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ACCURACY OF REAL-TIME LOCATION SYSTEM (RTLS) FOR MANUFACTURING SYSTEMS

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Abstract: The main aim of the paper is presentation of measurements and analysis of the RTLS accuracy obtained during laboratory tests. One of the objectives was to assess suitability for applications in the mechanical industry enterprises. Tests were carried out using the Ubisense RTLS Series 7000. The three stages of testing are presented. The first concerns to the coordinates measurement of the tag located in random points. The second test is based on checking the impact of various obstacles on positioning accuracy, that can exist in industrial environment, by registering interference causing by obstacles made of popular materials. The third test is related to the analysis of the path drawn on the basis of the marker movement along the path determined in the test room. Based on the received results it is possible to notice discrepancies between physical coordinates and those determined by the system.

Key words: RTLS, indoor locating system, UWB, production processes optimisation, data acquisition, production management.

1. INTRODUCTION

Manufacturing systems consist of a countless number of components interacting with each other to ensure the correct implementation of technological processes. Some of these elements, e.g. work in progress, human resources, tools etc. constantly change their location. These movements, for various reasons, are not always sufficiently monitored or not monitored at all in supervised control and/or management systems. Usually, only selected points can be registered, e.g. in machines and buffers with a known location on the product route. Lack of access to data about the detailed trajectory of selected objects and their position along the route in internal transport, as well as their speed and acceleration, makes impossible the optimization of their flow, especially in terms of the current situation in the manufacturing system, i.e. in the case of overloading of transport routes, traffic jams, etc. In connection with the above the main expectation in relation to RTLS is to obtain information about the position of important items and also system components in motion, whose location is desirable but not recorded in existing control systems.

2. INDOOR LOCATION TECHNOLOGIES

Location systems used inside buildings must meet many different conditions than outdoor systems. Despite the fact that the room is able to provide constant weather conditions, uniform temperature and pressure, in most cases guarantees access to electricity and the Internet, and in addition usually monitored areas are relatively small, the system has to face slightly different problems. Among them, it can be distinguished:
- presence of separate rooms, corridors, passages that hinder the "visibility" of the objects being tracked,
- other obstacles as rooms equipment that can suppress the signal required for the location,
- the presence of electrical or other devices that may cause electromagnetic interference.

In connection with the above, in order to meet the expectations regarding the positioning of objects, the location systems are built based on various available technologies such as Radio Frequency, Wi-Fi or Vision Systems [8, 16]. Overview of indoor location systems, algorithms and technologies like Tactile and polar systems, cameras, Magnetic systems, INFRared, Sound, UWB, Pseudolites, Infrastructure systems, RFID, WLAN/WiFi, Other RF, High Sensitive GNSS, Inertial Navigation etc. are described in detail e.g. in [2, 5, 7, 16, 21, 22].

Each of the solution has a different range and positioning accuracy. The comparison of accuracy and ranges is shown e.g. in [13, 14]. The calculated ranges are obtained mainly in tests carried out under optimal conditions, so it is possible that there are differences in the measurements occurring in other rooms. Authors also present the most frequently used location method, on the basis of which the position of an object in the reference system is determined. A comprehensive overview and analysis of indoor location systems in dependence on accuracy and coverage can be find in [8, 11, 16, 18, 23].

2.1 Location systems classification based on type

One of the criteria of classifying location systems is the method of making measurements and the place where the received data is processed. Based on these properties, three main groups can be distinguished [12]: network-based systems, handset-based systems and hybrid systems.

Network-based systems are based on signal measurements made by stationary receivers. The signal is emitted or reflected from the object being located. The final calculation of the coordinates of the object is realised in a control station, which can be located at a large distance from the positioned object. Examples of technologies placed in this group of systems are: Received Signal Strength (RSS), Angle of Arrival (AoA), Time of Arrival (ToA), Time Difference of Arrival (TDoA), Fingerprinting (FP) [14]. The big advantage of these systems is the possibility of using the existing infrastructure in the building, which translates into a relatively low installation cost. However, this affects the feeling of limiting the privacy of people operating in the monitored area. These solutions are usually with less accuracy in positioning than in other systems.

The most important feature that distinguishes Handset-based systems from Network-based systems is that the calculation of location coordinates takes place in the receiver which is also the object being tracked. The signals sent by transmitters (e.g. satellites) are received by the specialised mobile module, and based on them it is possible to perform the calculations necessary to determine the location. Due to their characteristics, these systems are able to provide greater privacy, because the signal along with information about the position does not have to go to a separate control station. This advantage, however, is paid by the higher price of the necessary equipment. Examples of Handset-based systems are technologies based on the use of satellites, such as: the US-made GPS, the European Galileo and GLONASS made by Russia.

