Proceedings of the of the 17th Conference on Computer Science and Intelligence Systems pp. 593–597
DOI: 10.15439/2022F248
ISSN 2300-5963 ACSIS, Vol. 30

Room mapping system using RFID and mobile robots

Mariusz Skoczylas
Department of Electronic and Telecomunication Systems
Rzeszow University of Technology,
al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
Email: msko@prz.edu.pl

Łukasz Gotówko
Department of Electrodynamics and Electrical Machine Systems
Rzeszow University of Technology,
al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
Email: l.gotowko@prz.edu.pl

Mateusz Salach
Department of Complex Systems
Rzeszow University of Technology,
al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
Email: m.salach@prz.edu.pl

Bartosz Trybus
Department of Computer and Control Engineering
Rzeszow University of Technology,
al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
Email: btrybus@prz.edu.pl

Marcin Hubacz
Department of Computer and Control Engineering
Rzeszow University of Technology,
al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
Email: m.hubacz@prz.edu.pl

Bartosz Pawłowicz
Department of Electronic and Telecomunication Systems
Rzeszow University of Technology,
al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
Email: barpaw@prz.edu.pl

***Abstract*—The article presents a prototype indoor space mapping solution using RFID transponders. The autonomous robot reads the information they contain using a set of several readers, which improves the process. The design of the robot prototype is based on the STM32 NUCLEO module. Two types of transponder grids are considered, square and triangular. Simulation results for both grid types show the efficiency of reading information from transponders by the moving robot.**

I. Introduction

AUTONOMOUS navigation robots are currently the subject of much research, and the RFID technique [1], [2], [3] is often used in experimental developments as part of a robot navigation and indoor mapping system [4], [5]. Such systems are used to identify objects with passive or semi-passive tags equipped with a writable memory with an information capacity far superior to the currently used barcodes [1]. RFID systems can be used in many areas, particularly in the ISM field (Industrial, Scientific, Medical). Building exploration, surface, and space mapping using such robots is also a promising area of research [6], [7]. Complex systems consisting of a robot group can also pose communication challenges [8], [9].

A great advantage of RFID systems is that the information can be read from multiple tagged objects simultaneously. A robot that is equipped with an RFID reader can use information and coordinates stored in RFID transponders embedded in walls, floors, doors, and furniture [10], [11]. This is illustrated in Fig. 1.

Unfortunately, reading the information does not provide knowledge about the location of the object on a surface or in space. Therefore, quickly reaching the correct object can be a problem. Therefore, in the field of RFID systems, the problem of mapping the space in which transponders are located is an important research area [12], [13], [14], [15], [16], [17], [18].

