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Cooperative Positioning System for Indoor Surveillance Applications

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Abstract— This paper presents basic characteristics of the problem of positioning errors propagation in collaborative multi robot environments. We propose two localization methods to achieve a cooperative positioning system using a collaborative autonomous robotic team for indoor surveillance applications. Based on case study simulation results, we were able to evaluate the error propagation process and to obtain the two-dimensional (2D) localization errors for the two proposed methods: Iterative Least Square (ILS) Localization and Backtracking Particle Filter (BPF) Localization.

Keywords—component; Ultrasonic Waves; Line of Sight; Indoor Positioning; Collaborative Robots; Least Squares; Particle Filter.

I. INTRODUCTION

There are many methods for environment monitoring and surveillance, and some of the most interesting are based on mobile robots. In [1], the authors present four different classes of intelligent security robots (ISR), developed in the last decade: teleoperated robots, distributed robots, surveillance robots and law-enforcement robots (LERs). The teleoperated security robots [2] are robots which are remotely controlled by an operator. Distributed robots [3] are robots with autonomous capability which depend on their team members in order to take decisions. Surveillance security robots [4] are autonomous robots which take decisions if an abnormal activity is being perceived within a surveyed area. Law-Enforcement robots [5] are autonomous robots which employ versatile architectures to handle weaponry. All these four categories have been surveyed and analyzed in [1]. One of the comparison results concludes that the distributed robots class is considered the ideal solution because the probability of successfully completing the task is higher than in the case of single robots.

A crucial aspect in surveillance applications is the origin of the abnormal activities. The origin can be accurately obtained if the localization and mobility of the robotic system are continuously managed during the (whole) surveillance process.

In this paper we present a cooperative positioning system for indoor surveillance application with a more focus on the balance between: environment independency, localization accuracy and hardware costs. We are using a cooperative localization approach, based on mobile landmarks, because we address a wide range of applications, where the fixed

landmarks (beacons) are not installed, or the natural landmarks are very hard to recognize. To reach an accurate localization for the cooperative positioning system, we have proposed in [6] an extension device for each robot, called IRULT (Inter-Robot Ultrasonic Localization Turret). With this extension, each robot can measure the distance to its neighbors using ultrasonic signals. Currently, we are working in 2D space and we plan to extend our system in 3D space.

The surveillance application presented in this paper is evaluated using two proposed localization algorithms: Iterative Least Square (ILS) and Backtracking Particle Filter (BPF). The simulation results show that BPF method has a better accuracy.

II. LOCALIZATION METHODS

In this section we will discuss some existing localization methods. We do not discuss about methods which involve angles measurement in determining position. Angle measurement is a good alternative for position determination but requires special hardware.

We will show some existing positioning methods based on distance measurement. In our approach, as in the related approaches, the common aspect what we have is the distance measurement, each robot can measure the distance to its neighbors. If the robot r_u , with the unknown coordinates (x_u, y_u) , measures n distances $d_1, d_2 \dots d_n$ to the robots $r_1, r_2 \dots r_n$, with the known coordinates $(x_1, y_1), (x_2, y_2) \dots (x_n, y_n)$, then we will obtain a system with n equations and two unknowns:

$$\begin{cases} (x_u - x_1)^2 + (y_u - y_1)^2 = d_1^2 \\ (x_u - x_2)^2 + (y_u - y_2)^2 = d_2^2 \\ \vdots \\ (x_u - x_n)^2 + (y_u - y_n)^2 = d_n^2 \end{cases} \quad (1)$$

Considering that in practice the distance is measured with a tolerance, the obtained system can be solved in many ways. Next, several existing methods will be presented.

A. Linear Least Squares (LLS)

The authors in [7] consider for the system (1) an error ε for distance estimations, which makes $d_i = \hat{d}_i - \varepsilon$, so that the system becomes:

$$\begin{cases} (\hat{x}_u - x_1)^2 + (\hat{y}_u - y_1)^2 = \hat{d}_1^2 - \varepsilon \\ (\hat{x}_u - x_2)^2 + (\hat{y}_u - y_2)^2 = \hat{d}_2^2 - \varepsilon \\ \vdots \\ (\hat{x}_u - x_n)^2 + (\hat{y}_u - y_n)^2 = \hat{d}_n^2 - \varepsilon \end{cases} \quad (2)$$

Where $(\hat{\cdot})$ denotes the estimation of (\cdot) and ε is an independent normal variable with zero mean. This system can be linearized, by subtracting one of the equations from the remaining $n-1$ equations, into $Ax \approx b$. The resulting system of linear equations can be solved by the following parameter estimation:

$$x = (A^T A)^{-1} (A^T b) \quad (3)$$

In [8] a linear closed-form solution is used based on difference of squared range measurements (LCS-DSRM). This method has several merits: for example, there are no local minimum (LM) and red sea zone (RSZ) problems, and computational load is reduced.

