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AN INDOOR-OUTDOOR POSITIONING SYSTEM BASED ON THE COMBINATION OF GPS AND UWB SENSORS

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ABSTRACT

Today localization techniques are gaining popularity because of the high interest for many business cases as well as for emergency/security scenarios including real-time tracking, navigation, clock synchronization … The need to obtain a precise position in a short time at any point, leads to use an efficient navigation system. In outdoor environments, GNSS (GPS, Galileo,...) is used and provide a good accuracy, but in the indoor environments, GNSS signal is deteriorated due to the signal degradation by different obstacles, so other techniques are used to locate users such as IR, RF, Cellular network or GNSS repeater. This paper provides a new design of Indoor-Outdoor positioning system based on the combination of data from UWB and GPS sources.
Keywords: *Indoor Localization, Fusion Data, UWB, GNSS, RF Localization, Sensor Network.*

1. INTRODUCTION

Several systems for position detection have been proposed and implemented. For applications in outdoor environments (excluding buildings), Global Navigation Satellite System (GNSS) such as GPS system, based on a constellation of satellites, is generally used [1]. However, the GNSS signal doesn't strong sufficiently to penetrate through different materials used in construction, also the phenomena of reflection and multipath fading limit the utility of GNSS in dense urban or in the indoor environments. This is why indoor location systems have been developed. They can be classified into three broad categories based on the transmission medium used: InfraRed (IR), UltraSound (U.S.) and RadioFrequency (RF).

The first indoor positioning system proposed is based on IR technology called "Active Badge" developed by AT & T in 1992 [2]. This system provided to each person a badge periodically transmits an identification with an IR beam received by one or more receptors installed in the building (*Figure 1*). The position of the mobile is then determined using the position of the closest receiver. All systems based on IR require to the user wearing of badge in outside of clothing to allow the line of sight between the transmitter and the receiver, which is not possible in all cases. In addition, the presence of sunlight is an obstacle for this technology because it disturbs the infrared transmission.

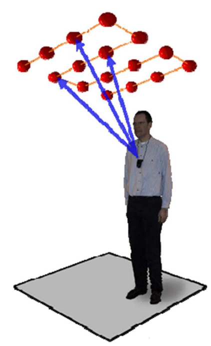

Figure 1: Localization by InfraRed

There is also a number of UltraSound localization systems presented in the literature: Constellation system, Active Bat and Cricket [3]. These tracking systems are used to estimate the positions accurately. However, they are also sensitive to noise and require the presence of a line of sight between the transmitter and the receiver. *(Figure 2)*

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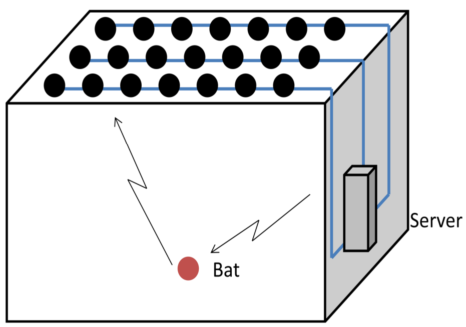

Figure 2 : Active Bat Architecture

Today, many public and private buildings are equipped with wireless IEEE 802.11b, a popular and inexpensive RF technology. Unlike ultrasonic and infrared signals, radio waves have the ability to penetrate walls which increases the coverage area, and minimizes the number of necessary equipment. Most 802.11b devices measure the signal strength of the received packets natively. A tracking system operator only information received power level allows implementing easily a location service. This is why systems are the most efficient location based on the analysis of the power level of the received signal. These systems are limited by the complex nature of radio signal (the effects of multipath, noise and interference) but have the advantage of not requiring line of sight between the transmitter and receiver. Among the radio frequency tracking systems, we find localization techniques based on: WLAN [4] [5] (*Figure 3*), ZigBee [6], Bluetooth, UWB (Ultra Wide Band) and RFID [7].

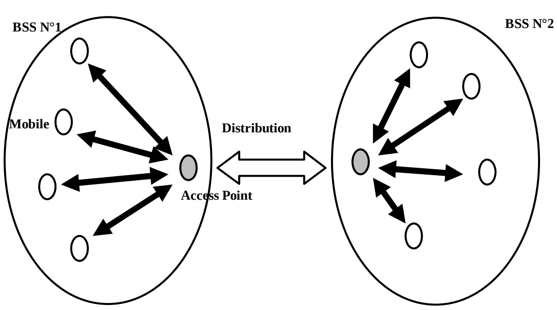

Figure 3: WLAN Architecture

Current approaches are moving towards hybridization using two or more localizations techniques and could realize independently the estimation of the position and provide continuity of service sought [8]. In general, the function is provided by GNSS (Global Navigation Satellite System, such as a GPS, GLONASS or the future system Galileo [9]) in the outdoor environment, and then complemented by another indoor technique. According to the different researches conducted in this area, the accuracy of the localization techniques are shown in *Table 1.*