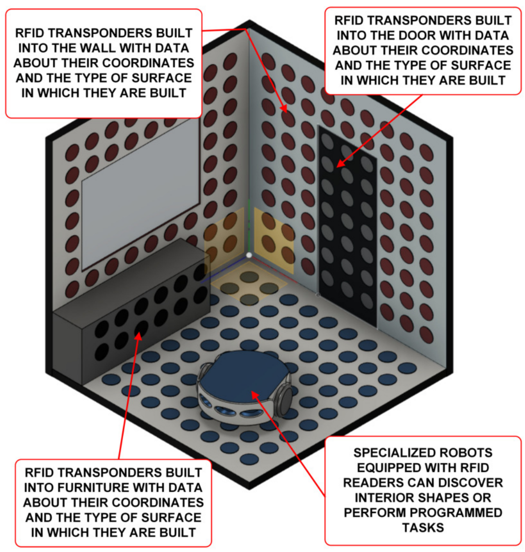


Fig. 1: The use of RFID transponder grids for indoor mapping with a robot

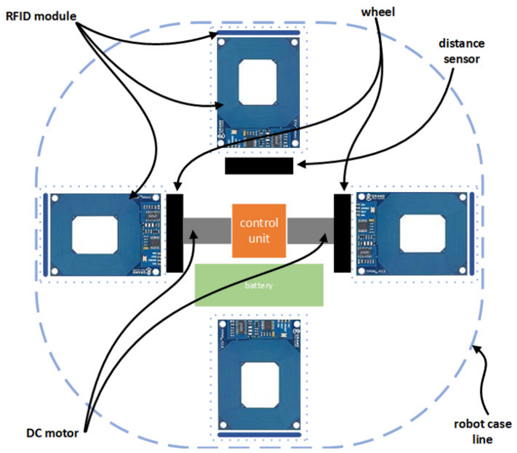


Fig. 2: An overview of the autonomous robot

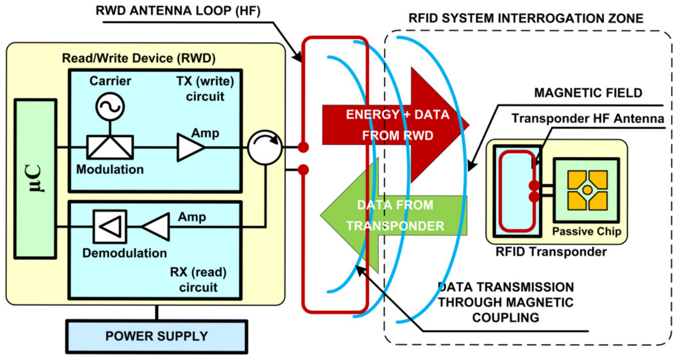


Fig. 3: General scheme of the RFID identification system

It has also been noted that it is possible to use this technique in a different way and attempt to determine the position of a mobile robot equipped with an RFID reader based on the readings and analysis of the signals obtained when reading information from tags placed at known locations [19], [20], [21], [22]. Many of the existing studies are based on the use of the RSSI (received signal strength index) method [22], [23]. This is sometimes extended with methods related to odometry and the use of EKF filtering to increase the accuracy of position estimation [24]. There are also original solutions based, for example, on the phase measurement of the signal reflected from the transponder and carrying the information read from the transponder [25].

However, the above-mentioned studies mainly cover a very obtuse mathematical apparatus and almost completely ignore the issue of location support with data stored in the transponder memory. This gap was very quickly recognized, which resulted in the development of various solutions using RFID transponders to determine the location and orientation of a robot equipped with an RFID reader, starting from simple solutions with information on how the robot should read the stored transponders [26] to advanced systems using measurement of the power of the signal reflected from RFID transponders placed in a grid [27].

II. Proposed solution

This work considers a room mapping system using a robot with four readers and the components shown schematically in Fig. 2. The nature of RFID systems must consider the fact that uninterrupted operation of readers is necessary to provide power to transponders deployed in space and to correctly read information from their memory.

Due to the principle of operation, it is possible to distinguish two types of solutions that determine the energy transmission in RFID systems. The first are systems operating on the principle of inductive coupling, and the second is propagation coupling. The energy transferred between the reader and the transponder is transmitted through a magnetic field (Fig. 3), and its amount depends on the surface and mutual position of the receiving and transmitting antennas. For proper operation of the system, it is necessary to activate the RFID transponder antenna with resonant frequency, because it causes maximal current flow in the antenna circuit.

Passive transponders are mostly used with inductive coupling. In the basic scenario each transponder transmits its serial number as long as it is in the area of correct reader operation. The maximum range is achieved when the magnetic field lines generated by the reader antenna are perpendicular to the winding plane of the badge antenna coil. If the field lines are parallel to the coil, the connection does not occur, and no power is provided. The maximum range of readers is mostly limited by administrative restrictions on the maximum allowable intensity of the magnetic field produced by the reader antenna.

Propagation coupling is used for communication in the UHF band. Here, in contrast to inductive coupled systems, the far-field region is used, and it is assumed that the electromagnetic field strength is independent of the presence of transponders in the field of the reader antenna. The information exchange between transponders and a reader is based on the modulation of magnetic field modulation.

The performance of an RFID system can be comprehensively described by the idea of interrogation zone. It describes field, energy and communication issues of RFID system components [28]. Proper estimation of this area allows a wider implementation of multiple object identification. Due to the different modes of operation, the interrogation zone is defined differently for inductive and propagation systems. However, in both cases, energy is transferred through radio waves, so each must comply with acceptable radiation standards based on CEPT/ERC 70-03 recommendations. Based on these guidelines, the minimum field strength needed to power the transponders can be determined [29]. Like any electrical/electronic equipment, a robot is a potential source of electromagnetic interference and must be designed in accordance with the requirements of EMC Directive 2014/30/EU. There are no subject standards for this class of equipment yet, so the evaluation must be done according to the requirements of the general standard IEC 61000-6-3 [29].

