Paving the Way to Industry 4.0: an Approach based on Multi-Agents System and Complex Event Processing

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Abstract— **The Internet of Things (IoT) industry has gone through several stages called industrial revolutions with the spread of the Internet and future-oriented technologies, this has led to a qualitative leap in the field of industrial production that depends on the machines communicating with each other, in order to control the manufacturing process accurately and with less cost towards the so-called Industry 4.0. However, two main difficulties are found: the massive collection of data from the industrial sensors and the real-time processing of the collected data which might be in heterogenous format due to the lack of standards. In this paper, we pave the way towards a cooperative Industrial IoT architecture using the agent paradigm and complex event processing techniques. This will permit benefiting from both agent features, to enrich the devices with autonomy, coordination and cooperation qualities between a set of manufacturing chains, and complex event processing, for a fast real time processing to improve decision making.**

Keywords-Industry 4.0; complex event processing; multiagent systems; manufacturing chain.

I. INTRODUCTION

The Internet of Things (IoT) industry has gone through several stages called industrial revolutions thanks to the spread of the Internet and the advances in future-oriented technologies. This has led to a qualitative leap in the field of industrial production that depends on the machines communicating with each other, in order to control the manufacturing process accurately and with less cost a new version of an industry emerged: it is called Industry 4.0.

The seamless integration and interconnection of all the different production processes and steps in a production chain, gives more transparency in its production processes as well as reducing the effort required. By using sensors at every stage of production, to identify the causes and quality issues, scrap and rework should be reduced. As a result of interconnecting different systems, production metrics and new daily business can be available in real time and provide the information needed to change and modify processes or resources without delay. In addition, it should enable network-related processes and mechanisms to act proactively in the event that unwanted events approach. As a result, the responsible persons should be notified immediately of problems in the manufacturing workflow and the causes of the problems should be easily identified based on the new data collected and the information through narrow networking of all machines and products.

Quality related information about faults and problems can be shared between machines and machines can inform the operator immediately. This should address the common problem of information exchange between people who work different shifts. Industry 4.0 motivated a transformation process of “regular” factories into smart factories based on digitization from singular production units, over whole productions floors towards globally interconnected production lines. Smart factories, factories of the future, or in general smart production environments apply building blocks such as sensor-based modules and systems, ubiquitous computing, IPv6, IoT and cloud computing to establish a cyber–physical (production) system (CP (P) S) infrastructure [1].

Our goal is to propose a system that links all the elements that depend on the production chain by connecting all production machines and sensors through the IoT, by connecting its Enterprise Resource Planning (ERP) system to the control system in manufacturing, operations, marketing, storage, distribution and delivery. Through this integration, the entire production chain becomes transparent; from raw material to delivery to the customer, which facilitates the normalization and auditing process. We expect to go one step further in this matter by facilitating the communication between the Industrial IoT elements through Multi-Agent Systems (MAS), and real-time processing of the acquired data with Complex Event Processing (CEP), among other technologies.

The rest of the paper is organized as follows. Section 2 introduces the background in the area of our research work. Then, in Section 3, we briefly discuss related works. Afterwards, Section 4 describes the proposed structure and its features. Finally, some conclusions and perspectives are presented.

II. BACKGROUND

This section provides some background firstly on Industrial IoT, secondly on software agents and finally on CEP.

A. Industrial IoT

The first three industrial revolutions are characterized as being driven by mechanical production relying on water and

 ISBN: 978-1-61208-861-7

steam power, use of mass labor and electrical energy, and the use of electronic, automated production respectively [2]. Whilst the supposed fourth industrial revolution (‘Industry 4.0’) was first proposed in 2011 in the context of the goal of developing the German economy [3]. This revolution is characterized by its reliance on the use of CPS capable of communication with one another and of making autonomous, decentralized decisions, with the aim of increasing industrial efficiency, productivity, safety, and transparency.

There is a considerable overlap between the concept of Industry 4.0 developed in Germany and the Industrial Internet concept, which originated in the United States. The definition of the latter now encompasses change for both business and individuals:

“*…the industrial internet is an internet of things, machines, computers and people enabling intelligent industrial operations using advanced data analytics for transformational business outcomes, and it is redefining the landscape for business and individuals a like*” [4].

