Evaluation of an UWB localization system in static and dynamic

Mickael Delamare[1,2], Remi Boutteau[1], Xavier Savatier[1], and Nicolas Iriart[2]

[1] Normandie Univ, UNIROUEN, ESIGELEC, IRSEEM, 76000 ROUEN, France.
[2] SIAtech SAS, 73 RUE MARTAINVILLE 76000 ROUEN, France.

Abstract. Applications in the context of the industry 4.0 need a precise localization. Indoor localization remains an open problem. Among the possible solutions, we see the emergence of Ultra Wide Band(UWB)-methods. The aim of this article is to evaluate an UWB system in order to estimate the position of a person in indoor environments. We have evaluated an UWB system to obtain results of the 3D localization of a moving person in buildings environment in real time. For that purpose, static and dynamic tests were established using a ground truth based on a motion capture system with a millimetric accuracy.

Keywords: Indoor localization · Ultra WideBand (UWB).

1 Introduction

Robotisation, especially in factories, leads to an increasingly close interaction between man and machine, a concept referred as cobotics. This evolution is accompanied by a growing demand for intuitive and efficient Human Machine Interfaces (HMIs) based on natural interaction. In this context, HMIs will involve the development of innovative hand-held human-machine interfaces relying on gesture-recognition to enable intuitive and non-intrusive control of industrial machinery. To achieve this task, accurate and very small form-factor sensors are required. The operator can himself evolve in a building or a workshop without being constrained by having cumbersome locating system. The capture of the movement or the posture must be coupled with a notion of accurate and absolute location in a building (workshop, warehouse); this information enables a natural and contextual interaction between the operator and a set of machines. Localization in indoor environment will be used in industry 4.0 or industry of the future which corresponds to a new way of organizing the means of production. This new industry is emerging as the convergence of the virtual world, digital design, management (finance and marketing) with real-world products and objects.

Observation and understanding of gesture and posture have been the subject of numerous studies. Many studies were presented regarding the gesture perception from a fixed sensor, the best known being the Kinect from Microsoft. However, all these solutions restrict the movements of the operator and limit the possibilities of natural interaction with a machine. Such as the distance or the field of view for a common use. Another approach is to observe the movement from a hand-held device. These solutions are generally based on inertial sensors such as accelerometers and gyroscopes; their assembly forms what is commonly called an IMU (Inertial Measurement Unit). IMU diffusion has increased with the development of MEMS technologies, which offer a good cost-to-performance ratio and is well adapted to the human size [6].

These solutions are the basis for Attitude Heading Reference System (AHRS) measurement devices. They are attitude measurement units because they allow a measurement of the orientation of the sensor in the terrestrial reference frame, a measurement that can be significantly improved thanks to data fusion algorithms [13]. A review of these filtering methods and the performance that can be achieved today with low-cost MEMS sensors can be found in [16].

Indoors localization solutions based on radio-frequency systems are equivalent to a GPS. These approaches are increasingly being investigated with the use of trilateration methods by using a transmitter-receiver distance information, known as RSSI for *Received Signal Strength Indicator*. The

RSSI is available in many telecommunication standards. More recently multilateration (measurement from transmission time differences called *Time Difference of Arrival* or TDoA between at least two transmitters and one receiver; transmitters being perfectly synchronized). The fact that the system to be located is itself active increases considerably the localization accuracy. There is a wide range of systems in this field. A review of these solutions shows that an accurate localization around 30cm is possible [14]. However, this performance degrades severely when there is no direct Line-Of-Sight between the terminals (fixed anchor in the building) and the receiver (Tag placed on the moving person) to be located. The accuracy of these solutions depends on the environment in which the system will be deployed, which is related to the use case. It should be noted that there is a strong excitement caused by the release of UWB radio solutions to the market wich promise to be even more efficient than the current ones.

The contribution of this work is a dynamic test with a millimeter accuracy ground truth in real time, to evaluate its precision and its accuracy, and to define if UWB localization sensors can be used for gesture recognition in 3D space.

