A middleware for inter-vendor mobile robot communication

by

Mai Khanh Isabelle Wilhelm

Matriculation Number 406187

A thesis submitted to

Technische Universität Berlin
School IV - Electrical Engineering and Computer Science
Department of Telecommunication Systems
Service-centric Networking

Master's Thesis

May 2, 2022

Supervised by:
Prof. Dr. Axel Küpper

Assistant supervisor:
M. Sc. Kai Gruntert

Eidestattliche Erklärung / Statutory Declaration

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbstständig und eigenhändig sowie ohne unerlaubte fremde Hilfe und ausschließlich unter Verwendung der aufgeführten Quellen und Hilfsmittel angefertigt habe.

I hereby declare that I have created this work completely on my own and used no other sources or tools than the ones listed.

Darmstadt, May 2, 2022 Mai Khanh Isabelle Wilhelm

Abstract

In this thesis, we show that lorem ipsum dolor sit amet.

Zusammenfassung

Hier kommt das deutsche Abstract hin. Wie das geht, kann man wie immer auf Wikipedia nachlesen `http://de.wikipedia.org/wiki/Abstract`...

Contents

1 Introduction

"Technologies that are emerging today will soon be shaping the world tomorrow and well into the future – with impacts to economies and to society at large. Now that we are well into the Fourth Industrial Revolution, it's critical that we discuss and ensure that humanity is served by these new innovations so that we can continue to prosper."

—Marinette DiChristina, Summer Davos Forum 2019, 01.-03.07.2019

Cyber-Physical Systems, the Internet of Things, and the Internet of Services are key technologies of Industry 4.0 and enhance the manufacturing process of companies [1] [**?**]. To stay competitive, manufacturing processes have to fulfill requirements such as consistency, cost-effectiveness, flexibility, efficiency, and quality. Those challenges are met by automating the process of manufacturing products [2][3][4]. Mobile robots such as Automated Guided Vehicles are used to adapt products better to the customers' needs and changing requirements [3][5].

Mobile robots are machines that use sensors and software to move in their surroundings. They can more easily react to changes than traditional industrial robots [12]. Currently, the adoption of mobile robots is hindered by a lack of communication standardization [1]. In terms of mobile robots, standardization includes interfaces to exchange data. To use mobile robots from different vendors a standard that guarantees a compatible use of interfaces is needed. The advantages of a multi-vendor strategy are that those mobile robots may cover different functionalities. Therefore, they can be more flexibly used in a production line and complete tasks that single-vendor strategies could not complete. In addition to increased flexibility, it is of high interest for industries to be vendor-independent to decrease repair and maintenance costs.

This thesis aims to identify approaches for mobile robot multi-vendor communication and to implement a software solution that realizes that interaction.

In this chapter, a background to the thesis is provided. The second section presents the research problem. Further, the task description, the research objectives, and questions are listed. Thereafter, the significance and the limitations of the thesis are listed.

1.1 Background

The idea of Industry 4.0 was first brought to public attention in 2011 as a project to digitize the industry [7]. Industry 4.0 aims to increase operational effectiveness and efficiency by automating processes, enabling flexible adjustments during production, as well as lowering material and human resources. Connecting devices and exchanging information between them increases the productivity of a facility. Since the devices often are from different vendors, standardized communication protocols are required to do so [8].

Even though Industry 4.0 technologies have been under development for several years, it still faces several challenges such as in real-time data exchange, security, and process flexibility. This thesis focuses on flexibility and data exchange challenges [8]. Because of multiple dependencies in a facility, changes are difficult to implement. Without standard systems become more complex with every change. Hence, a standardization between all devices in the facility is needed to ease communication between them [9][10]. As standards regarding hardware, software and communication are still in development, the companies' ability to use new technologies is limited [11].