Hybrid systems are a combination of the possibilities offered by the systems families mentioned above. In most cases, the coordinates of the location are obtained in a stationary network, to which the results of measurements made by the tracked object are sent. The main reason for the development of this technology is the desire to increase the reliability of the location estimation taking place in one process. Representatives of this group of systems are Assisted GPS (A-GPS) [9, 10] and Advanced Forward Link Trilateration (AFLT) [1].

2.2 Classification based on operating frequency

Positioning systems using wireless technologies can also be classified in terms of the frequency they use for work. This allows for quick determination of the operating range and accuracy of positioning, and thus features that influence the choice of technology to work in a given environment. Increasing the frequency translates into an increase in the positioning accuracy, but it also has an effect on the deterioration of the working range. three types of systems are most often distinguished: low, medium and high-frequency systems.

Low-Frequency positioning systems use waves with frequencies between 30 KHz and 300 KHz. They are used for positioning over a wide range, and in order to obtain sufficient accuracy, it is necessary to periodically perform system calibration.

Medium-frequency systems use waves in the range from 300 KHz to 3 MHz for operation. Their history dates back to the mid-1950s, when this technology was first used and used until the early 1970s. These systems operate positioning with signal flow time and phase differentiation. In order to ensure correct operation, they required continuous monitoring and calibration.

The last group of systems used to operate the waves in the range of 3 MHz to 30 MHz. These systems are most often used for positioning people and objects at relatively small distances up to around 100 meters. Despite the limited range, this technology is characterized by achieving the highest positioning accuracy compared to other groups.

2.3 Positioning methods

The positioning methods described below allow determining the position of the target object in a way that uses distance, angle or signal strength measurements. These techniques are effective both for 2D and 3D environments [19].

Cell of Origin **(**CoO**) -** using this method, the location of the source of a physical phenomenon with limited range can be estimated. This technique is not directly concerned with the solution of the location and recognition of the exact coordinates, and to the indication of the receiver to which the most powerful signal arrives. The biggest advantage of this technique is the ease of installation and high speed positioning, because the system does not have to be loaded with advanced processing algorithms. Positioning accuracy directly depends on the number of receivers in a given environment. Therefore, it is possible to create a problem consisting in incorrect selection of the antenna during the test of the signal strength. The position of the transmitter is then determined based on the antenna, which is not necessarily the best candidate. This phenomenon is most often found in work in a multi-storey environment. When there is a need to increase the accuracy of the location, the CoO method is often supported by another technology, the most popular of which is Time of Arrival. CoO technology is mainly used in cases where the main assumption is not the highest positioning accuracy. Examples are mobile wireless positioning systems. It is also used by public-safety answering points, e.g. emergency telephone number for people calling 112 in EU and many other countries or 911 in USA [16, 26].

The notions of lateriation, multilateration and trilateration refer to positioning methods based on distance measurements, omitting the angles of signal incidence. The position of the tracked object is most often determined on the basis of two or three measurements of the distance between the transmitter and the receiver, both in 2D and 3D. The term multilateration also appears as a separate term for distance measurements based on differences, so they refer directly to the TDoA method. Other examples of positioning methods described by the discussed concepts are, e.g., ToA, RTT or RSSI [1, 4, 16].

The Fingerprinting (FP) technique enables calculating the location of the traced object based on the measurement of the strength of the signal received from the transmitter, and then comparing the measured intensity with the values assigned to the given item stored in the database [15]. The implementation of this technology consists of two phases. The first phase, also known as the off-line calibration phase, consists in creating a map, which resembles the taking of fingerprints. In a given room, points are determined, their positions are determined by analytical calculations or determined empirically. They serve as reference points in which the intensity of the signal coming from stationary transmitters is measured. The values of the measured signal strength are stored successively in the database. The second phase, will be the exploitation phase, it consists in receiving the signal coming from stationary transmitters, through the mobile receiver, which is attached to the tracked object or person. The values of the signal strength received by the receiver are compared with the values previously stored in the database. The best value match determines the position of the tracked object. There is also another method of creating a map that does not require a complicated calibration phase. The signal strength values are calculated based on the signal propagation model. Fingerprinting technology is most often used with systems based on WLAN / WiFi [16, 20, 27].

