Coordination of an Autonomous Fleet

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***Abstract*— Automated Guided Vehicles are systems normally designed to follow predefined paths in order to work reliably and predictably. Giving such vehicles the capability to leave a predetermined path enables the system to cope with obstacles and to use energy efficient trajectories. However, industrial acceptance of such autonomous systems is low, due to the fear of unpredictable behaviour. This paper presents a system design which is capable of spatially adjusting the level of autonomy for control of desired behaviour.**

I. INTRODUCTION

Automated guided vehicles (AGV) are driverless mobile platforms used for transportation processes as well as for flexible system solutions on assembly lines. An AGV is normally designed to operate precisely on predefined tracks, similar to movement along rails. This simplifies on-board self-localization and trajectory control while shifting the burden of control over to the centralised AGV Control System (ACS) server, which controls all of the vehicles in order to prevent deadlocks on the tracks under time constraints. This paper discusses an approach to the distribution of track management that enables vehicles to compute spatially limited paths and trajectories for leaving predefined tracks on-board. The vehicle is able to deal with obstacles, to drive energy-efficiently and to communicate with other vehicles if needed, e.g., at crossings. As a result, the system proposed will be less costly during installation, but also more complex to coordinate as a fleet.

AGVs have been used since the Second World War, first of all as vehicles following rails and then later magnets, coloured bands and other markers integrated into the environment [1]. Nowadays, laser scanners [2] with markers are used to follow a virtual path. On-board self-localization and trajectory planning are still avoided, by just following the handcrafted virtual path assigned by a central ACS which controls the whole vehicle fleet, as shown in Figure 1. Prevention of collisions and deadlocks is imperative, and regular tasks, such as recharging or vehicle cleaning, are managed by the ACS, which generates operation orders based on the input from the Production Planning and Control (PPC). The following section presents our approach to coordination of a fleet of AGVs with an adjustable level of autonomy.

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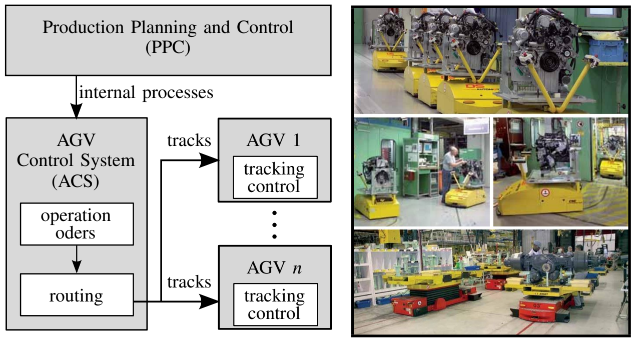

Fig. 1. This figure shows, to the left, the modules involved in a classical system. The PPC analyses general processes (e.g., costumer requests) for the ACS. The ACS identifies operation orders in internal processes and computes routing tables composed of sequences of line, arc and spline segments as tracks. A single AGV has to simply follow the tracks with a tracking control. No path planning is involved. To the right, AGVs in action on an automotive assembly line.

II. APPROACH

Currently deployed AGV systems use tracks that have been manually designed offline. These tracks are defined by a list of segments, for example, lines, arcs, and splines. An AGV's task is to follow these segments and to report on which segment it is currently driving. The segments are distributed by the ACS, as shown in Figure 1, for processing on the AGVs. Currently only two planning levels are needed:

- the overall routing on the centralised server and
- the tracking control on the AGV, which has to follow the designated segments.

We would like to present an approach which additionally enables an AGV system to:

- autonomously avoid obstacles on the track,
- solve situations without the ACS interfering, e.g., multi-robot situations, or pick and place actions,
- use optimised trajectories in order to drive time-, energy- and/or resource-optimally (e.g., in the face of floor abrasion) and
- to be easier to maintain and less expensive during system design and set-up.

Figure 2 depicts this approach. This can only be realised if AGVs are able to:

- localise themselves (even if vehicles are leaving a predefined track),
- communicate with each other and
- execute and adapt behaviour to solve local issues without centralised intervention.

