Dedication

Acknowledgement

Abstract

Keywords:

Contents

List of Figures

List of Tables

Glossary of Acronyms

NN RNN FL: fuzzy Logic

- **CAN** Controller Area Network
-

-

General Introduction

The latest events of the current decade have highlighted the challenges that manufacturers, suppliers, and end customers face during fluctuations in logistics and supply chain processes. Living in a VUCA world—Volatile, Uncertain, Complex, and Ambiguous—requires us to continuously adapt to changes and anticipate future events by preparing our developed environments and scaling our solutions. Simultaneously, it is crucial to maintain high standards that ensure productivity, enhance work safety, and optimize ergonomics.

In this context, the primary objective of intralogistics is to optimize, integrate, automate, and manage internal logistical flows of material and information within distribution centers, warehouses, or manufacturing plants. This subfield focuses on increasing operational efficiency by employing new technologies, such as autonomous robots.

Modernizing industrial environments through intralogistics offers significant potential for companies that adopt and adapt to it. However, convincing potential customers of the efficiency and impact of intralogistics robots presents challenges. These limitations include high training and implementation costs, changes to work routines, and the need for space and process adaptations.

A recent study from CBRE, the world's largest real estate services provider, revealed that European industrial and logistics investments increased by 16% in Q1 of 2024 compared to Q1 of 2023. Despite this, many warehouses are old, repurposed buildings that are unorganized due to the nature of their daily tasks. These brownfield warehouses are expensive to maintain and digitalize but represent ideal grounds for developing and utilizing fully autonomous systems. Unlike AGVs, autonomous vehicles possess the intelligence and capability to plan and execute their plans efficiently. They are designed to adapt to uneven terrains and unorganized working environments given the revolutionary technologies that they hold.

In this context, STILL, a KION group company, has been developing smart intralogistics solutions since its establishment more than a 100 years ago, successfully integrating automation into logistics. STILL offers a wide variety of products that cater to industries ranging from food retail to automotive manufacturing and chemical sectors. Their solutions address various customer challenges, such as reaching high shelves, order picking, palletizing, fleet management, and providing consulting services. Trusted by leading German companies like Siemens, STILL's products and services are renowned for their reliability and efficiency.

The STILL Autonomous Robots department focuses on developing and enhancing smart vehicles. These autonomous robots, with minimal cost-effective input from the warehouse environment, can perceive their surroundings, estimating their positions, efficiently planning future tasks, controlling their movements to reach destinations, executing desired actions, and making corrections if necessary. This focus on smart, autonomous vehicles demonstrates STILL's commitment to pushing the boundaries of intralogistics and automation.

In light of this, this thesis aims to contribute to the process of palletizing by optimizing a local path planning approach applied in the warehouse's stations near the shelves or spots where pallets are located for picking or in free placing areas. The developed approach seeks to plan the near-field path optimally while simultaneously avoiding obstacles.

The objective is to create predictable, repeatable, and explainable vehicle behaviors, demonstrating the autonomous vehicle's ability to generate effective solutions tailored to each specific scenario. By focusing on optimal, pattern-based near-field path planning, this thesis addresses the challenge of navigating complex intralogistics environments, ensuring maximum efficiency and safety in operations. This approach not only enhances the vehicle's performance but also showcases the potential of autonomous technology in transforming modern intralogistics.

This work encloses 4 chapters:

- **Chapter 1** gives a deep insight about the host company's structure, activities and products. Then it dives into the project context and it motivations, the studied problematic, the fundamental aspects of the work, the thesis specifications and, the work methodology.
- **Chapter 2** delves into the state of the art of the work area, then goes through a review of the literature that served as a base of the thesis and gave an overview of the existing solutions. Finally, it presents milestones followed in the course of the thesis work.
- **Chapter 3** explains the development steps of the approach: it presents the mathematical aspect of splines and their implementation in robotic path planning, explains the geometric division of the stations into transition zones, discusses the studied path discrimination approaches, and finally it explores the optimization approaches for the local path planning problem.
- **Chapter 4** explicits the steps it takes to implement the developed approach in the RACK framework, test them in the RACK simulation system, then on the automated vehicle, run different test scenarios and states the obtained results.

Chapter 1
Project scope

Chapter 1

Project scope

Introduction

This chapter is reserved to present STILL GmbH as the host company, its organizational structure, the mother company KION group. It will then proceed to describe the range of products that the company produces. The second part is dedicated to explain the problem statement, the motivation behind this thesis, and the project specifications. The final part will emphasize the work methodology adopted to carry out this project.

1 Host company: STILL GmbH

1.1 General information about STILL and KION Group and their vision

STILL GmbH, based in Hamburg, Germany, is a leading manufacturer of intralogistics solutions with 14 locations in Germany and a global sales network spanning 246 locations. Operating under the KION Group, Europe's largest forklift truck manufacturer, STILL boasts over 100 years of experience. The company develops highly efficient, client-tailored products, serving businesses of all sizes with a wide range of forklift trucks—from manually driven forklifts to high-reach trucks and fully automated vehicles—alongside consultancy services and software solutions.

STILL prioritizes smart logistics and energy optimization while maintaining award-winning product quality, catering to industries such as food and retail, automotive, and electronics. Employing over 9,000 people across departments like sales and marketing, research and development, production, mechatronics, and quality assurance, STILL remains at the forefront of intralogistics innovation.

KION Group is one of the global leaders in the fields of industrial trucks and supply chain solutions. It is the mother company of: Linde, Dematic Baoli, OM, Fenwick, and STILL who produce the goods and services of the group as detailed in Figure 1.1.

Present in 4 continents and hiring more than 42000 employees, KION's startegy is to ensure profitable ans sustainable growth while focusing on Automation and robotics deplyment as one of the main leaders of this growth.