B. Nonlinear Least Squares (NLLS)

System (1) can be solved by using any of the Newton type optimization algorithms. For example, in [9] the authors use the Newton-Raphson method for position calculation. In another related work, the Levenberg-Marquardt method is employed, which is simpler but drops out the second-derivative term and makes the positioning to be less robust [10].

In [11], the authors present an adaptive iterative least square method (AILS) to solve the problems that iterative least square (ILS) and direct solution (DS) methods have. Here, the non-linear equation (1) is linearized based on the first-order Taylor series expansion

$$\begin{aligned} d_i &\cong \sqrt{(\bar{x}_u - x_i)^2 + (\bar{y}_u - y_i)^2} \\ &+ \frac{\bar{x}_u - x_i}{\sqrt{(\bar{x}_u - x_i)^2 + (\bar{y}_u - y_i)^2}} \delta x_u \\ &+ \frac{\bar{y}_u - y_i}{\sqrt{(\bar{x}_u - x_i)^2 + (\bar{y}_u - y_i)^2}} \delta y_u \end{aligned} \quad (4)$$

where $(\bar{\cdot})$ denotes the nominal of (\cdot) and $\delta x_u, \delta y_u$ means the difference between the nominal point and the true location. The idea of AILS is to converge to the point with global minimum placing different initial nominal points (INPs) on the edges of the searching field.

III. COOPERATIVE ROBOTICS FRAMEWORK

This research has as a reference point the CORE-TX (Collaborative Robotic Environment – the Timisoara eXperiment) system, composed of a heterogeneous set of autonomous microsystems with embedded intelligence, a collaborative communication environment and a central entity with supervising functions [12]. The CORE-TX system interacts with the environment through autonomous microsystems with embedded intelligence called WITs

(Wireless Intelligent Terminals). The WIT consists of different specialized modules: a communication module, a perception module, a base processing module, a power management module, and a support and operation module. The perception module contains an extension device called IRULT (Figure 1), used in the positioning and location management of the WITs [6].

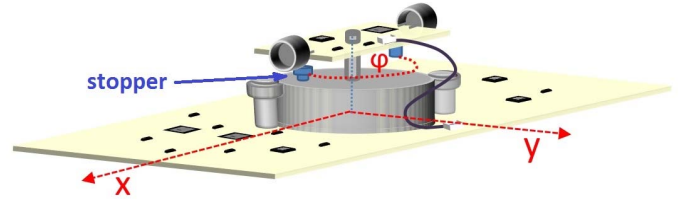


Fig. 1. IRULT as part of the perception module

Each robot in our research is built based on the WIT model. Equipped with an IRULT module, a robot cooperates with other neighboring robots in order to determine its orientation and position within the current environment. The IRULT device (Figure 1) consists of a stepper motor, two ultrasonic transducers and other interfacing circuits. Each transducer has a cone-shaped directivity range of about 50 degrees and can send and receive ultrasonic signals at a frequency of 40 KHz. These two transducers are mounted back to back at 180 degrees. Thus, by rotating two transducers, the robot has an omnidirectional range.

Based on the IRULT module, each robot can calculate the distance to another robot using the combined time of flight method (CTOF) [13]. This method also has the advantage of eliminating the errors generated by the multipath propagation. The distance measurement procedure is preceded by the alignment procedure [14].

The alignment procedure consists of the cooperation between two robots with wireless communication interfaces, to exchange the necessary commands, and is based on the continuous measurement of the intensity of the ultrasonic waves. Two robots performing the alignment procedure have different functions: one of the robots is the transmitter and the other one is the receiver. The alignment procedure can be performed in two ways:

- While the two robots rotate their turrets from one limit to the other, repeatedly and at different speeds, the receiver calculates the received signal strength indication (RSSI) of the ultrasonic signal sent by the transmitter.
- While the first robot rotates the turret, the second one maintains its turret at a certain angle. For each rotation of the turret of the first robot, from one limit to the other, the turret of the second robot increments its angle with a step given by the directivity range of the conical shape of the ultrasonic sensor.

Our cooperative robotics framework is based on the previously proposed methodology [15] which covers three localization levels:

- The first level consists of locating robots based on mobility prediction, using the dead reckoning method. At this level, each robot locates itself based on its own mobility and navigation resources, through local processing.
- The second level includes a class of techniques and rules by which a robot is located using distributed processing and cooperation with other neighboring robots, within the range of the maximum distance of cooperation.
- The third level is based on the coordinator node, which can be at the same time a monitoring and control node. Its role is to manage the mobility of the robots, to keep the localization accuracy coefficient at high values.

