Companion robot communication with road infrastructure as part of IoRT

Karolina Krzykowska-Piotrowska[1], Mirosław Siergiejczyk[1], and Piotr Olearnik[1]

[1]Warsaw University of Technology

August 11, 2023

Abstract

IFR forecasts and the conducted literature analysis prove that part of the research should be focused on adapting the companion robot to moving around in open space in external conditions. There is a visible interest in the use of robotic devices in the care and assistance of the elderly or disabled people. However, the external environment still contains many obstacles and barriers. According to the authors, the solution to some of the problems related to movement in outdoor conditions would be to communicate the companion robot with the road infrastructure, inter alia, via IoRT (Internet of Robotic Things). This is why the purpose of this article is to present the concept of communication of the companion robot with the road infrastructure.

Companion robot communication with road infrastructure as part of IoRT

Mirosław Siergiejczyk, Warsaw University of Technology, Faculty of Transport, Warsaw 00-662, ul. Koszykowa 75, e-mail:*miroslaw.siergiejczyk@pw.edu.pl*, ORCID:*https://orcid.org/0000-0003-1953-6262*

Karolina Krzykowska-Piotrowska, Warsaw University of Technology, Faculty of Transport, Warsaw 00-662, ul. Koszykowa 75, e-mail:*karolina.krzykowska@pw.edu.pl*, ORCID:*https://orcid.org/0000-0002-1253-3125*

Piotr Olearnik, Warsaw University of Technology, Faculty of Transport, Warsaw 00-662, ul. Koszykowa 75, e-mail:*kukulek772@gmail.com*

Acknowledgments

Research work financed by the state budget under the program of the Minister of Education and Science (POLAND) called "Science for Society" project number NdS/536964/2021/2021 amount of funding PLN 1,557,100 total value of the project PLN 1,557,100.

Authors declare no conflict of interest.

Abstract

IFR forecasts and the conducted literature analysis prove that part of the research should be focused on adapting the companion robot to moving around in open space in external conditions. There is a visible interest in the use of robotic devices in the care and assistance of the elderly or disabled people. However, the external environment still contains many obstacles and barriers. According to the authors, the solution to some of the problems related to movement in outdoor conditions would be to communicate the companion robot with the road infrastructure, inter alia, via IoRT (Internet of Robotic Things). This is why the purpose of this article is to present the concept of communication of the companion robot with the road infrastructure.

Keywords

companion robot, navigation, road infrastructure, IoRT

Introducion

The International Federation of Robotics (IFR) provides a definition of service robots, according to which „*a service robot is an actuated mechanism programmable in two or more axes, moving within its environment, to perform useful tasks for humans or equipment excluding industrial automation applications* "[1]. It is worth distinguishing two subtypes of service robots, which, according to the same organization, are defined as follows [1]:

a consumer service robot is a service robot built for use by everyone. Neither operation nor setup require a professionally trained operator.

a professional service robot is a service robot built for use by trained professional operators.

It is worth mentioning here that the IFR also provides classifications of robots, including service robots, according to which the companion robot is included in the category of AC robots ("applications", "consumer"), in the AC2 group - Social interaction where the main purpose of the robot is to interact with and entertain users at home and no professional training is required. At the same time, IFR estimates an annual increase in the number of robots by 15-18% starting from 2018. Usually, when researching the market, experts focus on industry and production, but robotization expansively goes beyond this area. IFR in 2022 has registered 1,010 companies producing robots worldwide, including almost 50% of companies from Europe. In addition to industrial robots, the sector of service robots is developing intensively. In the near future, such robots will not only perform simple tasks such as reminding about the time of taking medications, but also will initiate communication and ensure a pleasant entertainment.

The process of demographic aging of the European society, which is taking place and is projected for the future, poses many challenges to the world of science. One of them is to improve the quality of life of the elderly. The simultaneous process of aging and depletion of labor resources makes it necessary to direct research interests towards the potential of innovative aid devices, including companion robots. Although scientists have been designing robots to support the elderly or physically disabled for years, performing tasks that require the accuracy of movements of a few centimeters is still a big challenge.