Table 1: Comparison of the localization systems

System	Accuracy	Range	Signal	Cost
GPS	1-5 m	Outdoor	R F	High
Active Badge	7 cm	5 m	I R	Moderate
Active Bat	9 cm	50 m	U S	Moderate
Cricket	2 cm	10 m	U S	Low
UWB	10 cm	15 m	R F	Moderate
Landmarc	1-2 m	50 m	R F	Moderate
INS / RFID	2 m	Indoor	R F	Moderate

2. THE SYSTEM PROPOSED

The performances of the hybrid system are a promising area of research which we develop and propose a new design of an hybrid system composed by GPS and UWB sensors, used in both outdoor/indoor localization which provide the same capabilities as GPS but for an indoor environment.

2.1 UWB Technology

The UWB (Ultra Wide Band) is a modulation technique that involves very short pulses of frequency modulated into position, amplitude or polarity in a frequency band between 3.6 and 10.1 GHz and a low spectral density that meets the following criteria [10] [11] *(Figure 4):*

$$\frac{Freq_h - Freq_l}{Freq_c} > \eta \quad \underline{\text{and/or}} \quad Freq_h - Freq_l \geq m$$

Where:

η – Fractional bandwidth is greater than [0.20],

m – Minimum limit of bandwidth is [500 MHz],

$Freq_h$ – Upper frequency of the –10 dB emission point,

$Freq_l$ – Lower frequency of the –10 dB emission point,

$Freq_c$ – Centre frequency of the emission given by:

$$Freq_c = \frac{Freq_h + Freq_l}{2}$$

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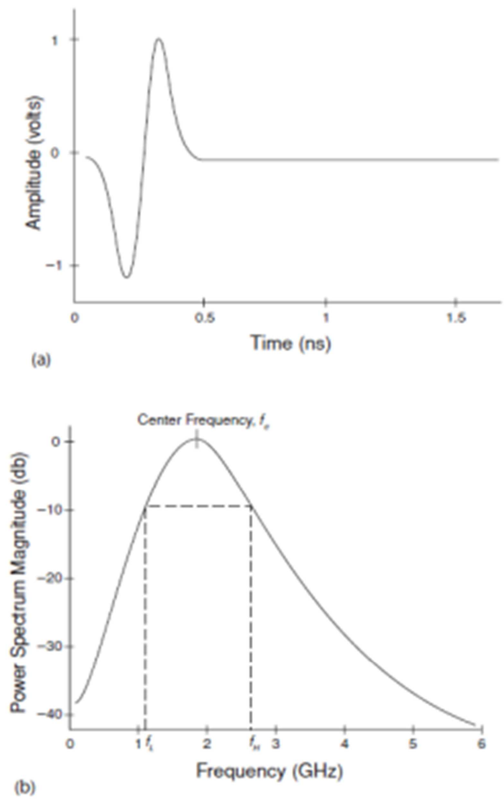

Figure 4: A 500 Picoseconds Gaussian Monocycle In (A) The Time Domain And (B) The Frequency Domain

The main characteristics and advantages of the UWB technology for localization application are [12] [13]:

1) ***Low susceptibility to Multipath Fading***: By comparison with other conventional radiofrequency communication systems, some UWB techniques offer much superior performance in indoor environment. They provide positioning accuracy better within a few centimetres, because the bandwidth is exceeding 0.5 GHz, and they are capable to resolve multipath components or reflections with sub-nanosecond delays and can be added constructively to provide gain over a single direct path in the multipath environment.
2) ***Superior penetration properties***: the low frequencies used by this technology, allow the signal to penetrate through a variety of materials.
3) ***System Simplicity***: the transceivers can be small due to a very low power of UWB signal, also this technique has no voltage controlled oscillator, mixer or power amplifier, which translates a lower material and assembly costs.
4) ***Secure Communications***: UWB pulses are time modulated with codes unique to each transmitter/receiver pair. The time modulation of extremely narrow pulses brings up security of UWB transmission, detecting picosecond pulses without knowing when they will arrive is next to impossible.
5) ***Immunity to Interference***.

2.2 Particle Filter & algorithm formulation

The location information is often noisy (ambient noise, susceptibility of equipment, interference, etc.). To improve the position's estimation, it is recommended to use a specific filter which takes into consideration the measurement, the historical trajectory and the characteristics of mobile's movements [14].