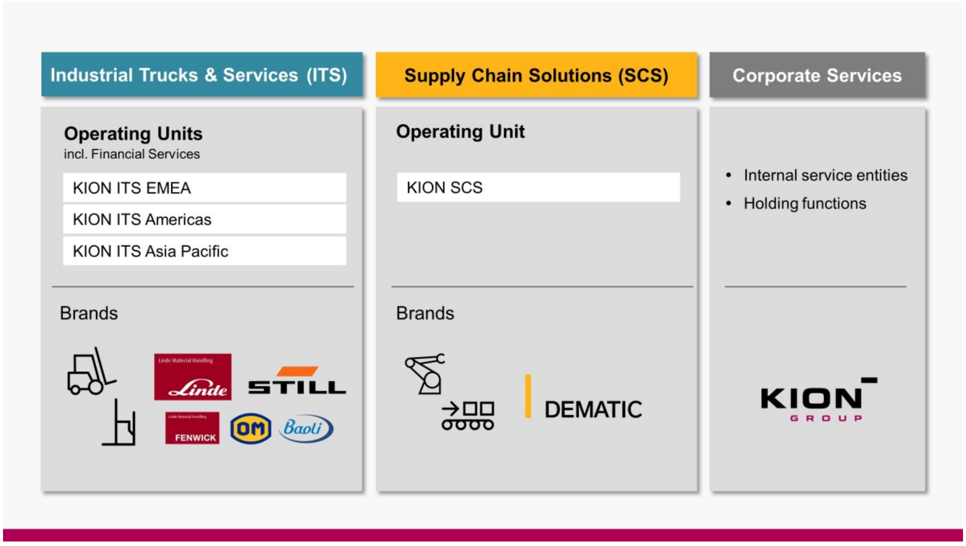

Figure 1.1: KION segment services and companies [1]

1.2 KION Management Hierarchy

The company is composed of departments managing the operations in all companies that are divided by scope of interest like R&D, Management, finances, etc.. Figure 1.2 illustrates the different areas of responsibility of the Executive Board. The Autonomous vehicles team belongs to the Mobile Automation department under CTO.

1.3 STILL Products

The 2017-established Autonomous vehicles team aims to develop fully automated solutions that leverage novel technologies to create innovative services delivered through forklift trucks. The vehicles are developed while keeping safety and high-performance as the main priorities.

iGo neo shown in Figure 1.6 is one of the main products developed by the department, it is a low level order picker transformed into the agent's autonomous assistant. Functioning in autonomous or semi-autonomous modes, it can follow the operator and their pace while avoiding obstacles and perceiving their surroundings as well as pick and place pallets in designed areas. Its added value is in preserving ergonomics of the operators by preventing heavy load carrying for long distances and decreasing the driving ascents and descents by 75% thus increasing the personal and collective performances [3].

Figure 1.2: KION Executive Board responsibilities as of 01.2024 [2]

As STILL specializes in forklift trucks, it counts many other products. Trucks are either Diesel or Gas fueled, or electric trucks that use Li-Ion batteries. Depending on the client's warehouse type, they can choose from a vast range of reach trucks Figure 1.3, hand pallet trucks Figure 1.4, double stacker trucks Figure 1.5, and Automated industrial Trucks Figure 1.6 [4].

Figure 1.3: STILL reach truck

Figure 1.4: STILL hand truck

Figure 1.5: STILL reach truck

Figure 1.6: STILL hand truck

Despite the impressive capabilities of the iGo neo and similar autonomous vehicles, the implementation of such advanced technology brings up several challenges, particularly in ensuring reliable and predictable behavior under all operating conditions. This leads to a key motivation for further investigation and improvement in the field.

1.4 Motivation and Problem Statement

While autonomous vehicles can be highly reliable and efficient in carrying out various tasks, their behavior is not always predictable or easily explained. The output often exhibits a stochastic nature. For example, an obstacle-avoiding solution planned by the autonomous vehicle may be safe and correct but might follow an unusually shaped path.

Such stochastic behaviors can lead to a lack of trust and interest in robotized forklift trucks from a customer's perspective. This unpredictability can cause customers to question the system's repeatability, fearing that it may not perform consistently in critical situations. Moreover, the unexpected nature of these behaviors can make it difficult for operators to understand and anticipate the vehicle's actions, further reducing confidence.

Adding to these concerns, many autonomous systems, particularly in the intralogistics sector, require significant commissioning efforts before they can be implemented in a new environment and begin their service. Whether it's a required software, sensors, or measurements, these systems demand substantial time and financial investment—two crucial resources that we aim to optimize.

As engineers, we are committed to developing optimal solutions that are easy to commission in a new environment. These so-called "plug-and-play" solutions reduce the effort required and allow customers to start benefiting from the autonomous features with just the physical truck on-site and some basic input from the warehouse map, the rest, is online recognition and processing. This approach significantly enhances the impact and convenience of the technology.

To address these issues, the autonomous vehicles department is dedicated to creating solutions that are not only reliable and efficient but also transparent and understandable. By focusing on explainable autonomous systems, the department aims to build greater trust with customers, ensuring they feel confident in the technology and are more likely to adopt and utilize these advanced robotic solutions.

This thesis discusses one such possible application of autonomous vehicles. The use case involves solving the following problem: as illustrated on Figure 1.7, after the vehicle enters the station- a limited area inside the warehouse where the shelf stands to palletize/depalletize, in predefined positions, it faces the following problematics:

- The vehicle's forks are not facing the destination shelf but rather the opposite direction, so a driving direction change is needed.
- The vehicle is heavy (1200 to 1500 KG) with an overall length of 2500 to 4000 mm which makes it both challenging and dangerous to change directions on its spot [5].
- The pallet docking process has to be very precise to avoid shifts and mistakes.