This paper is divided into two parts. First, we study the performance a UWB-based localization sensor named "UWB" in the rest of this paper, and evaluate the specification in a free space surrounded by metallic objects such as robots, infrastructure or doors in our laboratory. Secondly, we propose a complete evaluation of the system behaviour in static and dynamic conditions to see if UWB can be used to obtain an accurate 3D trajectory for gesture recognition.

2 State of the art of indoor localization technologies

For human-machine Interaction in the context of industry 4.0, it is necessary to be able to locate the operator in a large environment (above 20m range) and with good accuracy (with a 0.1 meter accuracy). Localization in an indoor environment will be used in industry 4.0, based on Maultz thesis [14] there are 13 technologies shown in Table 1 that can answer indoor-localization.

Systems based on cameras for indoor localization approaches are used in different ways. The first one is to have a 3D building model as a reference. The second system is the socalled viewbased approach. It consists in taking the current view of a mobile camera and comparing it with previously captured view sequences. This system arrived at centimeter accuracy and can cover a building [17]. The third system is coded targets used for point identification to locate a person. The system can know where the person is with a centimeter accuracy but does not store the trajectory made by the person [12]. The fourth system is the projection of reference points in the environment. This system needs a direct view of the same surface and it can be used for tracking with a millimeter accuracy [23]. The fifth system is using one camera or many cameras without reference by observing position change. This system can reach sub-centimeter accuracy and can cover $30m^2$.

Infrared systems based on active beacons or using natural radiation are mainly used for rough positional estimation or for detecting the presence of a person in a room. They have centimeter-meter accuracy level and can cover 1-5 meters in static conditions. They are a common alternative to optical systems operating in the visible light spectrum. An accuracy of 4cm has been reported and people can be tracked up to a distance of 5m [11] and centimeter accuracy in a retail store [3].

Tactile and polar systems have m-mm accuracy and can cover an entire room. The polar point method uses a distance measurement and an angular measurement from the same beacon to determine the coordinates of a nearby station. Tactile systems are high precision mechanical instruments which measure positions by touching an object with a calibrated pointer. We can not track an entire trajectory in 3D [14].

Localization systems based on propagation of sound waves have a centimeter accuracy and can cover 2-10 square meters. The sound is a mechanical wave so positioning systems use air and building materials as means of propagation [25]. Mechanical waves are not sufficiently accurate in indoor environments for industrial applications due to multipath which is a phenomenon that occurs when a radio signal propagates through several paths and is received on an antenna.

WLAN/WIFI systems have one meter of accuracy and can cover $20-50m^2$. Distance estimation using WLAN is generally possible from RSSI (Received Signal Strength Indication), ToA (Time of

Arrival), TDoA (Time Difference of Arrival) and RTT (Round-Trip Time). The accuracy of this kind of systems is not enough to handle an accurate trajectory estimation in the 3D space [9] [5].

RFID has dm-m level of accuracy and can cover 1-50 m. Most RFID systems rely on proximity detection of permanently mounted tags to locate a person. The accuracy of an RFID system is directly related to the density of tags deployment and reading ranges so it can be expensive in large areas. RFID systems can not do 3D trajectory tracking because most of them rely on proximity detection of permanently mounted tags to locate mobile readers [20].

Pseudolites use a similar methods of localization as the Global Navigation System (GNSS) but in indoor environments. Several difficulties such as multipath mitigation, time synchronization and ambiguity solving have limited this system to few applications in GNSS-challenged environments such as open pit mines [10] [8]. It can cover $10 - 1000m^2$ area and have a cm-dm accuracy.

Other radio-frequency systems such as Zigbee, bluetooth, Digital Television, Cellular networks, Radar, FM radio, Phones based on Digital Enhanced Cordless Technology have for best sub-millimeters accuracy and can cover 10-1000 square meters. However, performance levels and applicability vary greatly depending on several factors such as the use of preexisting reference infrastructure, pervasiveness of devices, signal ranges, power levels [14]. The best systems have an accuracy of 1m and can cover a building.

