UNIVERSITY OF MISKOLC
FACULTY OF MECHANICAL ENGINEERING AND INFORMATICS

THEORETICAL AND PRACTICAL ANALYSIS OF ROBOTIC SYSTEMS

SUMMARY OF PHD THESIS

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1. INTRODUCTION

1.1. Importance and objectives of the research theme

Today, Industry 4.0 has accelerated the spread of automation and mobile devices [1], and this has also been the case in the area of production support [2]. There is a growing demand for robotization and automation in Hungary and in the North Hungarian region. In the case of planning logistical process, modernization should always be pursued [3]-[6]. Robotics is gaining ground in both automation tools [7], industrial robots [8] and mobile robots [9]. At the same time, continuous improvements are also needed for industrial robots, e.g. designing a force feedback-based installation process [10].

Industry 4.0 also led to the release of driverless vehicles in the industry, including transport vehicles, which can be considered mobile robots [11] or Automated Guided Vehicles [12]-[13]. Automating a transport vehicle is still a complex task requiring a high level of expertise. Such a driverless transport vehicle or AGV is located in the Laboratory of High-Tech Logistics Systems at the Institute of Logistics of the University of Miskolc [16], [17], the carrier is part of a handling system [14]. This carrier is a custom-made prototype made by Gamma Digital Kft. in 2009 [14]. This AGV was no longer able to function automatically after the laboratory moved, as motion control [15] was developed in its previous location, a method which is no longer suitable for the relocation of AGV.

In general, various technologies are available [18] to determine the position of an AGV, such as inductive sensor [19]-[21], image processing [22]-[23] or LIDAR sensor. In my view, the recent method is largely useful because of its configurability. The position of the vehicle tested in the dissertation is also detected by the latest method and uses a virtual trajectory, such as the AGV developed in [24], but LIDAR sensors only detect the environment through a transformation algorithm.

The subject of the dissertation is the development of motion control and simulation capable of pre-planning the movement of the AGV and then controlling the servo motors to travel the planned trajectory at the desired velocity and angular velocity in order to achieve lower current consumption, in addition to make a simulation to detect each parameter.

The following modules are required for movement control and simulation between the two points: **a.** path planning module, **b.** trajectory planning module, **c.** speed-voltage conversion module using the speeds obtained from the trajectory planner, **d.** motion control and simulation of the engine electrodynamic model using voltages from the converter, **e.** simulation of the road and **f.** communication module**.**

The dissertation presents the design of a new path and trajectory planning solution that can be reused also after relocation. For robot control, such as in [25] and [26] literatures, different methods were used to control the robot's motors for mobile robots of different designs. In one case, the control is based on less reliable image processing, while in the other case the control was only discussed theoretically.

The first purpose of the dissertation is that the new path planning solution defines track points in two ways at the same time, taking into account the geometric structure of the AGV. The second purpose of the dissertation is to develop a new trajectory planning solution that calculates the velocities of the vehicle's driven wheels based on geometric and time data from the track points. In addition, the new path and trajectory planning solution is also designed to provide a more favourable solution for the power consumption of the drive.

The determination of the rate of current consumption is based on the current consumption of the propulsion engines, which can be simulated by models and measured by measuring instruments. The third purpose of the thesis is to develop a new modular system for determining the current consumption of the drive and simulation of the track.

The final purpose of the dissertation is to develop a new AGV monitoring measuring system that measures the voltage of power supply, drive current and receives navigation data.

1.2. Structure of the PhD thesis

The dissertation summarizes the development of the tasks set out in the objectives in the following structure.

Chapter 2 of the dissertation summarizes the literature on PhD research.

Chapter 3 describes the driverless carrier and six modules designed to control and simulate its movement.

The six modules of the control are processed in Chapter 4 based on Scilab software.