The Dead Reckoning method is based on estimating the position of the tracked object using references to previously marked positions and moving it relative to the known or estimated speed of movement [3, 16, 27]. The disadvantage of this solution is the presence of cumulative errors. The new positions are determined on the basis of the previous ones, so the inaccuracies during the first measurement result in an increasing increase in the discrepancy between the positioning result and the actual location of the object. The way of determining the position based on previously visited places also functions in the animal world and is known as path integration. The dead reckoning method is mainly used in marine, air and car navigation systems [3, 16].

3. TESTING ENVIRONMENT

The main issue of this work is to test the accuracy and repeatability of measurements while locating the objects in real time. The Ubisense Series 7000 system set was used for this experiment. Ubisense sets are one of the first RTLS (Real-Time Locating System) systems for commercial use. The test set consisted of two basic elements, namely transmitters (tags), receivers (sensors) and calculating control station equipped with the dedicated software and belong to the network-based system solution class. Tags sent UWB pulses, while fixed sensors captured the signal. The position is calculated on the basis of measurements resulting from the cooperation of TDoA technology (Time Difference of Arrival) and (Angle of Arrival). According to the manufacturer's assurances, in typical, optimal conditions, the accuracy possible to obtain is about 15cm. Sensors should be located at a distance of more than 10 meters, and in the case of ideal conditions, free of interference, their maximum effective working range is about 160 meters.

During tests the original Ubisense software package was used. It consists of several programs enabling configuration and management of devices and data processing [24].

The RTLS system was installed in a testing room with dimensions 9.5m x 5m with built-in channel 2.5m x 1.5m (Figure 1).

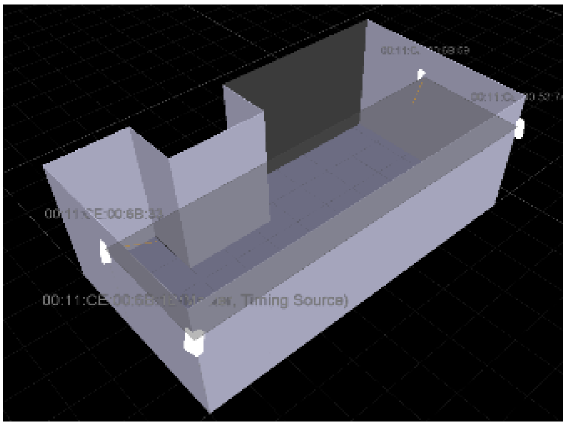

Fig. 1. The analysed area modelled in Ubisense Location Engine Config software. 3D view

The testing set, consists of 4 sensors (the minimum number of sensors needed to detect and locate the tag is two). Among the all connected sensors, one of them works in master mode, which is responsible for all communication with the server, while the rest works as auxiliary sensors - slaves. Sensors for communication between themselves and the server is based on Ethernet, using standard Ethernet switches, Wi-Fi connectivity and Cat5e cabling. The sensors can be powered via network cabling using PoE switches. Technical specifications of the Ubisense 7000 Series IP Sensor can be found in [24].

By determining the position of the sensors, two zones were established: Z1 and Z2 (Figure 2). Zone Z1 is defined inside a cuboid defined by sensors from the floor level (0) to the height of their suspension - 2.5 m. The remaining space of the room marks the zone Z2. The total size of the tested zones is close the border of the minimum sizes recommended by the manufacturer.

Two types of transmitters were used in the measurements: Compact Tag and Industrial Tag. The Industrial tag is slightly larger (71x64x47 mm vs 38 x 39 x 16.5 mm) and heavier (128g vs 25g) but has wider operating temperature range (-40 – 85°C vs -20 – 60°C) longer battery life (6 years vs 4 years) and also more mounting options.

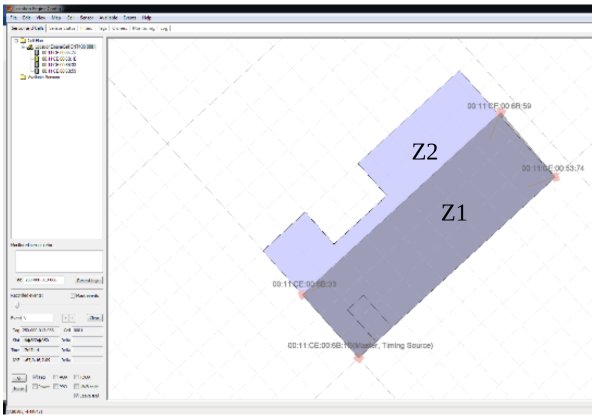

Fig. 2. The analysed area modelled in Ubisense Location Engine Config software. 2D view

4. MEASUREMENTS OF POSITIONING ACCURACY

The conducted tests relate to comparison of values read from the RLTS system to actual values in random points, checking the impact of various obstacles on positioning accuracy, and analysis of the path drawn on the basis of the marker movement along the determined path [17].