III. RFID TRANSPONDER ARRANGEMENT

Thanks to the use of a grid of RFID transponders (sensors), it is possible to build an environment that will determine the coordinates of the sensors, memorize parameters of the environment and the motion path of moving objects. Thus, this approach makes it possible to implement a control system for an autonomous mobile object [30]. The distribution of transponders, the correlation of distances between them and the area of correct operation of the RFID system significantly affects the number of simultaneously detected transponders. A larger number of transponders in the interrogation zone requires a longer time needed for transponder recognition (use of multiple identification algorithm, reading of data contained in memory of individual transponders). On the other hand, the time influences, to a large extent, parameters of movement of a mobile object, and mainly determines its movement speed. However, temporary lack of transponders in the interrogation zone causes, that the mobile navigation system loses for some time the actuality of position data.

Among the many possibilities for the deployment of transponders in the considered area, two rational solutions can be distinguished as shown in Fig. 4 with triangle and square distribution of transponders. If the activity areas of individual transponders have a circular shape (with radius R), according to the theoretical premises of total area coverage [31], the most economical solution is to locate transponders in the vertices of an equilateral triangle (with side length: $R\sqrt{3}$). However, the problem is more complicated, because this arrangement is superimposed by the area of correct operation of the RFID system (Interrogation Zone - IZ), which is usually approximated to the shape of a circle of radius R [32].