Inertial navigation systems is usually fused with complementary sensors which provide absolute location information due to drift and have few meters accuracy [14]. Footmounted systems can make use of zero velocity during the foot is in stance stage and have therefore a lower drift and can improve the accuracy below 1m [18] of the travelled distance. Compared to IMUs mounted at other body parts [21] with drifts being typically larger.

System based on magnetic field has centimeter-accuracy and can cover 10 meters area [4]. Different approaches range from systems dedicated for medical purposes using an artificial quasi static magnetic field with less than 1 m3 volume operating at mm-accuracy level. In indoor environments, with the same approach, we can have few meters accuracy covering storage aisles and a building [24] [1] but we can be perturbed by the magnetic field induced by electric motors inside industrial buildings.

Infrastructure systems are technologies that use the existing building infrastructure or embed additional infrastructure into the building materials such as Power Lines positioning, Floor Tiles, Fluorescent Lamps or leaky feeder cables as described in [14]. These systems have cm-m level of accuracy.

Technology	Typical Accuracy	Typical Coverage
Cameras	0.1mm-dm	1-10
Infrared	cm-m	1-5m
Tactile & Polar Systems	um-mm	3-2000m
Sound	cm	2-10m
WLAN/WIFI	m	20-50m
RFID	dm-m	1-50m
Ultra WideBand	cm-m	1-50m
High Sensitive GNSS	10m	'global'
Pseudolites	cm-dm	10-1000m
Other Radio Frequencies	m	10-1000m
Inertial Navigation	1%	10-100m
Magnetic Systems	mm-cm	1-20m
Infrastructure Systems	cm-m	building

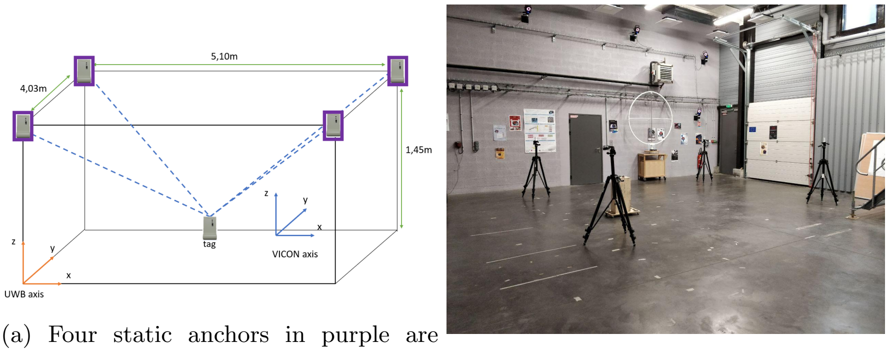
Table 1: Indoor positioning technologies as described in [14]

UWB (Ultra WideBand) is less expensive than others technologies and can be accurate even in Non-Line-Of-Sight (NLOS) conditions. It has the ability to carry signals through doors and other obstacles that tend to reflect signals with more limited bandwidth and higher power levels [7]. Syberfeldt *et al.* [22] proposed a review of existing techniques and systems for locating operators in a smart factory. In this comparison, we can see that UWB has a high precision compared to others indoor localization system and a medium cost for the industry. Alarifi *et al.* [2] established a Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis of UWB systems. The main benefits of UWB systems are a low-power consumption and the ability to penetrate different kinds of materials. This is due to the very short pulses that do not interfere with most of the existing radio systems. The weakness of UWB is the synchronization: due to his short pulses, it may take time to synchronize. This article comforts our choice of UWB as the best system for indoor localization.

3 Experimental Setup and Evaluation

3.1 Experimental setup

We decided to evaluate a UWB system from Decawave since it seems to be the most accurate [19]. To evaluate this system, four anchors must first be placed in the room used for indoor localization. We align anchors with laser measurements. One Anchor is chosen as reference (initialization at x=0 and y=0), and we must obtain the position of each anchor according to the initialization anchor as shown in Figure 1a.



