trains (say from 2 to 4, due to limited emitted power) will be allowed to receive or transmit data or video in any given area, including messages broadcast to passengers or security information sent to or from the control center, such as train status or problems encountered on the track or onboard. For this application, the distance between a train and a preceding one must be known to a precision in the sub-meter range over distances higher than one hundred meters in the train location application. So, for this application, it is important to use the positioning system able to operate with good performance in terms of the precision, positioning error and the processing delays. Another example can be cited concerning the public transport. In fact, knowing the position of our train or bus allows us to have pertinent information such as the lists of closest hotels, spectacles and restaurants. These examples demonstrate that localisation may be needed as a key component for numerous domains.

3.3. Existing technical solutions for indoor positioning

Several techniques and commercial systems are used for indoor localisation. For example, a WLAN-based system is used to calculate positions by measuring the received signal strength (RSS). RADAR [16] (Microsoft) and Place Lab (Intel) are WLAN-based positioning systems.
Indoor Positioning System Based on the Ultra Wide Band for Transport Applications

The infrared-based method is used with the sensors that recognize the unique ID codes of infrared devices. Although the structure of this system is simple and the cost is low, a limited visibility range and line-of-sight (LOS) obstructions are its weak points. Ultrasonic-based system uses the difference in the transfer speed between RF and ultrasonic signals. This system has the advantages of 3D position recognition, low-power, and low cost. The Cricket system (MIT) and the Active bat system (AT&T Lab) [17] both use ultrasonic technology. Another radio frequency technique identification RFID system utilizes a tag-and-reader scheme. Such tags contain circuitry that gain power from radio waves emitted by readers in their vicinity. They use this power to reply their unique identifier to the reader. This technique is very attractive because of the reasonable system price, and reader reliability but the major disadvantage of this technique is the very limited range, lower than 10m.

Using current generation non-dedicated narrow band WLAN/WPAN derived technologies, a few meter localisation accuracy is achievable in indoor environments. However, this level of performance appears insufficient for some specific applications and services for example transport applications. These applications usually necessitate high performance in terms of precision and processing delay. The UWB technique is an excellent signalling choice for high accuracy localisation in short to medium distance, due to its high time resolution and inexpensive circuit.

Commonly, a UWB signal is defined to be a signal with a fractional bandwidth $B_{fr}$ of more than 20% or an absolute bandwidth $B$ of at least 500 MHz. The absolute bandwidth is calculated as the difference between the upper frequency $f_h$ and the lower frequency $f_l$ of the -10 dB emission point (equation 1).

$$B = f_h - f_l$$  \hspace{1cm} (1)

The fractional bandwidth is defined as:

$$B_{fr} = \frac{B}{f_c}$$  \hspace{1cm} (2)

where $f_c$ is the center frequency ans is given by equation 3:

$$f_c = \frac{f_h + f_l}{2}$$  \hspace{1cm} (3)

Due to their large bandwidth, UWB signal is characterized by very short duration waveforms. A UWB system transmits ultra short pulses with a low duty cycle. So, the ratio between the pulse transmission instant and the average time between two consecutive transmissions is usually kept small. There are two competing technologies for the UWB Wireless communication systems, namely: Impulse Radio (IR) and Multi-band OFDM (MB-OFDM). The IR-UWB technique is based on the transmission of very short pulses with relatively low energy. The IR-UWB provides lower data rates (a few Mbits/s) at higher ranges (tens of meters) with the possibility to have the positioning function. The MB-OFDM system gives potentially very high rates (in the order of 500 Mbits/s) with very short ranges (a few meters), the very wide frequency band used being divided into 14 sub-bands (500 MHz each). Several proposals based on these two technologies have been submitted to the IEEE 802.15 [19]. Both technologies are valid and credible. In addition to high rate Wireless communication systems, UWB signals have also been considered for low rate Wireless communication that focus on
low power and low complexity devices. The IEEE formed the task group 4a standard for alternative PHY. The IEEE 802.15.4a provides high precision ranging /positioning and ultra power consumption. This standard is considered in this chapter. Two positioning systems are studied, DS-CDMA/UWB, and an original solution based on the orthogonal waveforms, and compared in terms of positioning errors.