There are numerous publications on robot navigation in the literature. For example, the monograph edited by Matveev, Savkin, Hoya and Wang [2] from 2016, which is primarily a study in detail and in a uniform way presenting the latest developments in this field. At the same time, the book extends its scope to obstacles subject to general movements, including rotations and deformations, i.e. changes in shape and size, and devotes much attention to reactive algorithms and rigorous mathematical research of proposed navigation solutions, showing the interdependence between mathematics and robotics. It is similar in the publication of Möller et al. (2021) [3], where it was recognized that the design of a robot serving society that can act as a companion must take into account different areas of research. In an article by Calderit et al. (2021)[4] presented a new framework for robot navigation by introducing the concept of time-dependent social mapping. The article describes how areas of interaction change over time and how they affect human conscious navigation. The literature also presents various concepts of mobile robotic platforms for performing specific activities, depending on the age of the people they work with. Solutions in this area are presented in e.g. Cavallo et al. (2014) [5]. The authors review the ASTROMOBILE system, designed to support the elderly by direct delivery of medications or reminders to take them. In addition, Costa et al. (2018) [6] reviewed an interactive robotic system called PHAROS for monitoring exercise for the elderly. A broader approach to the design of interactive social robots was presented by T. Kanda (2017) [7]. In turn, Koval et al. [8] assumed in their research that the robots would function in the urban environment, moving in public space. A network of sensors and models of pedestrian behavior were developed. An experimental evaluation of the Boston Dynamics (Spot) four-legged robot map-based autonomous navigation is presented. For this purpose, an integrated software and hardware system was proposed, which allows the location of the robot and assessment of the risk of path planning based on a known map. Robot Spot is first used to build an offline map of the environment using the Google Cartographer Simultaneous Localization and Mapping (SLAM) suite. In the next step, online environmental information from the sensors and an offline map are provided to the on-board computer to locate the robot.

IFR forecasts and the conducted literature analysis prove that part of the research should be focused on adapting the companion robot to moving around in open space in external conditions. There is a visible interest in the use of robotic devices in the care and assistance of the elderly or disabled people. However, the external environment still contains many obstacles and barriers. According to the authors, the solution to some of the problems related to movement in outdoor conditions would be to communicate the robot with the road infrastructure, inter alia, via IoRT(Internet of Robotic Things). This is why the purpose of this article is to present the concept of communication of the companion robot with the road infrastructure.

Internet of Robotic Things (IoRT)

The definition and architecture of IoRT was first presented by Ray (2016) [9]. He argued that in order to correctly formulate the assumptions of this concept, IoT and the Cloud Robotic should be combined, and it can even be considered that IoRT is an extended or advanced version of the Cloud Robotic. Ultimately he stated that Internet of Robotic Things „*is leveraging certain aspects of Cloud computing such as virtualization technology, and three service models (i.e., software, platform and infrastructure), while utilizing IoT and its enabling technologies to empower tremendous flexibility in designing and implementing of new applications for networked robotics to achieve the goal of provisioning distributed computing resources as a core utility* ". In the same publication, the author distinguished five layers of the IoRT architecture, i.e.:

- hardware/robotic things layer,
- network layer,
- Internet layer,
- infrastructure layer,
- application layer.

The same assumptions were confirmed in publication [10] with the exception that the authors clearly emphasized their application to the Multi Robotic System (MRS). A similar approach is presented in [11]. From the point of view of this article, it is important to identify two basic problems associated with MRS. The authors proposed solutions in the field of e.g. task planning or target tracking. Publication [12], in turn, presents a new IoRT architecture specifically addressing the issue of heterogeneity and interoperability of robots. The elements of architecture, connection with the environment, monitoring, planning system and knowledge base of the system were defined.

The challenges of IoRT are also presented in publication [13]. Importantly, the authors referred to the Industry 4.0, claiming that the IoRT concept, i.e. the convergence of the Cloud Robotic and IoT, generates various opportunities, both in business and science. It covers a number of sectors, including agriculture, manufacturing, health and education. At the same time, the technology and framework of the Internet of Robotic Things, as the authors emphasize, seem to have a significant impact on everyday life. It is therefore important to promote research and analysis on remote and automated applications.