4.1 Measurements in random points

The first test of positioning accuracy was the measurement of the coordinate of the tags, which was stationary in seven random points in the testing area. Points 4 and 5 were out of designated 1st zone (point 4 in Z-axis, point 5 in Y-axis) (Figure 3). The experiment was carried out for both Compact Tag and Industrial Tag. Ten results were obtained for each item, which were compared to the actual position.

The measurements, errors, deviations, and average values calculated from the results are presented in Tables 1-3. Detailed results of measurements obtained for Compact tag in point 1 are presented in Table 1 and Figure 4.

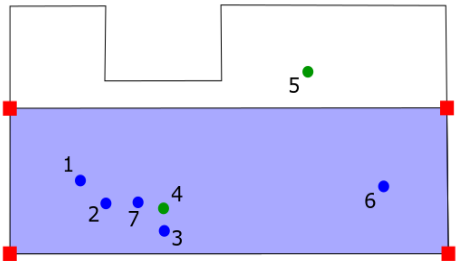

Fig. 3. Arrangement of measuring points for test 1. Green dots mean points out of zone 1

Table 1. Results of measurements with Compact Tag in point P1 – xyz: (2.5; 2.5; 0)

	Ubisense			Error		
sample	X	Y	Z	X	Y	Z
1	2.83	2.32	0.08	0.33	0.18	0.08
2	2.92	2.43	0.26	0.42	0.07	0.26
3	2.88	2.42	0.04	0.38	0.08	0.04
4	2.83	2.05	0.13	0.33	0.45	0.13
5	2.85	2.35	0.04	0.35	0.15	0.04
6	2.83	2.39	0.09	0.33	0.11	0.09
7	2.89	2.41	0.11	0.39	0.09	0.11
8	2.91	2.36	0.07	0.41	0.14	0.07
9	2.8	2.42	0.04	0.3	0.08	0.04
10	2.82	2.45	0.05	0.32	0.05	0.05
Avg	2.86	2.36	0.09	0.36	0.14	0.09
stdev	0.041	0.116	0.067	0.041	0.116	0.067
Gap	-	-	-	0.12	0.40	0.22

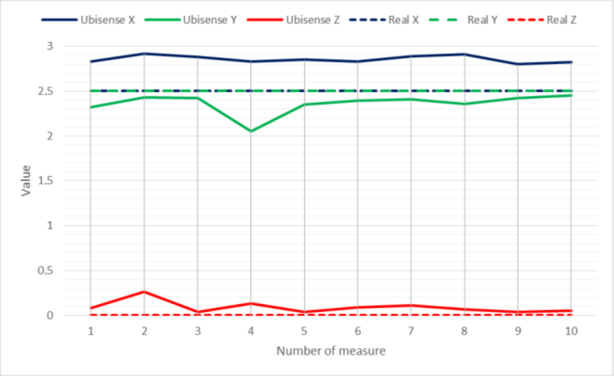

Fig. 4. Measurements for Compact Tag in point P1

In some samples the values appear significantly different from the average (e.g. sample 2 in Z and sample 4 for Y) which may indicate the occurrence of some temporary disturbances. It can also be noticed that all results are on one side of the range in relation to the actual value. For the X and Z axes results are larger, for the Y axis - smaller. A relatively small standard deviation can also be seen and the distances of the mean values measured for the X and Y axes - are greater than the gap size. Such noticeable results associated with offset may indicate the need for re-calibration of the measuring system.

Tables 2 and 3 present aggregated values for all measured points for both types of tags. the abbreviations in the table mean: 'Px actual' – real coordinates of point x, 'avg' – calculated average measure of position and deviation from the actual value (error), ‘stdev’ – standard deviation from the average measured value, ‘gap’ – the distance between max and min measured value.