4. The UWB proposed positioning system

4.1. The UWB waveforms

Some common UWB waveforms include Gaussian, monocycle pulse; pulse based on the modified Hermite polynomials. For example, the Gaussian and monocycle pulses (figure 3), given, respectively, the equation 4:

\[ w(t) = \exp \left( -\frac{t^2}{\tau} \right) \]
\[ v(t) = \frac{\tau}{\tau} \exp \left( -\frac{t^2}{\tau} \right) \]  

with \( \tau \) the pulse duration.

![Figure 3. Time representation of Gaussian and the monocycle waveforms.](image)

Other waveforms based on the orthogonal polynomial especially the Gegenbauer polynomials, can be used. These functions allow us to modulate the data and, simultaneously, guarantee the multi-user system [20]. Indeed, in the indoor localisation system the transmitters share the channel propagation. So, it is necessary to use a multiple access technique based on the orthogonal codes (for example: Gold code) or the orthogonal polynomials.

The MGF \( G_n(\beta, x) \) uses the weight function \( W(x) = (1 - x^2)^{\beta - 1/2} \) where \( \beta > -1/2 \) is a shape parameter, \( n \) is the degree of the function and \( x \) is the variable. These functions are orthogonal on the interval \([-1, 1]\) for \( m \neq n \):

\[ \int_{-1}^{1} w(x)G_n(\beta, x)G_m(\beta, x)dx = 0 \]  

These functions can be defined by a recurrence relation. Furthermore, they satisfy the differential equation 6.

\[ G_n(\beta, x) = 2n + \beta - 1 \frac{n}{x}G_{n-1}(\beta, x) - \frac{n + 2\beta - 2}{n} G_{n-2}(\beta, x) \]
Their expressions for the first few orders are given by the following equations:

\[
G_0(\beta, x) = (1 - x^2)^{\beta - 1/2}
\]
\[
G_1(\beta, x) = 2\beta x(1 - x^2)^{\beta - 1/2}
\]
\[
G_2(\beta, x) = \beta[-1 + 2(1 + \beta)x^2](1 - x^2)^{\beta - 1/2}
\]
\[
G_3(\beta, x) = \beta(1 + \beta)[-2x + (2 + \beta)\frac{4x^3}{3}](1 - x^2)^{\beta - 1/2}
\]
\[
G_4(\beta, x) = \beta(1 + \beta)\left[ \frac{1}{2} - 2(2 + \beta)x^2 + (2 + \beta)(3 + \beta)\frac{4x^4}{3} \right](1 - x^2)^{\beta - 1/2}
\]

(7)

The waveforms of the MGF \( G_n \) are shown in figure 4, for \( n = 1 \) to 4 and \( \beta = 1 \) versus time normalized to waveform duration \( T \). They are normalized here so as to have an energy of unity. Using Gegenbauer waveforms, a positioning system may be built, which requests up to 4 transmitters.

\[ \hat{d}_{TDOA} = R_{ij} - R_{ij} = c(\tau_i - \tau_j) = R_i - R_j \]

(8)

where \( \tau_{ij} \) is TDOA between receiver \( i \) and \( j \), \( R_{ij} \) is the range difference, \( \tau_i \) and \( \tau_j \) are TOA arrival estimates at transmitter (point) \( i \) and \( j \), while \( R_i \) and \( R_j \) are range estimates at transmitter \( i \) and \( j \). Figure 5 illustrates the principle of the TDOA technique in 2D.

There are 2 ways of obtaining TDOA estimates [8]. The first way which makes use of the cross correlation estimation technique of the received signal \( r_1(t) \) and \( r_2(t) \) to calculate the delay corresponding to the largest cross-correlation value.
For example, in the case of the server-based localisation, consider a signal $x(t)$ being radiated by a mobile and being received by two points (stations).

$$r_1(t) = A_1 x(t - y_1) + n_1(t)$$
$$r_2(t) = A_2 x(t - y_2) + n_2(t)$$

Equation 9 represents the received signals at the two points (Stations). $A_1$ and $A_2$ are the amplitudes of the received signals with delays $y_1$ and $y_2$, corrupted with noise $n_1(t)$ and $n_2(t)$. It is assumed that $x(t)$, $n_1(t)$ and $n_2(t)$ are real and jointly stationary, zero mean random processes and that $s(t)$, $n_1(t)$ and $n_2(t)$ are uncorrelated.

$$r_1(t) = x(t) + n_1(t)$$
$$r_2(t) = A x(t - Y) + n_2(t)$$

where $A$ is the amplitude ratio between the two received signals and $Y = y_2 - y_1$. TDOA estimation requires estimation of values of $Y$. A simple cross correlation technique is illustrated in figure 6.