B. *Software Agent*

The agent concept was essentially inspired by the fields of philosophy and psychology. Several definitions have been given throughout the years, where each definition addresses one or more aspects of this paradigm:

The agent is a software system [5][6] that has a specific purpose [7] in being able to react with a certain degree of independence [5] and autonomy [6] in a complex and dynamic environment [8]. This agent is characterized from a conventional software by its size and by the objectives and agendas on which it is based to accomplish its tasks [7] based on a set of knowledge and representation of predetermined objectives [5].

1) Characteristics of an Agent

An agent can also be distinguished from other software entities by holding the following features [9]: Autonomy, Social behavior , Reactivity, Pro-activity.

2) Interactions between Agents

An interaction is a dynamic linking of two or more agents through a set of reciprocal actions to achieve a specific goal. In this scope, an interaction situation is called a set of behaviors resulting from the grouping of agents who must act to meet their objectives, taking into account the constraints resulting from the more or less limited resources available to them and their individual skills.

In interactions between agents we sometimes fall into conflict situations, which are cases in which the objectives (intentions) of the agents are not compatible and / or the resources and the capacities of the agents are insufficient [10].

Interactions between agents are expressed in various forms; cooperation is the most commonly studied form of interaction in MAS. An agent avoids conflict situations to solve a problem through coordination or negotiation [10].

- Coordination: In the case of coordination, the agents work on problems whose solutions are useful for the other agents, so the work must be coordinated over time [11].
- Negotiation: The activities of agents in a distributed system are often interdependent and result in conflicts. Conflict resolution involves considering the points of view of the agents, negotiating between them, and using decision-making mechanisms regarding the purposes on which the system focuses [12].

3) Agent Types

The properties that characterize an agent determine its type. The main types of agents are as follow: Reactive Agent, Cognitive Agent, Proactive agents.

C. *Complex Event Processing*

CEP [13] is a technology that allows the capturing, analyzing and correlating of a large amount of heterogeneous data (simple events) with the aim of detecting relevant situations in a particular domain [14].

What we do is defining a series of event patterns that specify the condition that must be met from the content of the events of one or more incoming data streams for a situation of interest to be detected. This situation of interest detected by an event pattern is named complex event.

The software that permits the analysis of streaming data according to the defined patterns in real time is the CEP engine. Among the complex event engines, Esper stands out due to its maturity and performance, as well as the wide coverage of its EPL event pattern definition language [15].

III. Related Works

With linking all the elements of the production chain together, it leads to the creation of a large volume of data related to the production stages, the status of the product, the state of the production machines, the follow-up of the product quality and the state of stocks. In other words, this system provides information about the product, from the time it was raw material to the marketing stage, and to follow up on customer feedback after receipt and use. The volume of this information is called Big-Data, In turn, next to this term, the '3V' of Big-Data appeared, which refer to the Volume, Speed and Variety of the data generated by these systems [16], The first 'V' (Volume) refers to the huge amounts of information generated. The second 'V' (Velocity) refers to the speed with which said data is generated. Finally, the third 'V' (Variety) refers to the heterogeneity of these data that are generated. The ingestion and processing, analysis of this Big-Data is the one on which we are going to focus the main objectives of our research.

In general, many of the currently existing solutions for processing heterogeneous data sources [17]-[19] are forced to carry out a normalization process [20] or a pre-processing of the data to be able to analyze said information. In most cases, the normalization stage requires a lot of processing load, consuming resources and time. In addition, it is quite common in these systems to store the information to later reuse it in the analysis systems, thus causing storage costs.

Some works have tried to solve this problem by carrying out homogenization in data sources [21], which is not very efficient if we consider large networks of IoT devices with a multitude of devices as data sources. Others, such as in [21],

 ISBN: 978-1-61208-861-7

process batches of this heterogeneous information in order to normalize it, however, that means that we are not processing the information in real time, then situations of interest can go unnoticed and not be detected in time.

Among the various solutions currently in place, in [22] the author proposes to use MAS to process and analyze the large amount of information produced for the various interests of the factories, and this solution relies on the use of agents interacting with each other, applying the features of MAS overall system. The MAS cleans and monitors, collects data, and makes group decisions, and machine learning for Prediction and Health Management (PHM) of devices.

Therefore, in order to tackle this problem consisting of the need to collect this huge data from IoT, process it and analyze it in real time; in this paper, we propose a research plan based on the use of agent-based architectures, artificial intelligence and CEP to achieve agility and flexibility, as explained in the following section.