The structure and operation of the program for the planning of the driverless carrier's path is described in Chapter 4.1. On the basis of the intended path, the AGV's control system shall produce a trajectory containing velocity and angular velocity data as described in Chapter 4.2. The module detailed in Chapter 4.3 converts the velocity data from the trajectory planning module into the voltage input required for the DC motor electrodynamic model. Chapter 4.4 discusses the electrodynamic model of the DC motor used in the AGV, with a look at the elements of the load torque in the AGV. The program described in Chapter 4.5 simulates the track on the basis of angular velocity data from the motor model. Chapter 4.6 describes the communication module. The program specified with the graphical elements described in Chapter 4.7 places the simulation parts described in Chapters 4.3 to 4.6 in a module chain. This section describes how the module chain works through various examples.

Chapter 5 details the program improvements necessary for manual and automatic movement of the AGV in its own control system, which are necessary for the successful preparation and completion of fully autonomous motion control.

The design of the measurement system for motion control and control is discussed in Chapter 6, with the navigational data for position and orientation measurements and for monitoring to measure the voltage of the batteries and the current of the propulsion servo motors.

Chapter 7 processes the results of position, orientation, voltage, and current measurements and draws conclusions.

Chapter 8 summarizes the results of the dissertation in thesis statements.

Chapter 9 makes summary.

In the other chapters, which are not numbered, I thank those who helped the research, listed the literature used and my own, and put a list of charts and tables.

2. METHOD OF SOLVING OBJECTIVES

This chapter summarises the work described in the dissertation.

Literature overview

The subject of path and trajectory planning for robots has a wide range of literary backgrounds.

The basis for the processing of literature was the [27] literature, in which the chapter 'Path Planning and Trajectory Planning Algorithms: A General Overview' is relevant for the subject. This chapter deals with the algorithms of path and trajectory planning.[27]

Path planning generates track points and curves between two or more reference points. The problem with the planning of the trajectory generates the reference inputs for the robot controller, ensuring that the desired movement is achieved. Usually, the inputs are the trajectory designed by the track designer and the robot's dynamic and kinematic constraints.

[27] Literature divides each algorithm into two distinct groups in the field of path planning and trajectory planning. I detail the path planning methods in subsea 2.1 of the thesis, the trajectory planning methods in subsea 2.2, the previous trajectory planning solution of the AGV examined in the dissertation in subsea 2.3, and the interpolation and approximation solutions for path planning in subsea 2.4.[27]

Driverless carrier used within the frame of research

Chapter 3 of the dissertation details the driverless carrier used in the research and the structure of its control. The AGV used in the dissertation can be seen in the Figure 2.1.

AGV motion control operation

The structure of the control of the AGV implemented and the operation of its main program are set out in the Figure 2.2. The first step is to receive navigation data, such as position and orientation. This is linked to the pre-entered target positions and orientations through which the AGV passes or arrives at the finish line. Based on this data, the velocities of the wheels are produced in the main program using the two types of path and trajectory planning methods. Transmits wheel speed data to the conversion module and the DC motor electrodynamic model module. The latter module transmits angular velocity values on one branch and current values to the other branch to determine data transmission and current consumption. By comparing the power consumption, the main program selects the control method and generates the control signal for the motor controllers.

