Flexible Multi-Agent System for Distributed Coordination, Transportation & Localisation

Demonstration

Ruben Van Parys
KU Leuven, Belgium
ruben.vanparys@kuleuven.be

Maarten Verbandt
KU Leuven, Belgium

Marcus Kotzé
KU Leuven, Belgium

Jan Swevers
KU Leuven, Belgium

Herman Bruyninckx
KU Leuven, Belgium

Johan Philips
KU Leuven, Belgium

Goele Pipeleers
KU Leuven, Belgium

ABSTRACT

This demonstration presents *Flexonomy*, a flexible autonomous system for distributed coordination, transportation and localisation in a lab-scale factory floor. It illustrates the use of multi-agent systems in manufacturing and leverages new *Industry 4.0* design principles to cope with manufacturing requirements in factories of the future: rapidly changing customer needs, market volatility and shortened product life cycles. Three main contributions are identified: (i) distributed auction-based coordination allows local decision making and task allocation, (ii) distributed model predictive control-based transportation enables free space collision avoidance of automated guided vehicles (AGVs), and (iii) distributed vision-based localisation provides scalable and dynamic position information of key resources on the factory floor.

KEYWORDS

Agent Cooperation; Engineering Agent Systems

ACM Reference Format:
Ruben Van Parys, Maarten Verbandt, Marcus Kotzé, Jan Swevers, Herman Bruyninckx, Johan Philips, and Goele Pipeleers. 2018. Flexible Multi-Agent System for Distributed Coordination, Transportation & Localisation. In *Proc. of the 17th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2018), Stockholm, Sweden, July 10–15, 2018,* IFAAMAS, 3 pages.

1 INTRODUCTION

Industry 4.0 identifies a set of novel manufacturing paradigms to cope with rapidly changing customer needs, market volatility and shortened product life cycles, which factories of the future are faced with [1, 4]. They aim at increasing modularity, scalability and reconfigurability of manufacturing systems. The demonstration proposed here, consists of a flexible autonomous manufacturing system, denoted *Flexonomy* that leverages Industry 4.0 design principles from high-level coordination to low-level control. Figure 1 and the accompanying media [1] showcase the considered setup. The agent-based implementation consists of automated guided vehicles (AGVs) transporting products, mobile work stations with a robot manipulator or human picker and a modular camera system for agent localisation. Task allocation and coordination is taking care of by a distributed holonic system. The combination of different machines (AGVs and articulated robots) which have the ability to communicate with each other, as well as decentralised decision making that exists in the different parts of the system are two attributes typical of an Industry 4.0 system [2], which this demonstration aims to show.

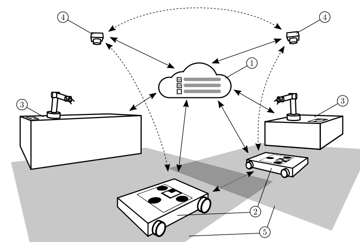

Figure 1: Overview of the considered setup with (1) a holonic (multi-agent) coordination system, (2) automated guided vehicles, (3) work stations and (4) a localisation system composed of different camera modules with their corresponding field-of-view depicted by (5). Arrows indicate the communication flow between the different agents.

Since the research behind the Flexonomy system is still under review [9], the focus here is on the implementation of the demonstration.

2 MAIN CONTRIBUTIONS

The demonstration shows three main components of the manufacturing process where modularity and distributed decision making have been implemented using multi-agent systems: (i) distributed auction-based *coordination* allows local decision making and task allocation, (ii) distributed model predictive control-based *transportation* enables free space collision avoidance of AGVs, and (iii) distributed vision-based *localisation* provides scalable and dynamic position information of key resources on the factory floor.

[1] available at https://youtu.be/z4fHsEDdQGY

Proc. of the 17th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2018), M. Dastani, G. Sukthankar, E. André, S. Koenig (eds.), July 10–15, 2018, Stockholm, Sweden.

2.1 Coordination

A holonic system is a particular multi-agent system consisting of *holons*, which are autonomous cooperating agents [3]. The holonic system distributes coordination and decision-making among holons allowing them to solve local problems locally. Scaling the system is therefore more straightforward compared to traditional centralised coordination. In this implementation, ADAptive holonic Control aRchitecture (ADACOR) [5] is chosen as a baseline. It is extended with an auction-based deliberation, using contract nets, to explicitly allocate appropriate resources for each task.

2.2 Transportation

In our Flexonomy setup, each AGV computes its own motion trajectory and communicates with its peers to avoid collisions. Increased modularity and scalability are clear advantages of this approach compared to a central motion coordination scheme. The implementation is an extension of an earlier presented distributed model predictive control (DMPC) approach [6–8] where priority rules are introduced to facilitate mutual collision avoidance of AGVs.

2.3 Localisation

Free space motion planning has a strong impact on localisation, as it now has to cover the entire workspace rather than predefined tracks. In the Flexonomy setup, a vision-based system with fixed cameras is chosen, due to its high information density and scalability as it is decoupled from the number of monitored agents. This distributed vision-based localisation system consists of a series of ceiling camera modules monitoring the work floor. Its main advantage is the ability to dynamically add or remove modules according to the work floor's size, turning the system into a scalable solution for the indoor localisation problem.

3 DETAILS ON AGENT-BASED COORDINATION

As mentioned in 2, the coordination system makes use of agent-based holonic control paradigm, ADACOR. This paradigm has four types of holons: the supervisor, task, product and operational holon [5]. Here, the supervisor holon is responsible for launching and terminating all other holons, as well as dispatching messages among holons. The task holon is created by the supervisor holon with each order and is responsible for executing its task by arranging services from operational holons. The operational holon is responsible for managing a specific resource in the work cell. In this demonstration there are two types of operational holons, one for the AGVs and one for the workstations. A product holon would not have added value in this use case. The holons make use of contract net protocol to execute their tasks.