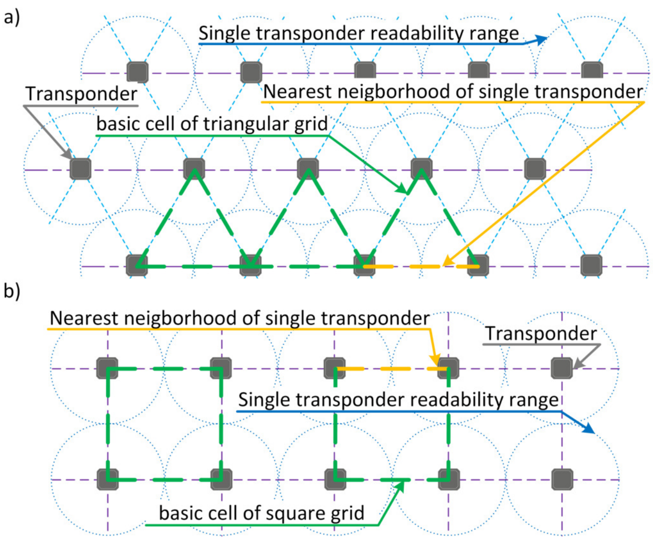


Fig. 4: The structure of transponders deployment: a) triangle, b) square

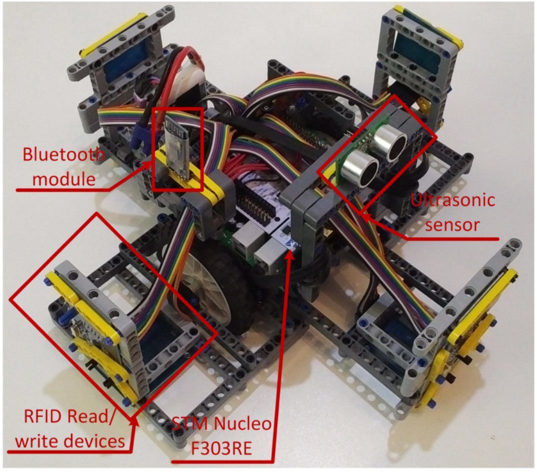


Fig. 5: Perspective view of the robot prototype

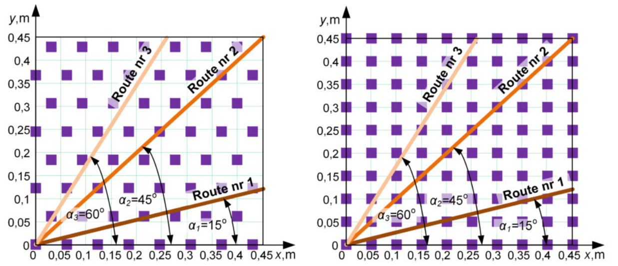
IV. THE MOBILE ROBOT

The robot built in this work is intended to be a mobile structure moving inside a building, i.e., in a closed and highly confined space. In order to reduce the likelihood of potential problems during the construction and use of the RFID system, the support structure was made entirely of materials that do not cause wave interference during RFID reader operation, i.e., plastic. A central STM32 NUCLEO-F303RE microprocessor unit with additional electronic components, such as a position sensor and a Bluetooth module, was placed on the support structure in the central part of the robot. The RFID readers were mounted in the robot, two per side in two different planes, horizontally and vertically, respectively. Additionally, a distance sensor has been placed at the front of the robot to detect and avoid obstacles. A Lipo battery pack is used as the power source for the robot.

For primary structure a LEGO mechanical components and drive assemblies were used to build the robot. The drive system consists of two servos. Each of them has an internal reduction gear, so their maximum torque is 8 N/cm and their maximum holding torque is 12 N/cm. In addition, the accuracy of the internal rotation sensor is 1 degree. On the prepared drive base, a skeleton of the supporting structure was mounted, to which the remaining components were then attached, such as: ultrasonic distance sensor, Bluetooth module eight RFID readers (Fig. 5); and indirectly through a special extension overlay: multiplexer, two motor control systems, microprocessor system, 9DoF inertial navigation unit.

V. RESULTS

An application in MathCad was developed for the computer simulation of selected structures of the distribution of transponders on a surface. Two types of structures were analyzed: a square grid and a triangular grid. The sizes of the surface on which the transponders are distributed can be freely defined, but since the structures in question are regular,



(a) (b)

Fig. 6: Assumptions to the simulation process for grid configurations: a) triangle, b) square

the analysis of a limited area of this surface is sufficient for simulation purposes. This is shown in Figure 6.

For comparison purposes, identical areas of 0.45m x 0.45m were assumed for both grid configurations. The distances between transponders, respectively for the triangular grid D_T and the square grid D_K, can be defined independently for both cases, but they are in close relation to each other. The case where for both structures, for any antenna position of the reader-programmer system with respect to the transponders, there is at least one transponder in the interrogation zone was chosen as the most reasonable one. The cases omitted are, in which, during movement, the control system does not detect any transponder and must use more advanced algorithms to correctly determine the location. The above assumption leads to the relationship:

$$D_T = 3/2 * \sqrt{3/2} * D_K \tag{1}$$

Considering relation (1), D_K = 0.05m was assumed, while D_T = 0.092m. The mobile object can move in any direction and according to any defined trajectory, but for simplicity of calculations, it was assumed that the movement will take place only along a straight line, for three different directions (Fig. 6), respectively: Route No. 1, Route No. 2 and Route No. 3). The shape of the region of correct operation was assumed to be a circle with a defined radius R (Fig. 7). The x-axis was discretized by running 100 equidistant lines, and the steps of analyzing individual motion trajectories correspond to their projections on the x-axis, for successive discretization steps. It follows from this that the scope of the analysis of the successive steps is limited to the shortest projection of the motion trajectory on the x-axis. This is the projection of Route 3 and determines the range of analysis in the interval <0;0.26 m>.

In order to illustrate the problem in question, below is an analysis of a selected case of configuration of spatial distribution of tags in correlation with the size of the interrogation zone of the RFID system. Fig. 8 compares the number of transponders in the interrogation zone for the selected structures of their distribution: square grid and triangular grid, respectively, when changing the position of the RWD system antenna according to the assumed motion trajectories.