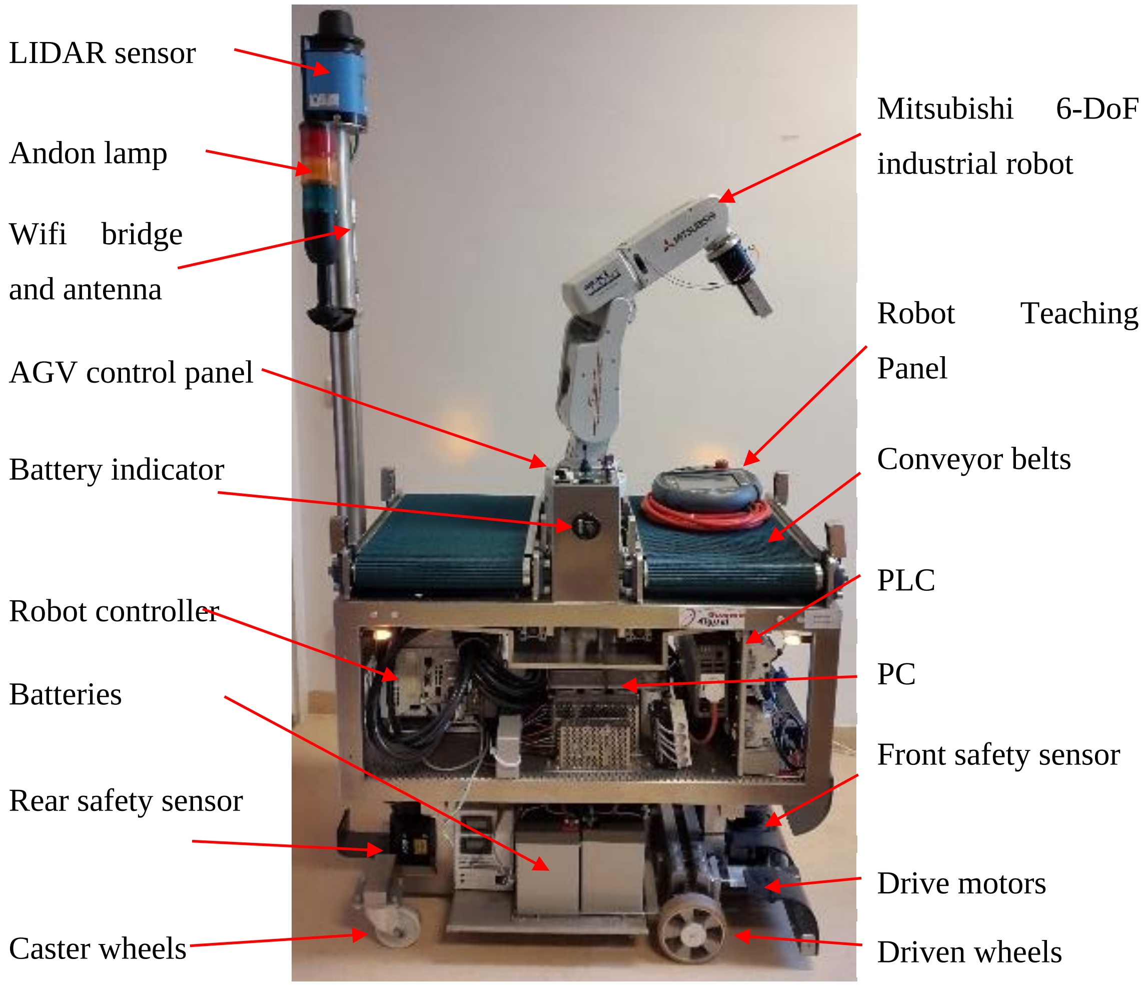


Figure 2.1. Used driverless transport carrier

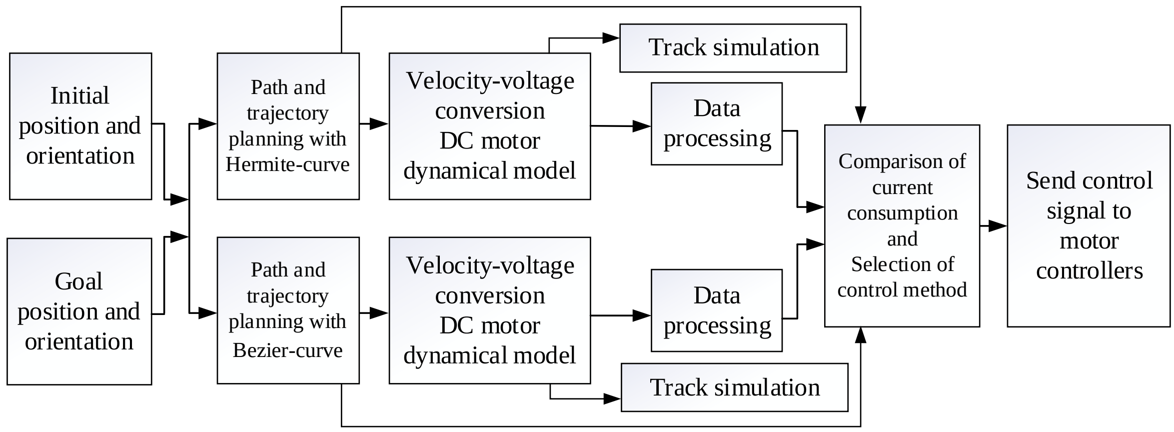


Figure 2.2. Construction of the design and control system for the forklift

Module system for AGV control

Chapter 4 of the dissertation details the six modules of the modular system developed for AGV control: **a.** path planning module produces the necessary track points for movement (Chapter 4.1 of dissertation); **b.** trajectory planning module generates the velocity of the driven wheels from the geometric and time data of the track points (Chapter 4.2 of dissertation), **c.