The cross correlation function of these two received is given by equation 11.

$$c(t) = \frac{1}{T} \int_{-\infty}^{\infty} r_1(t) r_2(t + \tau) dt$$

**Figure 5.** 2D TDOA Positioning technique.

**Figure 6.** The Cross Correlation Method for TDOA estimation.
with $T$ is the period of observation.

TDOA estimate $\hat{Y}$ is the value of $\tau$ that maximizes the cross correlation is given by equation 12.

$$\hat{Y} = \arg\max |c(t)|$$

The second method uses the substraction at the TOA estimates from two transmitters (points) to produce a relative TDOA estimate (equation 8). This requires a knowledge of timing at the two transmitters and thus requires a strict clock synchronization between the two transmitters. Also, this method has an advantage of eliminating the errors in TOA estimates common to all the transmitters. After the TDOA estimate step, a hyperbolic position location algorithm is used to produce an accurate and unambiguous solution to the position location algorithm.

Once the TDOA estimates have been obtained, they are converted into range difference measurements. Thereafter, these measurements are converted into nonlinear hyperbolic equations [11]. Several algorithms have been proposed for this purpose having different complexities and accuracies [12]. Here, we will focus on the mathematical model for hyperbolic TDOA equations based on the Chan technique. In fact, a non-iterative solution capable of achieving optimum performance in terms of positioning error was proposed by Chan [13]. This solution is a non-iterative and has a higher noise threshold than the others methods [12]. Furthermore, it provides an explicit solution that is not available for example in the Taylor-series method [13]. This method is used in the simulations given in this chapter, because essentially it is less sensitive to the channel propagation noise.

Let $(x, y)$ be the source location (mobile), and $(X_i, Y_i)$ be the known location of $i^{th}$ Base Station BS or transmitter, where $i = 2, 3...M$, $M$ being the total number of BSs taking part in the position location process. Moreover, assume that $BS = 1$ is the controlling BS. The range difference between source and the $i^{th}$ BS is given by equation 13.

$$R_i = \sqrt{(X_i - x)^2 - (X_i - y)^2}$$

Now, the range difference between base stations with respect to $BS = 1$ is given by equation 14.

$$R_{i,1} = cd_{i,1} = R_i - R_1$$

where $c$ is the signal propagation speed ($3.10^8 m/s$) and $d_{i,1}$ is the range difference distance between $i^{th}$BS and $BS = 1$. In order to find the $x$ and $y$ values, Chan method is used, producing two TDOAs, for the three base stations. So, the solution for $x$ and $y$ in terms of $R_1$ is written by equation 15:

$$
\begin{pmatrix}
x \\
y
\end{pmatrix}
= 
\begin{pmatrix}
X_{2,1} & Y_{2,1} \\
X_{3,1} & Y_{3,1}
\end{pmatrix}
^{-1}
\begin{pmatrix}
R_{2,1} & R_{3,1} \\
R_1 + \frac{1}{2} (R_{2,1}^2 - K_2 + K_1) \\
R_{3,1} - K_3 + K_1
\end{pmatrix}
$$

with

$$
\begin{aligned}
K_1 &= X_1^2 + Y_1^2 \\
K_2 &= X_2^2 + Y_2^2 \\
K_3 &= X_3^2 + Y_3^2 \\
R_{2,1} &= cd_{2,1} \\
R_{3,1} &= cd_{3,1}
\end{aligned}$$
On the right side of the above equation, all the quantities are known quantities, except $R_1$. Therefore, the solution of $x$ and $y$ will be in terms of $R_1$. When these values of $x$ and $y$ are substituted into the equation $R_{2,1}$, a quadratic equation in terms of $R_1$ is produced. Once the roots for $R_1$ are known, values of $x$ and $y$ can be determined. It should be noted that only the positive $R_1$ root must be considered. One of the roots of the quadratic equation is, in fact, either negative or too large to be within the cell radius.