IV. INDOOR SURVEILLANCE APPLICATION

We considered a surveillance application to evaluate the error propagation process and to obtain the two-dimensional (2D) localization errors for the two proposed methods: ILS and BPF. The application runs in an environment with no preinstalled sensors. As a case study, we assume the environment is an office with 6 rooms, which need to be monitored only during nighttime (between 10 PM and 07 AM). Initially, all robots are positioned in the first room. When the system is active, the robots are moving towards their target. Each robot has a predefined target to be monitored, for example some entrances or windows (Figure 2).

To maintain the highest localization accuracy during the surveillance process, the robots will define a set of settled groups called “localization webs” or abbreviated, “webs”. A web is composed of at least two robots. In this application each web is composed of two robots. In general, when a web contains more robots, the localization accuracy can be improved. For the current application we decided to use two robots for each web, firstly to reduce the number of overall robots and secondly to record some characteristics from a simple configuration which can be used as a reference point for the next complicated configurations. Overall we used 10 robots because we have defined 8 target points to be monitored (Figure 2), the additional 2 robots are used to establish a reference position; these two robots are permanently stationary in this application.

The route of the robots, the density of the webs and the number of robots are specific to each application. To simplify the discussion regarding map building and auto positioning of the webs, we manually determined the route of robots and the position of the webs.

A. Necessary Resources

The case study surveillance application uses 10 mobile robots. As specified in Section III, each robot is built according to the WIT model and must be equipped with an IRULT module. Therefore, each robot can perform the alignment process and can measure the distance to another robot.

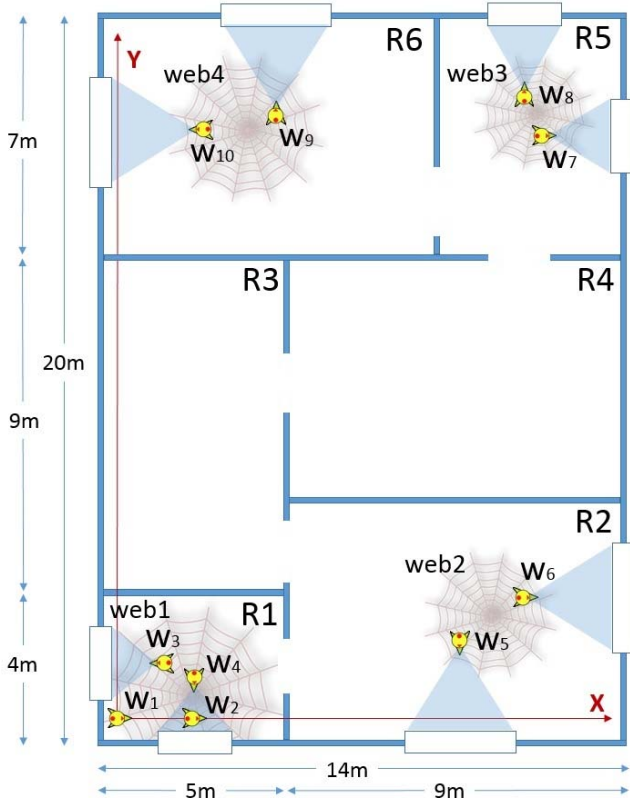


Fig. 2. Surveillance target

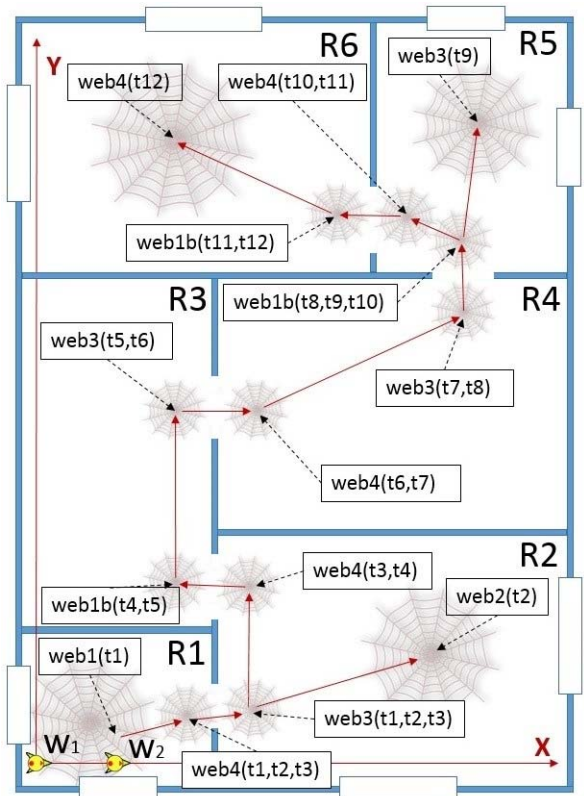


Fig. 3. System setup

The previous experimental results in [16] show that the tolerance for the alignment process is close to ± 10 degrees and the distance measurement error is approximately ± 5 mm.

