IoT and Robot Control Interoperability in Human-Robot Collaboration Environments

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Abstract

With humans and robots working in closer proximity in many industrial applications, there is a need to merge data from both. But robots typically manage information in middleware or control environments separate from the IoT, which is often the framework for human data information. This paper presents the advantages of IoT and robot control interoperability in human-robot collaboration environments for real-time logistic applications.

Keywords

UWB, RTLS, positioning, industry, HRI, robot, ROS, logistics, IoT, MQTT, IPS

1. Introduction

With the growth of Industry 4.0 and information technologies, there is increasing interest in process automation to optimize resources. Humans and robots must coexist in production plants. However, to increase staff performance rates, it is necessary to ensure comfortable and safe working conditions and balance economic goals and employee motivation. For many years, there has been a stream of research dedicated to Real-Time Location Systems (RTLS) to achieve this balance in industry human-robot interactions (HRI).

The functionalities of indoor positioning systems (IPS) are varied and can respond to needs or opportunities in a wide range of applications. Some of the most common functionalities are the following:

- **Real-time tracking of users, devices, or both**. Typically for the control of production plants, presence control, and location of heavily transited areas in different time zones.
- **Implementation of proximity alerts**. Sometimes it is convenient to know when an operator or a device is close to a defined area to execute an action. For example, in the field of industrial safety, if a worker approaches an area where there is an industrial robot in motion, it is desirable to stop the robot.
- **Warehouse management**. A handy application is the automatic management of stocks in current resource management programs. For example, when a device enters/leaves the warehouse, its availability is automatically updated in the program's database.
- **Process optimization**. For example, when a device enters a specific production area, it can start another production zone and start running another process. This reduces waiting times at workstations.
- **Routing and navigation**. These types of applications are similar to those offered by global positioning systems. It tries to select the shortest route from one point to another, but inside buildings.

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• **Study of behavioral patterns**. Much research is currently being invested in this area, especially in marketing. The aim is to determine how long users spend in certain areas to increase sales, improve infrastructures, or modify the processes.

There are various positioning technologies that operate based on radio waves, magnetic waves, acoustic waves, infrared, or satellites. However, the current trend is the implementation of radio-wave positioning systems in enclosed spaces. These are divided into narrowband radio communication systems, such as Bluetooth or WiFi, and ultra-wideband systems. In addition, 5G positioning should be considered, but this technology is not fully mature nowadays, there are still many limitations that need to be addressed before we see the technology widely deployed.

Ultra-wideband (UWB) technology has gained significant importance in the field of indoor positioning because it allows, in most cases, direct distance measurements with various calculation methods, not merely employing the received signal strength (Figure 1). This technology can generate positioning data with accuracies of less than 10 centimeters. It also provides greater robustness in environments where the presence of obstacles between transmitter and receiver is significant, as radio waves are very short signal pulses (in the order of nanoseconds) in an ultra-wide frequency band that hardly interfere with the signals of other positioning technologies and can pass through many structures [1]. This makes it easier to measure the signal's arrival time at the receiver, which makes this technology ideal for precise positioning calculations.

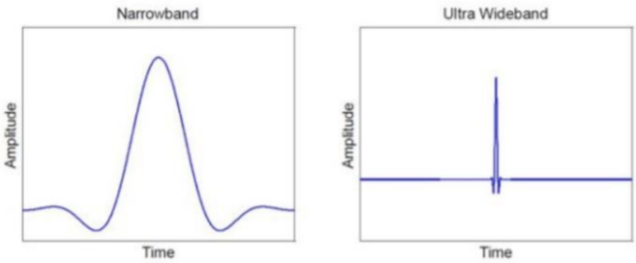

Figure 1: Common signal and UWB signal [2]

On the other hand, the radiated power levels of UWB chips are very low, in the order of half mW compared to several hundred mW for Bluetooth and tens of mW for WiFi. This means that the autonomy of the devices where the UWB chip is integrated is practically unaffected.

A comparative table with the technical data of the aforementioned indoor positioning technologies is summarized in the Table 1 [3].

Table 1
Comparison between indoor positioning technologies [3]

	Bluetooth	WiFi	UWB
Accuracy	1-5 m	1-15 m	5-30 cm
Frequency band	2.4 GHz	2.4-5 GHz	3.1-10.6 GHz
Coverage	<100 m	<150 m	<250 m
Data transfer	<20 Mb/s	<1 Gb/s	<100 Mb/s
Latency	>3 sec	>3 sec	<1 msec
Scalability	<1000 tags	<1000 tags	>10000 tags
Power consumption	Low	High	Low
Reliability	Very sensitive to Multipath, obstacles and interferences	Very sensitive to Multipath, obstacles and interferences	Not very sensitive to Multipath and interferences

These UWB localization systems allow greater human-robot interaction while providing relevant information on the efficiency of production systems. The integration of data from all points of a production process (machines, humans, products) allows the control, monitoring, and analysis necessary to achieve efficient systems. In the case of IoT systems, the use of communication brokers with MQTT protocol is one of the widely standardized solutions due to its simplicity and lightness.