Batth et al. (2018) [14] identified a set of characteristics features of IoRT systems (Fig. 1).

Fig. 1 Set of characteristics features of IoRT systems

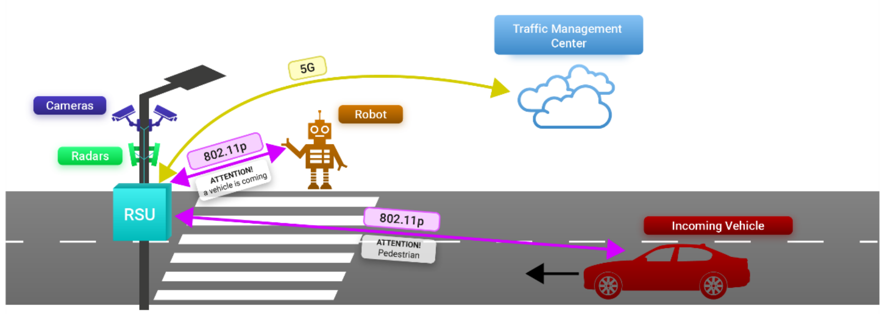
The concept of wireless communication of a companion robot with road infrastructure

The robot's perception system allows it to identify obstacles and potential threats in LOS (Line of Sight). The problem arises when a vehicle approaching a pedestrian crossing is obscured by an obstacle. Weather conditions and visibility on the road may also be a problem, where its limitation may result in incorrectly interpreted surroundings. A potential opportunity to enable the identification of threats beyond the line of sight NLOS (Non Line of Sight) is wireless communication. It is assumed that the robot in the road infrastructure will be identified as a pedestrian. Therefore, it can be considered that V2P (Vehicle to Pedestrian) systems are potential solutions in such communication. V2P is most often based on DSRC (Dedicated Short Range Communication) technology, which is considered by standard legislators and technical committees to be one of the most appropriate in terms of the safety of road users at risk. It constitutes a solid basis for the model of the discussed communication.

The 802.11p standard used by the PHY layer and MAC operating in the 5.9 GHz band was designed for V2X (Vehicle to Everything) communication. No need to establish a BSS (Basic Service Set) connection means that even in conditions of high mobility it is able to support the exchange of messages with relatively low delays. The use of a licensed band in this case allows for increased reliability and safety in sending critical messages between a pedestrian (robot) and a vehicle. The main barrier in designing a V2P communication system is equipping pedestrians with devices enabling transmissions in the assumed standard. In this case, smartphones can be a potential device for communication with vehicles. The barrier in the implementation of DSRC technology is its implementation in smartphones. Qualcomm Research in partnership with Honda R&D Americas Inc. already in 2014, it addressed this problem by developing the possibility of updating the Wi-Fi software in Android phones to support DSRC [15].

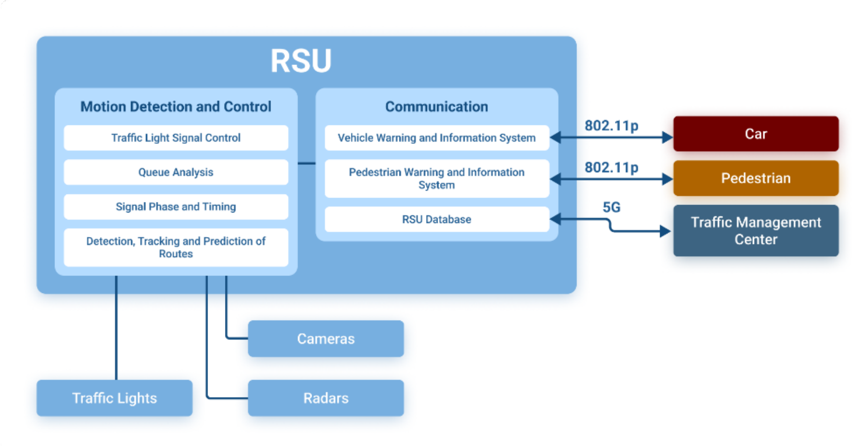
The security subsystem in a smartphone can be designed in a similar way to that of a vehicle, but reduced by an identification component. In addition, for obvious reasons, it has a different detection algorithm and other HMI capabilities. The smartphone is equipped with two additional modules: power consumption control and overload control. The power consumption control module reduces battery consumption by minimizing the duty cycle of the overall security system. In the case of the companion robot, it is assumed to use the DSRC module and configure it with the rest of the components in such a way that it is interpreted as a pedestrian in the above-described concept. Such an approach to the communication model will significantly reduce production and design costs, as it will be compatible with the existing infrastructure.