Considering the angle error and the fact that each transducer has a cone-shaped directivity range of about 50 degrees, we can conclude that the alignment error of ± 10 degrees maintains the ultrasonic transmitter to be in the visibility range of the ultrasonic receiver for the distance measurement (line of sight).

Because of its low angle accuracy, the alignment process has as main purpose to prepare the distance measurement process and not to establish the angular information between the robots. Therefore, in this application, the localization is performed using the distances and not the angles.

B. System setup

The first installation (calibration) can be made by manually positioning the webs (see also Figure 3). The global reference system xOy is defined by robots w_1 and w_2 , according to their initial positions. The orientation of robot w_1 is the same as the orientation of robot w_2 . Robot w_1 is the coordinator of the system. *Web1* is the first web defined by the system and initially consists of two robots: w_1 and w_2 . *Web1* is positioned in room R_1 .

The user specifies which rooms are going to be monitored. The system will be trained by manually placing the webs, so becomes serviceable. The second web (*web2*) is placed in room R_2 . To propagate the coordinates from room R_1 to R_2 , two temporary webs are necessary (*web4* and *web3*), each consisting of two robots (w_9 and w_{10} and, respectively, w_7 and w_8). Similarly, these steps should be followed, as shown in Figure 3, in order to locate *web3* in R_5 and *web4* in R_6 .

The web naming procedure illustrated in Figure 3 is $\text{web_name}(\text{timestamp})$. In this application there are four webs: *web1*, *web2*, *web3* and *web4*. *Web1b* derives from *web1*, and is used to propagate the localization. The red arrows in Figure 3 represent the localization propagation order for the webs. The timestamp associated to each web represents the instance when the current web is used. The propagation order is denoted with timestamp from t_1 to t_{13} .

The distribution of the robots in this scenario is just an example; the focus in this work is more on the propagation errors. In this scenario, another way, to initialize the system is to obtain the target coordinates of the all webs using an external system. For example, if the user does not possess the floor plan, this can be built using a laser range meter. After obtaining the floor plan, the user can simply establish the target coordinates of the temporary and final webs.

The autonomous positioning of the webs would be the best solution, but this subject will not be discussed in this paper.

C. Iterative Least Squares Localization method

The first method which we propose is based on the ILS method adapted to our case study: collaborative localization method using 2 robots and 2 references, propagated ad-hoc from one web to another.

For each step in the collaborative localization process, in order to localize a web, the previous reference web is considered, as shown in Figure 3. For each step we will have five distances to be measured, as exemplified in Figure 4:

$$\begin{cases} (x_3 - x_1)^2 + (y_3 - y_1)^2 = d_{13}^2 \\ (x_4 - x_1)^2 + (y_4 - y_1)^2 = d_{14}^2 \\ (x_3 - x_2)^2 + (y_3 - y_2)^2 = d_{23}^2 \\ (x_4 - x_2)^2 + (y_4 - y_2)^2 = d_{24}^2 \\ (x_4 - x_3)^2 + (y_4 - y_3)^2 = d_{34}^2 \end{cases} \quad (5)$$

Using the system of equations (5) and distance measurements, the location of robot w_3 and w_4 can be estimated based on the ILS method as follows:

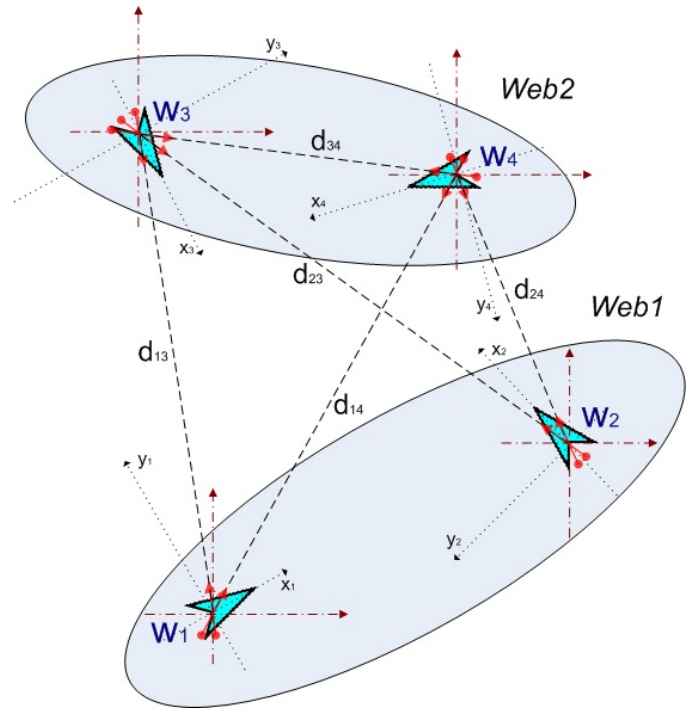


Fig. 4. Two robots: w_3, w_4 and two references: w_1, w_2

$$\begin{bmatrix} \tilde{\delta x}_3 \\ \tilde{\delta y}_3 \\ \tilde{\delta x}_4 \\ \tilde{\delta y}_4 \end{bmatrix} = (A^T A)^{-1} (A^T b) \quad (6)$$