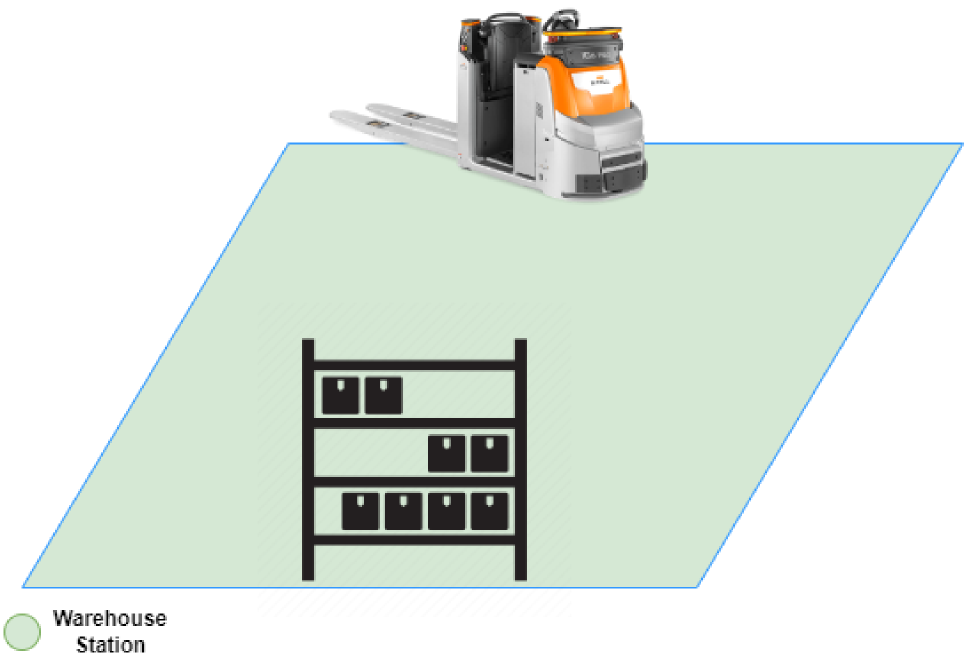

Figure 1.7: Vehicle setting in the station

The first inspiration for the proposed solution was the forklift drivers themselves. The experienced drivers all agree to solve the problematic – if it was to be solved manually, in the same way: to drive in an arc shape to a point, then to change the driving direction and orienting the vehicle to the destination position.

We would like to solve this problematic in a manner that:

- Imitate the manual driving process to pick a pallet when in the same situation (facing backward of the pallet).
- Implement a predictable local path planning algorithm for the vehicle operations inside a station.
- Reduce the computational expense used with the global dynamic path planning algorithms implemented through a pattern
- Choose an optimal path out of the various paths that can be driven.

1.5 Work Structure and Methodology:

Our team adopts an Agile Scrum methodology showcased in Figure 1.8 to ensure efficient and flexible project management. Here's how we approach our work:

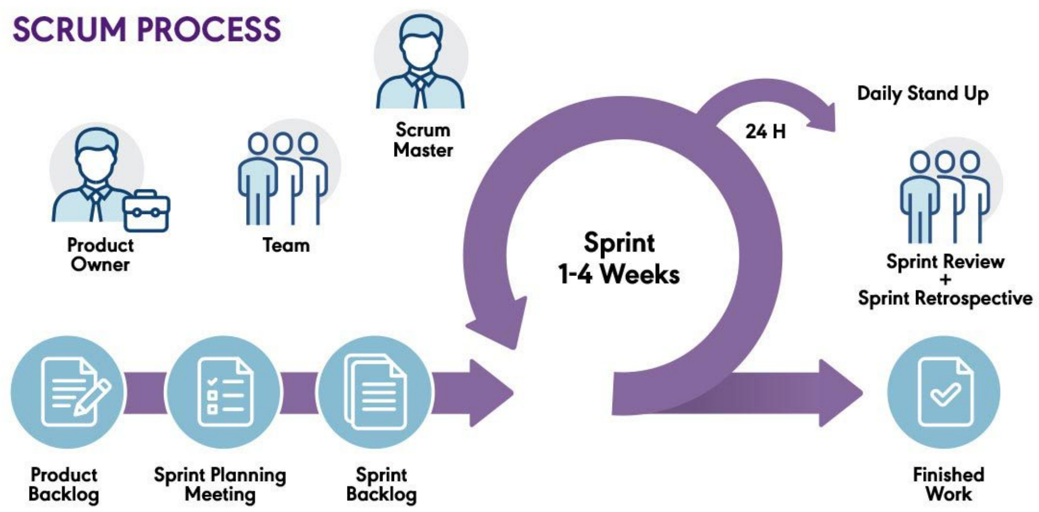

Figure 1.8: Agile Scrum Process [6]

1.5.1 Agile Scrum Framework:

- **Jira:** We use Jira to organize and track our tasks and progress. Jira allows us to create and manage tickets, which are detailed records of tasks, bugs, or features that need attention. Each ticket is assigned to team members and tracked through its development stages until completion.

- **Sprints:** Our work is organized into 2-week sprints. Each sprint is a focused period where we aim to complete a set of predefined tasks. At the start of each sprint, we hold a meeting to review the previous sprint: every team member presents their completed tickets, and communicates the changes or blockers that appeared during the process and plan for the next sprint: decide which tasks will be tackled during the sprint. This helps us maintain a steady pace and regularly deliver increments of our project.

- **PI Planning:** Every quarter, we engage in Program Increment (PI) planning with the mobile automation teams. The PI happens in two phases: each team prepares their planning for the next 3 months, then it is discussed and tailored again in a bigger round. This planning session helps us align our goals and strategies for the upcoming quarter. We review progress, set objectives, and coordinate with other teams to ensure that our work is aligned with broader project goals and company vision.

- **Daily Standups:** We hold 15 minutes long daily standup meetings to keep everyone on the same page. During these meetings, team members share updates on their progress, discuss any challenges they are facing, and outline their plans for the day. This practice promotes transparency and quick problem-solving.

1.5.2 Version Control:

- **GitHub:** We use GitHub for version control and code management. GitHub allows us to collaborate on code, track changes, and manage different versions of our project. Each team member can contribute to the codebase, and we use pull requests to review and integrate new features.

1.5.3 Communication and Collaboration:

- **Microsoft Teams:** We use Microsoft Teams for real-time communication and collaboration. Teams provides a platform for chatting, video calls, and sharing files, facilitating smooth and efficient interactions among team members.

