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A SELF-ORGANIZED MULTI-AGENT SYSTEM WITH INDUSTRY 4.0 COORDINATION AND BIG DATA BASED FEEDBACK

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ABSTRACT

The widespread use of cyber-physical systems heralds the arrival of Industry 4.0, the next phase of industrialization. The drive for vertical factory integration is a defining feature of Industry 4.0, which aims to build "smart factories" capable of utilizing adaptable and dynamic production technology. Here we showcase a smart factory architecture that combines smart shop-floor items like machines, conveyors, and goods with smart industrial networks, clouds, and supervisory control interfaces. We next explain a cloud-based coordinator and categorize smart objects into several kinds of agents. Agents' distributed cooperation and autonomous decision-making are the driving forces behind the process's great flexibility. To top it all off, the central coordinator's input and coordination are key to this self-organized system's great efficiency. In conclusion, the self-organizing multi-agent system that takes input into account and uses big data to coordinate its activities is what defines a smart factory. On the basis of this paradigm, we provide an intelligent method for agents to negotiate and work together. More than that, the research shows that deadlocks can be avoided by enhancing the coordinator's and agents' decision-making abilities through the use of complementing techniques. You can see how well the proposed negotiating mechanism and techniques to avoid impasse work in the simulation results.

Keywords: Industry 4.0, smart factory, cyber-physical system, multi-agent system, deadlock prevention

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I. INTRODUCTION

The demands of today's market necessitate that manufacturers exhibit greater manufacturing flexibility. One example is adjusting output to match demand in the market. With a personalized product, every client's needs are important, and corporate clients will love the ability to process orders in a way that suits their needs. One example of a flexible strategy for satisfying consumer needs is the Smart Factory concept, which Bosch Rexroth came up with [1]. Also, there are features that are directly associated to the market, features that are indirectly tied to the market, and economic concerns that are directly related to production costs. Trash disposal and environmental costs are on top of the list of charges related to materials, energy consumption, storage, distribution, etc. Finding the sweet spot between customer needs and overall product development costs while simultaneously making the most efficient use of available resources is, hence, of the highest significance. The gathering of information and the processing of that information also plays a very significant function in the context of gaining knowledge about the current state of the market and the preferences of customers.

The methodology known as Industry 4.0 integrates traditional production techniques with artificial intelligence and computer approaches. Some examples of these methods include handling enormous volumes of data, graph and Petri net network modeling, optimization, and linear programming. The goal of applying the previously mentioned techniques is twofold: obtaining comprehensive process data at any level and, secondly, to encourage self-organization throughout production. A more methodical approach is achieved when modeling the production process using models based on agent and holistic methodology. While the Principles of Industry 4.0 are relatively new, the ideas of agent and holon continue to be utilized to characterize the intricate processes taking place in the pursuit of the goals of the Fourth Industrial Revolution.

1.1 Agents and multi-agent systems

In the beginning, the term "agent" was applied in the domains of medicine and chemistry. It wasn't until later that it was utilized in the context of manufacturing processes. In the Meriam-Webster reference to medical terminology, the term "agent" is described as "something that produces or is capable of producing an effect" or "a chemically, physically, or biologically active principle" [2]. Both of these definitions are relevant to the field of medicine. It is important to note that in both circumstances, the focus is on the agent's active engagement in particular processes. The key to understanding both concepts is the emphasis on taking action. A new definition of the word "software agent" has been proposed. The Meriam-Webster Dictionary defines an agent as "a computer application designed to automate certain tasks (such as gathering information online)" [3], which is one explanation of what an agent is. Instead, the concept of a monitoring agent has already been developed by Burkhart and Millen [4] before 1989 ever came to a close. We have something that is similar to the multiagent environment that is common in the present world thanks to a family of performance monitoring tools for multiprocessor systems. It is the responsibility of every agent in this ecosystem to do their assigned tasks in their own special way.

2. LITERATURE REVIEW

An assortment of agents constitute this setting. Chapter 5 finds Franklin and Graesser discussing the many agent definitions they've come across. At long last, they've created their own, in accordance with the rules laid out for autonomous agents: "an autonomous agent is a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effectively affect what it senses in the future." Put simply, they have created their very own self-governing entity. Interaction between the agent and their surroundings is highlighted by Castelfranchi [6] as a crucial attribute based on this definition. Not only does the agent influence its immediate surroundings, it is also cognizant of the consequences that follow from these changes. When compared to other data processing modules or programs, this feedback is what really sets agents apart. It is the characteristic that distinguishes one agent from another. Another crucial aspect to think about is that this feedback is connected to how the agent perceives changes in their surroundings as a result of their activities. A distinct difference exists between this procedure and the internal feedback loop that occurs when an agent performs an action while being "aware" of it.

