An Autonomous Robotic System for Load Transportation

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I. Introduction

The process of loading, unloading and transporting of materials is one of the key issues for every production site and has a great impact on costs. Automated Guided Vehicles (AGVs) are robotic transporters that have been designed to help industries achieve high productivity at minumum cost. This paper presents an overview of an ongoing research effort by the universities of Örebro and Halmstad in Sweden together with Danaher Motion Särö, Linde Material Handling, and Stora Enso Logistics to develop a system of **M**ultiple **A**utonomous forklifts for **L**oading and **T**ransportation **A**pplications (MALTA) [1]. The ultimate goal of the project is to develop modularized components for continuous operation of autonomous transportation vehicles. Initially, the system will be tested on forklift trucks adapted to handle paper reels in a production facility (mill) and warehouse terminals with the following characteristics. First, the controlled forklift trucks are to be operating safely in dynamic environments shared with humans and other autonomously and manually driven vehicles. Second, the system must be able to compute dynamic vehicle paths online to ensure a more time-optimal flow of material. Finally, the proposed system is required to achieve flexible positioning of the load (paper reels) in different settings that include containers, lorry trailers, cargo trains, and on the floor (see Fig. 1).

Fig. 1. A warehouse of paper reels waiting to be loaded.

II. System Description

The autonomous system that we are currently developing is based on a modified Linde H 50 D diesel forklift truck that has a load capacity of 5000 kg (see figure 2). The standard version of the truck was modified by shortening the mast and replacing the forks with a clamp. The truck was retrofitted with an off-the-shelf AGV control system developed by Danaher Motion. The AGV control system comprises a set of hardware and software components (PC, IO modules, field bus controller, rotating laser ranger, etc.). The control system interfaces the actuators and sensors of the truck through the already built-in local CAN network. The main task of the AGV controller is to navigate the truck from an initial location to a goal location. To do so, an operator defines and uploads a layout of drivable paths specified as collection of line segments and B-splines.

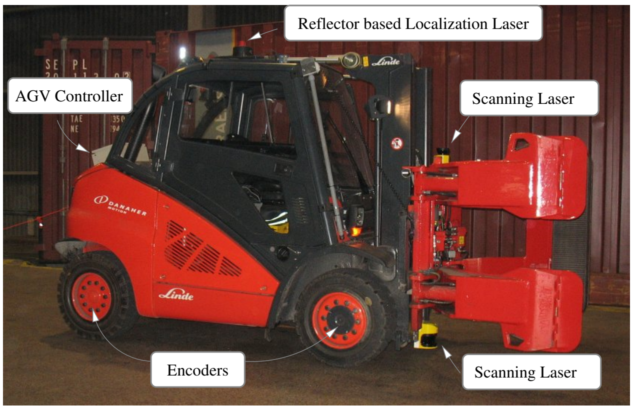

Fig. 2. A modified forklift truck retrofitted with an AGV controller and a reflector-based localization laser for guidance purposes. Two front lasers are used for reel detection and safe navigation.

The controller achieves navigation tasks by following an appropriate path. The position of the truck can be tracked using a spinning laser (installed on the top of the truck) and reflective markers installed in the environment. To detect paper reels and obstacles, two extra scanning lasers were incorporated into the truck (see figure 2).

In addition to the of-the-shelf AGV control system, an external module aimed for extended functionalities has been developed. The external module includes two main components: perception and navigation. The aim of the perception component is the detection and tracking of paper reels. Paper reels are modeled as circles whose positions and diameters

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are determined using laser range-data. The method used to detect paper reels is based on Taubin's work for fitting a circle to data points [2]. To estimate the reel position in a global coordinate frame, the global pose estimate of the truck, which is provided with the reflector-based laser localization system, is combined with the paper reel detection method. Essentially, the tracker keeps a global map of detected paper reels, such that the global position of each paper reel is updated using a Kalman Filter. The navigation component aims at generating runtime trajectories needed to achieve tasks of loading and unloading of paper reels. The trajectories are represented by cubic B-splines and they are executed by the AGV controller. The navigation component will also be responsible for ensuring safe motion, i.e., obstacle detection and avoidance. The functionalities of both components are implemented as a set of Player drivers [3] that run on an external PC. Communication between the onboard PC of the AGV controller and the external PC is implemented by a set of TCP/IP protocols using a wireless radio network.

III. Test Cases

AGV Verification Tests

The first conducted step was the integration of a modified forklift truck and an AGV control system to create an automated vehicle. The integrated AGV system performs navigation by following predefined static paths. This means that to pick up a paper reel, the position of the reel and its size together with a path segment leading to it have to be known in advance. In this tests, paper reels were successfully loaded and unloaded from 10 different fixed positions with different elevations. The tests were successfully repeated several times over a period of 4 months.

Evaluation of the Perception Component

While performing the previous AGV verification tests, data from the laser range-finder and AGV reflector-based localization was logged for the purpose of evaluating the reel detection and tracking component. Using the predefined positions as ground truth, the obtained results showed that the estimated absolute reel-position error (for the 10 different positions) was $0.027m$ with a standard deviation $\sigma = 0.013m$ (the results depend on the AGV's positioning accuracy). This was achieved by combining measurements using a Kalman filter for each of the ten reel position. Please note that the error in reel position (which, in our case, is less than 2% of reel diameter) was taken into account when opening the clamp to pick up reels.

Evaluation of the Entire System

The goal of these tests was to evaluate the extended capabilities of the original AGV system with runtime perception and navigation capabilities. The tests consisted in transporting a set of reels from a loading zone to a container. The reels were placed by a manually-driven truck inside the loading zone, i.e., the positions of the reels were not initially known to the system. To achieve the assigned task, the closest detected reel was selected as target to approach and pick up using an online-computed path (B-spline) starting at a predefined point. Similarly, the transportation of the reel into the container was carried out by following a path including a return B-spline and a set of predefined segments. To ensure that the target reel was appropriately picked up, i.e., to avoid the situation of the clamps hitting the reel when turning, the truck was forced to drive straight at the final part of the B-spline. The tests were successfully run a significant number of times to ensure that the entire system was working correctly.

IV. Discussion and Conclusion

We have presented an overview of our ongoing work of developing an autonomous robotic material-transportation system. The system is built on top of a retrofitted forklift truck with an "off-the-shelf" AGV control system together with extra sensors. The AGV navigation system works very reliably under normal conditions and is able to navigate the truck with an accuracy of approximately $1cm$. However, there are two main evident limits in the AGV system that need to be addressed. First, the infrastructure used for the reflector-based localization is difficult to setup in an efficient way, due to the high stacks of paper reels that will obscure the reflectors. Therefore, the indoor localization has to be addressed in a different manner. The second limitation of the AGV control system is its use of predefined paths, which means that the truck is not allowed to change path at runtime. A solution to this limitation is to generate and follow paths online. However, this raises the issue of safe navigation, as there are many unsafe and dangerous locations around the working site. This is currently addressed by providing predefined locations, where on-line path generation is allowed. Another open issue is the detection and handling of stacked reels that are not aligned vertically and that could also be sitting on more than one reel. Our intention is to use advanced 3D sensing modalities to detect and handle such situations.

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