1.2 Technical Topics

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Digitalization of an Indoor-Positioning Lab Using a Mobile Robot and IIoT Integration

Abstract

Industry 4.0, the Industrial Internet of Things (IIoT) as well as Smart Logistics depend on locating mobile assets. In contrast to outdoor locating, GPS is not reliable for indoor positioning. Instead, different real-time locating systems (RTLS) are used in industries for indoor locating when there is no chance of obtaining GPS-satellite signals. Students in engineering disciplines should know about the chances offered by and the limits of RTLS, for example through corresponding lab experiments. However, measuring the accuracy of RTLS is a time-consuming task. Our goal is to provide a remote RTLS-accuracy measurement experiment by digitalizing and automating the whole process.

This paper discusses adding remote experiment service to this lab, thus providing access to the lab infrastructure anytime and anywhere. A mobile robot was used to move an ultra-wideband (UWB) transponder and expose it to the RTLS measurement infrastructure. By optimizing the routing algorithm of a mobile robot, the required accuracy and appropriate safety features were justified and the accuracy of the robot reached 2 cm. It also passed all the static and dynamic obstacles with acceptable safety thanks to inbuilt sensors. The remote operation was also done in an IoT environment by implementing the MQTT data transfer protocol. For remote users to be able to operate our RTLS system via MQTT, we developed a software program. When running this program, our DigiLab4U Laboratory Management System (LabMS) is able to send commands to the RTLS system and receive positioning measurements of a mobile object (in our case RTLS tag) via MQTT messages. Thus, the real route and the measured route can be compared and the difference can be analyzed by students remotely.

Keywords

Automated Guided Vehicle (AGV), RTLS, Industrial Internet of Things (IIoT)

1 Introduction

To enable indoor positioning within industrial applications different real-time locating systems (RTLS) are used by some industries (Uckelmann & Wendeberg, 2015). The University of Applied Sciences Stuttgart (HFT Stuttgart) provides laboratories equipped with different RTLS solutions to be used for research and education. In industrial environments and indoor applications particularly, high accuracy is sought after for position estimation. Objects within the range of the system can be located in real-time through the use of active UWB transponders. In the past, a person placed UWB transponders at specific locations inside the Position Lab and used the Ubisense system to locate the asset. However, in some conditions, this person would be placed between the tag and Ubisense receivers, which could affect the experiment's accuracy. In parallel, the real position was measured manually. Both sensor measurement and physical measurement were compared to analyze the accuracy of the results provided by the system. In engineering education, students need to understand the accuracy and limits of such systems. Doing experiments in this lab, students are able to learn more about the general concepts of positing as well as take a deep dive into a specific RTLS configuration. However, up to now, students had to do lab experiments in the lab, thus limiting the access HFT students have to it and its operational hours, which have been even more limited during the current coronavirus pandemic.

The research project Open Digital Lab 4 You (DigiLab4U) (Pfeiffer & Uckelmann, 2019) aimed to digitalize and automate real laboratories in order to allow remote access to corresponding lab infrastructures. Automating the RTLS transponder placement was identified as the main challenge. Furthermore, the integration of remote access to control the available laboratory instruments using the Internet is the second requirement that is discussed in this paper. In the following sections, the research background of the project as well as its main challenges and proposed solutions will be discussed.

2 Background

In order to enable remote experiments for the DigiLab4U Positioning Laboratory, the main challenge was the automation of transponder movement. The corresponding lab is placed in a room which is not only being used as a laboratory, but also as a lecture room. Thus, it contains rigid and movable equipment. So, our proposed solution should be able to be flexible enough to operate in such an environment. Different automation methods such as a 3D-portal robot, controllable drones, and integrating several PLC controllers and a quadcopter (Keßler et al., 2021) were considered in an initial approach. Each of these methods has its own implementation, control, and integration challenges to satisfy the remote criteria. Finally, the Robotino mobile robot (Essaidi et al., 2020; Masmoudi et al., 2016), made by the company Festo, was selected as a suitable solution. The Robotino platform provides specific functionalities designed to be operated in a laboratory environment. It supports odometry functionality to move from its actual position to the desired destination (Baatar et al., 2014). Position estimation is another important feature that is also supported by an odometer (Bischoff et al., 2012). But, its accuracy can be affected by surface materials as well as the speed of the robot. Thererfore, some marking labels were added to the laboratory floor to achieve more accurate autonomous movements (Panigrahi & Bisoy, 2021). This functionality can be supported by different sensors such as Lidar (Wang et al., 2019), a North star sensor, or a camera (Alcantarilla et al., 2010). Detecting those labels via image processing algorithms, the mobile robot can calibrate itself and compensate for the occurring error between two marking labels. As a result, once the robot is in the vicinity of a nearby marking label, its movement strategy will be changed according to a set of behavior strategies (Goel et al., 1999). Robotino also has the ability to bypass static and dynamic obstacles and avoid any collision. The movement functionality developed for the Robotino will be discussed in more detail in the following sections. Defining an instruction set and developing a MQTT interface are the next steps to enable the mobile robot to be operated remotely.