In this paper we propose to use a Particle Filter which is a general Monte Carlo method. It works by representing the posterior estimation of the possible mobile's poses by means of a set of weighted samples (particles) and compute the position estimate. The major advantage of this approach is its capacity to combine measures from different kind of technologies. In our work we follow the *Sampling Importance Resampling* (SIR) algorithm [15].

We denote x_t, m_t as the system state and the measurement at time t. *(Figure 5)*

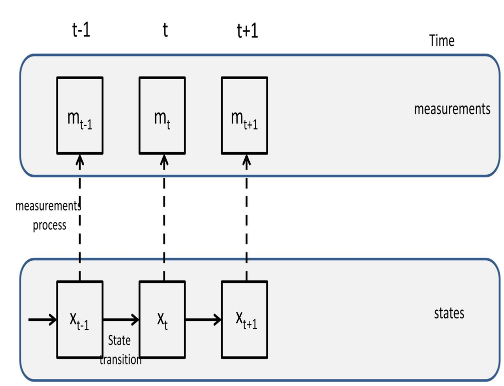

Figure 5: State Transition And Measurement Process In Particle Filter

This filter is generated by the following steps [16]:

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- ***Initialization***: sampling N particles $\{x^i(0), i=1 \ldots N\}$ according to the initial probability density function $p(x(0))$
- ***Prediction sampling***: For each particle x^i_t, get a new particle x^i_{t+1} from the transition $p(x_{t+1}|x^i_t)$.
- ***Importance Sampling***: For each new particle x^i_{t+1}, calculate $\omega^i_{t+1} = p(m_{t+1} \mid x^i_{t+1})$.
- ***Normalization and resampling***: The weights are normalized and finally resampled. In the resampling step, particles with low weight are deleted and particles with high weight are duplicated such that each particle has the same weight.

The corresponding algorithm: *SIR Particle Filter*

$$[\{x^i_t, \omega^i_t\}^N_{i=1}] = SIR[\{x^i_{t-1}, \omega^i_{t-1}\}^N_{i=1}, m_t]$$

For $i = 1:N$

$$Draw\ x^i_t = p(x_t \mid x^i_{t-1})$$
$$calculate\ \omega^i_t = p(m_t \mid x^i_t)$$

End For

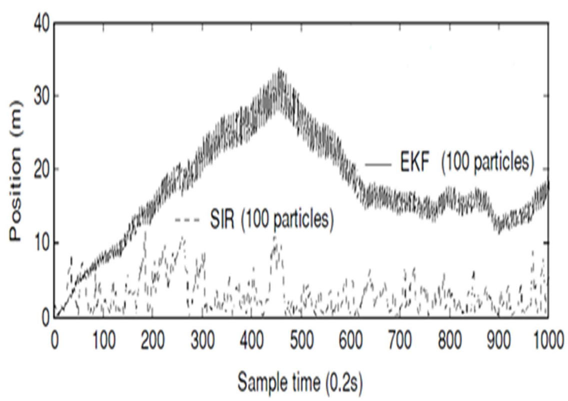
$$calculate\ total\ weight: t = Sum[\{\omega^i_t\}^N_{i=1}]$$

For $i = 1:N$

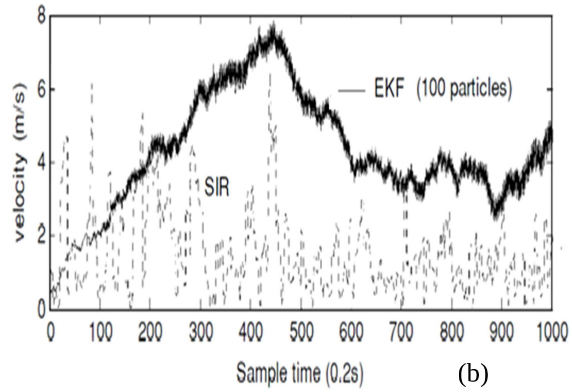
$$Normalize: \omega^i_t = \frac{\omega^i_t}{t}$$

End For

Resample: weights updating, particles updating



(a)



(b)

Figure 6: Comparison Between The SIR And The Extended Kalman Filter Concerning The Position (A) And Velocity Errors (B).

3. EXPERIMENTS

In this study, a model was established, based on the *Figure 7*, in order to measure the real positions to investigate more precisely the combination of these two tracking systems that are complementary in terms of radio coverage. The architecture implemented allows for interactions between different technologies to provide a final location more accurate compared to that given by each of these sensors. Each location technology gives an estimated position of the mobile, after combination and filter applying, we extract a single position which is the best position returned by each of these sensors.

