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Technical Paper

A mobile robot based sensing approach for assessing spatial inconsistencies of a logistic system

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ABSTRACT

This paper demonstrates the potential benefits of the integration of robot based sensing and Enterprise Information Systems extended with information about the geometric location and volumetric information of the parts contained in logistic supermarkets. The comparison of this extended world model with hierarchical spatial representations produced by a fleet of robots traversing the logistic supermarket corridors enables the continuous assessment of inconsistencies between reality, i.e., the spatial representations collected from online 3D data, and the modelled information, i.e., the world model. Results show that it is possible to detect inconsistencies reliably and in real time. The proposed approach contributes to the development of more robust and effective Enterprise Information Systems.

1. Introduction

With robots becoming increasingly flexible and capable of sensing and interacting with complex environments, great challenges and opportunities appear in terms of its vertical integration as flexible and adaptive Cyber-Physical Systems (CPS) in large industrial setups [1,2]. In fact, the development of Enterprise Information Systems (EIS) shows potential for more complex interaction with CPS deployed in industrial applications [3–5].

The objectives of this paper are twofold. First, it presents the development of a service oriented logistic system, based on a world model concept that enhances traditional logistic systems with dynamic geometric and semantic data. Second, the paper demonstrates how the world model can be integrated with mobile robot based sensing to assess inconsistencies in a logistic supermarket [6].

The motivation for this work comes in the context of the European project FP7 – STAMINA,[1] where a mobile manipulator (see Fig. 1) is being developed to perform picking operations in logistic supermarkets.

The STAMINA robot is a mobile manipulator capable of navigating in the logistic supermarket composing a kit, i.e., picking parts available in shelves and boxes placed on the ground. When close to a box the robot relies on local sensors to achieve the required accuracy to perform the picking of a part, but the search for a part has to be limited to a small space for the robot to perform efficiently. To support the operations of the robot there was the need to develop a world model based logistic system, which identifies all the physical objects available in the logistic supermarket. All the parts and containers (shelves and boxes) to be handled are located in the logistic supermarket and identified in terms of their geometrical dimensions and their internal structure (e.g. a shelf has several levels containing small boxes). This logistic world model is encapsulated in a service oriented logistic planner, which acts as the central node for the overall logistic system providing adequate interfaces to different systems, such as the robots, the software component managing the robot fleet, the Manufacturing Execution System (MES)/Enterprise Resource Planning (ERP), and the local operator responsible for the logistic supermarket.

This paper demonstrates the potential and interoperability of the world model based logistic system, by developing techniques that allow a fleet of robots to continuously check the consistency of the logistic world model while traversing the logistic supermarket corridors. Those techniques are based on the use of octree-based algorithms to either perform octree with octree comparisons or to check if the relevant volumes of the supermarket space are consistent with the information present in the logistic world model. Octrees are hierarchical structures, which can be dynamically constructed and updated using a probabilistic approach to combine multiple measurements over time, optimizing spatial search and discretizing space, and thus enhancing the proposed approach

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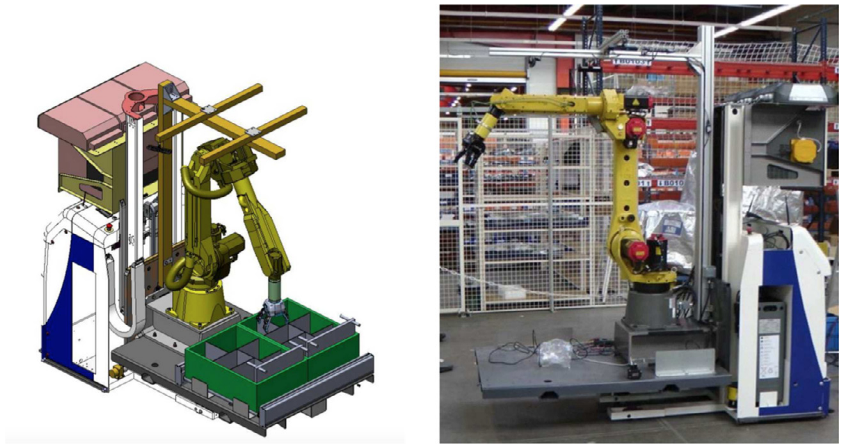
[1] http://stamina-robot.eu.

