The RTS-STILL Robotic Fork-Lift

Variable pallet pick-up and 3D localisation in industrial environments

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Motivation

The material flow within the product manufacturing cycle i.e. from the work benches to the storage is very expensive and can be optimized in many companies, so that the efforts to find favorable and flexible systems continues to be of great importance. According to the use the material flow requires various systems. These are on one hand fixed installed systems, such as conveyer belt, rolling belts, rail-mounted transport installations and conventional automatic guided vehicle systems (AGVS) with high throughput on simple and pre-defined transport channels. On the other hand conventional, manually operated, fork-lift trucks are widely used for flexible and partially complicated material handling. Due to their universal capabilities fork-lift trucks are used in almost every company.
Although the automatic guided vehicle systems have been used for automation since the 1960s, the restrictions of these systems in contrast to conventional fork-lift trucks are substantial. In order to overcome these limitations the STILL GmbH in cooperation with the University of Hannover, Institute for Systems Engineering developed a prototype of a new flexible AGV. The key features of this prototype are the ability to localize and navigate freely without additional infrastructure and the ability to automatically pick up pallets at variable positions and at variable heights. Independently of these autonomous capabilities the vehicle keeps all its in series features that make dual-use possible.
In the following the RTS-STILL Robotic Fork-Lift (see Figure 1), the prototype of new flexible AGV, will be described as it was presented at the international logistics fair CeMAT 2005 in Hannover.

Cooperation between research and industry

STILL GmbH is a leading provider of fork-lift trucks, industrial trucks and services for Intra-logistics in Europe, while the Institute for Systems Engineering, Real Time System Group (RTS) is doing research in the area of mobile robotics. As the RTS focus lies on 3D perception and navigation in real world environments the development of the RTS-STILL Robotic Fork-Lift was an exciting challenge for both partners.
Due to the cooperation between RTS and STILL it was possible to test new results from robotic research in real industrial environments. Based on a modular software framework

it was possible to run navigation and perception algorithms on the 3t fork-lift truck that have been previously tested on small service robots. On the other hand STILL has enabled us to present autonomous robots to a broad audience at the CeMAT 2005. Feedback from customers and users gives impulses for future research.

Figure 1. The project platform: Still FM14i with additional sensors for autonomous operation.

State of the art

For many years automatic guided vehicles have been used in the industrial world. But current systems have got a limited field of application. This fact can be attributed to the navigation systems and sensors that are in use. As the navigation systems need extra infrastructure the route of an AGV is fixed and a change of the route causes a change of the infrastructure [1]. Many of these navigation system need either passive or active elements on the floor - e.g. optic, inductive, magnetic or transponder guidance [2].

Meanwhile an increasing number of laser navigation systems comes into use [3]. In this approach the automatic guided vehicle can localize itself with the help of strategically fixed reference points in form of reflectors. In this case a 2D rotating laser head installed in the vehicle transmits a laser ray, which is reflected back to the vehicle. The position of the vehicle can then be traced by a defined position of the reflectors [4,5]. The iFork AGV uses this kind of 2D localization to navigate freely and avoid obstacles[6], whereas the fixed infrastructure is still needed.

Another limitation is the required centimeter accuracy at pallet pick up positions. This requirement makes handover between human and machine especially difficult. Two systems that are able to handle variable pick up positions on the ground level are the AMTS Project [7] (based on camera) and a system from EADS SPACE Transportation GmbH [8] (based on 2d laser ranges). Folk-lifts that are able to do variable pick up on different levels are not known in this moment.

Project approach

In order to carry out the project to develop a flexible robotic fork-lift truck, a standard reach truck type FM 14i manufactured by STILL GmbH was modified, so that it complied with the safety demands for a robotic vehicle and could be steered completely by way of an embedded computer and also by a fork-lift truck driver.
In order to operate the lift truck autonomous the embedded computer must take over the tasks given, which are usually undertaken manually by the fork-lift truck driver, for example the nominal value details for the speed, steering movements or the steering of the mast for the handling of the load.
Furthermore the system must be capable of identifying the position of the palettes and to localize itself in the industrial environment, in order to operate automatically.
The embedded computer in this project is a so-called “SPB” (scalable processing box) developed by the Institute for Systems Engineering with an Intel Pentium II 700MHz processor. The software architecture of the SPB is based on an embedded Linux distribution named LiRE (Linux Real-time Environment) [9], and includes the real time extension RTAI (Real-time Application Interface), whereby a real-time data processing is guaranteed. The self-developed software for the system consists of modules and is independent of the platform as well as independent of the hardware [10]. The communication between the individual modules is carried out over a mailbox system.

Results of research and development

In order to comply with the safety demands for the robotic fork-lift truck a bumper has been installed on each side, which in the case of a collision with an obstruction brings it to a stop immediately. The robotic fork-lift truck is equipped with two 2D safety laser scanners, which enables it to measure the distance from obstructions and if necessary to lower its speed down to a stop. During the testing development phase a radio emergency stop system was used in order to stop the robotic vehicle from a distance.
The two laser scanners, which are required to avoid collisions or the recognition of obstructions, can also be employed as an additional environment identifier, whereby one 2D laser scanner is installed facing the direction of the fork, so that it can identify a palette on the floor.
The first prototype purpose was to demonstrate the reaching and lifting of a palette on the floor. The basic requirement for this is the robust identification of a palette by the 2D laser scanner in the direction of the fork. For this purpose the palettes where modified at first with adhesive reflectors manufactured by 3S, type Scotchlite 3000X (see Figure 2).