- **Microsoft Outlook:** Outlook is used for email communication and scheduling. It helps us manage meetings, track important messages, and coordinate tasks and deadlines.

By integrating these tools and practices, we ensure a structured yet flexible workflow, enabling us to adapt to changes, communicate effectively, and deliver high-quality results.

Chapter 2
State of the Art

Chapter 2

State of the Art

Introduction

The intralogistics sector is undergoing a significant transformation due to the integration of digital tools such as connected industries and robotics. The cluttered and highly dynamic nature of this environment makes it challenging to successfully implement robotic solutions.

The first steps in digitalizing logistic processes with robots involved the use of Automated Guided Vehicles (AGVs). First introduced in 1955, AGVs perform tasks like material handling. AGVs are managed by top-level software that handles task planning, providing the vehicles with intermediate waypoints to navigate from start to end points [7].

However, the decentralized decision-making approach of AGVs makes them unresponsive to changes in their environment. For example, AGVs localize themselves using specific and precise anchors physically located in their workspace.

This localization mechanism helps them follow the assigned path. As a result, even a simple environmental change of the dispositionsrequires an update of the measurements and maps on which the planning is based. Another example is that an AGV is unable to plan and execute a solution if it encounters an obstacle on its way to the goal or it arrives at a shifted destination. In such cases, the AGV's reaction is to stop and wait for top-level instructions [8]. This behavior decreases productivity and disrupts the planned sequence of tasks until an intervention is managed.

To overcome these disadvantages of AGVs, Autonomous Mobile Robots (AMRs) were introduced. AMRs are equipped with a decentralized control system, enhanced perception of their surroundings through more complex hardware, and advanced software to manage and integrate these hardware additions (Figure 2.1).

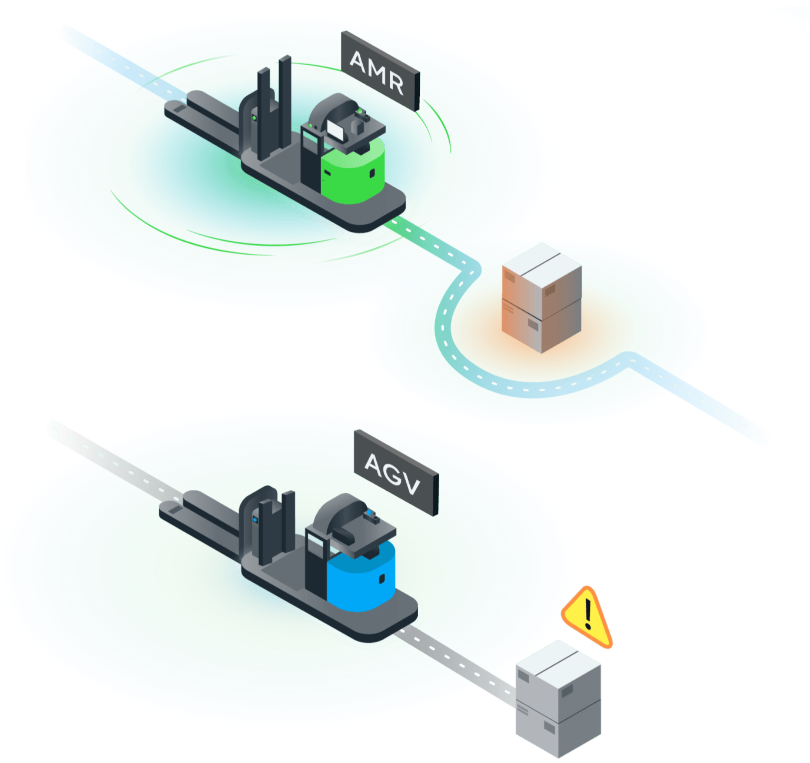

Figure 2.1: AMR and AGV behaviors at presence of an obstacle [9]

In addition, they grant a fast integration into new environments due to smart perception and recognition technologies. AMRs use this data as input to smart algorithms that enable it to plan its missions, navigate to its destination, avoid collisions, and execute missions all while collaborating with humans in the working space. The Autonomous vehicles do not require an automation expert or a roboticist's presence to be configured or to deal with complex situations. It is able to solve such situations individually due to the scalable software that it has on board.

On the one hand, this evolution enables AMRs to navigate more dynamically and adaptively within intralogistics environments, improving overall efficiency and responsiveness. On the other hand, the level of flexibility that AMRs brings important safety and efficiency considerations [7].

One of the main challenges is developing the navigation mechanisms. In a logistics environment, it is crucial to comply with the nature of the workspace. The AMR should recognize the location of materials to be handled and be able to navigate to and from those locations to next missions. Building a flexible and efficient solution requires a deep understanding of the situations and special cases that the vehicle may encounter and a study about how to create scalable solutions for such events.

Before diving into the methodologies and technologies used to address this thesis' topic, it is relevant to examine the related works. This research will serve later in the thesis as a guiding outline. Literature helps to investigate the level of progress that other researchers reached in similar topics, prevents re-invention of existing concepts, and pushes to ethically exploit the developed technologies. For this thesis, it is important to deeply examine the research papers and scientific resources to build a solid foundation of knowledge, identify the gaps in some studies, and propose novel solutions.

In this context, this state-of-the-art report, delves into pathplanning and near-field path planning for mobile robots in general and for intralogistics AMRs specifically. Then, it examines possible solutions for path creation and generation. Afterwards, it studies the decision-making science approaches that can be used to evaluate and optimize path suggestions. Finally, this chapter outlines the methodology to be followed throughout this scientific work(Figure 2.2).