Also, Castelfranchi has its own line of agents that they sell to clients. To start, he notes that the agent is more of a mindset than an IT framework; it's a style of thinking that can describe complex, multi-layered, distributed, and dynamic events [7]. This is the first point of interest that he makes. Furthermore, he claims that the root of agents' autonomy is the capacity of agents to learn, investigate, and elaborate on their experiences.

They are not merely the command-driven object or the fixed program; rather, they behave in a manner that is more complicated. The findings make it possible to take into account the agents in a more comprehensive manner, as a particular modeling methodology. Conversely, neither the architecture nor a precise definition of an agent is present. In their 1994 survey, Wooldridge and Jennings offered multiple competing interpretations of agenthood [8-11]. One of these components makes up the BDI architecture. The acronym BDI stands for three things: belief, desire, and intention. Its abbreviation, BDI!, depicts the state of the system as seen through an agent. Georgeff et al. [12-16] noted that beliefs are a type of found knowledge, lending credence to the claims made by Wooldridge and Jennings [17-19]. On the other hand, it is feasible that beliefs do not convey each and every piece of knowledge that is known about the world. In addition to defining the final state of affairs, the desire (goals) is crucial to getting back up after a setback (case analysis and reasoning). In other words, there is a substantial relationship between the two. The third component, which is referred to as Intentions, is tied to the process of pursuing the goal.

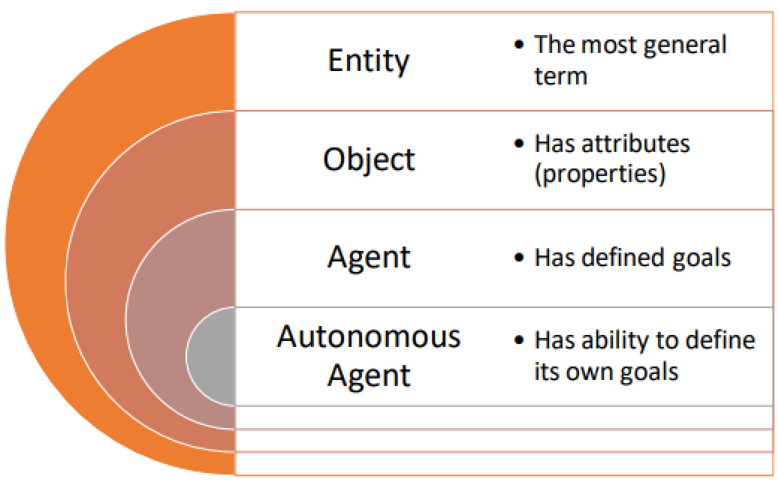

Figure 1. Hierarchy of entities

The hierarchical organization is popular in industrial processes and one of the oldest types of organizations since it is the most frequent structure for most enterprises. Substructures can also be separated, as pointed out by Balaji and Srinivasan [20-22]. An example of one of these substructures is a straightforward hierarchical system in which the highest-ranking agent has complete decision-making authority. Another is a uniform hierarchy, where multiple agents have the power to make decisions.

Figure 2. Facilities for both (a) federated agents (b)independent agents

In comparison to hierarchy, the solution of federation (shown in Figure 2a) is superior for applications that are on a vast scale. The following are the four categories of federations that can be distinguished from one another: facilitators, brokers, matchmakers, and mediators. Although each category is explained in great detail in [23-29], it is important to provide a few words regarding brokers and facilitators that are involved. One may argue that the facilitator groups the agents as they allow them to communicate with each other and use another facilitator to communicate with agents located at a distance. The broker, who is analogous to the facilitator, is not bound to work with a certain team of agents but can, with the help of any other broker, discover the additional agent required to finish an assignment.

For remote manufacturing systems, the autonomous agent architecture shown in Figure 2b is a good choice. The fact that it permits an infinite number of interactions makes it ideal for use in systems with a small number of agents.

