An Autonmous Robotic System for Load Transportation

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Abstract

This paper presents an overview of an autonomous robotic material handling system. The goal of the system is to extend the functionalities of traditional AGVs to operate in highly dynamic environments. Traditionally, the reliable functioning of AGVs relies on the availability of adequate infrastructure to support navigation. In the target environments of our system, such infrastructure is difficult to setup in an efficient way. Additionally, the location of objects to handle are unknown, which requires that the system be able to detect and track object positions at runtime. Another requirement of the system is to be able to generate trajectories dynamically, which is uncommon in industrial AGV systems.

1 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 with minumum cost. Typical examples include automotive factories, warehouses , paper mills, and mines [4, 2, 6]. AGVs come essentially in two forms today: AGVs guided by wires in the floor and AGVs guided by visual markers in the environment (e.g., reflective markers). AGVs with wires in the floor require both specific infrastructure (wires) and are restricted to follow those wires, like a train on rails. AGVs with reflective markers have the drawback of requiring additional infrastructure but can modify their paths, e.g., to navigate around obstacles.

There have been sevaral works aiming at extending the functionalities of traditional AGVs. Typical extended functionalities include high-level decision making and flexible path planning on top of traditional wire-guided AGVs [7], task scheduling (see, e.g., [9]), environment-specific perception using laser scanners to recognize ceiling details and pallets [5], and vision-based navigation that exploits naturally occurring visual features [3].

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) [8]. 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 in dynamic environments shared with humans and other autonomously and manually driven vehicles ensuring safe operation. 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.

The remainder of the paper is organized as follows. Section 2 gives a description of the working environment, while section 3 is devoted to presenting the system. Section 4 summarizes our first test cases, and section 5 includes a discussion of the open research issues.

2 The Environment

Figure 1 shows pictures of paper warehousing terminals where MALTA vehicles are intended to operate. The first picture shows stacks of paper reels that are temporarily stored before they are transported to customer sites using cargo trains and trailer-trucks. The warehouse environment is characterized by the presence of manually driven trucks fitted with clamps used to load and unload paper reels. The handled paper reels can weigh up to 5000 kg and have a diameter in the range of 950 - $800mm$ and a height in the range of 550 - $2800mm$. They are covered with a protection paper/plastic and have printed labels that can be read with a bar code reader.

The environment includes also trailer-trucks used to transport paper reels from the paper mill to the terminal. When trailer-trucks arrive at the warehouse, clamp-fitted trucks are assigned to unload their cargo in predefined areas of the terminal. The paper reels are unloaded either on the floor or on top of other reels. The clamp-fitted trucks are also assigned to loading containers, lorry trailers, and wagons of cargo trains. The activities of loading/unloading are performed in parallel, which makes the environment highly dynamic.

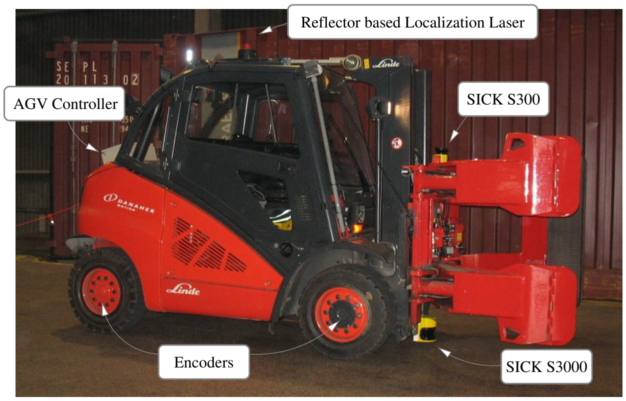

Figure 2. A modified forklift truck retrofitted with an AGV controller and a reflector-based localization laser for guidance purposes. Two front lasers are used for reel detection and safe navigation.

The pictures show also some examples of the difficulties that the system must detect in order to achieve its assigned tasks correctly. For instance, the cylindrical shape of the pillar support shown in the bottom picture can be mistakenly detected as a paper reel. Another example is of stacks that are not perfectly aligned in the vertical direction. These are few of the challenges that the onboard perceptual system must address.

3 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. To detect paper reels and obstacles, two extra laser rangers were incorporated into the truck (see figure 2).

The modules of the system are shown in figure 3, and they are described in the following subsections.

3.1 The AGV Controller

The AGV controller comprises a set of hardware components that include an onboard PC running Linux and a set of Input/Output modules used as interfaces to control the truck. Communication between the different components of the controller is implemented using the CanOpen protocol.