Where $[\tilde{\delta x}_3, \tilde{\delta y}_3, \tilde{\delta x}_4, \tilde{\delta y}_4]^T$ denotes the estimated errors of the nominal points $[\bar{x}_3, \bar{y}_3, \bar{x}_4, \bar{y}_4]^T$,

$$A = \begin{pmatrix} a_{13} & b_{13} & 0 & 0 \\ a_{23} & b_{23} & 0 & 0 \\ 0 & 0 & a_{14} & b_{14} \\ 0 & 0 & a_{24} & b_{24} \\ -a_{34} & -b_{34} & a_{34} & b_{34} \end{pmatrix} \quad (7)$$

$$b = \begin{pmatrix} \tilde{d}_{13} - \bar{d}_{13} \\ \tilde{d}_{23} - \bar{d}_{23} \\ \tilde{d}_{14} - \bar{d}_{14} \\ \tilde{d}_{24} - \bar{d}_{24} \\ \tilde{d}_{34} - \bar{d}_{34} \end{pmatrix} \quad (8)$$

$$a_{ij} = -\frac{\hat{x}_i - \bar{x}_j}{\bar{d}_{ij}} \quad (9)$$

$$b_{ij} = -\frac{\hat{y}_i - \bar{y}_j}{\bar{d}_{ij}} \quad (10)$$

$$\begin{cases} \bar{d}_{ij} = \sqrt{(\bar{x}_i - \bar{x}_j)^2 + (\bar{y}_i - \bar{y}_j)^2}, & \text{if } i=3 \text{ and } j=4 \\ \bar{d}_{ij} = \sqrt{(\hat{x}_i - \bar{x}_j)^2 + (\hat{y}_i - \bar{y}_j)^2}, & \text{otherwise} \end{cases} \quad (11)$$

where $(\tilde{\cdot})$ denotes the measurement of (\cdot) , $(\bar{\cdot})$ denotes the nominal of (\cdot) and $(\hat{\cdot})$ denotes the estimation of (\cdot) .

The nominal point is updated using the estimate:

$$\begin{bmatrix} \bar{x}_3 \\ \bar{y}_3 \\ \bar{x}_4 \\ \bar{y}_4 \end{bmatrix} = \begin{bmatrix} \bar{x}_3 \\ \bar{y}_3 \\ \bar{x}_4 \\ \bar{y}_4 \end{bmatrix} + \begin{bmatrix} \tilde{\alpha}_3 \\ \tilde{\delta}_3 \\ \tilde{\alpha}_4 \\ \tilde{\delta}_4 \end{bmatrix} \quad (12)$$

Equations (6) and (12) are iterated until:

$$\begin{bmatrix} \tilde{\alpha}_3 \\ \tilde{\delta}_3 \\ \tilde{\alpha}_4 \\ \tilde{\delta}_4 \end{bmatrix}^T \begin{bmatrix} \tilde{\alpha}_3 \\ \tilde{\delta}_3 \\ \tilde{\alpha}_4 \\ \tilde{\delta}_4 \end{bmatrix} < \varepsilon \quad (13)$$

In our situation we used $\varepsilon = 0.05\text{mm}$.

D. Backtracking Particle Filter Localization method

The second method which we propose is based on the particle filter with an adaptive backtracking model. In this example application, all the webs are created using two robots and, therefore, the localization process will have to rely on two mobile references. The following steps will be performed further on:

- Step 1 – localization of a robot using two references. Two measured locations (solutions) will be obtained, as the intersection of two circles.

Observation: The distance measurements are performed repetitively, to filter the measurement noise which is assumed as a zero mean stationary Gaussian random process.

- Step 2 – select one of the two measured solutions from the previous step, based on the results from the alignment process (bearing angle information).

- Step 3 – create an estimated surface, based on the measured solution from Step 2 and the known tolerance of the IRULT module.

Observation: The estimated surface needs to be established because of the occurrence of non-Gaussian errors in the distance measurement.