3. METHODOLOGY

3.1 System Architecture.

Figure 3 shows the four main components of a smart factory's architecture: physical resources, industrial networks, clouds, and monitoring and control terminals.Deploying physical resources turns them into smart objects that can communicate with each other via the industrial network. Numerous information systems, like enterprise resource planning (ERP), may interface with people through terminals and gather massive volumes of data from the physical resource layer in the cloud. This being the case, the physical framework permits the unfettered flow of immaterial data across a cosmos interconnected by networks. This results in the construction of a CPS, which is characterized by the profound integration of informational entities and physical artifacts.

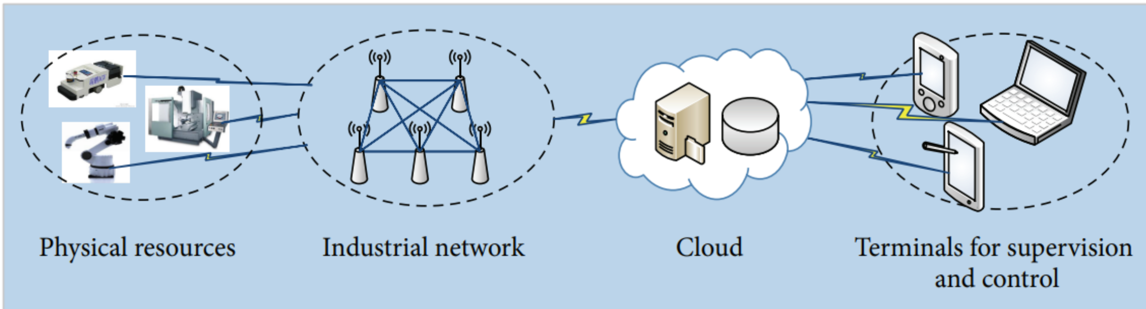

Figure 3: An overview of the Industrie 4.0 smart factory's architecture.