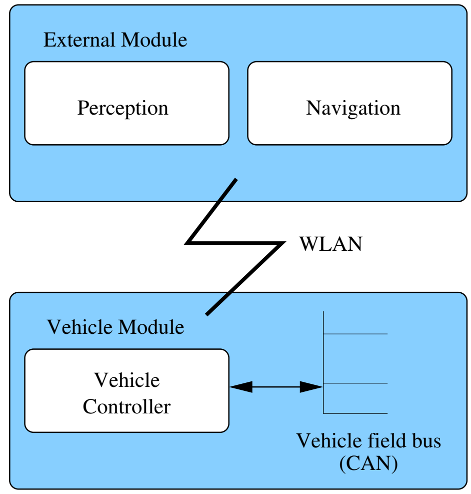

Figure 3. The two main modules of the MALTA system. The first module includes the AGV controller that implements a traditional AGV functionalities (navigation using reflective markers). The AGV controller is connected to the CAN network of the vehicle. The second module includes a perception component to detect paper reels and obstacles and a navigation component for generating dynamic paths.

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 Bsplines. 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 allow for dynamic navigation, the system also accepts runtime trajectories specified as B-splines.

3.2 External Module

The second module includes two main components: perception and navigation. The main aim of the perception component is the detection and tracking of paper reels, while 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 Bsplines 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 [1] 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.

Figure 1. A warehouse of paper reels. Left) Stacked paper reels waiting to be loaded. Middle) Reels to be unloaded in the warehouse terminal. Right) A concrete pillar that has the same cylindrical shape as a paper reel.

Paper reel detection

Laser range data was used for finding the position and diameter of the paper reels (modeled as circles). The method used to detect paper reels is based on Taubins work for fitting a circle to data points [10]. To extract the data points, laser range scans are processed as follows. First, range scans are divided into segments, if the distance between two consecutive scan points is larger than a predefined threshold. The circle fitting algorithm is applied for each extracted segment to obtain reel position and diameter. Finally, all paper reels that have a diameter falling outside a predefined interval of acceptable reel diameters are rejected.

Paper reel tracking

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 data association process, i.e., establishing the correspondence between sensed reels and the reels in the global map, is performed using the Euclidean distance to associate the closest reel in the map with the sensed one unless the distance is greater than a threshold. If no corresponding reel in the global map is found, a new paper reel is added to the map. To improve the position estimate of the reels, especially when the truck is turning quickly, the truck pose estimate is interpolated using the time stamp of both the laser and the localization readings. To avoid to track/update reels that are outside of the loading/unloading area, reels that fall outside this region are simply neglected.

4 Test Cases

The autonomous vehicle system described in this paper builds upon different commercially-available subsystems. The first conducted step was the integration of a modified forklift truck and an AGV control system to create an automated vehicle. Therefore, the first tests were aimed at verifying the correct and reliable operation of the integrated AGV system. The second series of tests aimed at the evaluation of the perception component using off-line data, while the objective of the last series of tests was the verification of the functionalities of the entire system.

AGV Verification Tests

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 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 poses. Only measurements performed at a distance less than $8m$ were considered. Please note that the error in reel position (which, in our case, is less than 2% of reel diameter) is taken care of 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. This meant that the positions of those reels were not known to the system. This scenario was one of the first requirements that the system should be able to fulfill.

To achieve the assigned task, the closest detected reel was selected as target to approach and pick up using an online-computed paths (Bpline) starting ata predefined point. Similarly, the transportation of the reel into the container was carried out by following a path including a return spline and a set of predefined segments. To ensure that the target reel was picked up appropriately, 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 spline.

5 Discussion and Conclusion

We have provided an overview of our ongoing work with developing an autonomous robotic material-transportation system. The intended goal is to have a fleet of autonomous forklift trucks operating in dynamic production environments with intermediate storage, loading of containers and train wagons. The system is also intended to work in close cooperation with manual trucks as well as other autonomous trucks. 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, see figure 1. Therefore, the indoor localization has to be addressed in a different manner, e.g., by laser scanners or cameras pointing to the ceiling. One observation is that paper reels are rather easily detected in 2D laser scans and could therefore be suitable as landmarks in the context of SLAM.

The second limitation of the AGV control system is it use of predefined paths, which means that the truck is not allowed to change path at runtime. Driving safely the truck with an online generated path is a main issue as there are many unsafe and dangerous locations around the working site that are impossible to detect using a 2D laser scanner alone, e.g., a one meter drop down to the train tracks. This is currently addressed by providing predefined locations, where on-line path generation is allowed. Up to now reels have been detected using only 2D laser data. Other sensing approaches will be required when stacked reels are handled. One open issue is to detect and handle stacks that contain reels which are slightly shifted horizontally and that could also be sitting on another stack. Our intention is to use advanced 3D sensing modalities to detect and handle such situations, e.g., 3D laser scanning and stereo vision.

Acknowledgment

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