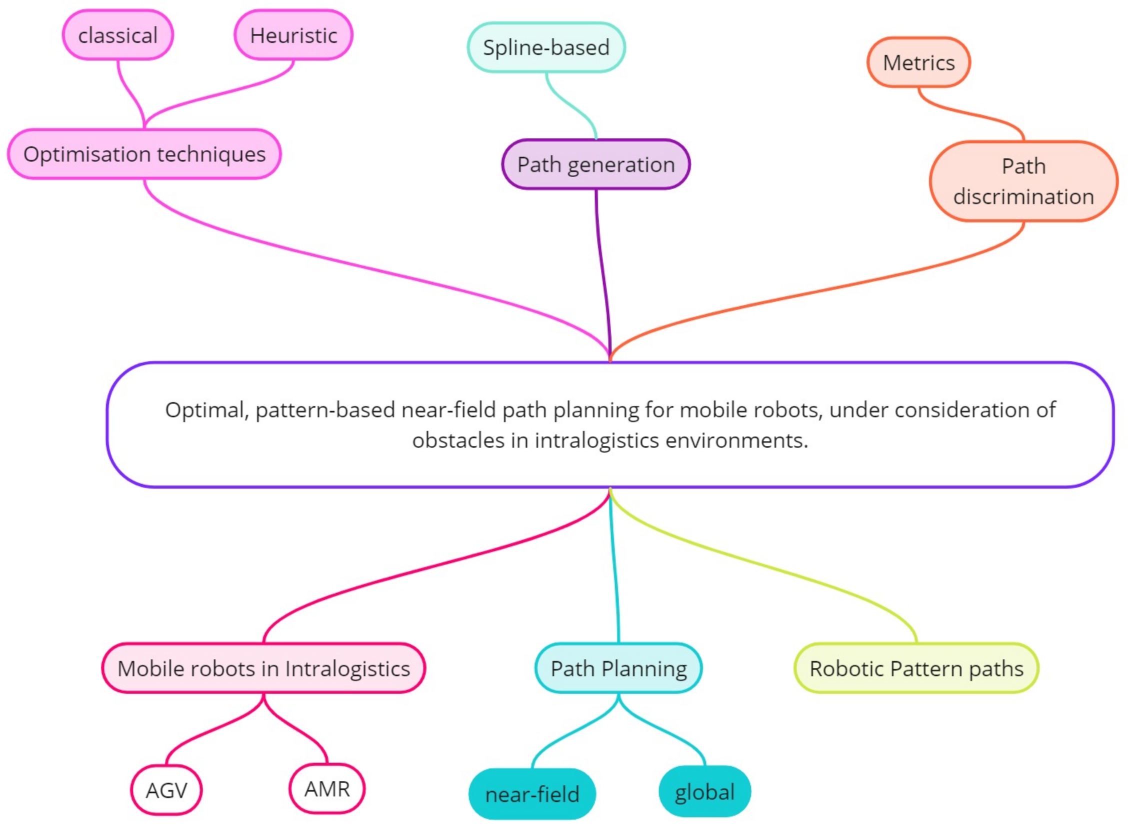

Figure 2.2: Mind map of the key topics

1 Path Planning

1.1 Path Planning for autonomous robots

Path planning for mobile robots involves creating and generating efficient routes for the robot to travel from a starting position (A) to a target position (B), ensuring minimal time and travel distance while avoiding collisions with nearby objects.

In complex environments, it is challenging for robots to move randomly and fulfill their missions. However, with appropriate input from various sensors, such as laser scanners, cameras, and LiDAR, robots can perceive their surroundings and plan accordingly. This application is especially relevant in dynamic intralogistics environments where operators and employees are moving around; boxes and pallets are being transported or stocked; and in warehouses with multiple layers of shelves that must be handled safely and carefully. Autonomous robots, as the name suggests, are standalone systems that must compile and process such input and generate, with the support of powerful algorithms, efficient paths. Path planning serves as the crucial link between the robot's sensor input and its motion control [10].

Literature and scientific studies differentiate between two main types of path planning: global and local path planning. Global planning involves finding an optimal path from the start to the target position based on sensor input within a known, static environment, whereas local planning focuses on real-time obstacle avoidance, typically used while moving to avoid dynamic obstacles [11].

This review will investigate the developed path planning approaches to differentiate between them and eventually decide on the suitable method that servies the thesis.

1.2 Importance and Challenges

Efficient path planning is essential for ensuring the safe handling of objects in the environment. In intralogistics, the materials being handled—whether goods, manufacturing systems, storage shelves, or other vehicles—are valuable and must be treated with care. Moreover, safety is a critical concern, especially when human safety and protection are involved. To pass quality tests, autonomous forklifts must meet personal safety requirements. These requirements include, but are not limited to, maintaining a safe distance from both static and dynamic objects and people, as well as detecting surroundings at any height and time. By following an efficient path, overall productivity increases since operations are repeated many times throughout the day. An efficient path optimizes both length and smoothness, thereby reducing travel time. Additionally, efficient path planning conserves the truck's energy, reducing the frequency of recharging.

However, developing efficient paths comes with certain limitations. Several studies have compared various planners, analyzing the advantages and drawbacks of each. One common drawback is excessive computational time: if the algorithm takes too long to process (in the range of seconds), it leads to long latencies and vehicle stops. While experts might understand this behavior, clients may find it unacceptable, leading to doubts about the vehicle's efficiency or even disinterest in the product.

In very crowded or complex areas, some planners may struggle to generate a viable path, which could cause the vehicle to fail in navigating such environments, thus limiting its usefulness in real-world scenarios. In these specific cases, some path planning algorithms perform better than others. Therefore, it may be beneficial to equip the autonomous vehicle with more than one approach for solving such situations (in Section ... the OMPL: Open Motion Planning Library is presented as one of the available and most recent tools in RACK). Additionally, embedded PCs, often used in these systems, have limited processing power and must handle large amounts of data quickly. Achieving short computational times can be challenging, potentially impacting the vehicle's performance.

Furthermore, sensors can produce noise or shadows, leading to uncertainty in the data about the terrain. This uncertainty can cause the planner to make errors, affecting the vehicle's ability to navigate accurately and safely [12].

1.3 Global Path Planning

At the beginning of the research phase for this thesis, it was important to look at the available types of path planning methods. Science generally distinguishes between three general approaches of Global Path Planning all having the same aim to plan the path from a start to a goal position within a pre-mapped environment: grid-based methods, sampling-based methods, and artificial intelligence-based methods [13].