(a) Four static anchors in purple are placed in a rectangle. The tag is placed in the area of the anchors in LOS.

(b) Placement of anchors in the laboratory.

Fig. 1: Our UWB setup

We obtain the position of each anchors with a VICON motion capture system. The area of testing in Figure 1a is in the lab with a LOS condition and in an industrial environment with a metallic structure, robots and a metallic door close to the testing area as shown in Figure 1b. The Tag is mounted on a support and placed on a wooden cart with a height of 0.7m to verify the trajectory in 3D in the inner area of the UWB system.

3.2 Tests and Evaluation

Static Measurement Precision The first test is to place the tag in the inner area of the UWB anchors. This test will give us the distribution of the UWB points when the tag is static. The results of the static test are given in Table 2. The mean error on the 3 XYZ axes is $1cm$ and the average range is $10cm$. The values are distributed around the average value with a standard deviation of

$0.011m$. This means that the UWB system is not precise in a static situation, but has a high accuracy of $10cm$ on average. UWB is accurate up to $10cm$ in static and behaves like a sphere around the target with a range value of $10cm$. When a person is not moving, we know where the person is with an accuracy of $10cm$.

Static LOS test	X-axis	Y-axis	Z-axis	2D	3D
Mean error	0.01m	0.01m	0.01m	0.01m	0.01 m
Range	0.09m	0.10m	0.11m	0.095m	0.1m
Standard deviation	0.010m	0.014m	0.011m	0.012m	0.011m

Table 2: Comparison of mean localization errors and standard deviation with a static test in Line-Of-Sight condition.

Dynamic Measurement Evaluation and Precision of a trajectory With the Vicon system [15], we will compare the exact 3D point of the Vicon with the 3D point of UWB in real-time. The first test we made was a trajectory inside the inner area of the UWB anchors. The test was made in the laboratory in LOS with industrial conditions.

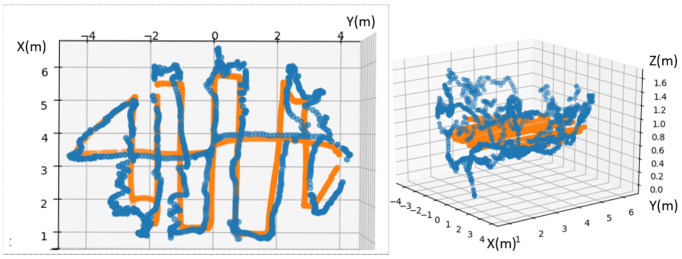


Fig. 2: Trajectory made in the laboratory with LOS conditions in 2D and 3D with VICON (orange) and UWB (blue) in meters.

In XY measurement we have $21cm$ of accuracy as shown in Table 3. That means we have 78% of precision for this trajectory in XY. We can use UWB for real time localization and in dynamic. We have $0.24cm$ of accuracy in 3D (XYZ) only 40% of values for Z-axis are precise, they are not around the mean value. The Z-axis is not trustable for dynamic localization and for motion gesture recognition. This result shows that, in dynamic localization, we can use UWB for motion tracking with X-Y axis in real time but not in 3D because the Z-axis is not trustable. Figure 2 highlights that the Z-axis measurements are wavy.

Dynamic Measurement Evaluation and Precision of mapping The third test is to realize a mapping of the inner area and outer area of the UWB system to evaluate its behaviour. We covered the maximum area and try to see if the accuracy/precision changed. Comparing to our first test we have an accuracy of $23cm$ in the inner area and $25cm$ in the outer area in 2D and $23cm$ and $24cm$ in 3D that is close to our first result in dynamic localization shown in Table 3. These two tests

Dynamic measure	X-axis	Y-axis	Z-axis	2D	3D
Mean error	0.20m	0.22m	0.32m	0.21m	0.24m
Range	0.73m	0.64m	0.87m	0.65m	0.75m
Standard deviation	0.13m	0.14m	0.29m	0.135m	0.186m

Table 3: Table of dynamic trajectory.

show that UWB is homogeneous for a covered area even outside of the area defined by its anchors in industrial LOS conditions. UWB is really good for dynamic localization in indoor environments. We lose precision compared to our static results. We had $10cm$ accuracy in static measurement, we had $0.24m$ accuracy in dynamic localization as shown in Table 4.