Vendors provide their specific applications and interfaces for mobile robots [11]. Therefore, using mobile robots from different vendors to profit from their different strengths and functionalities increases the programming costs [13]. Further challenges are missing external interfaces for communication and a lack of documentation. While some vendors of mobile robots provide detailed documentation of the mobile robot's integration and interfaces, others do not [14].

This thesis is conducted in cooperation with the TU Berlin [15] and the BASF Group which is an industry leader in chemistry [16]. The BASF Group has been working since 2021 on a cooperation project with Stäubli WFT, Sick, and Toyota in which two mobile robots from different vendors are interacting with each other. For that, a mobile robot from Stäublie WFT is manually loaded with chemical goods and transports them further from production to a warehouse. The goods get automatically unloaded after user input by a mobile robot from Toyota [17][18][19][20].

1.2 Research Problem

A communication standard for mobile robots is critically important, especially for industries using multi-vendor mobile robots solutions [8]. A communication standard enables applications and mobile robots to exchange data. It is similar to human language in which unique terms are defined. The term which describes e.g. an action the mobile robot should perform should be understood by any device in the production system. Moreover, defining a standard interface for mobile robots is part of a communication standard.

Different communication protocols and standards for industry 4.0 are under development. [11] As such, these standards are still not completed. Industry 4.0 and mobile robots are a broad field to cover. Therefore, every standard covers a specific mobile robot type for a specific industry area. Several standards are designed for mobile robots in the automotive industry. Specific information about the mobile robots such as manufacture, model name, motors, manipulators, or actions can be exchanged with those protocols. The standards demand the mobile robot to be compliant with its requirements. In addition, to use these standards and protocols in a multi-vendor environment, a middleware is required that addresses the external interfaces of the mobile robots and exchanges their data through protocols. Currently, there exist only middleware solutions integrating mobile robots from the same vendor and connecting a control system to it.

Industry 4.0 is rapidly evolving and to fulfill its flexibility requirements interactions between multi-vendor mobile robots are needed. Current approaches, do not enable a communication between applications and mobile robots with different interfaces for automatic processes. As a result, a middleware enabling multi-vendor robot communication is of critical importance.

This will be adressed in this paper.

1.3 Task Description, Research Objectives, and Questions

Given the lack of middleware to enable communication to mobile robots from different vendors, this thesis aims to identify and implement this approach. A middleware implementing this approach will be created and tested on several mobile robots from different vendors. Through the middleware applications will be able to communicate to mobile robots from different vendors with different interfaces and vice versa.

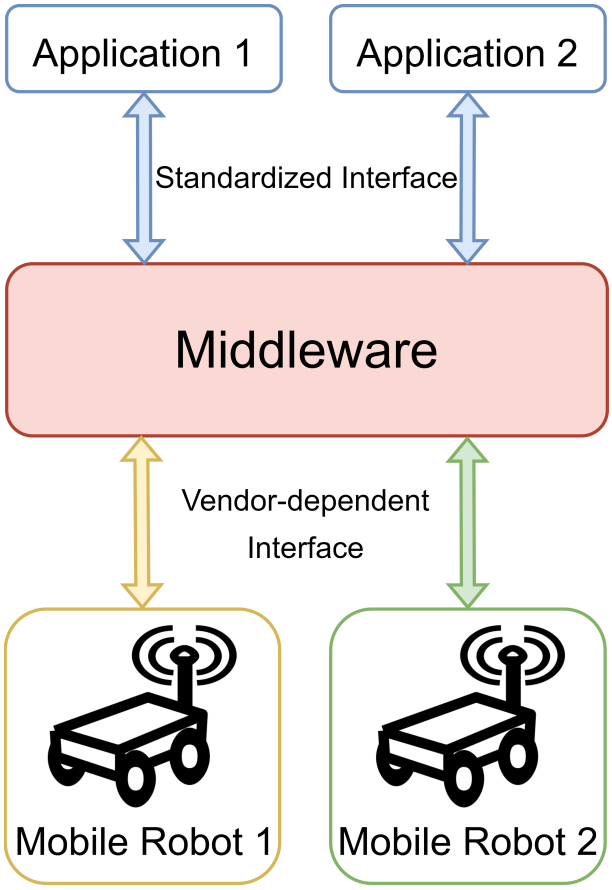

Figure 1.1: Middleware for multi-vendor mobile robot communication[1]