Table 2. Aggregated results for Compact Tag

	actual/measured [m]			error [m]		
points	X	Y	Z	X	Y	Z
P1 actual	2.5	2.5	0			
avg	2.86	2.36	0.09	0.36	0.14	0.09
stdev	0.041	0.116	0.067	0.041	0.116	0.067
gap	-	-	-	0.12	0.4	0.22
P2 actual	3.12	1.7	1.23			
avg	3.52	1.66	1.15	0.4	0.05	0.08
stdev	0.045	0.03	0.016	0.045	0.03	0.016
gap				0.14	0.1	0.04
P3 actual	4.9	1	0.47			
avg	5.29	0.8	0.39	0.39	0.21	0.08
stdev	0.04	0.065	0.057	0.04	0.065	0.057
gap				0.12	0.19	0.18
P4 actual	4.9	1.48	2.74			
avg	5.18	1.62	2.27	0.28	0.14	0.47
stdev	0.049	0.086	0.136	0.049	0.086	0.136
gap				0.17	0.31	0.39
P5 actual	5.78	4.16	0.73			
avg	6.2	4.14	0.58	0.42	0.05	0.15
stdev	0.051	0.058	0.049	0.051	0.024	0.049
gap				0.16	0.07	0.17
P6 actual	8.68	2.23	1.79			
avg	8.89	2.28	1.9	0.21	0.05	0.11
stdev	0.031	0.029	0.043	0.031	0.029	0.043
gap				0.11	0.08	0.13
P7 actual	4.69	1.61	1.45			
avg	4.97	1.61	1.49	0.28	0.02	0.05
stdev	0.021	0.034	0.068	0.021	0.027	0.06
gap				0.06	0.07	0.17
avg err	-	-	-	0.334	0.094	0.147
avg stdev	0.04	0.06	0.062	0.04	0.054	0.061
avg gap	-	-	-	0.126	0.174	0.186

Table 3. Aggregated results for Industrial Tag

	actual/measured [m]			error [m]		
	X	Y	Z	X	Y	Z
P1 actual	2.5	2.5	0			
avg	2.96	2.37	0.23	0.46	0.14	0.23
stdev	0.038	0.13	0.083	0.038	0.121	0.083
gap				0.12	0.38	0.28
P2 actual	3.12	1.7	1.23			
avg	3.53	1.6	1.15	0.41	0.1	0.09
stdev	0.034	0.024	0.058	0.034	0.024	0.051
gap				0.1	0.07	0.14
P3 actual	4.9	1	0.47			
avg	5.4	0.82	0.29	0.5	0.18	0.18
stdev	0.093	0.052	0.057	0.093	0.052	0.057
gap				0.31	0.17	0.18
P4 actual	4.9	1.48	2.74			
avg	5.2	1.33	2.16	0.3	0.2	0.58
stdev	0.052	0.142	0.088	0.052	0.05	0.088
gap				0.16	0.16	0.27
P5 actual	5.78	4.16	0.73			
avg	6.15	4.02	0.88	0.37	0.14	0.17
stdev	0.045	0.085	0.108	0.045	0.085	0.074
gap				0.13	0.28	0.24
P6 actual	8.68	2.23	1.79			
avg	8.78	2.24	1.82	0.1	0.02	0.05
stdev	0.066	0.028	0.068	0.066	0.017	0.053
gap				0.18	0.05	0.13
P7 actual	4.69	1.61	1.45			
avg	4.97	1.59	1.59	0.28	0.05	0.14
stdev	0.059	0.054	0.049	0.059	0.031	0.049
gap				0.17	0.09	0.14
avg err	-	-	-	0.346	0.119	0.206
avg stdev	0.055	0.074	0.073	0.055	0.054	0.065
avg gap	-	-	-	0.167	0.171	0.197

The data obtained shows that only in the case of the X axis for all points the measured values are greater than real dimension (avg error 0.334 and 0.346). For Y and Z axis the differences are much smaller (0.094-0.206) and measured values are on the both sides of an actuals. On the other hand, average of standard deviation of measured values (measurement uncertainty) for axis X are the smallest (0.04-0.055 vs 0.06-0.074 for Y and 0.062-0.073 for Z direction).

At P4 located in zone 2, above the level of sensors, can be noticed a much larger measurement error in Z axis (0.47 and 0.58) than average (0.147 and 0.206). This indicates a significant loss of measurement accuracy in the area above the sensors. Measurement data from point P5 lying outside zone 1 but below the sensor level do not show worse values in any axis.

The measurement accuracy for both types of sensors are similar, although with the compact tag it shows a slightly higher accuracy. Gaps sizes are comparable.

4.2 Measurements with obstacles

The second test was based on checking the impact of various obstacles on positioning accuracy. The tags were placed in a cardboard box (CaBo), a plastic container (PlCo), a metal bowl (MeBo), and near a ringing mobile phone (RiPh).

This research was conducted to answer the question how much obstacles made of popular materials cause disruptions in the operation of systems based on UWB technology. The test was made using the Compact Tag. Together with the obstacle, it was placed in three random places in the tested room (Figure 5), and then registered its position ten times.

