MTConnect Student Challenge: Idea Creation

Multi-agent Control of Manufacturing Systems

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Ilya Kovalenko
Organization: University of Michigan
Phone Number: (850) 445-8185
Email address: ikoval@umich.edu

Miguel Saez
Organization: University of Michigan
Phone Number: (734) 834-8983
Email address: migsae@umich.edu

Section I: Abstract

Currently used control systems lack the necessary flexibility in order to deal with a variety of challenges faced by manufacturing companies in daily activities. Machine shutdowns, varying customer demand, and other factors bog down the efficiency of industrial production lines. Thus, the idea of multi-agent systems is presented. These systems have been previously proposed, but have yet to be implemented on a wide scale. Reasons include integration and standardization issues associated with current manufacturing system. In addition to adapting to current industrial standards, future manufacturing technological trends (e.g. cloud computing) will need to be integrated in order to fully recognize the capability of these control frameworks. Utilizing MTConnect can solve these challenges and push manufacturing facilities to address the flexibility challenges faced by the manufacturing sector. Leveraging MTConnect with cloud services, a multi-agent processing and control schematic is presented in this paper. The presented technology can be implemented on the Industrial Automation Testbed at the University of Michigan. With this testbed, multiple scenarios can be run in order to validate the multi-agent framework and investigate how the framework integrates with existing state-of-the-art technology available for manufacturing companies today.

Section II: Proposed idea

Currently, manufacturing companies face challenges such as responding to rapid changes in product demand, varying customer requirements, and malfunctioning equipment. Current strategies for controlling these manufacturing systems through centralized and hierarchical control lack the operational flexibility to adapt to these stochastic changes [1]. Multi-agent systems have been proposed to provide better flexibility and responsiveness than traditional hierarchical methods [1][2]. A number of multi-agent architectures have been created, yet they've only been implemented in very specific scenarios [2]. Some of the proposed architectures have been compared using a list of specific Intelligent Manufacturing Systems requirements [3]. Even with the push toward agent based systems, a number of challenges have to be addressed before multi-agent control can be used in industrial systems. One challenge stems from producing a standardized framework that can be easily implemented in industry today [4]. Such a standardized framework would need to be integrated with current controllers, simulations, and other resources (e.g. the cloud, big data) [4]. Another challenge is showing that the proposed multi-agent systems will provide stable and optimal performances when compared to current practices [5]. In order to create an intelligent multi-agent system, learning will be investigated and integrated into the control framework [4]. The system, through interactions and historical decisions from each of the agents, should be able to learn from past cycles and improve performance over time.

A robust analysis of current multi-agent systems and framework application is lacking. Agent based control has been shown to be effective for particular scenarios (using simulation or a small amount of machines), but has not been proven to work for all manufacturing systems. Thus, the idea is to create a generalized manufacturing system control framework based on a multi-agent system model that is flexible, robust, and effective. It will be able to update plans throughout the production cycle in order to improve system performance. Additionally, the framework will incorporate learning to improve system performance over time. Experimental validation of this control architecture will require the use of MTConnect with the Industrial Automation Testbed at the University of Michigan. A variety of scenarios will be explored to demonstrate system adaptability and effectiveness. Specifically, the following have to be accomplished in order to put the idea to practice:

Define the term agent and classify different agent types used in a manufacturing setting. It is necessary to identify the available information, capabilities, states, and goals that are generated for each agent class in a general manufacturing system. Understanding the machine class based on machine data will be important during the evaluation of a system's state.

Organize the agents into dynamic structures with proper communication and cooperation strategies. It is important to understand the agent dynamics within a manufacturing system including: (1) defining the conflict resolution and decision making processes for the various types of agents, (2) defining individual and global goals that need to be attained, and (3) defining the necessary communication strategies to obtain the minimum necessary computational capacity in order to mitigate the tradeoff between system performance and system robustness. These parameters can then be tuned in order to create a manufacturing system that is robust, yet has optimal performance.

Develop and implement algorithms that will improve agent performance. Agent decisions will be updated over time using collected data, machine learning, and advanced optimization methods to improve the performance of each agent. The system response to stochastic changes in the system (such as machine shutdown or varying customer demand) should improve as each agent gathers more data about its own and the system's objective.

Design a multi-agent control framework for manufacturing systems. All of the different types of agents (virtual and physical, reactive and planning, etc.) must be integrated into a single framework to enable the enhanced system performance. An example of this integration is shown in Figure 1. It is anticipated that the multi-agent architecture will be more adaptable to market/demand/product variability that exists in the current manufacturing paradigm.