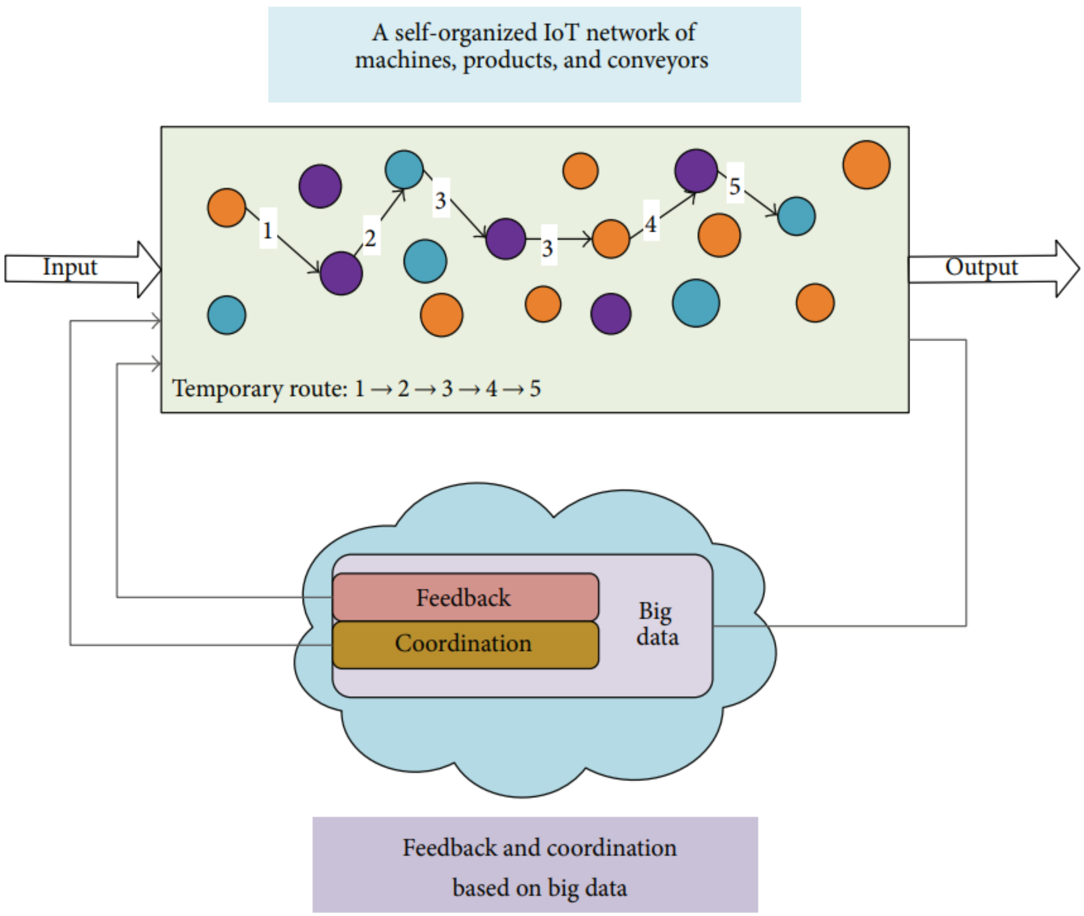

Figure 4: Industrie 4.0 smart factory operational mechanism.

3.2 Operational Mechanisms.

Looking at the smart factory through the eyes of a control engineer reveals it to be a closed-loop system, as shown in Figure 4. The control loop revolves around the network of intelligent artifacts. Not only does the intelligent artifact possess the capacities of the three Cs, but it also possesses autonomy and sociality. What we mean when we talk about autonomy is that the intelligent artifact is able to make decisions on its own; no other entities are able to directly affect its behavior. We imply by the term "sociality" that the intelligent objects have a shared understanding of a common body of information and adhere to a shared set of guidelines for negotiating. As a result, a civilization composed of intelligent artifacts has the potential to produce a manufacturing system that is very adaptable, a system that is capable of self-organization and reconfiguration, and that appears to be humanoid or intelligent.

4. THE AGENT-BASED MODELLING IN THE CONTEXT OF INDUSTRY 4.0

It is possible to assert that the information technology-related domains play a preeminent position among the nine pillars that make up Industry 4.0. Because the multi-agent approach is so common in modern technological developments, we should pay extra attention to developments like autonomous robotics, cloud computing, and simulation. Consequently, engineers should not shy away from employing agent-based models under these conditions. The power of intelligent machines to self-organize the production process, network communication networks, and other aspects of Industry 4.0 are the center of attention in this specific inquiry. Because of their traits, such as goal-setting, organization-building, and goal-within-an-organizational-organizational-ability, intelligent agents serve as models for units involved in the production process.

Taking a more pragmatic approach to the issue, it is important to note that the production systems that adhere to the philosophy of Industry 4.0 are structurally distinct from those that are based on other manufacturing concepts. Commonly employed for administrative purposes, enterprise resource planning (ERP) systems have a centralized design. However, existing systems, which are built on cyber-physical systems, may often create suitable links continuously, according to the needs. They draw on data that is spread out over multiple databases that, when combined, form a complete picture. In contrast, many different types of organizational structures can be explained by multi-agent systems since they are sufficiently broad.