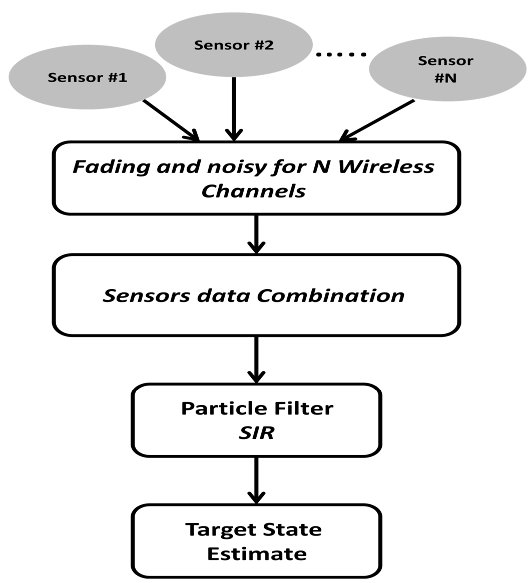


Figure 7: Structural Framework Of The Proposed Indoor-Outdoor Positioning System

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In our test scenario, three UWB sensors are placed, in the main entrance the building as showed in *Figure 8*, at the coordinates $R_1(X_{UWB1},Y_{UWB1})$, $R_2(X_{UWB2},Y_{UWB2})$ and $R_3(X_{UWB3},Y_{UWB3})$ to cover the indoor part, the mobile is equipped with UWB antenna (PulsON410 [17]), GPS Receiver and odometry system.

Before starting the test, we have established a database which contained the real coordinates of the positions that the mobile will pass while testing (Off line phase). During the mobile's movement, the signal from UWB, GPS, and the combination of both, when available, is used for estimating the Mobile location. We stored these different values and compared to the real coordinates collected in the first phase.

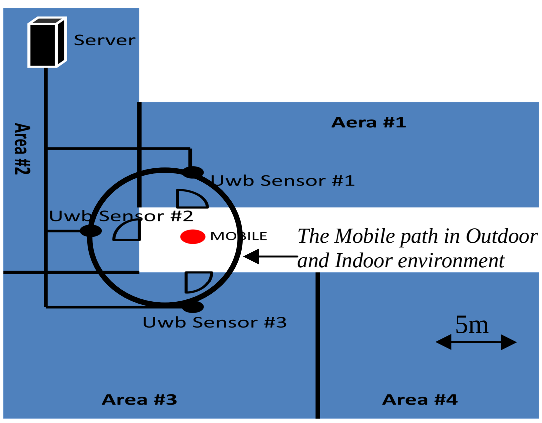

Figure 8: Plan Of The Laboratory, Including The Location Of The UWB Sensors

We have compared three different situations:

a) The Mobile position is determined only by the odometry system,
b) The Mobile position is estimated based on the UWB sensors,
c) In the Outdoor environment, the GPS information is also combined to improve Mobile localization.

We defined the error function ε(x,y,z) as:

$$\varepsilon(x,y,z) = \sqrt{(x - xi)^2 + (y - yi)^2 + (z - zi)^2}$$

With:

(x,y,z) the real coordinates (Off line phase)
(x_i,y_i,z_i) the estimated coordinates

In the *Figure 9*, the gray area represented the test's period where the signals from GPS and UWB are combined, this part of experience corresponded to the portion between Sensors #3 and #1 (outdoor environment) where data from GPS and UWB sensors are available. Note that in certain phases of our test scenario, the mobile received the signal from only one or two sensors (three sources are, at least, necessary to estimate the mobile by triangulation) which explains the localization errors on the Indoor part.

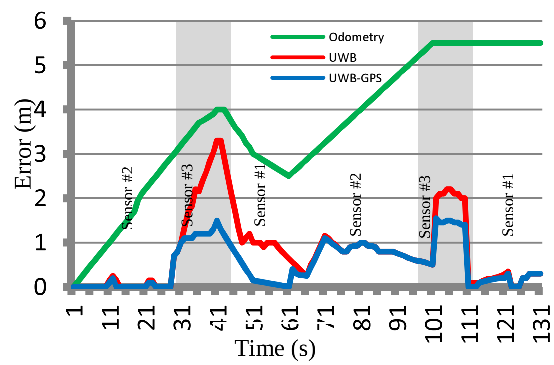

Figure 9: Localization Error For The Three Situations Along Two Loops

4. CONCLUSION

In this paper, after a theoretical study, we have presented and tested our positioning system for indoor and outdoor environment by the fusion of data from two kinds of technologies GPS and UWB in order to estimate the mobile's position. The *SIR Particle Filter* is used to integrate the non-linear information from different sensors. This hybrid system provides a result more accurate than a system based on one technology.

In the future we plan to implement our LIFS (Localization Information Fusion System), which combines data from more sources (RF, IR, Visual sensors) also using another GNSS such as the European system called Galileo.

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