### 4.3. Positioning system based on the DS-CDMA technique

The first presented system is based on the DS-CDMA technique. So, for each emitter (Base Station) a pseudo code is attributed. In this study, the gold code is chosen due to its good orthogonality propriety. The bloc diagram for each transmitter (BS) is described in figure 7. The transmitter is composed of the coded and the modulated (antipodal modulation) operation using Gaussian waveforms. The antipodal modulation (analog to binary phase shift keying) is used for all data bits from each transmitter. The receiver unit, figure 8, consists of the demodulated and decoded function in order to retrieve the signal of each BS. Finally, the localisation technique based on Time Difference of Arrival is used to calculate the estimated position of the mobile.

![Figure 7. Block diagram of transmitter (BS).](image)

![Figure 8. Block diagram of the receiver (MS).](image)

### 4.4. System based on the Modified Gegenbauer Functions

The second system is based on the Modified Gegenbauer Function MGF. In this case, we attributed one MGF order for each BS. For example, order 1 (G1) is for SB1, order 2 (G2) for BS2 and order 3 (G3) for BS3. The Block diagram of the transmitter is given by figure 9. The receiver unit consists in demodulating and calculating the MS position using the TDOA technique figure 10.
5. Simulation results

In order to compare two systems DS-CDMA/UWB and the MGF/UWB, we calculate the positioning error considering different channel propagation models. So, in order to send information from one point to another, the transmitted signal must travel through the propagation channel to reach the receiver (mobile station). In this chapter, two channels are used: the Additive White Gaussian Noise AWGN channel with a uniform spectral power density and the IEEE 802.15.3a channel. The proposed system was considered to deliver positioning in tunnels, especially subway transportation areas; hence the choice of using a IEEE 802.15.3a channel in order to evaluate, in simulation, the proposed solutions. The IEEE 802.15.3a model was developed from around 10 contributions, all referring to distinct experimental measurements, performed in indoor residential or office environments [5]. The IEEE 802.15.3a model is based on the Saleh Valenzuela formalism. Parameters are provided to characterize the clusters and ray arrival rates ($\Lambda$ and $\lambda$), as well as the inter and intra-cluster exponential decay constants ($\Gamma$ and $\gamma$). Four sets of parameters are provided to model the four following channel types (figure 11):

- The channel model CM 1 corresponds to a distance of 0-4 m in a residential Light Of Sight LOS situation;
- The channel model CM 2 corresponds to a distance of 0-4 m in a residential Non Light Of Sight NLOS situation;
- The channel model CM 3 corresponds to a distance of 4-10 m in an office NLOS situation;
- The channel model CM 4 corresponds to an Office NLOS situation with a large delay spread $t_{rms} = 25$ ns.

The key parameter of the UWB signal is the choice of waveforms. Two waveforms are used, in this section, and evaluated in terms of the positioning errors in IEEE 802.15.3a cases. The first one is the Gaussian pulse, the second waveform is the Modified Gegenbauer pulse. Figures 12 and 13 illustrate the results of the simulations realised in Matlab software. These figures show that the MGF waveforms give better results than the monocycle waveforms in terms of positioning error. Especially, in the case of a very noisy channel SNR> -9 dB. These performances decrease in the absence of line of sight. The MGFs are less sensitive to the propagation channel effects than the monocycle waveforms.

In figure 14, the positioning errors are evaluated for different SNR values and different waveforms numbers in two cases: the proposed system based on the CDMA-UWB with gold
code (7 chip) and the second proposed system based on the Modified Gegenbaeur functions. In this case, the channel effect is a simple AWGN channel. We show that, when increasing the number of MGF, the positioning error decreases. For example, the positioning error is less than 1.5 cm for SNR > -10 dB when we attribute seven Gegenbauer pulses per base station. For DS-CDMA solution, using code Gold length N = 7 chip, the positioning error is higher than 1.5 cm for SNR > -6 dB. We conclude that MGFs give a better performance than the
DS-CDMA, even if we use one order for each transmitter system. Another advantage of the MGF positioning system is the processing delay lower than the DS-CDMA solution. In fact, in the MGF positioning system the modulation and the multiple access technique are realised simultaneously. These performances increase if we attribute more than one Modified Gegenbauer pulse per transmitter.