- Step 4 – Selection of a nominal solution from the estimated surface. A nominal solution represents here a preliminary solution.
- Step 5 – Validation of the selected nominal solution from the previous step by comparing the distances between robots. A total of 5 distances will be checked here: robot₁–robot₂ (w_1-w_2), robot₁–reference₁ (w_1-rw_1), w_1-rw_2 , w_2-rw_1 and w_2-rw_2 . All the comparisons are performed between measured distances (taking into account the tolerances) and the distances calculated based on the nominal solution. If a single distance does not match, then another nominal solution will be selected. If no solution can be found to match all five conditions, then the position of the previous web must be recalculated.

V. SIMULATION RESULTS

In order to compare the two proposed methods, i.e. ILS and BPF, we performed an extensive set of simulations using the proposed scenario. The simulations consider the floor plan of a small office with six rooms, measuring approximately 14 m x 20 m (280 m²).

Our developed simulator is based on the Monte Carlo technique considering non-Gaussian errors in the real-world distance measurements. Due to the simulations, we were able to evaluate the error propagation process and to obtain the two-dimensional (2D) localization errors for the two proposed methods: ILS and BPF.

For each method we generated 30000 particles using different tolerances for the distance measurement: ± 1 mm, ± 2 mm, ± 3 mm, ± 4 mm and ± 5 mm. For example, the results of the BPF method using a distance measurement tolerance of ± 1 mm are shown in Figure 5. All other results are shown in Figure 6. The proposed application can be functional if the achieved distance measurement tolerance is ± 1 mm. As shown in Figure 5, a poorer tolerance may affect the robots in finding the rooms entrances.

The results for the ILS and BPF methods are presented in Table 1, for the case when the distance measurement tolerance is ± 1 mm. The ILS method is ten times faster than BPF, but BPF has a higher accuracy. Furthermore, the results presented in Figure 6 also show that the positioning accuracy of the BPF method is higher than that of the ILS method.

Currently, the prototypes of IRULT module we built in-house, achieve a tolerance of ± 5 mm. We are working on improving this module to reach the target tolerance of ± 1 mm. In parallel, using the developed simulator, we are evaluating some localization aspects, for example the propagation errors and moving strategies.

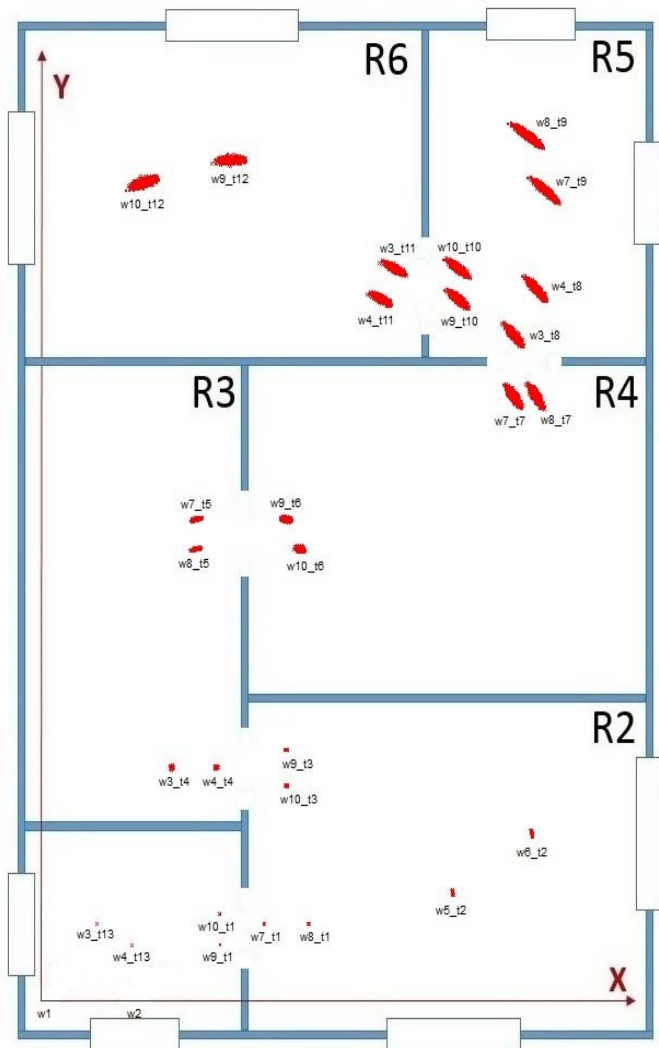


Fig. 5. Two-dimensional localization errors using the BPF method with the distance measurement tolerance of ± 1 mm

VI. CONCLUSION

One of the important problems in the development of a cooperative positioning system for indoor surveillance applications is to establish an appropriate positioning methodology for the environments with no preinstalled artificial landmarks.