On the other hand, using the ROS (Robot Operating System) platform as middleware for interaction with robots is also a widely accepted solution within robotics applications. This middleware provides standard operating system services such as hardware abstraction, low-level device control, implementation of commonly-used functionality, inter-process message passing, and packet maintenance.

This article evaluates a UWB localization system and its application to determine the position of humans and robots in industrial environments with high accuracy for its integration into the ROS architecture of a mobile robot to track operators in their logistic tasks.

2. Interoperability between ROS and UWB

In this paper, we have an IoT indoor positioning system with UWB technology with which the location of assets in a given workspace can be obtained with high precision. On the other hand, the aim is to implement a logistics application for tracking operators by mobile robots to facilitate working conditions and comfort. There is also a mobile robot with the ROS software architecture. The main objective here is to achieve the interconnection of both systems (robot control and IoT system) to implement such an application.

2.1. UWB positioning system by Pozyx configuration

The system is composed of three different parts (Figure 2).

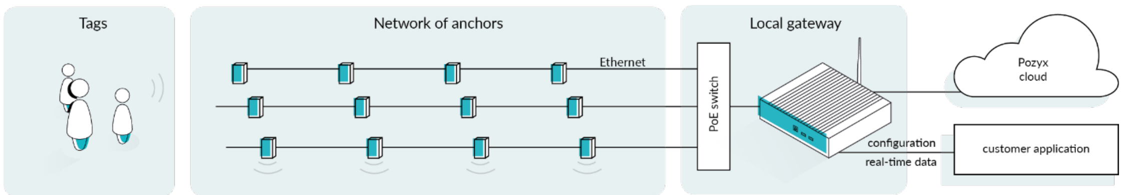

Figure 2: Components of the Pozyx positioning system [4]

Firstly, a **network of antennas and tags** form the main structure of the communication system to obtain the real-time positioning of people or mobile objects. The tags are mobile devices whose position is to be known as well as the orientation if needed. At the same time, the antennas are devices that are fixed at a given position and receive the information emitted by the tags.

Secondly, a **gateway**. This device is the positioning server and connects the antennas via Ethernet. It also collects the data it receives from the antennas and converts it into positions. The Gateway enables the connection to the Pozyx web application and the ROS module developed to access the data generated by the positioning system. To do this, an MQTT bridge must be made through the public IP generated by the Gateway when it connects to the Internet and through port 1883.

Finally, the **web interface**. Here the devices can be configured, and it allows us to view the trajectories followed by the tags connected to the server in real-time.

2.2. RB-1 mobile robot from Robotnik company

RB-1 is an autonomous mobile robot for transporting loads indoors that supports loads of up to 50 kg and has up to 10 hours of autonomy [5]. The Figure 3 shows the laser sensor used for navigation and localization and a Red Green Blue Depth (RGB-D) sensor for obstacle detection.

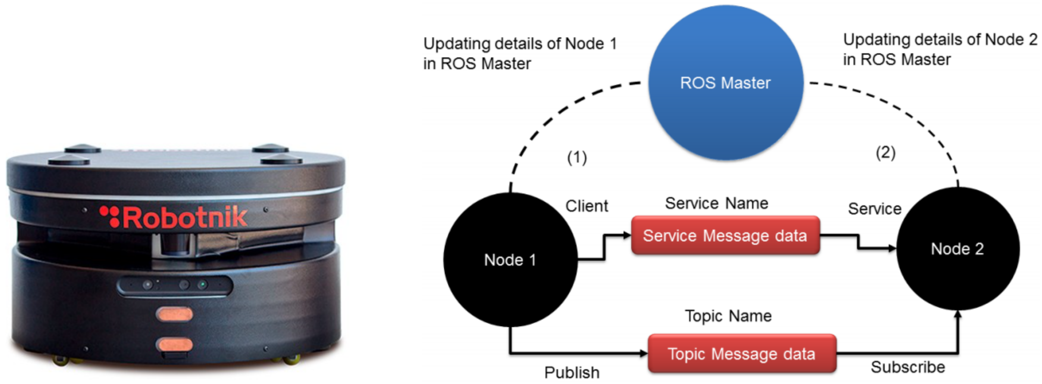

Figure 3: RB-1 base from Robotnik company / Basic operating scheme of ROS [7]

RB-1 is based on ROS, an open-source framework based on a graph architecture where processing takes place in nodes that can receive, send and multiplex messages from sensors, control, states, schedules, and actuators, among others [6]. These nodes communicate with each other under the hierarchy of the Master node, as shown in the above diagram. Thus, each node sends messages to a particular topic. Sending messages to a topic is called "publishing," and reading the data of a topic is called "subscribing." Messages can be of integer, floating-point, or Boolean type, but a given topic can only send or receive one type of message at a time.