IV. PROPOSAL

In order to address and try to solve this problem, which is to collect this Big-Data from Industrial IoT, and process and analyze it in real time, in this thesis we propose to apply different models to those used or proposed by the above-mentioned works: agent-based architectures and artificial intelligence for manufacturing systems with the delivery of ERP to the production chain and to the manufacturing and process control system. Besides, create a self-organizing, cloud-supported architecture that includes cloud computing and smart agents to communicate and negotiate across networks using CEP. Ontological representations of the knowledge base are created and Machine Learning techniques are incorporated to provide an advanced information basis for decision-making by agents, thus enabling dynamic reconfiguration between agents in a collaborative way to achieve agility and flexibility.

As previously explained, an agent is a software robot [23][24] with a specific purpose and the ability to interact and make decisions with a certain degree of independence and autonomy in a complex and dynamic environment and has the ability to control its own behaviors. The agent is distinguished by its size and the goals and agendas on which it is based to accomplish his tasks based on his knowledge and the representation of the pre-determined goals. When the system contains a group of agents, it becomes a MAS and the goal of this system is the collective goal of the agents that is achieved through each agent performing the assigned tasks for him and to carry out joint tasks with other agents through communication, coordination and cooperation among them. MAS will be of great utility in our proposal because they will permit to manufacturing chain to coordinate, negotiate, and plan operations between them to achieve a global goal.

JADE is a platform implemented with the JAVA language. This framework is intended for developers who are interested in creating MAS, and which provides a language of communication predefined and represented in the FIPA-ACL standards. Among the advantages offered by the JADE platform we can mention unlimited interoperability for the applications they take support, and the independence of this platform from the operating system or hardware on which it is implemented [25]. Therefore, with JADE we will be able to simplify communication between agents integrated in manufacturing chain.

On the other hand, once we are able to receive and process huge amounts of data from the Industry 4.0, it is necessary to carry out an analysis on these data in order to detect situations of interest in real time. For this purpose, we are going to apply CEP [13]. As previously introduced, CEP allows us to process, analyze and correlate large amounts of information in the form of events - a simple event is a representation of a change in state - with the aim of detecting situations of interest (complex events) in real time [14].

Our main objective with CEP is to analyze the information from the Industry 4.0 as soon as it reaches our system, so that we do not need to store it in any persistence system if it is not necessary [15]. With CEP we are going to analyze, process and react to event streams from Industry 4.0, which makes it an ideal technology to be combined with the previously mentioned Jade platforms. We will define the situations of interest that we want to detect through the use of complex event patterns, whose syntax depends on the CEP solution to be used. The information, in the form of events, will be compared with these previously defined patterns and complex events (an event representing a situation of interest) will be detected when the conditions specified in the pattern are satisfied.

We plan to integrate agents into all elements of the production chain so that each production chain becomes a MAS and the production chains communicate with each other through the cloud. this proposal allows to improve product quality through real-time chain communication and data sharing.

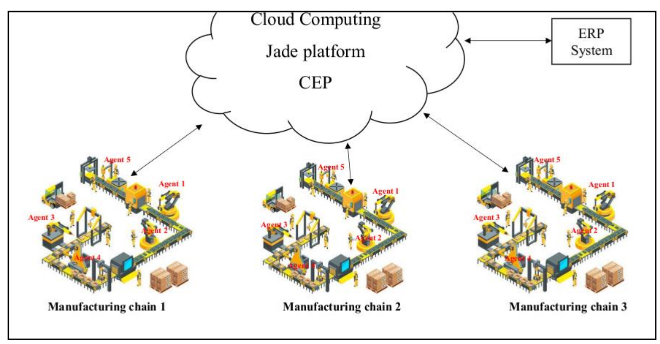

Figure 1. Our proposal architecture.

We propose an industrial collaborative architecture, as shown in Figure 1, which allow a set of manufacturing chains to collaborate between them and offer a high degree of autonomy, coordination and cooperation thanks to the use of MAS and doing the real-time processing of all the heterogeneous data collected with CEP.

V. CONCLUSION

In this paper, we have shown our work-in-progress proposal for a cooperative Industrial IoT architecture using the agent paradigm and CEP. We will benefit, on one hand, from agent features to enrich the device with autonomy, coordination and cooperation qualitie s between a set of manufacturing chains, while on the other, we will benefit from CEP to process the collected data in real time to improve the decision making and have a competitive advantage. Besides, once the proposed architecture is fully implemented, we expect to test it in a real manufacturing scenario.

ACKNOWLEDGMENT

This work was partially supported by the Spanish Ministry of Science and Innovation and the European Regional Development Fund (ERDF) under project FAME [RTI2018-093608-B-C33].

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