In this paper we have described a scenario for indoor surveillance applications, where distributed robots were used applying the localization methodology [15] we have previously developed and proposed. We have presented a simple setup of the indoor surveillance system and two proposed localization algorithms: ILS and BPF. Examining the results of these simulations, we can conclude that the positioning accuracy of the BPF method is as expected higher than that of the ILS method. In addition, the positioning accuracy of both methods is reliable enough to be used for indoor surveillance applications,

provided that the lower tolerance is achieved for distance measurement.

TABLE I. SIMULATION RESULTS FOR THE ERROR PROPAGATION USING THE ILS AND BPF METHODS WITH THE DISTANCE MEASUREMENT TOLERANCE OF ± 1 MM

Robot	SIMULATION RESULTS				
	Time	Target Coordinates		ILS Absolute error [mm]	BPF Absolute error [mm]
		X [mm]	Y [mm]		
w1	t1	0	0	0	0
w2	t1	0	0	0	0
w7	t1	5000	1500	10,67	10,33
w8	t1	6000	1500	15,48	16,30
w9	t1	4012	1100	6,59	7,34
w10	t1	4003	1700	7,09	7,76
w5	t2	9230	2110	66,17	52,61
w6	t2	11010	3260	96,81	80,77
w9	t3	5500	4900	41,45	41,70
w10	t3	5500	4200	32,99	36,55
w3	t4	2930	4555	59,55	51,26
w4	t4	3930	4555	42,30	38,70
w7	t5	3479	9400	167,00	140,60
w8	t5	3479	8820	146,65	134,87
w9	t6	5500	9400	167,47	140,99
w10	t6	5800	8820	150,02	131,70
w7	t7	10600	11800	398,25	319,58
w8	t7	11100	11800	416,14	334,22
w3	t8	10600	13000	437,17	354,90
w4	t8	11100	13900	482,56	397,68
w7	t9	11310	15820	562,04	470,40
w8	t9	10910	16890	593,40	503,23
w9	t10	9350	13700	425,17	349,60
w10	t10	9350	14300	448,09	371,88
w3	t11	7920	14300	415,48	348,46
w4	t11	7620	13700	385,73	317,40
w9	t12	4260	16410	470,63	430,58
w10	t12	2300	15970	456,73	431,38
w3	t13	1250	1500	1,76	1,83
w4	t13	2040	1090	1,74	1,88

It is expected that this performance is applicable to many other environments besides the currently presented field. Future work will focus on the moving strategies of the robots in order to minimize the positioning error.

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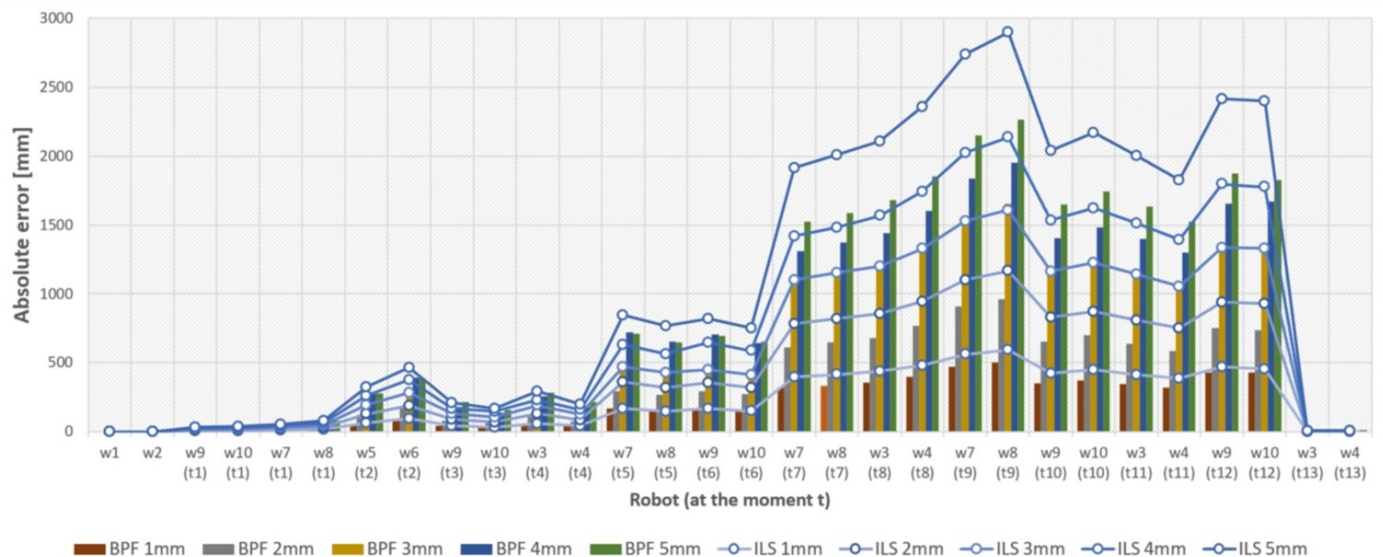