http://dx.doi.org/10.1016/j.jmsy.2017.02.016



(a) (b)

Fig. 1. Mobile manipulator to perform kitting operations: (a) virtual model, (b) real robot.

outcome. Since this evaluation of consistency is carried out using volumetric information exclusively, it is possible that the system is tricked if an object with a similar volume is presented to the system. However, we believe that a simple volumetric evaluation is sufficient to detect the majority of the errors in logistic systems. Furthermore, this can be used as a preprocessing step to dedicated object recognition systems which will, in turn, be able to complement the volumetric consistency detection in cases where it fails.

The remainder of the paper is organized as follows: Section 2 describes related work, Section 3 details the software architecture of the proposed system, Section 4 presents the world model concept and Section 5 describes the spatial change detection mechanisms used to find inconsistencies. Finally, Section 6 presents the results, and Section 7 draws the conclusions.

2. Related work

The use of robots as mobile nodes in sensing systems has been explored in several contexts, namely for environmental monitoring [7], mobile mesh networks [8] or terrain exploration [9]. In the industrial context, however, the research on robot sensing is more focused on the robot needs for localization and interacting with the environment. In this context it is particularly interesting the integration of the robot as a CPS that is deeply interconnected with others sensors and the network infrastructures of modern industrial plants.

Cyber-Physical Systems may be seen as systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet [10]. More simply, they are integrations of networked and/or distributed feedback systems between computation and physical processes, through which physical processes affect computations and vice versa [11,12]. They exhibit adaptive, predictive and intelligent behaviour and strong relations are established with other concepts and technologies like systems of systems, IoT, big data and analytics, and cloud technology [10–12].

The feedback nature of a CPS naturally requires the existing physical objects and processes to be translated into cyber space as virtual models so that they can be monitored and controlled as well as improving the virtual model through feedback data provided by the physical space.

This paper addresses logistic supermarkets comprised of different types of automotive components (parts) organized in different types of containers (large boxes on the ground and small boxes contained within shelves of different sizes). This physical environment is in constant transformation as parts are picked from a box, placed inside a kit and as boxes get empty they are replaced by new ones. This dynamic is increased as automotive parts evolve constantly in the life cycle of a vehicle, and parts are added, suppressed or replaced each period of time (from one to several months), causing possible changes in the way the supermarket is organized in order to optimize the access to the parts.

The introduction of mobile manipulators in the supermarket for picking parts and placing them in a kitting box requires the physical objects located in the supermarket to be represented in a virtual model, describing all their structural geometrical aspects, manipulation behaviour and location in space. If cognitive capabilities are incorporated in the mobile manipulator so that it is able to sense its environment and, based on the sensory input reason, plan and act accordingly, high levels of flexibility and adaptation are achieved. However, the dynamics of the supermarket model (i.e., the logistic world model) must consider inputs from the technician(s) responsible for maintaining the supermarket and automatic consistency checks to ensure that the model is reliable and accurate. This is very different from modern manufacturing robots that work mostly blindly and are based on a large set of specific assumptions, e.g., part locations and timing and are unable to deal with uncertainties (e.g. physical objects are not located where they are expected, physical objects are detected in places expected to be empty).

According to many authors [10,13,14], the development of Cyber-Physical Production System (CPPS) breaks the traditional automation pyramid, well represented by a five-level hierarchical model in ISA-95[2]/IEC 62264 standard [15] into a distributed set of co-operating and collaborating entities, presenting advanced behaviour such as intelligence, proactivity, fault-tolerance and reusability [13,16,17]. As these entities need to interoperate both at cyber and physical levels, the service-oriented approach [18,19] appears as a promising solution: the functionality implemented by each entity is made accessible through a defined service interfaces and messaging protocols; new functionality may be discovered in the service ecosystem thus enabling the construction through

[2] http://isa-95.com.