For each order, a task holon sends out a stock request to all workstation (operational) holons. Should there be insufficient stock, the task holon informs the user. Otherwise, it decides which workstation holons will be used to complete the order by selecting as few workstation holons as possible to complete the order. The task holon informs the workstation holons of the winning holons. An RFP is then sent to all AGV (operational) holons which consists of all the waypoints required to complete the order. Using Travelling Salesman Problem, the AGV holons calculate the shortest path required to complete the order, and then reply with their bids. The task holon analyses the bid responses, and the AGV holon with the shortest time estimate wins the order. The AGV executes the order, stopping at each waypoint to receive parts. On arrival at each point, a message is sent from the AGV holon to the workstation holon informing it of the AGV's arrival. The workstation holon then commands its corresponding robot to pick and place the required parts into the AGV's carrier tray. When this process is complete, the workstation holon informs the AGV holon of this, which then commands its corresponding AGV to move to the next waypoint. Once the AGV has transmitted all required waypoints, it moves to the offload position. Once offloaded by the user, it moves to its standby position which is away from the centre of operations. Should another job already be in its work queue, it moves directly to its next required waypoint and does not go via its standby position.

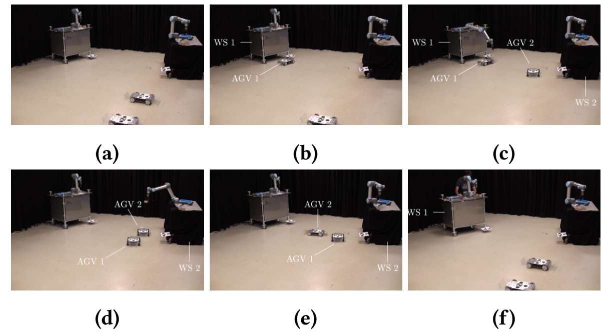

Figure 2: Series of interesting situations which arise throughout the demonstration.

4 DEMONSTRATION

Figure 2 highlights a few interesting situations which arise during the demonstration. The first order consists of two products. Since none of the work stations has both products, the responsible AGV has to stop at both work stations. Based on the received bids for the task, the coordination module selects one of the two AGVs which are idling on their home positions (Figure 2a). While the selected AGV, AGV 1, is busy collecting the first order at work station WS 1 (Figure 2b), a second order has been dispatched, which is logically granted to AGV 2. This order requires products which are available at the work station WS2 (Figure 2c). While AGV 2 is being loaded at WS 2, AGV 1 has finished its task at WS 1 and approaches WS 2 (Figure 2d). Thanks to priority-based collision avoidance, queuing arises: AGV 2, being loaded, has highest priority and is avoided by AGV 1. As AGV 2 is located at the target position of AGV 1, it waits until AGV 2 leaves. As AGV 1 was already moving when AGV 2 was commissioned to leave its docking position, AGV 1 gets priority over AGV 2 and is avoided by the latter while it approaches the docking point of WS 2 (Figure 2e). Once both AGVs have accomplished the orders, work station WS 1 is relocated (Figure 2f) and the experiment is repeated to demonstrate the reconfigurability and flexibility of the developed setup.

REFERENCES

[1] Malte Brettel, Niklas Friederichsen, Michael Keller, and Marius Rosenberg. 2014. How virtualization, decentralization and network building change the manufacturing landscape: An industry 4.0 perspective. *International Journal of Mechanical, Industrial Science and Engineering* 8, 1 (2014), 37–44.

[2] Mario Hermann, Tobias Pentek, and Boris Otto. 2016. Design principles for industrie 4.0 scenarios. In *System Sciences (HICSS), 2016 49th Hawaii International Conference on*. IEEE, 3928–3937. https://doi.org/10.1109/HICSS.2016.488

[3] Arthur Koestler. 1970. Beyond Atomism and Holism - the Concept of the Holon. *Perspectives in Biology and Medicine* 13, 2 (1970), 131–154. https://doi.org/10.1353/pbm.1970.0023

[4] Heiner Lasi, Peter Fettke, Hans-Georg Kemper, Thomas Feld, and Michael Hoffmann. 2014. Industry 4.0. *Business & Information Systems Engineering* 6, 4 (2014), 239–242. https://doi.org/10.1007/s12599-014-0334-4

[5] Paulo Leitão and Francisco Restivo. 2006. ADACOR: A holonic architecture for agile and adaptive manufacturing control. *Computers in Industry* 57, 2 (2006), 121–130. https://doi.org/10.1016/j.compind.2005.05.005

[6] T. Mercy, Ruben Van Parys, and Goele Pipeleers. 2017. Spline-Based Motion Planning for Autonomous Guided Vehicles in a Dynamic Environment. *IEEE Transactions on Control Systems Technology* PP, 99 (2017), 1–8. https://doi.org/10.1109/TCST.2017.2739706

[7] Ruben Van Parys and Goele Pipeleers. 2017. Distributed model predictive formation control with inter-vehicle collision avoidance. In *Proceedings of the 2017 Asian Control Conference*. 2399–2404.

[8] Ruben Van Parys and Goele Pipeleers. 2017. Distributed MPC for multi-vehicle systems moving in formation. *Robotics and Autonomous Systems* 97 (2017), 144–152. https://doi.org/10.1016/j.robot.2017.08.009

[9] Ruben Van Parys, Maarten Verbandt, Marcus Kotzé, Jan Swevers, Herman Bruyninckx, Johan Philips, and Goele Pipeleers. 2018. Distributed Coordination, Transportation & Localisation in Industry 4.0. (2018). Under review.