According to the definition, communication in the V2I (Vehicle to Infrastructure) model enables vehicles to communicate with systems managing road infrastructure. By processing data from many sources, these systems are able to visualize the road situation. Data from management systems are then sent to road users, which allows them to take specific actions. The concept is based on direct communication between the robot and the vehicles via a shared DSRC channel. By placing a roadside RSU (Road-Side Unit) equipped with cameras and radars between the robot (pedestrian) and the vehicle, the effectiveness of the communication system between the robot and the road infrastructure could be significantly increased (Fig. 2).



Rys. 2 Example of robot-RSU-vehicle communication

The robot and the vehicle connect to the RSU using the 802.11p standard. Based on data from radars, cameras and the communication module, the RSU is able to warn the robot and the vehicle about a potential threat. The additional use of the RSU will protect against a scenario where the approaching vehicle will not be equipped with the DSRC module or it will be out of order. In such a situation, RSU will be able to independently check the speed of the approaching vehicle and warn the robot about it. Key data collected by the roadside unit is sent via the 5G network to the Cloud Traffic Management Centre via IoRT. The roadside unit can also be part of traffic signals at pedestrian crossings. Communication with the unit that is part of the traffic light will allow to control road traffic. This makes the reliability of information independent of the cameras and radars, thereby reducing the likelihood of false news.



Rys. 3 Simplified block diagram of a RSU

The block diagram of the RSU presented in Fig. 3 has been divided into two main blocks. The motion detection and control block is responsible for detecting, tracking and predicting the routes of objects. In addition, this block is responsible for analyzing queues, controlling traffic lights and modifying the phase and time of the SPAT (Signal Phase and Timing) signal to improve traffic flow and save fuel. The communication block consists of information and warning systems for pedestrians and vehicles. In order for these systems to function, it is necessary to use the DSRC module and transmitting and receiving antennas, thanks to which roadside units will be able to exchange information with road users. An additional element of the communication block in the proposed diagram is the RSU database system, which collects data received from the block of traffic detection and control as well as warning and information systems and shares them with the Traffic Management Center via IoRT. Communication between the database and the center will be enabled by 5G technology, which requires the use of a transmitting and receiving antenna and a GSM module.

Conclusions and recommendations

Real-time communication with the robot requires stable connectivity throughout the network coverage area. This means that despite the decrease in the received signal strength indicator, the delays should be relatively low and the bit rates should be stable. Higher bit rates in the case of robot operation, they are not as important as delays and connection stability. In the 802.11p standard, there is no need to establish a connection with the BSS, which enables immediate broadcasting in the channel, recommendation: care for data security - the standard does not provide it. In turn, the main advantage of DSRC is the possibility of multi-directional monitoring of the traffic situation (in the NLOS option) without fear of obstacles. The appropriate range is about 1 km, and the effectiveness of the technology with response systems has been confirmed at speeds of up to 500 km/h. In addition, if the 802.11 (WiFi) standard is included in the communication, it should be remembered that transmission security remains an issue. Problems that often arise with WiFi systems are due to improper hardware selection, poor design, or incorrect software configuration. IoRT additionally gives the possibility of collecting, processing and transmitting data through cloud.

References

[1] Müller, Ch.; Graf, B.; Pfeiffer, K. (Eds.): World Robotics 2022 – Service Robots, IFR Statistical Department, VDMA Services GmbH, Frankfurt am Main, Germany, 2022.

[2] Matveev, A.S.; Savkin, A.V.; Hoy, M.; Wang, Ch. Safe Robot Navigation Among Moving and Steady Obstacles, Elsevier, 2016.