![Graph](image13)

**Figure 13.** The positioning error in case of monocyle waveforms in IEEE 803.15.3a channel.

6. Measurements results

An experimental setup was established to validate the proposed indoor positioning system. The tested system is based on the gegenbauer waveforms. The measurement setup is illustrated in figures 15 and 17. $S_1$, $S_2$ and $S_3$ are the position of transmitting antennas. The transmitter signal is generated using Arbitrary Waveform Generator 10GHz and the monopole antenna omni-directional adapted to the 800 MHz - 19 GHz band (figure16). The received signal is measured by oscilloscope. The mobile position is calculated using the TDOA technique. The test results, realised using the configuration 17, are illustrated in figure 18 and in table 1. These results show that the positioning error is repetitively about 18 cm.

![Graph](image14)

**Figure 14.** The positioning error for different SNR values.
Figure 15. Experimental setup for indoor positioning system.

Figure 16. Monopole antenna.

Figure 17. Configuration used in the measurements.

<table>
<thead>
<tr>
<th>Acquisition</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
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<td>Positioning error (cm)</td>
<td>17,5</td>
<td>12</td>
<td>19</td>
<td>18,5</td>
<td>20,03</td>
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<td>processing delay (s)</td>
<td>0,87</td>
<td>0,79</td>
<td>0,67</td>
<td>0,80</td>
<td>0,82</td>
</tr>
</tbody>
</table>

Table 1. Positioning error results

7. Future work

In the future work, localisation systems for railway transport using UWB radio and Time Reversal (TR) techniques will be studied and evaluated. In fact, Time Reversal channel pre-filtering facilitates signal detection and helps increasing the received energy in a targeted area. In this context, a proposed UWB-TR techniques for the precise location of trains is
Figure 18. The test results.

illustrated in figure 19. It shows the particular case of a railway tunnel. The balises are geo-referenced. UWB/TR balises will be installed on the side of the track. The UWB/TR balises are kilometer markers. On arrival in the range of the UWB communication, the train computes its absolute localisation to the balises using time of arrival information. Moreover, several simple UWB transmitters are located in the balises to enable focalization. The local Channel State Information (CSI) between any balise transmitter and virtual optimal balise localisation along the track is identified a single time during the initial installation. This information is then introduced as pre-filtering data in the different UWB transmitters. Therefore focalization is obtained in this virtual localisation area whenever the train passes, potentially improving the absolute localisation process.

Figure 19. TR-UWB localisation system proposed.

The principle of the proposed TR-UWB system uses three stages: first the channel impulse response is measured and recorded at the transmitter Tx. Then, this impulse response is
reversed in time and transmitted in the propagation channel to the receiver Rx. The original signal we have chosen to be transmitted, associated with the impulse response, is the second derivative of Gaussian function; it is an ultra short pulse with duration of 500 picoseconds. This principle can then be described by noting s(t) the transmitted pulse, h(t) the complex impulse response of the channel and h∗(−t) the complex conjugate of the time reversed version of h(t). We note by y(t) the received signal without TR and yr(t), the received signal with TR at the receiver. Their expressions are given by equations 16 and 17:

\[ y(t) = s(t) \otimes h(t), \quad (16) \]
\[ y(t) = s(t) \otimes h^*(−t) \otimes h(t). \quad (17) \]

where \( \otimes \) represents the convolution operation. From equation 17, we deduce the equivalent impulse response \( h_{eq}(t) \) which corresponds to the autocorrelation function of the channel equation 18:

\[ h_{eq}(t) = h^*(−t) \otimes h(t). \quad (18) \]