** speed-voltage conversion module generates the voltage needed to propel the DC motor using the velocities obtained from the trajectory planner (Chapter 4.3 of dissertation), **d.** DC motor electrodynamic model with the use of voltage from the converter (Chapter 4.4 of dissertation), track simulation module, **e.** based on the angular velocity (Chapter 4.5 of dissertation) and **f.** communication module for transmission (Chapter 4.6 of dissertation).

Chapter 4.7 of the dissertation details the graphically programmed modular system from modules **c-f.**, as set out in the Figure 2.3. through various examples.

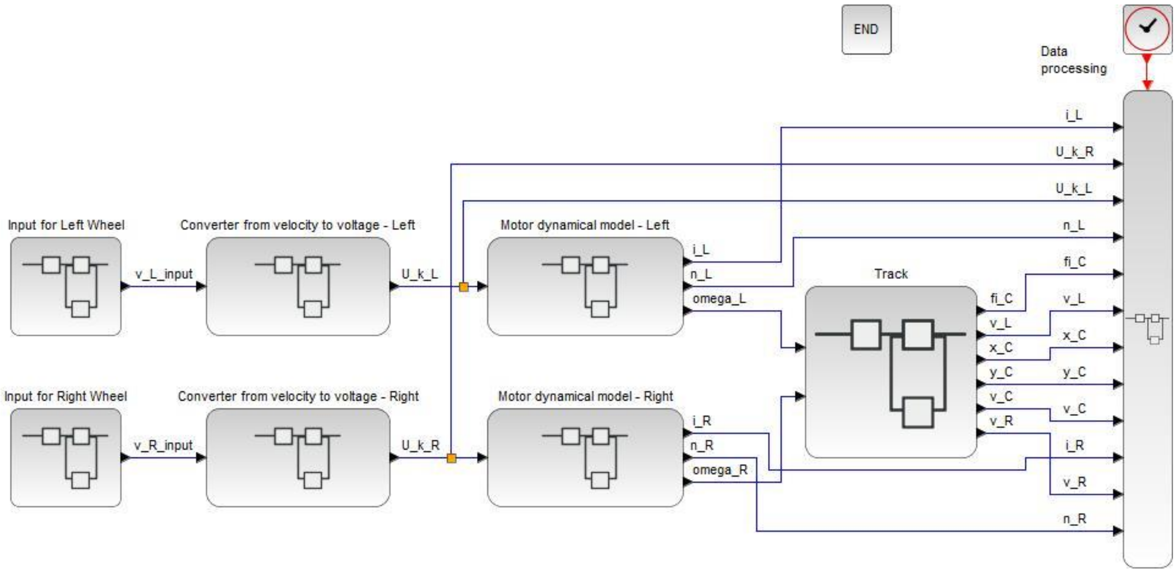


Figure 2.3. Simulation program from the graphically programmed part of the control