Grid-based methods involve discretizing the environment into a grid of cells, where each cell represents a small, discrete part of the space. Then, the algorithm visits the grids to decide which cells will be used for the path based on the occupancy or cost and calculates the fitness function from start to the reached point in A* algorithm for example or from the reached point to the destination for Dijkstra Algorithm. While this method seems easy to understand and quite simple to implement, it is computationally intensive because of the number of grids to evaluate and the repetitiveness and constrained in direction (Figure 2.3)

Sampling-based algorithms do not discretize the entire environment into a grid but instead randomly sample the space to construct a path: the samples are distributed in a manner that they avoid the obstacles and serve as a roadmap for to create a start-to-end path [15]. The exact approach to transform the roadmap into a continuous path depends on the algorithm like PRM or RRT.

Sampling-based algorithms present advantages like handling big environments and complex situations, however, they can also be computationally intensive and demanding in such situations. Figure 2 shows the difference in the resulting optimal path in a cluttered environment where with 1 core the algorithm successfully finds a feasible path, and, as the cores double, the computed path improves its quality as the search tree expands.

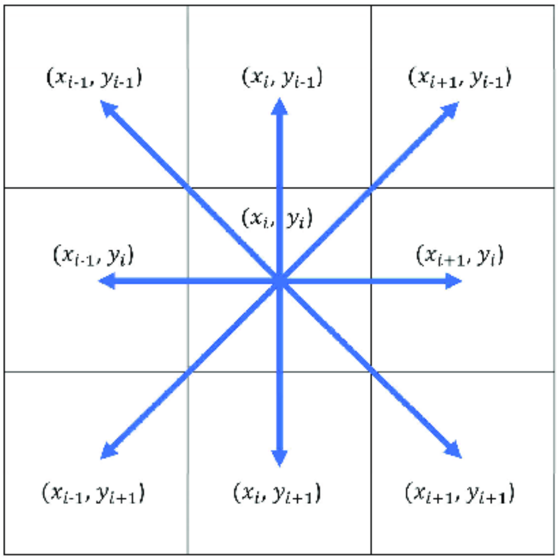

Figure 2.3: 8 direction possibilities to move from the current cell to the next cell [14]

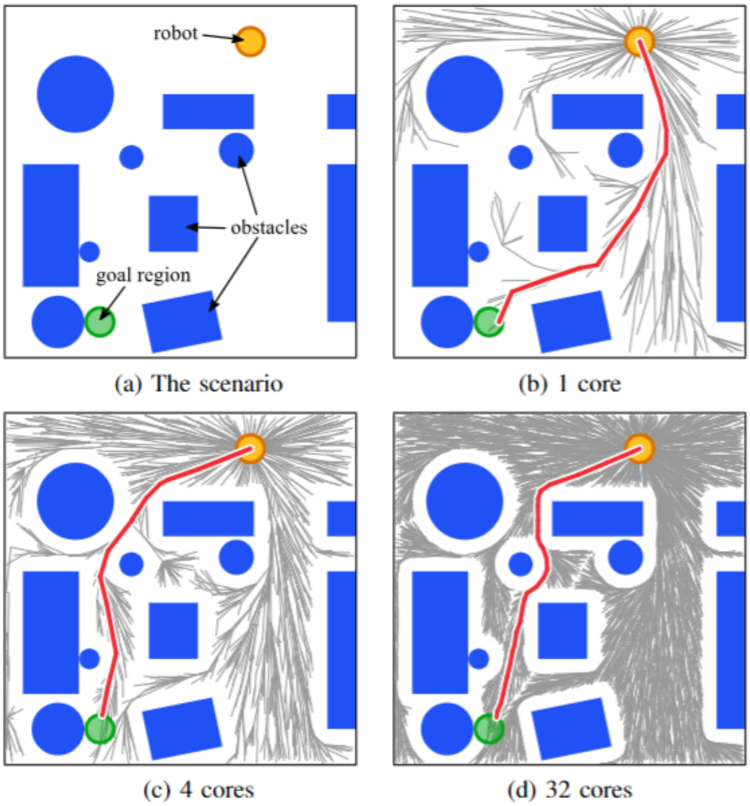

Figure 2.4: 8 direction possibilities to move from the current cell to the next cell [16]

As for artificial intelligence-based methods, also known as heuristic and metheuristic approaches, leverage the use of neural networks, machine learning and deep learning, and evolutionary algorithms. These methods learn from experience, adapt to changes, and optimize paths in complex environments. They are good at handling dynamic and unpredictable scenarios, making them suitable for tasks like autonomous driving, robot navigation, and logistics.

To start with, Neural networks (NN) are inspired from the biological harmonious connection of the brain neurons that gives it the ability to process big amounts of data and generate ideas and decisions and solve problems. The NN is built in a way that enables it to get its input in a form of data and process it by learning, improving and adjusting the output to the desired results. NN are able to perform Parallel processing: the information is transmitted in two directions to the neuron in the case of Recurrent Neural Networks (RNN) that allows for learning fron current and past inputs to the NN. This approach improves the computation time and overall performance. The NN is then able to process complex solutions and create paths for difficult environments. It is well suited for unpredictable situations as it is built to adapt to the available input and the desired output. However, it presents a practicality challenge. Althugh the performance an results can be impressive, yet, in a real-time context, it is hard to rely on solutions that require extensive computational efforts and need long durations to process solutions. In addition, the number of neurons and layers have to be scalable and depends closely on the level of complexity that the vehicle is to deal with [12].

Fuzzy Logic (FL), on the other hand, is a way of thinking that mimics how humans make decisions, especially when things are unclear or uncertain. Instead of working with exact numbers, it uses "fuzzy" terms like "good", "average" or "bad" to make decisions. Input numbers are clustered following the fuzzy sets or intervals and assigned a value using membership functions. Later the values are interfered and defuzzified to genearte the ouput as a command value. In robotics and path planning, FL helps robots navigate by allowing them to handle uncertain situations, like avoiding obstacles or finding the best route, even when the environment is not fully known. Instead of needing exact data, the robot can employ fuzzy terms like "close" or "far" to understand its surroundings. For example, if an obstacle is "somewhat close," the robot can smoothly adjust its path to avoid it. FL also helps the robot choose the best route by weighing various factors like distance and safety, even when the information is not perfect. This makes the robot better at handling unpredictable environments and making flexible and optimal decisions. However, one disadvantage is that it can be tricky to create the right rules for the robot to follow, and the system can become complicated as more rules are added. It may present a scalability problem because in unpredictable and dynamic environments it is not simple to decide about fixed fuzzy sets that would be practical in all of the cases [12].