3 Ubisense System and Data Communication

GPS has successfully proven its ability to accurately determine positions when used outdoors. However, it is known that this technology is not suitable for indoor positioning. Therefore, tracking systems that provide real-time indoor locating are required. In comparison to GPS for an outdoor application, indoor RTLS solutions are less standardized and differ in accuracy when determining positions. The authors (Ruiz & Granja, 2017) specifically refer to the UWB-Ubisense platform, as it achieves higher accuracy compared to Bluetooth Low Energy or WiFi-based RTLS solutions by using better algorithms and including additional parameters to calculate real-time position data. Now, more and more UWB-based solutions are competing in a small market.

Like other Ubisense installations (Corrales et al., 2008), the specified setup used in the DigiLab4U positioning laboratory consists of the installation of four Ubisense satellites (Figure 1).

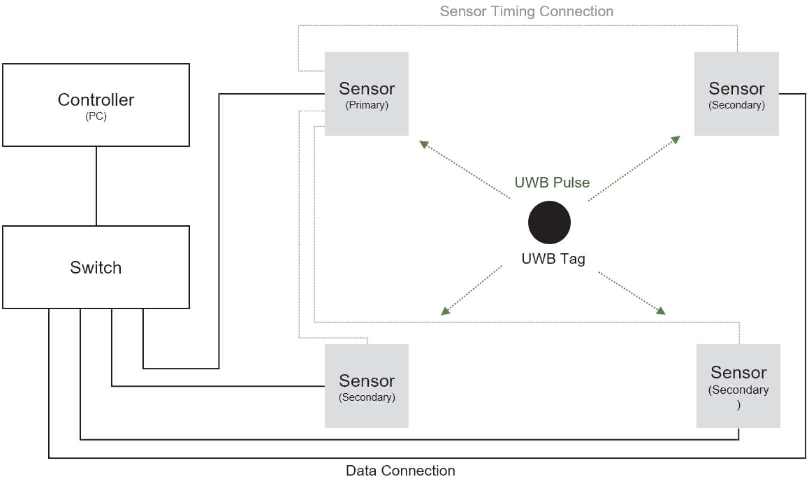

Figure 1: Ubisense architecture (Corrales et al., 2008)

These sensors are positioned in the corners of the laboratory area. The system determines the current positions of the transponders and reports the coordinates to the tracking system. This includes information on the current coordinates (X, Y, Z) with a time stamp and a parameter indicating the standard error.

Ubisense provides a software interface for application development. For the development of the position laboratory, a software component was implemented using the .NET library. Here, the application enables the processing of the position data calculated by the Ubisense system.

The Position Lab connects a variety of systems to perform experiments. Within the system components, different sets of data are processed. In addition to measurement results and telemetry data, it is also necessary that the system can process control commands. Furthermore, the communication interface should satisfy special requirements in order design a robust system with a high degree of flexibility. MQTT has become a standard choice for M2M applications in IoT environments due to these properties (Mishra & Kertesz, 2020).

The server and client architecture specified in the MQTT standard allow data to be communicated between IT systems. Messages are transmitted via a central broker to clients with an active connection. A client is able to transmit data in a strictly structured way by subscribing to or publishing a topic. The communication in the DigiLab4U position laboratory is managed by two central topics, which handle the exchange of sensor readings and the execution of control commands. The fact that control commands are processed by this system means that special security requirements must be met. Only authorized users should be able to send control commands through the designated topics. Therefore, each user must be authenticated.

The proposed architecture allows the communication of the measurement results and control of components that are relevant for the operation of measurements. As a result, the system provides the data required for the user to be able to compare and assess the accuracy of the position data.

4 Mobile Robot Automation

Previously, robot systems were restricted to a stationary position. Mobile robots represent the next step in the development of robotics in that they can execute the same tasks as their stationary predecessors but, in addition, can move away from one position to another. This provides the prerequisites for dealing with countless additional tasks. The main motivation for the creation and development of mobile robots is due to the desire to use the robots to operate alongside humans in the same environment. This part of the paper contains a scheme for efficient automation of a mobile robot (Robotino) with an indoor positioning system (Ubisense). Three wheels on the robot are used to control the omnidirectional movements (Panigrahi & Bisoy, 2021). The wheels are mounted symmetrically at 120 degrees from each other. Robotino is a fully functional, high-quality mobile robot system with omnidirectional drive. In addition, it is equipped with a webcam and several types of sensors, analog for distance measurement, e.g., binary for collision protection and digital for checking the current speed. The programming of the robot was done in a Sequential Function Chart (SFC), a Function Block Diagram (FBD), and Lua script languages using Robotino View.