On the other hand, there are services when an interaction between nodes is required. Services have a message type definition, so we can send a service request to another node that performs it. The result of the service is sent as a response. The node must wait until the result is received at the other node. This is also shown in the diagram above.

The library is oriented for a UNIX system (Ubuntu -Linux) although it is also being adapted to other operating systems.

2.3. Interconnection module between the localization system and the robot

For the two systems to interoperate, it is necessary to create an interconnection module to be executed in the mobile robot. First of all, the antennas read the position of the active tags, in this case, the operator tag and the mobile robot tag. This information is processed in the Gateway or server, where the MQTT broker is. Now, it is possible to subscribe to the topic that the broker raises with the positions of the tags. Next, a module is developed in ROS with an MQTT client to receive the position data of the tag carried by the operator and the robot tag. This position data can be filtered to calculate the trajectory that the robot must follow to stay close to the operator at all times, always maintaining a safety margin. The functional diagram is shown in Figure 4.

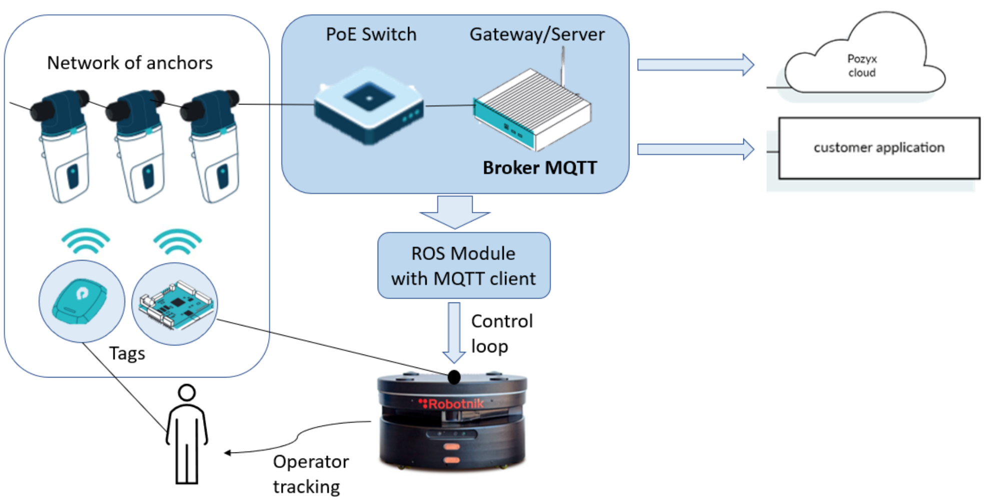

Figure 4: Interoperability scheme between ROS and UWB system

3. Application

Service robotics is booming in the logistics sector. The automation of processes and optimization of resources is constantly growing, aiming to reduce heavy or tedious tasks for operators. The industry increasingly requires autonomous robots to move freely around the work environment without being constantly supervised by operators.

However, in order to be able to track the human, the robot first needs to identify the human. Taking advantage of the UWB localization system makes it easier to track using tags without integrating artificial vision into the robot, as is usually the case. This system provides the robot with information on the human's position without processing the data obtained by its sensors. Moreover, as each tag has its identifier, the robot only needs to be told which tag to follow.

This application aims to free operators from transporting small or medium-sized loads through production areas, which guarantees greater comfort for the operator and improves risk prevention in terms of industrial safety (Figure 5). The robot tracks the operator (tag holder) employing the UWB localization system, always respecting a safety margin between the robot and the operator. The robot continuously reads the operator's position through an MQTT client implemented in the ROS module developed and tries to stay close to the last position read. Thus, when the operator stops to perform a task, the mobile robot stops, and the operator can place the load to be transported on its platform. Once the load has been deposited, the operator starts his trajectory again, followed by the robot towards a new destination point where the load will be deposited. It is important for the navigating robot map and the map loaded in the Pozyx interface to calculate the coordinates of the tags to have the same origin, so the coordinates in the robot map are the same as the coordinates in the Pozyx map.