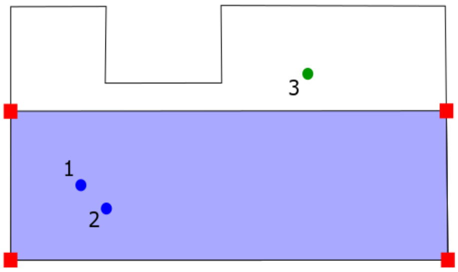

Fig. 5. Arrangement of measuring points for test 2

Detailed results of measurements obtained in point P1 are presented in Table 4 and Figures 6-8. In case of metal bowl, the results presented in following tables and figures relate to partial coverage by this obstacle. When the tag was completely covered by a metal bowl, it lost its connection with the system and it could not be measured.

As in test 1, the measured values in point P1 deviate from the actual value with the given offset. In X and Z axis are larger, in Y axis smaller for each obstacle. The measurement error in relation to the actual value is the smallest in the case of the Z axis. They are comparable for X and Y. The absolute deviations are similar for all obstacles and axes. No significant differences can be identified between the results for the individual obstacles.

Tables 5-7 present aggregated values for all measured points for the considered obstacles.

Table 4. Results of measurements in point P1

	Ubisense			**Error**		
	X	Y	Z	X	Y	Z
Cardboard box	2.84	2.06	0.23	0.34	0.44	0.23
	2.93	2.1	0.34	0.43	0.4	0.34
	2.71	2.04	0.26	0.21	0.46	0.26
	2.79	2.03	0.1	0.29	0.47	0.1
	2.77	1.94	0.29	0.27	0.56	0.29
	2.78	2.08	0.15	0.28	0.42	0.15
	2.79	2.06	0.19	0.29	0.44	0.19
	2.76	2.09	0.21	0.26	0.41	0.21
	2.78	2.02	0.18	0.28	0.48	0.18
	2.72	2.03	0.19	0.22	0.47	0.19
Plastic container	2.85	1.95	0.14	0.35	0.55	0.14
	2.92	2.05	0.09	0.42	0.45	0.09
	2.79	2.15	0.12	0.29	0.35	0.12
	2.89	2.11	0.27	0.39	0.39	0.27
	2.78	2.08	0.4	0.28	0.42	0.4
	2.8	2.1	0.3	0.3	0.4	0.3
	2.78	2.11	0.4	0.28	0.39	0.9
	2.76	2.14	0.12	0.26	0.36	0.12
	2.81	2.15	0.12	0.31	0.35	0.12
	2.79	2.11	0.08	0.29	0.39	0.08
Metal bowl	2.82	2.19	0.24	0.32	0.31	0.24
	2.91	2.21	0.01	0.41	0.29	0.01
	2.9	2.05	0.35	0.4	0.45	0.35
	2.89	2.23	0.12	0.39	0.27	0.12
	2.8	2.18	0.12	0.3	0.32	0.12
	2.95	2.1	0.36	0.45	0.4	0.36
	2.98	2.08	0.24	0.48	0.42	0.24
	2.89	2.07	0.19	0.39	0.43	0.19
	2.92	2.11	0.08	0.42	0.39	0.08
	2.91	2.08	0.27	0.41	0.42	0.27
Ringing phone	2.98	1.94	0.11	0.48	0.56	0.11
	2.93	2.05	0.21	0.43	0.45	0.21
	2.81	2.14	0.04	0.31	0.36	0.04
	2.95	2.14	0.17	0.45	0.36	0.17
	2.9	2.23	0.35	0.4	0.27	0.35
	299	2.2	0.18	0.49	0.3	0.18
	2.98	2.18	0.16	0.48	0.32	0.16
	3.01	2.21	0.13	0.51	0.29	0.13
	2.97	2.15	0.19	0.47	0.35	0.19
	2.98	2.17	0.25	0.48	0.33	0.25