As part of the remote experiment infrastructure, this robot should be integrated into DigiLab4U LabMS. This feature is implemented by creating a Python application that communicates with the robot via UDP. As a LabMS supports MQTT (Adineh et al., 2022), the application implemented should use the interface to the LabMS provided.

Robotino View

Robotino View is an integrated development environment (IDE) specifically designed for the Robotino robot. The IDE supports fast and easy development of SFC, FBD, and Lua script programs. It is a professional tool for creating simulation models. The programming of the Robotino is implemented by creating the function blocks and these function blocks are operated via SFC.

Outline of the Robotino's Automation

The goal of the Robotino is to move inside a specified zone in the laboratory environment. The mapping of the Positioning lab is shown in figure 2.

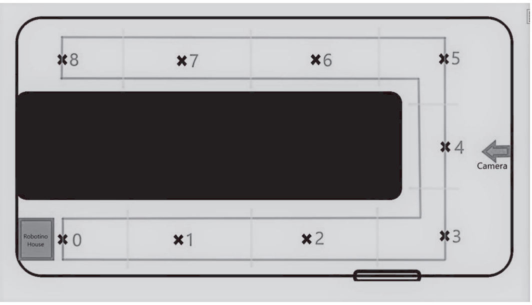

Figure 2: Room mapping with marking labels (crossed points)

There is a U-shaped area for the robot's movement and the crossed points are the marking label locations. The area can also contain some static and dynamic obstacles. The goal of the robot is to receive the command based on the 3D dimension and arrive safely at the desired position within an optimized time frame. 9 marking labels are attached to the ground to be identified and mapped by the camera. The Robotino will move between the marking labels and after an initial calibration, the robot will move to the defined position using 2D coordinates. Finally, a Z-axis actuator will play its role in enabling the robot to reach its final position. The main function blocks implemented are:

- Rotate and approach
- Marking label settings
- Angle calibration
- Collision-free
- Movements around the obstacles
- Driving

A rotate and approach function block has the controls to rotate the Robotino and to find and approach the marking label to compensate for an encoder error. Marking label settings generate the commands for the Robotino to go to the specified marking labels based on the nearest current marking label and the nearest marking label to the final position. Angle calibration is another important function block for appropriate positioning. This function block operates based on the upcoming marking label to specify the fixed angle of the gyroscope that is attached to the robot. Collison-free and movement between and around the obstacles were also a big challenge to ensure that the mobile robot can be operated remotely. These function blocks work with the signals generated from infrared sensors, collision detection sensors, and a laser scanner. Finally, the drive function block has the controls to move the robot based on an odometer and control the movements using all the signals generated.

5 Conclusions

In the course of the research, an investigation into multiple feasible methods of “RTLS transponder positioning automation” was conducted, resulting in the selection of a Festo Robotino platform to be integrated into the laboratory environment. The mobile robot can be programmed with the “Robotino View” application, a visual drag and drop programming environment. It supports “close loop control” and “concurrent functions block operation” via a sequential function chart (SFC). The developments were inspired by similar concepts for an Automated Guide Vehicle. For example, the Robotino was programmed to be able to detect and bypass obstacles. Furthermore, the use of label markings on the floor as well as image processing algorithms allowed the system to achieve a higher accuracy in planning and mapping the defined routes.

Additionally, the integration of the Ubisense RTLS into the Position Lab infrastructure was achieved. The communication of the individual components was implemented by using an MQTT interface.

6 Future Work

After automated RTLS transponder positioning and a remotely operable Ubisense system have been integrated, remote experiments can be executed. Furthermore, implementing Laboratory Management System (LabMS) libraries from DigiLab4U will enable the development of an integrated platform to manage remote experiments by interacting with instruments using IIoT protocols for device communication. By providing a web-based user interface, as has been done for RFID Labs (Pfeiffer et al., 2022), the DigiLab4U infrastructure and underlying services can be accessed by users.

Safety is currently provided by limiting access to the corresponding room during test cycles. However, this process is not yet automated. As the room can be accessed by students when no testing is performed, the robot needs to be secured to avoid (un-)intended damage. To achieve this, an automated robot garage is planned. The educational outcomes still need to be evaluated during lectures. A corresponding evaluation is planned during the summer term 2022.

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