	UWB mapping	X-axis	Y-axis	Z-axis	2D	3D
Inner	Mean error	0.30 m	0.17m	0.23m	0.23m	0.23m
	Range	1.07m	0.60m	1.37m	0.56m	1.01m
	Standard deviation	0.18m	0.001m	0.20m	0.18m	0.12m
Outer	Mean error	0.23m	0.27m	0.23m	0.25m	0.24m
	Range	0.98m	1.05m	1.03m	1.01m	1.02m
	Standard deviation	0.028m	0.15m	0.19m	0.09m	0.12m

Table 4: Errors of the dynamic measurements.

Study of the influence of anchors This test was made to verify the behavior of UWB in the inner area of UWB in dynamics with four and six anchors. We place four anchors exactly as in the Figure 1a and one more on the floor in one corner of our cube. And then two more on the floor in corners. With the use of 4 anchors, the 3D positioning error is $0.24 \pm 0.19cm$ with a Z error of $0.32 \pm 0.29cm$. The number of anchors mainly influences the Z measurement: with 6 anchors, the Z error is $0.16 \pm 0.01cm$ while the 3D error decreases slightly: $0.20 \pm 0.12cm$.

Conclusion

In this article, we describe the behaviour of an Ultra WideBand system in static and dynamic cases by comparison with a ground truth obtained with a motion capture system. We have an evaluation of the precision and accuracy of the UWB system which is really good in the X-Y axes but not trustable along the Z-axis. We confirm that precision and accuracy are better by adding anchors when performing dynamic localization. UWB systems can not be used for gesture recognition. Nevertheless, they can be a really good choice for localization, even in dynamic, and can be more robust if we add more anchors. Z-axis needs to be improved, mostly in terms of precision, and this can be achieved by data fusion with other sensors. Our future works will be the improvement of the accuracy and precision of the system by the addition of an IMU and a barometer.

References

1. Al-Hamad, A., Ali, A., Elhoushi, M., Georgy, J.: Indoor Navigation using Consumer Portable Devices in Cart/Stroller p. 13