Program development of AGV control

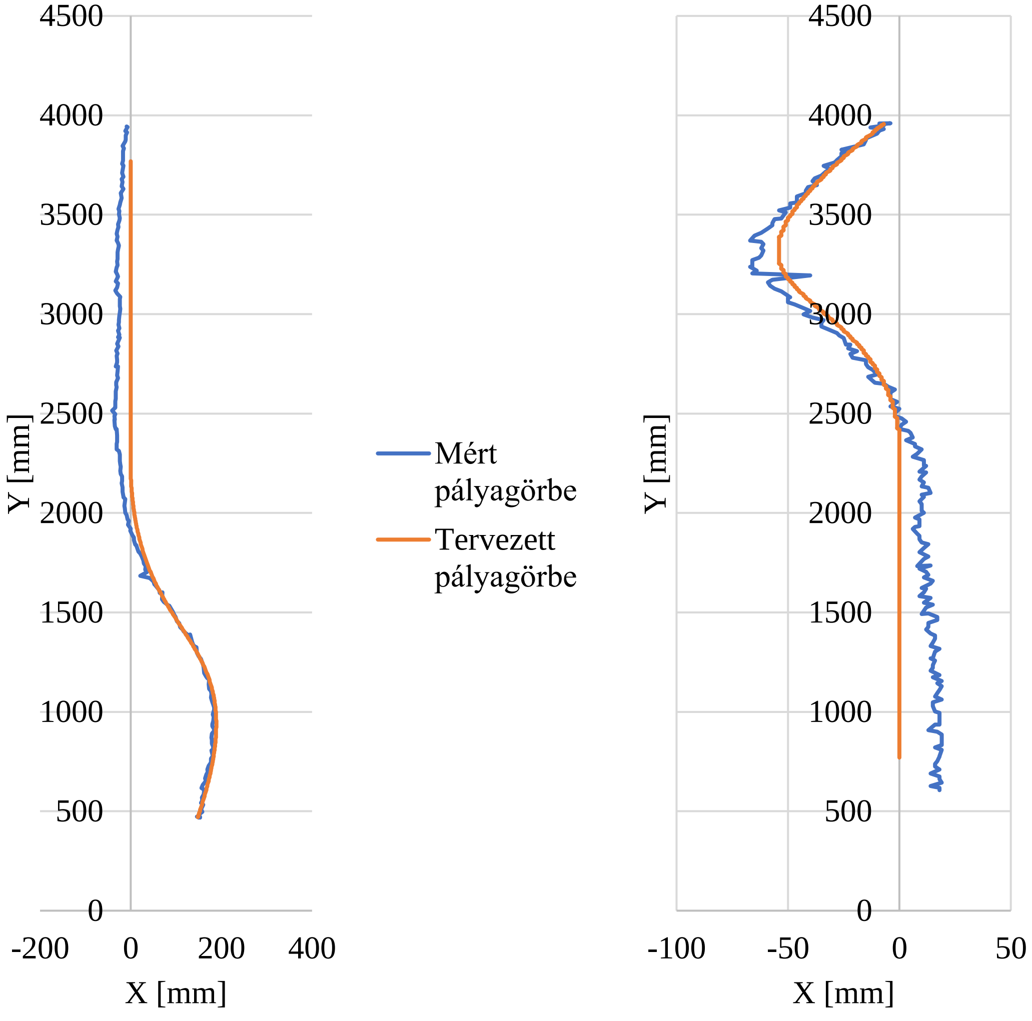
Chapter 5 of the dissertation deals with the programming of driverless carrier control. The hardware components and network devices of the AGV are included in Chapter 5.1 of the dissertation. The Chapter 5.2 of the dissertation describes the manual movement of the forklift, using the joystick on its control panel. Chapter 5.3 of the dissertation details the possibilities of programming the automatic movement of the AGV. This includes safety features, such as immediate interruption of power to motors in the event of an emergency. Automatic movement between obstacles is done in a straight line alternating with the help of front-rear safety sensors. Later, as an upgrade, automatic movement already uses navigation data to implement simple movements.