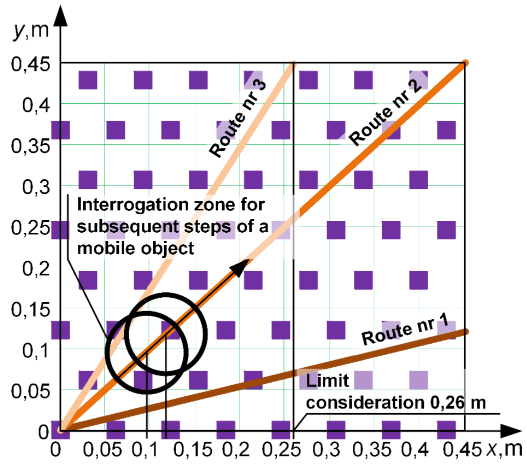


Fig. 7: Interrogation zone and limit consideration

The structure of transponder distribution has a significant influence on the number of transponders, located in the interrogation zone, as well as the dynamics of changes of this number. For comparison purposes, a statistical analysis was performed according to the relation:

$$Sr_{KwTr} = \frac{\sum \frac{l_{IdKw_k} - l_{IdTr_k}}{l_{IdKw_k}}}{100} * 100 \tag{2}$$

where: k is the step of the mobile object (interrogation zone) along the x-axis, l_{IdKw} - number of transponders in the interrogation zone of the RFID system for a square grid, l_{IdTr} - number of transponders in the interrogation zone of the RFID system for a triangular grid. The number of transponders is greater for the square grid, on average by more than 30%. For example: for road 1: $Sr_{KwTr} \approx 33\%$, for road 2: $Sr_{KwTr} \approx 35\%$, and for road 3: $Sr_{KwTr} \approx 29\%$. The

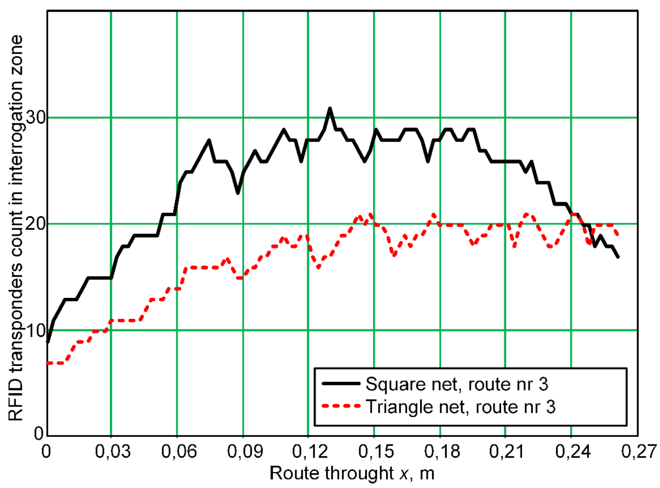


Fig. 8: RFID transponders count in interrogation zone with radius R = 0.15m

observed, rapid increase in the number of transponders in the first phase of traffic (slope of characteristics for road x up to about 0.12m) is caused by reaching the point where there is a full coverage of the IZ into the zone marked with transponders.

The above conclusions lead to the conclusion that the higher resolution of the transponders with respect to the interrogation zone, results in a percentage of more information for a square grid than for a triangular grid. This situation significantly affects the need to process more data in order to decide the next step in the movement of the mobile object, and thus requires an increase in the computing power of the control system or a reduction in the maximum speed of movement of the mobile object.

ACKNOWLEDGMENT

This project is financed by the Minister of Education and Science of the Republic of Poland within the "Regional Initiative of Excellence" program for years 2019–2022. Project number 027/RID/2018/19, amount granted 11 999 900 PLN.

REFERENCES

[1] K. Finkenzeller, *RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification*, 2nd ed. Wiley Publishing, 2003. ISBN 0470844027

[2] S. ISO/IEC 14443-3, *Identification cards - Contactless integrated circuit cards - Proximity cards*. International Standard: ISO/IEC, 2016.

[3] S. ISO/IEC 15693, *Identification cards - Contactless integrated circuit cards - Vicinity cards*. International Standard: ISO/IEC, 2010.

[4] T. D. Chuyen, R. V. Hoa, N. D. Dien, and T. L. Nguyen, "Mobile robots interacting with obstacles control based on artificial intelligence," in *Proceedings of the 2021 Sixth International Conference on Research in Intelligent and Computing*, V. K. Solanki and N. H. Quang, Eds., vol. 27, 2021, p. 13–16.