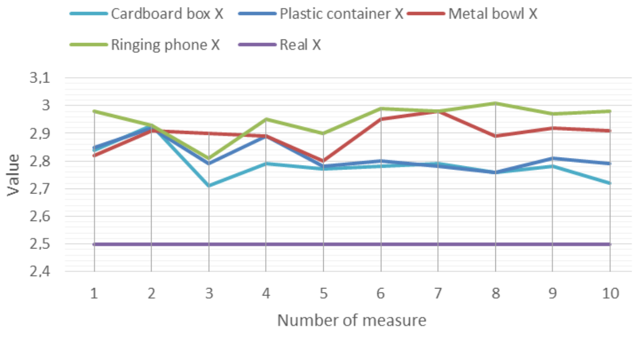

Fig. 6. Comparison of measurements in point 1 – X-axis

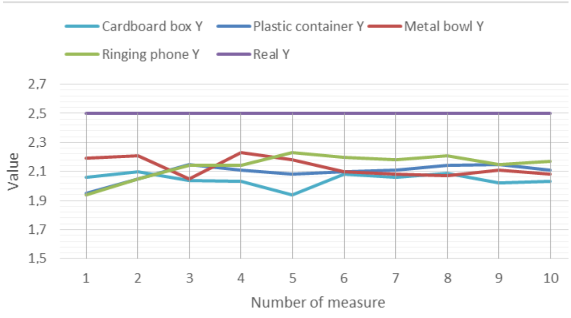

Fig 7. Comparison of measurements in point 1 – Y-axis

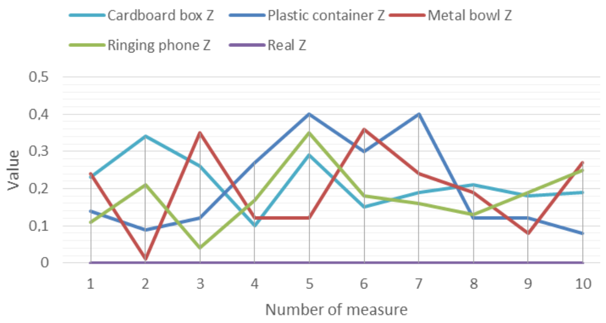

Fig. 8. Comparison of measurements in point 1 – Z-axis

Table 5. Aggregated measurement results in point P1

Point 1: X = 2.5; Y = 2.5; Z = 0							
		Ubisense			**Error**		
		X	Y	Z	X	Y	Z
CaBo	avg	2.787	2.045	0.214	0.287	0.455	0.214
	stdev	0.062	0.046	0.069	0.062	0.046	0.069
PlCo	avg	2.817	2.095	0.204	0.317	0.405	0.254
	stdev	0.053	0.06	0.127	0.053	0.06	0.251
MeBo	avg	2.897	2.13	0.198	0.397	0.37	0.198
	stdev	0.054	0.066	0.115	0.054	0.066	0.115
RiPh	avg	2.95	2.141	0.179	0.45	0.359	0.179
	stdev	0.058	0.086	0.083	0.058	0.086	0.083

Table 6. Aggregated measurement results in point P2

Point 2: X = 3.12; Y = 1.7; Z = 1.23							
		Ubisense			**Error**		
		X	Y	Z	X	Y	Z
CaBo	avg	2.783	2.047	0.191	0.337	0.347	1.039
	stdev	0.113	0.053	0.139	0.113	0.053	0.139
PlCo	avg	3.459	1.488	1.236	0.339	0.212	0.05
	stdev	0.058	0.029	0.069	0.058	0.029	0.044
MeBo	avg	3.583	1.643	1.226	0.463	0.057	0.024
	stdev	0.024	0.03	0.032	0.024	0.03	0.021
RiPh	avg	3.475	1.7	1.25	0.355	0.028	0.036
	stdev	0.062	0.037	0.049	0.062	0.023	0.038

Table 7. Aggregated measurement results in point P3

Point 3: X = 5.78; Y = 4.16; Z = 0.73							
		Ubisense			**Error**		
		X	Y	Z	X	Y	Z
CaBo	avg	6.247	4.329	0.621	0.467	0.169	0.109
	stdev	0.013	0.045	0.043	0.013	0.045	0.043
PlCo	avg	6.198	4.025	0.815	0.418	0.135	0.095
	stdev	0.03	0.077	0.066	0.03	0.077	0.049
MeBo	avg	6.173	4.111	0.666	0.393	0.051	0.172
	stdev	0.078	0.046	0.215	0.078	0.044	0.134
RiPh	avg	6.122	4.339	0.818	0.342	0.183	0.174
	stdev	0.118	0.198	0.176	0.118	0.194	0.078

At points P2 and P3, as in P1, it can be notice a significant shift in the values of the dimensions according to the X axis. The reading in the Y and Z axes for P2 and P3 looks slightly different - the values are no shifted. At this stage of research it is difficult to indicate the cause of this phenomenon. Minor anomalies were also noted in samples 3X (error 0.02 vs avg = 0.342) and 2Y (error 0.7 vs avg = 0.183) of point P3 at RiPh obstacle which significantly differed from the other values. They affect much higher values of the standard deviation - 0.118 in the X axis and 0.194 in the Y axis in relation to other results.