While Neural Networks and Fuzzy Logic offer powerful approaches for handling uncertainty and complex decision-making, another key area in artificial intelligence for path planning is the use of meta-heuristic algorithms. Meta-Heuristoc algorithms are inspired from biological and natural processes for evolution and survival. Unlike NN and FL, that rely on data as input to generate decisions, meta-heuristic algorithms explore the solution space by evolving random solutions for the problem and optimizing them by rounds until a stopping criterion or set of criteria is satisfied (see more in section ...: Optimization Algorithms). Approaches like Genetic Algorithms (GA) have been used for path planning by Ahmed Elshamli et al. [17]. The The robusteness of their solution is the adaption of the solution to dynamic environments. They evolve their GA using variable size chromosomes, where each node represents a waypoint of the path, then they measure the quality of each path using an evaluation function. A modified

Genetic Approach is then applied to each population: Crossover, mutation, **Repair** infeasible paths, **Shorten**, then **Smoothen** feasible paths while dynamically checking for new obstacles. The approach is tested in static and dynamic environments and has achieved proven efficiency when it comes to local optima challenges and survivig the best elements of the population. While the use of the GA itself is robust and successful, it can be challenging to recreate the algorithm and to add the improvements. In addition, the tests the ran are limited to a simple simulation with unrealistic situations and obstacle setting as displayed in figure 2.8.

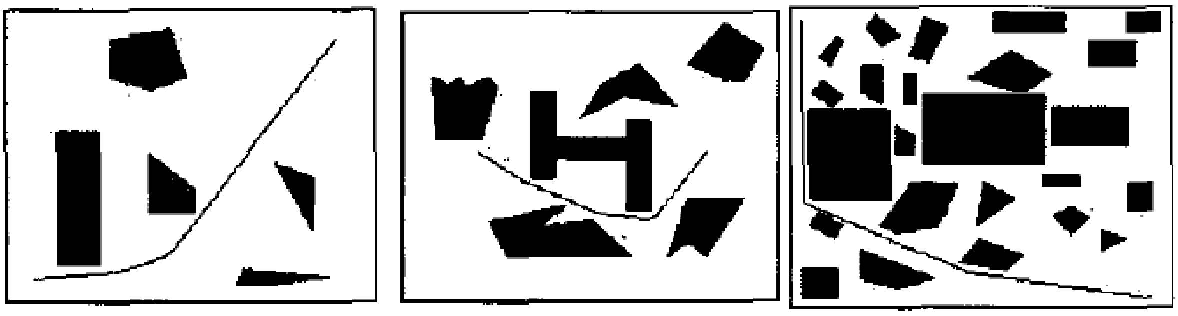

Figure 2.5: Simple obstacle environment

Figure 2.6: Intermediate obstacle environment

Figure 2.7: Complex obstacle environment

Figure 2.8: GA Test scenarios [17]

1.4 Local Path Planning

Local path planning is a process used by robots to make real-time decisions about how to move safely and efficiently in their surroundings. Unlike global path planning, which focuses on finding the best overall route from a starting point to a destination based on astatic map, local path planning deals with navigating the environment directly around the robot while considering real-time data input from sensors [18]. This involves quickly responding to obstacles that suddenly appear or changes in the terrain, ensuring the robot can continue moving without collisions. Local path planning is crucial for the safe and effective operation of robots, especially in environments where situations can change in a fast manner. For example, in busy spaces with moving people or vehicles, a robot needs to be able to make quick adjustments to avoid accidents. This type of planning allows the robot to react immediately to new information, making it essential for applications where unpredictability and quick responses are vital, such as in autonomous vehicles or service robots. Local path planning is crucial for the safe and effective operation of robots, especially in environments where conditions can change rapidly. For example, in busy spaces like warehouses with moving people or vehicles, a robot needs to be able to make quick adjustments to avoid accidents. This type of planning allows the robot to react immediately to new information, making it essential for applications where unpredictability and quick responses are vital, such as in autonomous vehicles or service robots.

Common Techniques Reactive Methods: Reactive methods are approaches in local path planning that focus on immediate obstacle avoidance and making quick adjustments as the robot moves. Techniques like the Vector Field Histogram (VFH), Dynamic Window Approach (DWA), and Potential Fields are commonly used. These methods help the robot react to obstacles directly in its path by quickly calculating a safe direction to move. They are called "reactive" because they respond to the environment in real-time, allowing the robot to navigate around obstacles as soon as they are detected.

Sensor-Based Approaches: Sensor-based approaches rely on data collected by the robot's sensors, such as LIDAR, sonar, or cameras, to make decisions about where to go next. These sensors help the robot create a map of its surroundings, which can then be used to identify obstacles and safe paths. Techniques like occupancy grids and point cloud processing are used to interpret the sensor data and guide the robot's movements. This approach allows the robot to have a detailed understanding of its immediate environment, making it more capable of avoiding obstacles and navigating complex spaces.

1.5 OMPL

2 Spline based Paths

3 Metrics

4 Optimization Techniques

Chapter 3
Design and development of the Control Interface

Chapter 3

Design and development of the Control Interface

Introduction

In this chapter, we delve into the heart of the iHEX system's functionality – the Control Interface (CI) software which forms the cornerstone of communication and control, enabling seamless interaction between the MC and the SCs. This chapter presents the design, development, and test of the CI on both the MC and SC and the integration of both of them.