Figure 2. Palette modified with reflectors

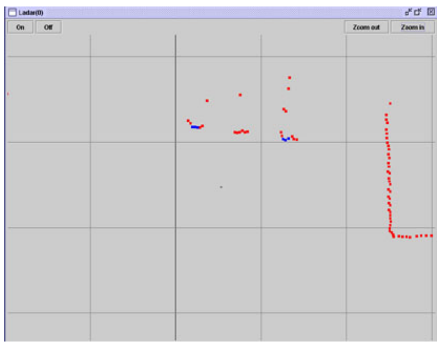

Figure 3. Depth image from laser scanner

The developed algorithm for the identification of the position of the palette shows that it is capable of recognizing the exact position within a two dimensional image, which is traced by a laser scanner which calculates its position from the remissions from the reflectors. It is then possible with the positioning of the reflectors to enable orientation and positioning of the marked palette in the space. The respective depth image from the laser scanner can be seen in Figure 3. The scanned points on the reflectors can be seen in blue.
The established coordinates of the palettes identified position, are at disposal in real time, so that position details for the further path planning and control for the contact with a palette can be carried out. The trajectory planning and the ensuring vehicle control for the contact and lifting of the palette have been developed based on the palette identification. The fork-lift truck in its starting position is a few meters from the palette. However, the palette is in sight of the fork-lift trucks 2D laser scanner and can be recognized as described. The preeminent goal is to achieve a precise and collision-free docking of the fork-lift truck to the palette.
The purpose of the trajectory planning is to generate a path from a starting to an ending point, which is suitable for the used vehicle to travel, whereby the geometric configurations of the vehicle must be taken into consideration.
In this work the established movement plan for docking are used to draw up suitable guiding points of the nominal path and then lead to creation of the movement plan. The assisting points comprise of the relative distance of the fork-lift truck from the palette and the actual position of the fork-lift truck. With the help of these guiding points a polar-spline will be generated from the movement plan. One can see an example of a trajectory for the docking of a fork-lift truck on the palette in Figure 4.

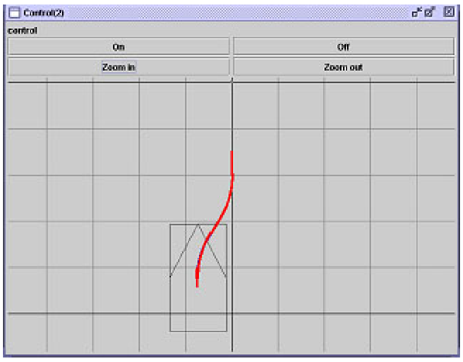

Figure 4. Trajectory for docking

Figure 5. 3D laser scanner

In general driving along the trajectory without a control unit is not sufficient for the precise docking of the fork-lift truck on the palette. For this reason a vehicle control for the docking process is employed, which controls the fork-lift truck precisely by way of odometry data and the continual identification of the palettes position and passed to the feedback control system.
A further laser scanner is mounted on the mast of the fork-lift truck between the forks so that the palettes can be taken from shelving systems and platforms at various heights. The measuring system moves together with all movements of the mast allowing the positioning of palettes modified with reflectors relative to the mast and therefore to the vehicle.
In order to allow automatic movement of the reach truck, it must be capable of locating itself in the environment. A 2D localization and a 3D localization are implemented for the localization of the fork-lift truck, which does not require any alteration or modification of

the environment, as for example making it necessary to install reflectors. The 2D localization utilizes the sensor information from the 2D laser scanner mounted on the fork-lift truck to determine its position. The actual position of the fork-lift truck is established on a previously prepared environmental map through a process of a Monte Carlo localization. This information can afterwards be used by a navigation module to drive along a set path.
Alternative to the 2D localization, the RTS utilizes a 3D localization, with the assistance of a 3D laser scanner specially developed by RTS for navigational tasks (see Figure 5) [11]. The 3D laser used to establish the position of the fork-lift truck by way of the ceiling structure of the building [12]. In this approach the ceiling structure is perceived three dimensional by the 3D laser scanner and once more with the previously prepared ceiling map and the Monte Carlo procedure the actual position of the fork-lift truck is determined. The localization by way of the ceiling structure provides a reliable navigation procedure, because normally the ceiling structure does not change within an industrial environment even over a long period of time and changes in the rest of the environment, such as remodeling of the shelving system, partition walls etc, do not influence the localization.

Figure 6. RTS-STILL Robotic Fork-Lift, as presented at the CeMAT 2005

Achieved innovation

The robotic fork-lift truck developed during cooperation complies with the safety demands for a robotic vehicle and also enables a dual-use operation. Moreover the fork-lift truck enables the identification of palettes, picking them up and automatically put them down again in another place. The essential innovation of the system is that the palettes, as with the usual systems, do not have to be put at a pre-defined hand over point, but instead are recognized by way of laser scanners and picked up flexibly from varying positions and at varying heights autonomously. Thereby on one hand, the transfer from manual to robotic work can be optimized and on the other, flexible transport operations with high demands of positioning can be implemented e.g. automatic unloading of a lorry.
A further significant innovation in comparison to the usual automatic guided vehicle systems can be found in the localization equipment installed in the fork-lift truck, which is in the form of 3D environmental information. Using the 3D environmental information for the navigation of a robotic fork-lift truck and the ceiling localization resulting from this also allows navigation in a highly changeable environment without equipping the environment with artificial landmarks or path guidance systems.

The functional efficiency of the robotic fork-lift truck was demonstrated at the STILL GmbH stand at CeMAT 2005 fair in Hannover from 11th to 15th October 2005 together with a fully automatic commissioner lift truck, whereby the flexible picking up of palettes on the floor and on a platform as well as free navigation with the assistance of the ceiling characteristics being demonstrated (see Figure 6 and video).

http://www.rts.uni-hannover.de/mitarbeiter/lecking/RTS_STILL_CEMAT2005.wmv

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