Fig. 6. Simulation of the error propagation using the ILS and BPF methods

REFERENCES

- [1] T. Theodoridis, H. Huosheng, "Toward Intelligent Security Robots: A Survey" Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on, vol. 42, issue 6, pp. 1219–1230, November 2012.
- [2] B. Gaspers, J. Welle, D. Schulz, "Opening doors with a mobile manipulator without force-torque feedback", Safety, Security, and Rescue Robotics (SSRR), 2013 IEEE International Symposium on, October 2013.
- [3] R. P. Rocha, D. Portugal, M. Couceiro, F. Araujo, P. Menezes, J. Lobo, "The CHOPIN project: Cooperation between human and robotic teams in catastrophic incidents", Safety, Security, and Rescue Robotics (SSRR), 2013 IEEE International Symposium on, October 2013.
- [4] R. Salman, I. Willms, T. Sakamoto, T. Sato, A. Yarovoy, "Environmental imaging with a mobile UWB security robot for indoor localisation and positioning applications", Microwave Conference (EuMC), 2013 European, October 2013.
- [5] A. Amanatiadis, K. Charalampous, I. Kostavelis, A. Gasteratos, B. Birkicht, J. Braunstein, V. Meiser, C. Henschel, S. Baugh, M. Paul, R. May, "The AVERT project: Autonomous Vehicle Emergency Recovery Tool", Safety, Security, and Rescue Robotics (SSRR), 2013 IEEE International Symposium on, October 2013.
- [6] A. Stancovici, M. V. Micea, V. Cretu, V. Groza, "Relative Positioning System Using Inter-Robot Ultrasonic Localization Turret", International Instrumentation and Measurement Technology Conference (I2MTC), 2014 IEEE, pp. 1427 – 1430, May 2014.
- [7] A. Boukerche, H. A. B. F.Oliveira, E. F. Nakamura, A. A. F. Loureiro, "Chapter 12 – Localization systems for wireless sensor networks", in Algorithms and protocols for wireless sensors, Hoboken, New Jersey, John Wiley & Sons, Inc., pp. 307-340, 2009.
- [8] S. Y. Cho, B. D. Kimm, "Linear closed-form solution for wireless localisation with ultra-wideband/chirp spread spectrum signals based on difference of squared rangemeasurements", IET Radar, Sonar and Navigation, Vol. 3, Iss. 4, pp. 255-265, 2013.
- [9] K. Kumakura, A. Suzuki, T. Iyota, "Code division positioning by continuous signals using spread spectrum ultrasonic waves", Indoor Positioning and Indoor Navigation (IPIN), 2013 International Conference on, October 2013.
- [10] W. H. Press, W. T. Vetterling, S. A. Teukolsky, B. P. Flannery, "Numerical Recipes in C", Chapter15, pp.681-688, Cambridge University Press, 1986.
- [11] S. Y. Cho, Y. W. Choi, "Access point-less wireless location method base on peer-to-peer ranging of impulse radio ultra-wideband", IET Radar, Sonar and Navigation, Vol. 4, Iss. 5, pp. 733-743, 2010.
- [12] R. D. Cioarga, M. V. Micea, B. Ciubotaru, D. Chiciudean, D. Stancu, "CORE-TX: Collective Robotic Environment - the Timisoara Experiment", in Proc. 3rd Romanian-Hungarian Joint Symp. Applied Computational Intellig., SSCI 2006, Timisoara, Romania, pp. (495–506), May 2006.
- [13] M. V. Micea, A. Stancovici, D. Chiciudean, C. Filote, "Indoor Inter-Robot Distance Measurement in Collaborative Systems", 10th International Conference on Development and Application Systems, Suceava, Romania, May 27-29, 2010.
- [14] S. Indreica, A. Stancovici, M. V. Micea, V. Cretu, V. Groza, "Simulator Based Study of Robot Alignment and Localization", 2013 IEEE International Symposium on Robotic and Sensors Environments (ROSE), October 2013.
- [15] A. Stancovici, S. Indreica, M. V. Micea, V. Cretu, V. Groza, "Relative Localization Methodology for Autonomous Robots in Collaborative Environments", International Instrumentation and Measurement Technology Conference (I2MTC), 2013 IEEE, pp. 1730 – 1733, May 2013.
- [16] Mihai V. Micea, Andrei Stancovici, Sinziana Indreica, "Distance Measurement for Indoor Robotic Collectives", in the book: Mobile Robots / Book 2, InTech, ISBN 978-953-307-842-7, 2011.