2. Alarifi, A., Al-Salman, A., Alsaleh, M., Alnafessah, A., Al-Hadhrami, S., Al-Ammar, M.A., Al-Khalifa, H.S.: Ultra wideband indoor positioning technologies: Analysis and recent advances. Sensors **16**(5), 707 (2016)
3. Arai, T., Yoshizawa, T., Aoki, T., Zempo, K., Okada, Y.: Evaluation of Indoor Positioning System based on Attachable Infrared Beacons in Metal Shelf Environment. In: IEEE International Conference on Consumer Electronics (ICCE) (2019)
4. Blankenbach, J., Norrdine, A.: Position estimation using artificial generated magnetic fields. In: Indoor Positioning and Indoor Navigation (2010)
5. Cui, Y., Zhang, Y., Huang, Y., Wang, Z., Fu, H.: Novel WiFi/MEMS Integrated Indoor Navigation System Based on Two-Stage EKF. Micromachines **10**(3) (2019)
6. Dobkin, B.H.: Wearable motion sensors to continuously measure real-world physical activities. Current opinion in neurology **26**(6), 602 (2013)
7. Dragomirescu, D., Kraemer, M., Jatlaoui, M., Pons, P., Aubert, H., Thain, A., Plana, R.: 60ghz Wireless Nano-Sensors Network for Structure Health Monitoring as Enabler for Safer, Greener Aircrafts. Proceedings of SPIE - The International Society for Optical Engineering **7821** (2010)
8. Fujii, K., Sakamoto, Y., Wang, W., Arie, H., Schmitz, A., Sugano, S.: Hyperbolic Positioning with Antenna Arrays and Multi-Channel Pseudolite for Indoor Localization. Sensors **15**(10), 25157–25175 (2015)
9. Gansemer, S., Grossmann, U., Hakobyan, S.: RSSI-based Euclidean Distance algorithm for indoor positioning adapted for the use in dynamically changing WLAN environments and multi-level buildings. In: 2010 International Conference on Indoor Positioning and Indoor Navigation. pp. 1–6. IEEE, Zurich, Switzerland (Sep 2010)
10. Ghassemlooy, Z., University, N. (eds.): 2010 7th International Symposium on Communication Systems, Networks & Digital Signal Processing (CSNDSP 2010): Newcastle upon Tyne, United Kingdom, 21 - 23 July 2010. IEEE, Piscataway, NJ (2010), oCLC: 837962027
11. Khoshelham, K., Elberink, S.O.: Accuracy and Resolution of Kinect Depth Data for Indoor Mapping Applications. Sensors **12**(2), 1437–1454 (2012)
12. Liao, X., Chen, R., Li, M., Guo, B., Niu, X., Zhang, W.: Design of a Smartphone Indoor Positioning Dynamic Ground Truth Reference System Using Robust Visual Encoded Targets. Sensors **19**(5), 1261 (Jan 2019)
13. Madgwick, S.: An Efficient Orientation Filter for Inertial and Inertial. Magnetic Sensor Arrays (2010)
14. Mautz, R.: Indoor positioning technologies. Habilitation Thesis, ETH Zurich (2012)
15. Merriaux, P., Dupuis, Y., Boutteau, R., Vasseur, P., Savatier, X.: A Study of Vicon System Positioning Performance. Sensors **17**(7), 1591 (2017)
16. Michel, T., Genevs, P., Fourati, H., Layada, N.: On attitude estimation with smartphones. In: Int. Conference on Pervasive Computing and Communications (2017)
17. Niu, Q., Li, M., He, S., Gao, C., Gary Chan, S.H., Luo, X.: Resource-efficient and Automated Image-based Indoor Localization. ACM Transactions on Sensor Networks **15**(2), 1–31 (2019)
18. Renaudin, V., Merminod, B., Kasser, M.: Optimal data fusion for pedestrian navigation based on UWB and MEMS. In: IEEE/ION Position, Location and Navigation Symposium. pp. 341–349 (2008)
19. Ruiz, A.R.J., Granja, F.S.: Comparing Ubisense, BeSpoon, and DecaWave UWB location systems: indoor performance analysis. IEEE Transactions on instrumentation and Measurement **66**(8), 2106–2117 (2017)
20. Shi, W., Du, J., Cao, X., Yu, Y., Cao, Y., Yan, S., Ni, C.: IKULDAS: An Improved kNN-Based UHF RFID Indoor Localization Algorithm for Directional Radiation Scenario. Sensors **19**(4), 968 (Jan 2019)
21. Susi, M., Renaudin, V., Lachapelle, G.: Motion mode recognition and step detection algorithms for mobile phone users. Sensors **13**(2), 1539–1562 (2013)
22. Syberfeldt, A., Ayani, M., Holm, M., Wang, L., Lindgren-Brewster, R.: Localizing operators in the smart factory: A review of existing techniques and systems. In: International Symposium on Flexible Automation (ISFA). pp. 179–185 (2016)
23. Tilch, S., Mautz, R.: Current investigations at the ETH Zurich in optical indoor positioning. In: Workshop on Positioning, Navigation and Communication (2010)
24. Vandermeulen, D., Vercauteren, C., Weyn, M.: Indoor localization Using a Magnetic Flux Density Map of a Building. In: International Conference on Ambient Computing, Applications, Services and Technologies (2013)
25. Wang, Y.T., Li, J., Zheng, R., Zhao, D.: ARABIS: an Asynchronous Acoustic Indoor Positioning System for Mobile Devices. arXiv:1705.07511 (2017)

LNCS Homepage, `http://www.springer.com/lncs`. Last accessed 4 Oct 2017