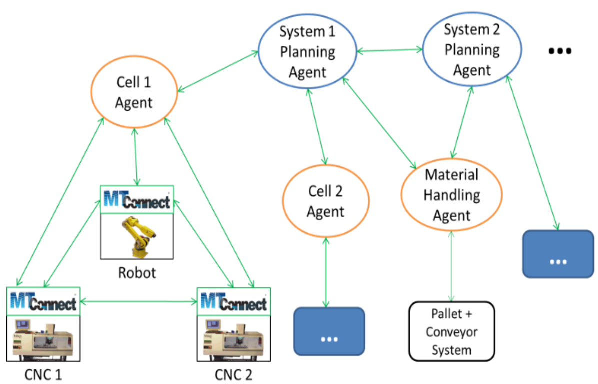

Figure 1. Proposed multi-agent interaction and implementation for a manufacturing system showing the following: physical agents (black), virtual agents (orange and blue), mix of various agents (filled blue) and the communication network (green).

Improvements in system flexibility and responsiveness that result from the multi-agent framework will provide long lasting benefits in manufacturing. Agent-based control will lead to "smarter" machines and machine controllers that are able to make real-time decisions during manufacturing processes. Cooperation and coordination between agents will lead to more efficient, safer, and flexible manufacturing lines that can handle various types of customer demands. Based on historical data and agent communication, optimal production settings and configurations will be calculated. Finally, research on the integration of this framework with current industrial devices such as MTConnect will allow for industry-ready implementations of the framework. The framework will be tested using the University of Michigan Industrial Automation Testbed described in the following subsection.

Experimental Implementation: The University of Michigan, partnering with Rockwell Automation, has recently upgraded a manufacturing testbed for the purpose of simulating the environment found on an industrial plant floor. A schematic of the Industrial Automation Testbed is shown in Figure 2. Industrial Automation Testbed at the University of MichiganFigure 2. This testbed has two Fanuc Robots, one ABB robot, and four Denford CNC milling machines. All of this equipment is connected by two conveyor lines. The testbed has been outfitted with the latest technologies used in the manufacturing industry including radio-frequency identification (RFID) tags and sensors, connection to a cloud database, and communication through an EtherNet/IP network. Additionally, a simulation is currently being built that could expand the testbed in order to simulate a large manufacturing plant floor. This cyber-physical system will be used to test the proposed control system framework and to run a variety of scenarios that occur in an industrial setting in order to verify the framework.

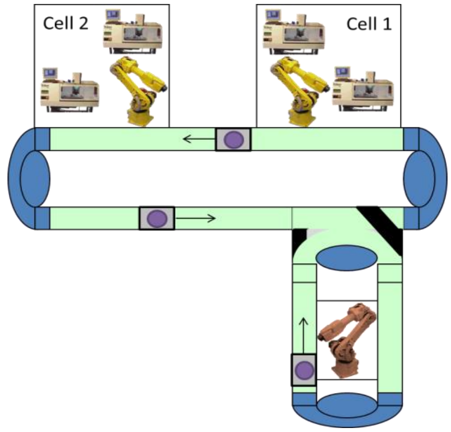

Figure 2. Industrial Automation Testbed at the University of Michigan

Section III: Technical Requirements:

Due to recent technological enhancements, implementation of multi-agent systems has become a possibility. The next subsection outlines the technological enablers and agent-based control needs to leverage this technology for effective use in manufacturing systems.

Technological Enablers:

Data Collection: The amount of information available from a manufacturing facility is growing due to the availability and implementation of various sensors [6]. A big push toward digital manufacturing, or the utilization of data over all parts of a product life cycle, has been driven by the availability of information from all parts of the manufacturing system [7]. Sensors that are able to read the characteristics of the machines on the manufacturing floor, obtain the status of material handling systems, and read and write information to the work parts are being implemented in industry today. Power monitors, RFID sensors, and computer vision allows for tracking and updating the status of the different parts of the manufacturing system. The large amount of data enables a broad range of data analytics and optimization assessments that agents can access to make better decisions for enhanced manufacturing system performance. Importantly, multiple hierarchical levels of

