Cooperative cloud robotics architecture for the coordination of multi-AGV systems in industrial warehouses

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\textbf{ABSTRACT}

In this paper we introduce a novel cloud robotics architecture that provides different functionalities to support enhanced coordination of groups of Automated Guided Vehicles (AGVs) used for industrial logistics. In particular, we define a cooperative data fusion system that, gathering data from different sensing sources, provides a constantly updated global live view of the industrial environment, for coordinating the motion of the AGVs in an optimized manner. In fact, local sensing capabilities are complemented with global information, thus extending the field of view of each AGV. This knowledge extension allows to support a cooperative and flexible global route assignment and local path planning in order to avoid congestion zones, obstacles reported in the global live view map and deal with unexpected obstacles in the current path. The proposed methodology is validated in a real industrial environment, allowing an AGV to safely perform an obstacle avoidance procedure.

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1. Introduction

Factory logistics is a crucial aspect for the production flow in industrial plants: since the transportation of raw materials and final products is a very frequent operation in a warehouse, any bottleneck and inefficiency strongly affect the overall energy consumption, impacting on the factory productivity and competitiveness on the market. In the last decades the goods production flow in industrial environments has reached high levels of automation in all manufacturing processes, allowing to improve the safety for workers, increase the efficiency of the production and reduce costs. However, factory logistics is still marginally integrated in automated manufacturing processes and it involves manual operations performed by human workers and manually driven forklifts: this arouses inefficiencies together with high risky working conditions for workers \cite{1} and problems in product traceability. To cope with the lack of efficiency and flexibility in factory logistics, warehousing in modern industries can rely on Automated Guided Vehicles (AGVs) \cite{2}, and integrated systems for the complete handling of logistic operations. AGV systems (Fig. 1) are employed for managing the automatic transportation of raw materials and final products among different locations of an industrial site and they are typically employed to pick up a pallet of goods from the end of an automated production line, and bring it to the warehouse, or from the warehouse to the shipment \cite{3,4}. A complete survey relative to the principal technologies employed for the AGVs deployment in industrial plants is presented in \cite{13}. The use of AGVs is becoming widespread in the last few decades: Amazon Robotics \cite{5,6,7} is one of the most popular solutions adopted in distribution centers for handling the goods delivery. Because of the presence of huge and heavy loads to be managed \cite{8}, the complete automation in factory logistics is still not achievable within real production plants, therefore, it is mandatory to have human workers and hand-driven forklifts that cooperate with the AGV systems. In order to avoid dangerous working situations for human operators, AGVs are equipped with certified laser scanners designed to guarantee the detection of all unforeseen obstacles in the neighbourhood of each AGV. Moreover, to enhance safety in the presence of unpredictable events, additional constraints are applied to the motion of the AGVs, defining a roadmap \cite{9–12}, that is a set of predetermined paths along which AGVs are constrained to move (Fig. 2) in order to perform their tasks. As illustrated in \cite{13}, in most of modern automatic warehouses the use of a roadmap is a common strategy, that allows to reduce the complexity of the optimization problem for the coordination of the AGV systems. The AGV fleets are typically handled by a centralized control system, usually referred to as Warehouse
Management System (WMS), that is in charge of assigning the tasks (usually referred to as missions) to the AGVs and coordinating their motion.

The contribution of this paper concerns with the definition of a centralized and cooperative architecture designed to enhance the coordination of AGVs in real industrial environments. Some preliminary results have been presented in [14] and [15]. In this paper we describe in detail the centralized cloud system responsible for providing several services over the network of AGVs: multi-sensor data fusion, mission assignment, time synchronization, visual data representation, global navigation and local path planning.

The paper is organized as follows. In Section 2 we present an overview of the system under consideration, highlighting the motivation of the principal technologies integrated to enhance the performance. Subsequently, Section 3 introduces the main architecture of the cloud system, whose implementation strategy is illustrated in Section 4. The experimental validation of the system is reported.
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