1 Control Interface (CI) on the MC

1.1 Multithreaded architecture:

In the design of the CI on the MC, a multithreaded architecture was adopted to meet the dynamic and concurrent demands of communication, command processing, monitoring, and logging within the iHEX system. The use of multithreading was essential in ensuring a responsive and efficient operation of the control software.

1.1.1 Multithreading need

A fundamental requirement for the Control Interface is its ability to handle multiple tasks simultaneously. The MC must efficiently **manage communication with the server**, **manage communication with the SCs via CAN Bus**, **continuously monitor the health of the CAN network**, and **maintain a log of system activities**. This multifaceted demand necessitates a multithreaded approach to prevent bottlenecks and ensure timely execution.

1.1.2 The <pthread.h> library

Chapter 4
Design and development of Printed Circuit Boards

Chapter 4

Design and development of Printed Circuit Boards

Introduction

In Chapter 4, we dive into the essential process of creating the electronic foundation of the iHEX system—Printed Circuit Boards (PCBs). These PCBs serve as the crucial framework where all the electronic parts of the iHEX system come together, ensuring seamless communication and control. This chapter explores the design, development, and roles of four specific PCB types: Main PCB, IO PCB, LED PCB, and Dock PCB.

1 Architecture

Based on the specifications and the company needs, we designed the global hardware architecture. It is mainly composed of 4 designed PCBs:

- Main PCB is the motherboard that brings the main electronic components of the SC together. Each SC is composed of one Main PCB that is connected directly to an IO PCB.
- IO (Input-Output) PCB mainly ensures connectivity and interaction with the other SCs. It is connected to the Main PCB on one side. On the other side, it is connected whether to IO PCBs of other static SCs or Dock PCBs.
- Dock PCB ensures the interaction and control of the iHEX mobile element newly connected. If it exists, whether in a static or mobile element, it is connected to the SC through the IO PCB.
- LED PCB controls the LED strip. Each LED PCB is part of a SC. It is plugged-in directly on the Main PCB.

General conclusion

Bibliography

[1] KION group website. URL: https://www.kiongroup.com/en/About-us/Management/ consulted on 19/07/2024

[2] KION group website. URL: https://www.kiongroup.com/en/About-us/KION-at-a-glance/ consulted on 19/08/2024

[3] STILL website, iGo Neo page. URL: https://www.still.de/en-DE/trucks/new-trucks/order-pickers/opx-20-25-igo-neo.html

[4] STILL website, iGo Neo page. URL: https://www.still.de/en-DE/trucks/new-trucks.html

[5] iGo Neo datasheet. URL: data.still.de/assets/products/Vehicles/Order_Pickers/OPX_iGo_neo/pdfs/OPX_EN_TD.pdf?mod=1681891889&s=baf72412ac0d268f13b017603ca95ea2

[6] Agile Scrum article. URL: https://top20review.com/phuong-phap-agile/

[7] Giuseppe Fragapane, René de Koster, Fabio Sgarbossa, Jan Ola Strandhagen, Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda, European Journal of Operational Research, Volume 294, Issue 2, 2021, Pages 405-426, ISSN 0377-2217, https://doi.org/10.1016/j.ejor.2021.01.019.

[8] Moshayedi, Ata Jahangir & Liao, Liefa & Kolahdooz, Amin. (2021). Gentle Survey on MIR Industrial Service Robots: Review & Design. 10.

[9] AMR vs. AGV Figure, Vecna Robotics Website. URL: https://www.vecnarobotics.com/amr-vs-agv/, consulted on 28.07.2024

[10] Lixing Liu, Xu Wang, Xin Yang, Hongjie Liu, Jianping Li, Pengfei Wang, Path planning techniques for mobile robots: Review and prospect, Expert Systems with Applications, Volume 227, 2023, 120254, ISSN 0957-4174, https://doi.org/10.1016/j.eswa.2023.120254.

[11] Marín, Pablo & Hussein, Ahmed & Martín Gómez, David & de la Escalera, Arturo. (2018). Global and Local Path Planning Study in a ROS-Based Research Platform for Autonomous Vehicles. Journal of Advanced Transportation. 2018. 1-10. 10.1155/2018/6392697.

[12] Mohd. Nayab Zafar, J.C. Mohanta, Methodology for Path Planning and Optimization of Mobile Robots: A Review, Procedia Computer Science, Volume 133, 2018, Pages 141-152, ISSN 1877-0509, https://doi.org/10.1016/j.procs.2018.07.018.

[13] Zhang B, Zhu D. A new method on motion planning for mobile robots using jump point search and Bezier curves. International Journal of Advanced Robotic Systems. 2021;18(4). doi:10.1177/17298814211019220

[14] H. -T. Lee, H. -M. Choi, J. -S. Lee, H. Yang and I. -S. Cho, "Generation of Ship's Passage Plan Using Data-Driven Shortest Path Algorithms," in IEEE Access, vol. 10, pp. 126217-126231, 2022, doi: 10.1109/ACCESS.2022.3225571.

[15] Sertac Karaman and Emilio Frazzoli. 2011. Sampling-based algorithms for optimal motion planning. Int. J. Rob. Res. 30, 7 (June 2011), 846–894. https://doi.org/10.1177/0278364911406761

[16] c. Ichnowski and c. Alterovitz, "Parallel sampling-based motion planning with superlinear speedup," 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems, Vilamoura-Algarve, Portugal, 2012, pp. 1206-1212, doi: 10.1109/IROS.2012.6386194.

[17] A. Elshamli, H. A. Abdullah and S. Areibi, "Genetic algorithm for dynamic path planning," Canadian Conference on Electrical and Computer Engineering 2004 (IEEE Cat. No.04CH37513), Niagara Falls, ON, Canada, 2004, pp. 677-680 Vol.2, doi: 10.1109/CCECE.2004.1345203.

[18] Q. Jin, C. Tang and W. Cai, "Research on Dynamic Path Planning Based on the Fusion Algorithm of Improved Ant Colony Optimization and Rolling Window Method," in IEEE Access, vol. 10, pp. 28322-28332, 2022, doi: 10.1109/ACCESS.2021.3064831

Annexes