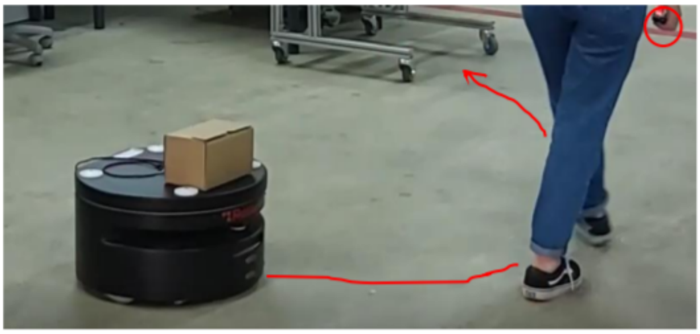

Figure 5: Operator tracking using ROS module developed for logistics applications.

The code developed to achieve this application would be as follows. Firstly, establishing the identifier of the tag that the robot carries and the identifier of the tag that it must follow. Secondly, the user has to create an MQTT connection thread to the broker in the ROS module (Figure 6) to obtain the data collected by the UWB localization system. This data is classified according to the identifier of the tag that emits it. Thus, the operator's position is continuously published in the robot's path planning algorithm in another thread because the update frequency of the Pozyx positioning data is higher than the frequency of the robot control loop. In this case, as the robot receives the operator's position at a high frequency, it can shorten the trajectory to be followed if, instead of saving all the positions received, it gives priority to the last one. Therefore, despite the trajectory followed by the human, the robot will track with a longer sampling period than the one for the positioning reading with the UWB location system.

The robot, knowing its position, moves in the direction of the operator's tag, respecting a safety margin around it. However, the robot moves only if the change in actual coordinates compared to previous coordinates is bigger than a specific tolerance, to avoid the robot moving due to the positioning noise of UWB positioning data when it is in a static position.

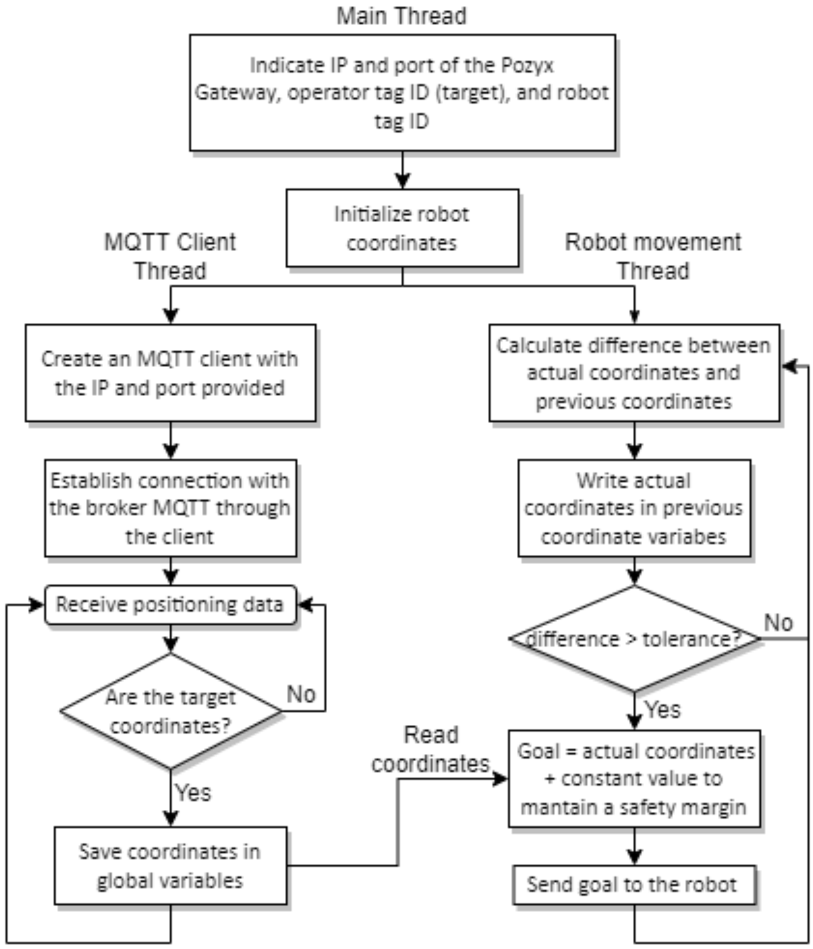

Figure 6: Logical structure for developed ROS module

Thus, the mobile robot tracks the operator employing a virtual sensor, maintaining the robot's autonomy to avoid any obstacles that may come between the robot and the operator during the tracking of the trajectory, in this case, with the conventional sensors installed in the robot.

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