…………..Piotr Biernacki................
(candidate's first and last name)

.........piotr.biernacki@polsl.pl ....
(email address)

………..Gliwice, 21.08.2025 ....
(city, date)

Abstract

Title of doctoral dissertation: “Methods supporting the docking precision of AGV systems to the assembly station”

The aim of the dissertation was to develop methods for increasing the precision of AGV docking to a required point of a given assembly station. The work was carried out as part of the international project CoBotAGV, whose objective was to integrate AGV systems with collaborative robots and to enable their relocation between assembly stations while ensuring accurate and repeatable docking.

The solution developed within the doctoral dissertation is intended for industrial applications, using only the onboard resources of the AGV, primarily 2D LiDARs and odometry - without the need to expand the AGV system with additional perception subsystems. The objective of both the project and the doctoral research was to achieve high docking accuracy while maintaining the process flexibility required by the Industry 4.0 concept.

An additional challenge, arising from the CoBotAGV project requirements, was the lack of possibility to build and use an environmental map.

In response to the challenges posed, a set of methods was proposed to improve accuracy and precision through calibration and filtering of measurements provided by the AGV subsystems. An innovative positioning system was developed for determining the AGV’s position relative to the assembly station, based on a reflective spatial marker detected and identified by a 2D LiDAR. All developed methods were integrated into a coherent system executing docking and verifying the AGV’s position after docking, based on calibrated measurement data.

Within the doctoral work, the measurement characteristics of distance sensors and odometry were analysed, and methods for their improvement were developed and validated. The proprietary Adaptive Calibration Method (ACM) for distance sensors reduced measurement errors by up to 79%, while the Adaptive Calibration with Median Filtering method (MSCwMF) further improved distance measurement precision by more effective noise suppression. A rotational odometry calibration method (2DLAT) was also developed, using data from a calibrated 2D LiDAR to limit the accumulation of systematic odometry errors. Filtering methods based on moving average and median filters were assessed and applied, resulting in a significant reduction of the standard deviation of distance measurements from 2D LiDARs. In addition, calibration methods for distance sensors using machine learning techniques (NC and RC) were developed, reducing measurement errors to below 1 mm.

A key innovative element of the docking procedure developed in this dissertation is the 2D marker with reflective codes (2DM-RC) and its detection and identification method, based on 2D LiDAR data, taking into account both distance measurements and the intensity of reflected laser beams. Thanks to the reflective structure of the marker segments, which forms a binary “code”, it is possible to simultaneously recognise elements of the assembly station and accurately determine its position and orientation relative to the AGV. This enables continuous recalibration of the docking trajectory and compensation of odometry drift.

All developed components were integrated into a docking system based on the Robot Operating System (ROS), including software nodes for communication with the AGV's processing unit, calibration and filtering of distance measurements, odometry calibration, 2DM-RC marker detection and identification, navigation, docking, and automatic verification of the AGV's position after docking. The system was experimentally tested on the "Formica 3" prototype platform by AIUT. The tests showed that calibration of distance sensors and odometry clearly increases the accuracy of the achieved docking point; continuous recalibration relative to 2DM-RC markers effectively eliminates accumulated odometry errors; and the post-docking verification procedure makes it possible to determine the precise position and orientation of the AGV relative to the assembly station and to calculate correction values required for further operations of the collaborative robot.

The achieved results confirm all the theses of the work: calibration increases measurement accuracy, filtering improves measurement precision, the use of a spatial marker enables accurate positioning of the assembly station, and the reduction of measurement errors translates into improved docking accuracy. The original contribution to the field of technical computer science and telecommunications includes: the ACM, MSCwMF, NC, and RC calibration methods for distance sensors, the 2DLAT rotational odometry calibration method, and the reflective spatial marker 2DM-RC with its detection and identification algorithms.

As a result, a complete data processing chain has been created, enabling accurate and repeatable AGV docking to an assembly station in variable industrial conditions and supporting the implementation of the Industry 4.0 concept.