1.3.1 Task Description

The tasks of this thesis can be categorized into three groups: what must be completed, what should and what may be completed, and what may be completed. In the following list, the tasks of the thesis are described where the numbering corresponds to a prioritization of the tasks.

[1] Beasley G. Autonomous Mobile Robots Icon, available at https://www.kindpng.com/imgv/iixwbwo_autonomous-mobile-robots-icon-hd-png-download/

What must be done:

- **Two mobile robots from different vendors must be controllable via a middleware**
  The thesis aims to develop a middleware through which an application controlling the mobile robots and mobile robots from different vendors can communicate with each other. Therefore, the middleware should enable bidirectional communication to two mobile robots from different vendors, adapted to their external interfaces.
- **The mobile robots must be able to drive from point-to-point**
  Mobile robots can execute different actions. One of those actions is the ability to drive. It must be possible to communicate to the mobile robots to execute a drive action through the middleware.
- **The middleware must have a connection to applications that can control the mobile robots and track and document the process**
  Mobile robots usually have their vendor-specific process control system. Manufacturing Execution Systems (MES) control and document the production process [21]. The middleware must have a connection to a MES to be able to control both mobile robots from different vendors.

What should be done:

- **The middleware should have a connection to a business process management (BPM) system**
  BPM systems aim to improve business processes by modeling, analyzing, optimizing, and automating the processes [22]. The middleware should have a connector to the BPM system so that the process of the mobile robots' actions, e.g. driving, can be modeled.
- **The middleware should enable the exchange of information through existing communication protocols and standards**
  Using existing communication protocols and standards for the data exchange benefits the communication through the middleware by defining interfaces and compatibility requirements. It also enables the potential of the middleware by making it easier to add more mobile robots and further applications to the middleware.
- **The use of a mobile robot for a task should be assigned depending on its functional requirements or data**
  Selecting which mobile robot should be used should not be selected randomly, but by the mobile robot's functionalities e.g. whether it can pick up a load, and what its dimensions are. Other criteria for choosing a suitable mobile robot can be the distance to the task or the battery level.
- **The middleware should integrate further mobile robots**
  The middleware should be able to easily integrate further mobile robots from different vendors with different interfaces.
- **Exceptional cases of no suitable robots being available should be handled**
  If no mobile robot which meets the functional and technical requirements exists, an error message should be sent out. Examples of no suitable mobile robot being available could be both mobile robots being out of battery or both mobile robots not having the function the task requires them to have e.g. picking up a too heavy load.

What may be done:

- **The mobile robots may be able to charge**
  After having added the possibility that the mobile robots perform a drive action, it is desired that it may be possible to communicate to the mobile robots through the middleware to charge.
- **The mobile robots may be able to pick up and drop off a load**
  It may be possible to communicate to the mobile robots through the middleware to pick up and drop off a load as well.
- **A manual user input to select a mobile robot may be added to the BPM system to select a suitable mobile robot**
  If both mobile robots are suitable to perform the action an option to the BPM system may be added to manually select the mobile robot. For that, a study on where to add the manual user input may be desired.