Development of a measuring system for AGV monitoring

A measuring system has been set up as part of the motion control and to check it. To process measurement data in a Microsoft Office Excel spreadsheet, a file save section has been added to the program, which is discussed in Chapter 6.1 of the dissertation. Chapter 6.2 of the dissertation describes the current and voltage measurement part of the measuring system. Chapter 6.3 of the dissertation summarizes the reception and use of voltage, current and navigation data on the PC.

AGV experiments and measurements

Chapter 7.1 of the dissertation describes the series of measurements carried out taking into account the different technical conditions, in which the engine speed depends on the effects. Chapter 7.2 of the dissertation presents the different examples and results measured by the LIDAR sensor. Chapter 7.3 of the dissertation, using the measuring system detailed in Chapter 6 of the thesis, processes the results measured during the automated forward and reverse movement shown in the Figure 2.4.



(a) Forward motion (b) Reverse motion

Figure 2.4. X and Y coordinates of measured position - AGV automatic track control

3. THESIS STATEMENTS - NEW SCIENTIFIC RESULTS

The following thesis statements are the new scientific results of the researches that are developed as part of the doctoral research work:

T1. I have developed a new path planning solution that uses two methods simultaneously, Hermite curve and Bezier curve, to determine the track points needed to control the movement of a driverless transport vehicle with two conveyor belts. The geometry of the track can be prescribed from the initial point and orientation recorded by the LIDAR sensor, and in a one-segment case with the position and orientation of the target, or in multi-segmented cases by specifying the positions and orientations of the passage and targets.
Relevant publication: [S1]

T2. I have developed a new trajectory planning method that determines the velocity of the driven wheels of a driverless transport vehicle with two conveyor belts, depending on the orientations and coordinates of the intended track points and the time.
Relevant publication: [S1]

T3. Using wheel speed data resulting from the output of the trajectory planner, I have developed a new modular system that generates track simulation and drive current, as well as transmits data (velocities, rotation speeds, voltages, currents, positions and angles) to the main program. In the electrodynamic model of the DC engine, I matched the load torque to the characteristics of the AGV.
Relevant publications: [S3], [S5], [S9]

T4. To determine the parameters needed to control the AGV, I have developed a new measuring system that receives AGV’s navigation data, measures motor currents and voltage of lined batteries, which is transformed into a suitable form for the control system.
Relevant publications: [S2], [S4], [S6]

4. POSSIBLE APPLICATION OF THE RESULTS AND FURTHER PLANS

One of the objectives of the doctoral research was to implement a new path and trajectory planning method that determines track points and produces wheel speeds. These methods are still a task to be solved in the case of a custom-made industrial AGV.

To determine the current consumption, I used the electrodynamic model of the DC motor. I divided the incriminating torque in the model into two parts and detailed their definition. To determine the counter torque due to rolling resistance, I made measurements, which I evaluated to determine the rolling factor. Taking into account the power consumption in the industry is aimed at extending the operation of driverless vehicles operating from the battery. I used the angular velocity data resulting from the output of the electrodynamic model for orbit simulation and presented the communication module for transmitting the data.

The next part of my dissertation discussed the program improvements needed to control the AGV, which implements manual and automatic movement. These program developments can be used in industry when programming AGV.

For the rest of my thesis, I developed a measurement system for the condition monitoring of AGV. The measurement system includes receiving navigation data, measuring voltage and current, and then transforming these data for the control program running on the PC. During the measurements, I discussed the motor speed and AGV position, as well as the results of automatic movement using track control. The use of a state monitoring system is becoming increasingly necessary in order to monitor an industrial handling system.

My further development plans include simulation and implementation of the industrially specific tasks of AGV control. For further development, I consider it important to meet the requirements of Industry 4.0 technology, such as the creation of AGV's digital twins.

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