[5] M. Baïou, A. Quilliot, L. Adouane, A. Mombelli, and Z. Zhu, "Algorithms for the safe management of autonomous vehicles," in *Proceedings of the 16th Conference on Computer Science and Intelligence Systems*, M. Ganzha, L. Maciaszek, M. Paprzycki, and D. Ślęzak, Eds., vol. 25, 2021, p. 153–162.

[6] M.-S. Jian and J.-S. Wu, "Rfid applications and challenges," in *Radio Frequency Identification*, M. B. I. Reaz, Ed. Rijeka: IntechOpen, 2013, ch. 1.

[7] T. Sanpechuda and L.-o. Kovavisaruch, "A review of rfid localization: Applications and techniques," vol. 2, pp. 769 – 772, 06 2008. doi: 10.1109/ECTICON.2008.4600544

[8] F. Grabowski, A. Paszkiewicz, and M. Bolanowski, *Wireless networks environment and complex networks*. Switzerland: Springer International Publishing, 2015, vol. 324. ISBN 978-3-319-38545-7

[9] M. Hubacz, B. Pawłowicz, and B. Trybus, "Exploring a surface using rfid grid and group of mobile robots," in *Automation 2018*, R. Szewczyk, C. Zieliński, and M. Kaliczyńska, Eds. Cham: Springer International Publishing, 2018. ISBN 978-3-319-77179-3 pp. 490–499.

[10] C. Li, L. Mo, and D. Zhang, "Review on uhf rfid localization methods," *IEEE Journal of Radio Frequency Identification*, vol. 3, no. 4, pp. 205–215, 2019. doi: 10.1109/JRFID.2019.2924346

[11] S. Willis and S. Helal, "Rfid information grid for blind navigation and wayfinding," in *9th IEEE International Symposium on Wearable Computers, ISWC 2005*. IEEE, 2005. doi: 10.1109/ISWC.2005.46. ISBN 0769524192 pp. 34–37.

[12] G. Yang and J. Saniie, "Sight-to-sound human-machine interface for guiding and navigating visually impaired people," *IEEE Access*, vol. 8, pp. 185 416–185 428, 2020. doi: 10.1109/ACCESS.2020.3029426

[13] H.-Y. Yu, J.-J. Chen, and T.-R. Hsiang, "Design and implementation of a real-time object location system based on passive rfid tags," *IEEE Sensors Journal*, vol. 15, pp. 1–1, 09 2015. doi: 10.1109/JSEN.2015.2432452

[14] C.-Y. Yao and W.-C. Hsia, "An indoor positioning system based on the dual-channel passive rfid technology," *IEEE Sensors Journal*, vol. 18, no. 11, pp. 4654–4663, 2018. doi: 10.1109/JSEN.2018.2828044

[15] Q. Wen, Y. Liang, C. Wu, A. Tavares, and X. Han, "Indoor localization algorithm based on artificial neural network and radio-frequency identification reference tags," *Advances in Mechanical Engineering*, vol. 10, no. 12, p. 1687814018808682, 2018. doi: 10.1177/1687814018808682

[16] J. Pomarico-Franquiz and Y. Shmaliy, "Accurate self-localization in rfid tag information grids using fir filtering," *IEEE Transactions on Industrial Informatics*, vol. 10, 02 2014. doi: 10.1109/TII.2014.2310952

[17] S. P. Subramanian, J. Sommer, S. Schmitt, and W. Rosenstiel, "Ril — reliable rfid based indoor localization for pedestrians," in *2008 16th International Conference on Software, Telecommunications and Computer Networks*, 2008. doi: 10.1109/SOFTCOM.2008.4669483 pp. 218–222.