1.3.2 Research Objectives

The thesis intends to fulfill four main research objectives to achieve the research aim:

- **RO1 -** To identify the current state of the art in mobile robots multi-vendor communication
- **RO2 -** To identify suitable communication protocols and communication standards for the middleware and to identify which information needs to be exchanged to perform the desired actions (driving, charging, picking up, and dropping of a load) on the mobile robot
  1. To identify communication protocols and communication standards for mobile robots
  2. To compare these protocols and standards in terms of their strengths and weaknesses
  3. To identify required functionalities and information to communicate between two mobile robots and control them to drive, charge, pick up and drop off a load
  4. To evaluate suitable communication protocols and communication standards for two mobile robots to drive, charge, pick up and drop off a load
- **RO3 -** To identify approaches to use existing protocols and communication standards for the data exchange between two mobile robots and a process management application through the middleware
- **RO4 -** To identify the requirements and how applications such as a BPM system can be integrated into the middleware
  1. To identify the required functionalities of the BPM application to control the mobile robots
  2. To identify an approach to integrate a process management application into the middleware and to exchange information between the application and two mobile robots

1.3.3 Research Questions

From those set of research objectives one main research question arises:

RQ1 - How to improve communication of process automation systems with mobile robots from different vendors?
The focus of this research question is to simplify the integration of multiple mobile robots from different vendors.

The main research question composes of several sub-research questions that this thesis aims to investigate:

1. What is the state-of-the-art for multi-vendor mobile robots approaches in production plants?
2. Which protocols and communication standards exist for multi-vendor mobile robots communication?
3. What are the strengths and the weaknesses of each of these approaches?
4. How effective are those protocols and communication standards for a middleware enabling communication between a process management application and two mobile robots to perform driving, charging, picking up, and dropping off a load actions?
5. What data do need to be exchanged and which functionalities are required for an application to control mobile robots from different vendors to drive, charge, pick up and drop off a load?
6. How can a BPM system and a MES application be integrated into a middleware to allow communication between those applications and multi-vendor mobile robots?

There is an optional research question that is of interest in regards to mobile robots multi-vendor systems that this thesis may aim to investigate:

RQ2 - How do mobile robots from different vendors communicate with each other in a production plant?
This research question consists of further interesting aspects that this thesis may cover:

1. What are advantages and disadvantages of direct communication between mobile robots from different vendors in an automated production plant?
2. What are the challenges of direct and indirect communication between mobile robots from different vendors?

1.4 Significance

The pilot project from the BASF Group which uses two different mobile robots in their production line has been configured specifically for those two mobile robots and the given tasks of driving, loading and unloading. To unload the products on top of the first mobile robot, the second mobile robot needs to be manually activated through user input [18]. Fully automating this process reduces significantly the costs and error-proneness, as well as increases the production efficiency. This thesis will bring the industry a step closer to fully automating mobile robot systems from different vendors.

This thesis will contribute to the development of mobile robot multi-vendor strategies and

approaches for industries that use multiple mobile robots in production. The thesis may also be a proof-of-concept for existing protocols and standards, as well as show improvement potential. This thesis is working toward easily integrating multiple mobile robots from different vendors into an automated system without complex configurations ("plug and play"). Mobile robots can be used more flexibly in production plants which will help the industries to stay competitive.

1.5 Limitations

This thesis will implement a middleware for two mobile robots from different vendors for specific actions such as a point-to-point movement. Therefore, the middleware may be limited to the external interfaces and the functionalities of those two mobile robots. It will not be compatible with all existing and future mobile robots. However, it is desired that the middleware is implemented in such a way that it facilitates the process of integrating other mobile robots with similar external interfaces to the two it has been designed for. Furthermore, the middleware may only be using specific protocols and communication standards. It will also not be compatible with all MES, BPM systems, and process control systems.

1.6 Outline

The rest of the thesis is organized as follows: TO BE DONE FOR THE THESIS PAPER

2 Related Work

The state of the art goes here...

3 Concept and Design

Describe the concept and the design of your work here

4 Implementation

Describe the details of the actual implementation here...

5 Evaluation

The evaluation of the thesis should be described in this chapter

6 Conclusion

Describe what you did here

List of Tables

List of Figures

Appendices

Appendix 1

```
for($i=1; $i<123; $i++)
{
    echo "work harder! ;)";
}
```