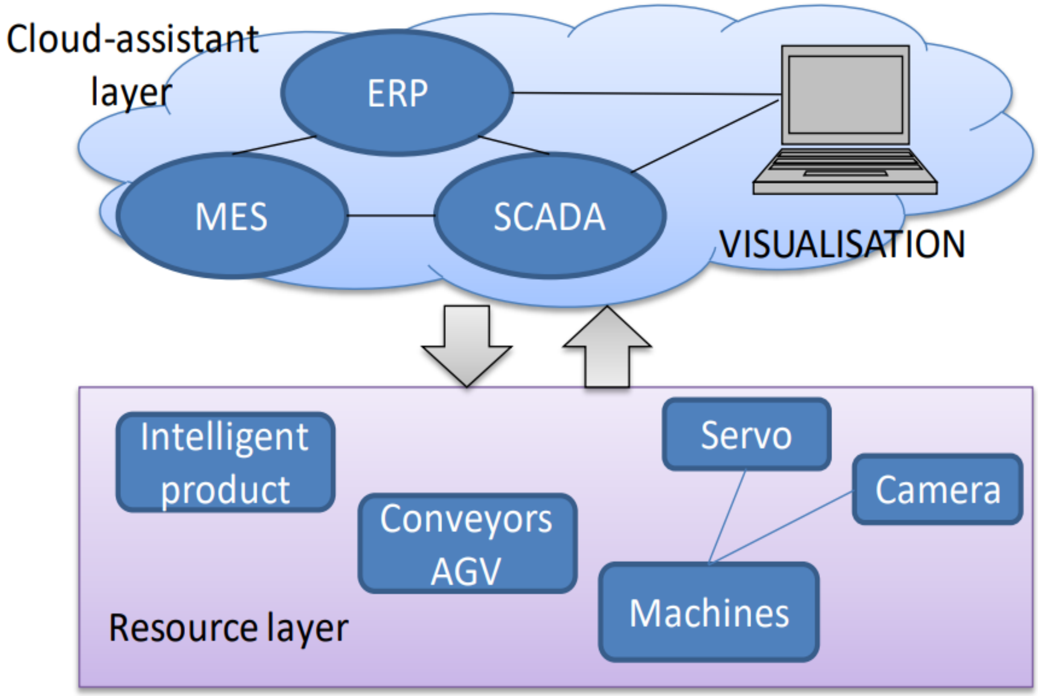

Figure 5. CASOA design of a system that complies with Industry 4.0 standards

An example of an agent-based architecture proposal for an Industry 4.0 compatible manufacturing system is now available. In contrast to the first article, which simply includes generic information, the second paper provides an illustration of a production system. Be sure to differentiate between the following four categories of agents: machining agents, conveying agents, product agents, and supplementary agents. There are two types of machines used in manufacturing and testing: machining agents and conveying agents. Conveyors, robots, and automated guided vehicles are examples of machining agents. In addition to this, they provide an example of a system that facilitates communication and collaboration amongst agents. This system is adapted to the specific circumstances of the case, and it cannot be considered a general recipe. In contrast, they addressed the hypothetical system that is compliant with Industry 4.0. The system in question is comprised of ten distinct agents, each of which serves a specific purpose. Product, resource, order, system, machine, software, maintenance, control, vision, and artificial intelligence are all agents in this context. Product agents include market forces, product demands, product characteristics, and machine vision. System agents include product requirements and process capabilities. Machine agents include things like control systems and control configuration. Software agents include things like algorithms. Maintenance agents include things like real-time inspection and diagnosis. Control agents include things like controllers and sensors. Artificial intelligence agents include things like expert domains and knowledge bases. Regrettably, the offered architecture's particulars were left unsaid. Taking into consideration the two techniques that have been shown, it is possible to assert that the example that has been presented focuses mostly on the manufacturing process and the shop floor level, whilst the other approach that has been presented is more comprehensive and also encompasses the administrative aspects. When considering the remaining cases, it is important to consider the CASOA architecture, which is depicted in Figure 5.

For an agent-based model to work with Industry 4.0, some assumptions on the system's architecture are made. These assumptions can be developed on the basis of the factors that have been presented above.

- Although it is not required, it is recommended to design a collection of agents at the plant level to represent the product, machinery, and interoperational transit. Think about the possibilities of agent categorization based on their relationship to a machining cell or assembly line while you make your architectural option. To achieve this goal, a federated structure can be employed.
- When it comes to mobile agents (AGVs), it is possible to take into consideration team or coalition structures. However, due to the specifics of Industry 4.0, it is advised that distributed databases be utilized.
- Mixed architectures may be utilized in situations when cloud manufacturing is being used to model systems. This presents a particular problem that must be overcome. The type of architecture will be the primary factor in determining the mode of communication that will be utilized amongst agents, and in the majority of projects, a mixed type mode will be utilized.

CONCLUSIONS AND FUTURE WORK

We anticipate that cutting-edge AI, big data, cloud computing, and the Internet of Things (IoT) will make it possible to realize the Industrie 4.0 smart factory. Through conversation and negotiation, the smart machines and products can reorganize themselves to produce a wide range of products in a flexible manner. The IoT allows for the collection of massive amounts of data from smart items, which can subsequently be transferred to the cloud. To maximize the system's efficiency, this paves the way for big data analytics-based feedback and cooperation across the board. Above, we can see the self-organized reconfiguration that defines the smart factory's design and operational mechanism. Big data also defines the feedback and coordination that makes it tick. When it comes to solving global problems, the smart factory helps get us closer to a more sustainable production mode. It has the potential to result in revolutionary business models and perhaps have an impact on our way of life. We are doing the correct thing by simultaneously implementing the technologies that are already available and promoting technological developments. This is despite the fact that the adoption of smart factories is still facing some technical obstacles. It has already been possible to construct various application demonstrations using the technologies that are currently available.

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