[18] C. Jiang, Y. He, X. Zheng, and Y. Liu, "Omnitrack: Orientation-aware rfid tracking with centimeter-level accuracy," *IEEE Transactions on Mobile Computing*, vol. 20, no. 2, pp. 634–646, 2021. doi: 10.1109/TMC.2019.2949412

[19] L. Yang, J. Cao, W. Zhu, and S. Tang, "Accurate and efficient object tracking based on passive rfid," *IEEE Transactions on Mobile Computing*, vol. 14, no. 11, pp. 2188–2200, 2015. doi: 10.1109/TMC.2014.2381232

[20] S. S. Saab and Z. S. Nakad, "A standalone rfid indoor positioning system using passive tags," *IEEE Transactions on Industrial Electronics*, vol. 58, no. 5, pp. 1961–1970, 2011. doi: 10.1109/TIE.2010.2055774

[21] A. Motroni, P. Nepa, A. Buffi, and B. Tellini, "Robot localization via passive uhf-rfid technology: State-of-the-art and challenges," in *2020 IEEE International Conference on RFID (RFID)*, 2020. doi: 10.1109/RFID49298.2020.9244884 pp. 1–8.

[22] A. Motroni, A. Buffi, and P. Nepa, "A survey on indoor vehicle localization through rfid technology," *IEEE Access*, vol. 9, pp. 17 921–17 942, 2021. doi: 10.1109/ACCESS.2021.3052316

[23] C. Wu, B. Tao, H. Wu, Z. Gong, and Z. Yin, "A uhf rfid-based dynamic object following method for a mobile robot using phase difference information," *IEEE Transactions on Instrumentation and Measurement*, vol. 70, pp. 1–11, 2021. doi: 10.1109/TIM.2021.3073712

[24] C. Röhrig, D. Heß, and F. Künemund, "Constrained kalman filtering for indoor localization of transport vehicles using floor-installed hf rfid transponders," in *2015 IEEE International Conference on RFID (RFID)*, 2015. doi: 10.1109/RFID.2015.7113081 pp. 113–120.

[25] B. Tao, H. Wu, Z. Gong, Z. Yin, and H. Ding, "An rfid-based mobile robot localization method combining phase difference and readability," *IEEE Transactions on Automation Science and Engineering*, vol. 18, no. 3, pp. 1406–1416, 2021. doi: 10.1109/TASE.2020.3006724

[26] C. Wu, B. Tao, H. Wu, Z. Gong, and Z. Yin, "A uhf rfid-based dynamic object following method for a mobile robot using phase difference information," *IEEE Transactions on Instrumentation and Measurement*, vol. 70, pp. 1–11, 2021. doi: 10.1109/TIM.2021.3073712

[27] C. Jiang, Y. He, X. Zheng, and Y. Liu, "Orientation-aware rfid tracking with centimeter-level accuracy," in *2018 17th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN)*, 2018. doi: 10.1109/IPSN.2018.00057 pp. 290–301.

[28] P. Jankowski-Mihuowicz, W. Kalita, and B. Pawowicz, "Problem of dynamic change of tags location in anticollision rfid systems," *Microelectronics Reliability*, vol. 48, no. 6, pp. 911–918, 2008. doi: https://doi.org/10.1016/j.microrel.2008.03.006 Thermal, Mechanical and Multi-physics Simulation and Experiments in Micro-electronics and Micro-systems (EuroSimE 2007).

[29] S. IEC 61000-6-3, *Electromagnetic Compatibility - Part 6-3: Generic Standards - Emission Standard For Residential, Commercial And Light-industrial Environments*. International Standard: IEC, 2020.

[30] M. Hubacz, B. Pawłowicz, and B. Trybus, "Using multiple rfid readers in mobile robots for surface exploration," in *Automation 2019*, ser. Advances in Intelligent Systems and Computing, R. Szewczyk, C. Zielinski, and M. Kaliczynska, Eds., vol. 920. Springer, 2019. doi: 10.1007/978-3-030-13273-6_56 pp. 608–615.

[31] R. Kershner, "The number of circles covering a set," *American Journal of Mathematics*, vol. 61, no. 3, pp. 665–671, 1939. [Online]. Available: http://www.jstor.org/stable/2371320

[32] M. Konieczny, B. Pawłowicz, J. Potencki, and M. Skoczylas, "Application of rfid technology in navigation of mobile robot," in *2017 21st European Microelectronics and Packaging Conference (EMPC) Exhibition*, 2017. doi: 10.23919/EMPC.2017.8346907 pp. 1–4.