The autocorrelation function is used to evaluate temporal focusing. This characteristic is very beneficial for the application to the UWB system [14] [15]. To study the temporal focusing, we evaluate the focusing gain (FG), by considering the impulse response channel \( h(t) \) and the equivalent impulse response channel \( h_{eq}(t) \). FG is then defined as equation 19:

\[ FG_{dB} = 10 \log_{10} \left( \frac{\max(|h_{eq}(t)|^2)}{\max(|h(t)|^2)} \right) \quad (19) \]

For performance evaluation in terms of temporal focusing, we calculated the focusing gain (FG), for different channel models. FG is obtained after determining the Power Delay Profile in the case of UWB-IR is denoted \( PDP \) and \( PDP_{TR} \) in the case of TR-UWB. PDP determines average power of scattering components occurring with propagation delay, it gives the intensity of a signal received through a multipath channel as a function of time delay. Expression of \( PDP \) and \( PDP_{TR} \) in both cases is then given by equations 20 and 21.

\[ PDP = |h(t)|^2 \quad (20) \]
\[ PDP_{TR} = |h_{eq}(t)|^2 \quad (21) \]

The equation giving the expression of FG can be written equation 22:

\[ FG_{dB} = 10 \log_{10} \left( \frac{\max(PDP)}{\max(PDP_{TR})} \right) \quad (22) \]

Figures 20 to 23 show a comparison between \( PDP \) and \( PDP_{TR} \), and, then, we can find a temporal focusing and increase the amplitude of the power from \( PDP \) to \( PDP_{TR} \). This translates into results on the evaluation of FG in table 2. Thus we find, using successively CM1 to CM4, the FG increases due, in particular, to many multipaths. Indeed, time reversal take advantage of the complexity of the channel, which would be very beneficial for the purpose of locating in confined environments, such as tunnels.

Simulations were performed using the channel models CM1, CM2, CM3 and CM4. Table 3 presents a comparative study between the UWB-IR system and TR-UWB system, in terms of temporal focusing and Root Mean Square Error RMSE of localisation, treated in a particular
Figure 20. (a) PDP and (b) PDP_{TR} for CM1.

Figure 21. (a) PDP and (b) PDP_{TR} for CM2.

<table>
<thead>
<tr>
<th>Channel model</th>
<th>CM 1</th>
<th>CM 2</th>
<th>CM 3</th>
<th>CM 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>GF [dB]</td>
<td>7.27</td>
<td>8.03</td>
<td>9.94</td>
<td>11.69</td>
</tr>
</tbody>
</table>

Table 2. Focusing gain FG for different channel model

case. This study shows that, with the combination of UWB in TR, we get better information in terms of localisation error. Indeed, in the particular case treated, the RMSE is 7.45 cm in the case of CM3 for the UWB-IR system, whereas it is only 1.12 cm for the TR-UWB system. This remark also applies to CM1, CM2 and CM4.

These first results show that the proposed solution allow us to significantly reduce the localisation errors, especially of the channel propagation environments complex. The next step will be dedicated to validating these results through experimentations in real environment.
Table 3. Comparison between UWB-IR and UWB-TR in terms of FG and positioning error in CM1, CM2, CM3 and CM4, SNR=8 dB

8. Conclusion

In this chapter, the indoor positioning system based on the UWB technique is presented. The indoor localisation application is given, especially for railway transport. The existing indoor positioning technique is presented. The UWB technique chosen to establish positioning system is introduced. Two proposed systems are presented and evaluated in terms of localisation error using AWGN and IEEE 802.15.3a channels. The first one is based on the
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Direct Sequence Spread Spectrum UWB technique. The second one is based on the Modified Gegenbauer orthogonal waveforms. The simulation results show that the second proposed system is less sensitive to noise. This is due to the good orthogonal propriety of the MGF functions. These results are validated by tests using laboratory instruments. Thereafter, the new positioning system for railway application using UWB radio and Time Reversal techniques is presented. The first results show that the combination of UWB and Time Reversal TR can reduce the localisation error thanks to the characteristic of TR technique, including the temporal focusing. In the future work, these simulations results will be validated by tests in real environments.

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9. References


International Symposium on Personal, Indoor and Mobile Radio Communications, pp. 1 - 6, Helsinki, Finland.