Generally, on the basis of the obtained data it can be concluded that the tag location does not matter and non-metallic obstacles do not significantly interfere with position registration.

4.3 Accuracy of track mapping

The third test of positioning accuracy was the comparison of the path registered by the RTLS based on the movement of the tag and the track determined in the testing room. Five tests were carried out for Compact Tag and Industrial Tag. The track consisted of three points located in zone 1, between which the tags were moving at steady speed, without stops, at the same height (Z axis). Based on the obtained results, charts were created (Figures 9 and 10) using dedicated Ubisense software. It is possible to notice discrepancies between physical coordinates and those determined by the system.

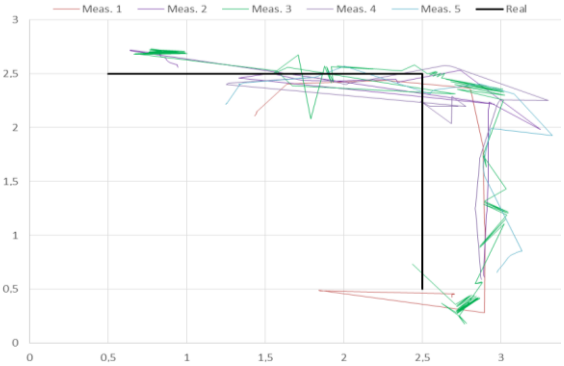

Fig. 9. Results of measurements for Compact Tag

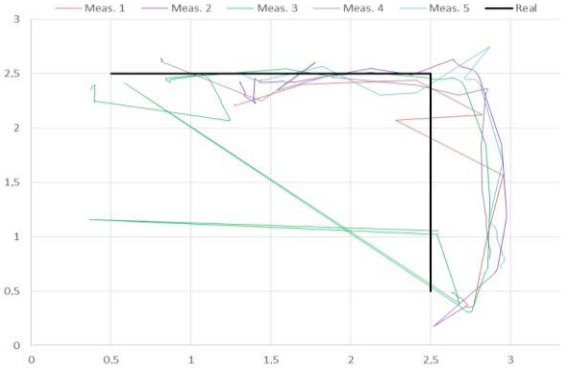

Fig. 10. Results of measurements for Industrial Tag

It can be seen that, as in previous tests, the largest inaccuracies occur when registering positions according to the X axis. Positions relative to the Y axis are much more accurately reproduced.

5. CONCLUSIONS

The paper presents positioning accuracy tests with using Ubisense RTLS Series 7000. Three types of tests were carried out: checking the positioning accuracy at random locations, the impact of interference on positioning accuracy and track mapping accuracy.

During the positioning accuracy test, at many points, for 10 measurements carried out in the same, unchanging conditions, usually 1-2 measurements noticeably differed in accuracy from the others. At this stage of the research, this could not be justified. Two zones were separated for testing purposes, depending on the location relative to the sensor system. The measurements show that the positioning accuracy of the points in both zones is similar, except for the point located above the sensor plane - then a larger error in the Z axis is noticeable. In the case when the tags were inside the zone 1, the measurement results regarding the Y axis and the Z axis were not subject to excessive shift. The largest errors appeared during the positioning of the X axis. This is most evident in the test regarding the comparison of tracks traversed by tags, during which all measurements were shifted by a similar value in only one direction. There are also individual jumps of positions, which may be due to the conditions in which the tests were carried out.

Positioning errors achieved similar values for both Compact Tag and Industrial tag, but in some cases they were higher for the latter.

The obstacles used in the second test were to demonstrate the effectiveness of UWB signal propagation. As expected, the cardboard box and plastic container had no effect on the formation of excessive blemishes. The ringing cell phone also did not cause results that were different from those obtained under normal conditions. However, the metal bowl had a significant influence on the location process. If the tags were covered by this obstacle, the system completely lost contact with them. In the presented test and with partial cover the system was able to position the tags, but at some points the fluctuations of the results obtained could be noticed.

The system was installed in the room smaller than recommended by the manufacturer. The lowest recommended distance between the sensors should be 10m, while during the experiment, these distances were 5m and 9.5m. Another condition that could cause bigger interference was the room equipment, containing computer devices and automation systems with PLCs. These conditions could cause additional reflection of the UWB signal but these conditions are more similar to industrial ones.

Despite that conditions the accuracy of 15cm assumed by the manufacturer is achievable. Most of the results obtained oscillate around this value, and even in individual cases it can be seen that the system was able to position the tag much more accurately. It is also sufficient for applications in the mechanical industry enterprises especially in the area of organization of production flow.

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