[3] Möller, R.; Furnari, A.; Battiato, S.; Härmä, A.; Farinella, G.M. A survey on human-aware

robot navigation, Robotics and Autonomous Systems, Elsevier, Volume 145, November 2021.*https://doi.org/10.48550/arXiv.2106.11650*

[4] Calderita, L.V.; Vega, A.; Bustos, P.; Núñez, P. A new human-aware robot navigation framework based on time-dependent social interaction spaces: An application to assistive robots in caregiving centers, Robotics and Autonomous Systems, Elsevier, Volume 145, November 2021.*https://doi.org/10.1016/j.robot.2021.103873*

[5] Cavallo, F.; Aquilano, M.; Bonaccorsi, M.; Limosani, R.; Manzi, A.; Carrozza, M.C.; Dario, P. Improving Domiciliary Robotic Services by Integrating the ASTRO Robot in an AMI Infrastructure. In Gearing Up and Accelerating Cross-fertilization between Academic and Industrial Robotics Research in Europe; Rohrbein, F., Veiga, G., Natale, C., (Eds.); Springer: Cham, Switzerland, 2014; pp. 267-282.*https://doi.org/10.1007/978-3-319-03838-4_13*

[6] Costa, A.; Martinez-Martin, E.; Cazorla, M.; Julian, V. PHAROS—PHysical Assistant RObot System. Sensors 2018, 18, 2633.*https://doi.org/10.3390/s18082633*

[7] Kanda, T. Enabling Harmonized Human-Robot Interaction in a Public Space. In Human-Harmonized Information Technology, Nishida, T., Eds.; Springer: Tokyo, Japan, 2017; pp.115-137.*https://doi.org/10.1007/978-4-431-56535-2_4*

[8] Koval, A.; Karlsson, S.; Nikolakopoulos, G. Experimental evaluation of autonomous map-based Spot navigation in confined environments, Biomimetic Intelligence and Robotics, Volume 2, Issue 1, 2022, 100035, ISSN 2667-3797,*https://doi.org/10.1016/j.birob.2022.100035*

[9] Ray, P.P. Internet of Robotic Things: Concept, Technologies, and Challenges, IEEE Access, vol. 4, pp. 9489-9500, 2016,*https://doi.org/10.1109/ACCESS.2017.2647747*

[10] Homayun Kabir, Mau-Luen Tham, Yoong Choon Chang, Internet of robotic things for mobile robots: concepts, technologies, challenges, applications, and future directions, Digital Communications and Networks, 2023, ISSN 2352-8648,*https://doi.org/10.1016/j.dcan.2023.05.006.*

[11] Verma, J.K.; Ranga, V. Multi-Robot Coordination Analysis, Taxonomy, Challenges and Future Scope. J Intell Robot Syst 102, 10, 2021*https://doi.org/10.1007/s10846-021-01378-2*

[12] Loza-Matovelle, D., Zuniga, C., Zalama, E. et al. Task Planning System with Priority for AAL Environments. J Intell Robot Syst 107, 19, 2023,*https://doi.org/10.1007/s10846-023-01806-5*

[13] Madaan, G., Swapna, H.R., Singh, S., Arpana, D. (2023). Internet of Robotic Things: Issues and Challenges in the Era of Industry 4.0. In: Kumar, R., Pattnaik, P.K., R. S. Tavares, J.M. (eds) Next Generation of Internet of Things. Lecture Notes in Networks and Systems, vol 445. Springer, Singapore.*https://doi.org/10.1007/978-981-19-1412-6_8*

[14] R. S. Batth, A. Nayyar and A. Nagpal, Internet of Robotic Things: Driving Intelligent Robotics of Future - Concept, Architecture, Applications and Technologies, 2018 4th International Conference on Computing Sciences (ICCS), Jalandhar, India, 2018, pp. 151-160,*https://doi.org/10.1109/ICCS.2018.00033*

[15] X. Wu et al., Cars Talk to Phones: A DSRC Based Vehicle-Pedestrian Safety System, 2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall), Vancouver, BC, Canada, 2014, pp. 1-7,*https://doi.org/10.1109/VTCFall.2014.6965898*