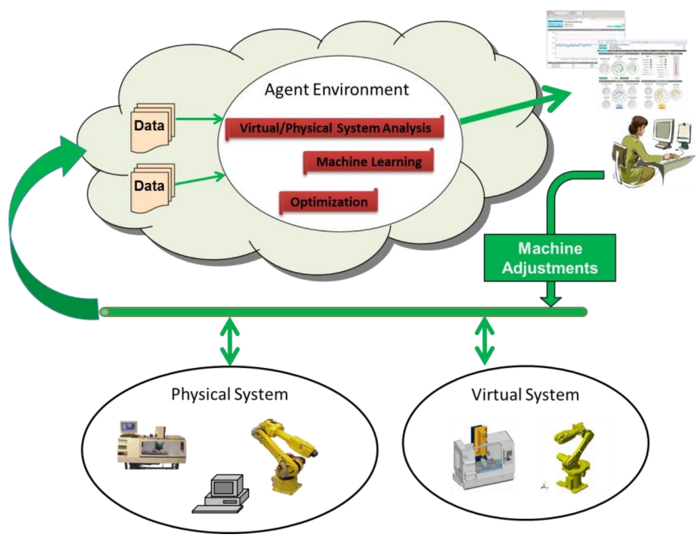

Figure 3. Proposed data flow of a manufacturing system showing the following: physical and virtual system integration, communication network (green), cloud services, and dashboards for user interface.

analysis can be conducted with groups of agents for faster, and more targeted data assessment and response. This hierarchical approach could be used to pass information from one level to another. For example, individual and system level trends could be identified by agents in one plane and used to identify actions in the physical plane.

Data Storage and Analytics: With the increasing availability of cloud services for data storage and processing [8], data collected using various sensors can be managed and analyzed more effectively. Figure 3 shows an illustration of the proposed multi-agent system, where analytics are often performed in the cloud. These analytics will be used to determine system performance in terms of: (1) local task completion, (2) global system optimization, (3) scheduling, (4) predictive maintenance, and (5) system learning. In current cloud manufacturing systems, the continuous collection of information results in large data bases where relatively little is being done with the data. The proposed multi-agent framework will leverage this data for improved monitoring and understanding of the system dynamics, and thus, enhanced system performance. By standardizing (in part with MTConnect) the manner in which information is collected, stored, and analyzed, parameters such as performance, quality, and processing time can be compared across multiple manufacturing enterprises.

Agent Communication: Standardized communication needs to be established in order for multi-agent systems to be effective in a manufacturing system environment. Agent interactions can only be standardized if a common communication protocol can be established. The following section describes how MTConnect can fulfill this role.

MTConnect Utilization: With a large and diverse combination of machines on the plant floor, the proposed framework needs a standardized way of communicating and resolving issues between agents. MTConnect will be used to ensure that all of the physical agents can effectively communicate with each other to achieve local and global goals. MTConnect will provide the necessary data to track and monitor all components within the manufacturing system; thus enabling better control and optimization. In the absence of MTConnect, agents cannot obtain a global perspective; they must rely on specifically coded information about local agents. For example, manufacturers often provide a minimum quality threshold that the system must meet. By using MTConnect, all agents will provide standardized information about their specific capabilities. From this data, a part agent will determine the most efficient and cost effective path through the system that guarantees the quality requirement will be achieved. The standardized protocol utilized in MTConnect enables more direct comparison across multiple machines for optimized scheduling and state evaluation.

Section IV: Benefits and Impact:

Implementation of agent-based control in manufacturing will improve total manufacturing performance. Utilizing well-structured physical and informational agents will improve industrial operations by increasing utilization, reducing unexpected downtime, and operating on a real-time production scheduling. Moreover, machine level performance will improve by optimizing around different parameters such as tool life, energy consumption, and quality. This will lead to more flexible and sustainable manufacturing. Thus, by implementing this multi-agent control framework, companies will obtain a competitive advantage and generate more profit. The benefits associated with the proposed idea can be classified by:

- **Machine:** Reduce energy consumption, increase tool life, and reduce unexpected downtime.

- **System:** Increase utilization, flexible scheduling, improve overall quality.
- **Enterprise:** Increase profit, new business opportunities.

Most of the technologies required for this project will be around control and software development. If utilizing an existing local machine or machine cluster controller is a possibility, then no major hardware upgrades or changes will be required. Redistribution of each controller’s domain and communication network will have to be performed. Return of investment will depend on technology currently installed in the shop floor. Companies with low level of automation might need to invest in more advanced control and communication infrastructure in order to fully utilize the proposed idea. We believe that an implementation of this technology can increase average overall equipment effectiveness (OEE). Currently, the average OEE of a manufacturing plan is 66%. The agent-based control will enhance plant productivity and drive the OEE closer to the world-class “85% or better” mark [9]. In addition, agent-based control can open up other smaller markets for the manufacturing systems. The flexibility provided by the agents will allow for smaller quantities of products to be produced without incurring lost production time on the main product lines. This will decrease the amount of idle time in the manufacturing plant and bring in extra profits from side-businesses, raising the plant’s total profit. For companies with necessary technology already in place (e.g: MTConnect, power monitors, cloud adapters, etc.), a 1 year return of investment is expected due to the limiting amount of upgrades needed. In addition, due to the implemented agent learning, the system will be guaranteed to keep improving its performance over time.

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