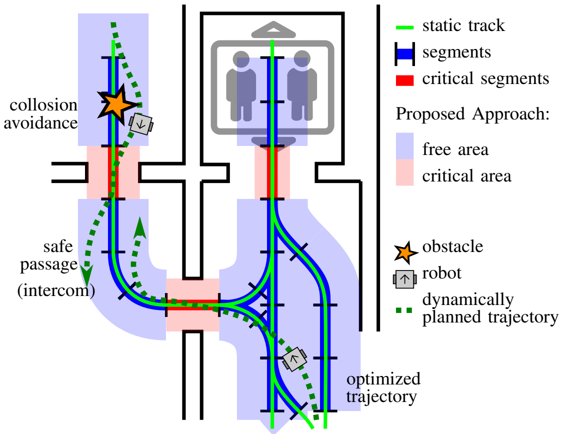

Fig. 2. The system currently used has a centralised path design based on pre-defined line and arc segments (blue). An AGV has to follow the static tracks (green) while the control system takes care of the routing. In contrast to the system currently used, the system proposed here uses pre-defined areas in which a vehicle is allowed to move freely. Obstacles can be circumnavigated and two or more vehicles are able to communicate directly with each other in order to plan trajectories for safely passing one another. Trajectories are locally planned and are time-, resource- or energy-optimised.

In the system proposed, the ACS distributes segments to the AGVs, similar to before, but encapsulates additional attributes. The additional segment attributes are used to signal the system what to expect and suggests a collection of behaviours from which one is selected by the AGV to manage the track segment. Typical behaviours are *stop if there is an obstacle* or *passing on the left is allowed*. In our approach, AGVs are also able to select one of two motion control algorithm to ensure a safe and established system behaviour in regions where no autonomy is allowed, e.g., in narrow passages, in elevators or at a fire door.

- A tracking controller based on a *flat system output* [3] which tries to follow tracks precisely.
- A *Model Predictive Control* (MPC) [4] which uses a local cost map of the environment sensed to deal with obstacles.

Both controls are able to stop in the presence of an obstacle, but the MPC is also designed to react to environmental changes by leaving the track.

The Behaviour Controller (BC) shown in Figure 3 plays a vital part in the new system. This module has to interpret information gained or received locally in order to set parameters for each module and to make binary decisions. Such binary decisions have to be made, for example, if the *scenario detection* module recognizes an obstacle on the track. The BC has to decide if it orders the vehicle to slow down and wait (perhaps the obstacle is a person who will soon leave the track), or trigger the navigation module to steer the vehicle around the obstacle. Such decisions are only possible by the system's integration of expert knowledge which is delivered to the BC from the ACS with segment attributes. This allows the system operator to spatially adjust the level of the vehicle autonomy and to simplify the decision-making process. On the ACS server, we would like to integrate a routing approach that uses Kronecker-Algebra

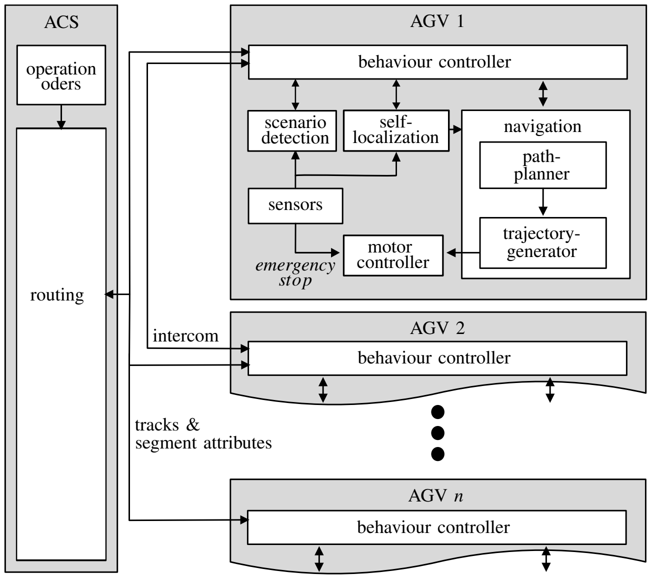

Fig. 3. AGV system overview: The AGV control system (ACS) gets orders from the production planning and control (PPC) (see Figure 1) and distributes them to the AGVs. The ACS also supervises the route planning of AGVs to optimise the execution time of all of the orders given to the system.

[5], which would not only allow computation of routing tables, but would also suggest velocities. Such an approach would reduce overall energy consumption by minimising stops.

III. Conclusion and Results

Many research questions are still up for discussion, such as life long mapping, knowledge representation, optimal multi-robot path planning, usage of smart building systems and the Internet of Things (IoT). We started to implement the proposed system using a simulated small production site in GazeboSim and to test the system using an existing ACS Server with promising results.

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