A CPS-Agent self-adaptive quality control platform for industry 4.0

Narjes Alaya*, Baudouin Dafflon§, Nejib Moalla* and Yacine Ouzrout*

* University Lumire Lyon 2
§ University Claude Bernard Lyon 1

Abstract—With the emergence of new requirements in manufacturing, mainly the product customization trend, implementing a solution for product quality control becomes an increasingly complicated task. In this modern industrial context, those solutions need to take into account the constant updates in the product design and combine its resources in the most effective manner in order to meet the new product specifications. By reason of the lack of available technical solutions, this task is usually carried out by human operators which is time consuming, tiring and not always a reliable solution. In the present work, a self-* automatic quality control platform based on cyber-physical systems and multi-agents paradigm is presented. The solution is validated within a real industrial use-case.

Keywords: Industry 4.0, Cyber-Physical System (CPS), Multi-Agent System (MAS), Automatic Quality Control (AQC).

I. INTRODUCTION

The modern industrial context is characterized by two important dimensions: On one hand, the need for collaboration in the form of companies-networks in order to face competitiveness especially for small and medium enterprises. On the other hand, the need of enabling products customization to better meet customer needs and exigences. Traditional manufacturing approaches have proven unable to address the emergent needs mainly because of their centralized and rigid conception. Consequently, nearly all of the recent production paradigms seek to adopt more agile approaches enabling responsiveness, robustness, self-*, and flexibility. These new needs have coincided with huge advancements in the technological area, mainly high availability and affordability of sensors, computer networks, the Internet of Things and the Artificial Intelligence. These circumstances have been at the origin of the industry 4.0 paradigm emergence. This new concept, which was used for the first time in 2011 in the Hannover Fair in Germany, involves the main technological innovations applied to production processes in the field of automation, control and information technologies [6]. It enables companies to schedule maintenance, predict failures and adapt themselves to new requirements and unplanned changes in the production processes in an autonomous way [7].

The fourth industrial revolution led to introducing the Cyber Physical Systems (CPS) as a new technological enabler allowing to build modular, intelligent and flexible systems. According to Lee [10], CPS are defined as autonomous systems, have a self-* behaviour, and are able to make decisions; this intuitively leads to consider Multi-agents system paradigm [24] as a valuable alternative to design CPS. Actually, agents are able to respond promptly and correctly to changes, due to their inherent capabilities of self-adapting to emergent events without external intervention [12].

In the present work, we are interested in automatizing the product quality control which represents one of the key application domains of the industry 4.0 for several reasons:

- It enables an efficient collaboration since it guarantees a better conformity to the product specifications.
- It allows partners to track the product state during the different manufacturing phases and have an idea about eventual problems.
- It gives the customers the possibility to update on-the-fly the specifications of the product to be manufactured without interrupting the process.

Traditionally, quality control is performed according to a test plan where the measurements and the decision criteria are defined. Those specifications are usually updated within a human intervention, which is suitable for mass production. But with today’s growing need for product customisation, the test plan should be constantly updated and configured because of the huge variety of products. This task is no longer possible to be performed by humans. For this reason, proposing an autonomous self-* quality control approach becomes an essential task.

In this paper, a CPS-Agent based quality control solution, in line with the industry 4.0 paradigm, is proposed. At this early development phase, there is a need to clearly define the CPS conception. In the following section of this paper, a proposal of a CPS design inspired by multi-agents systems is introduced. The proposed architecture is then used to implement a CPS-agent based framework for quality control. The framework will be finally validated within a real industrial use case.

II. THEORETICAL BACKGROUND

Advances in technology have engendered the Internet of Things (IoT) emergence [1] where embedded sensors are in charge of collecting data and sharing it through the network. Today’s technology is unable to store and process the huge amount of data generated through this process, this phenomenon is known as the Big Data challenge. In order to address this problem, many innovative concepts have been proposed particularly in the industry 4.0 context. One of the most interesting key-enablers that have drawn attention in the manufacturing field is the Cyber Physical System which is considered as an autonomous and reactive entity that interacts with its physical and logical environment. It
observes and predicts behaviour and makes decisions based on analytic and inferences. Every physical entity has its digital twin: a software model that mimics the behaviour of the physical asset. In contrast, IoT in common parlance is generally limited to the physical assets, not their digital models. In this early development phase, CPS design and implementation present many challenges and are still not defined. In the following section an approach of implementing CPS based on the IoT technologies and the Multi-Agents System paradigm is proposed.

A. CYBER PHYSICAL SYSTEMS

The reliability of a solution is measured by the requirements it is able to satisfy. The starting point is the 5-C architecture for Cyber Physical Systems as seen in [10] and presented in the figure 1. The pyramid represents a data life cycle through CPS: from raw data collected by the sensors into knowledge on which decision-making is based.

Five different levels should be taken into account while defining CPS architecture:

- **Smart connection level**: This level concerns the data collection from the different connected sensors. It also guarantees both vertical and horizontal communication between the different involved entities. At this level the data is still considered as row data. The use of IoT as an infrastructure for CPS presents a valuable solution at this stage.

- **Data to information level**: In this level data are converted from raw data into information. It corresponds to the data preprocessing phase. Machine learning and clustering algorithms can be used to assess the collected data accuracy [4]. Solutions based on Kalman filter [15] are widely used for data preprocessing mainly to estimate incomplete data or to remove noise. This process is applied at every sensor’s output.

- **Cyber level**: This level is also dedicated to process data but in a higher level. It concerns processing information coming from sensors and already preprocessed in the level below. The aim in this level is to build a complete cyber image of the concerned entity. Complex analytics such as deep learning are performed at this level. The resulting image, called the cyber twin, is used to infer additional knowledge.

- **Cognition level**: In this level a cyber physical system should be able to analyse the knowledge provided by the cyber twin in order to predict its potential failures, be aware of its degradation and estimate the time left to reach a failure. To this end, specific prediction algorithm are adapted based on historical data concerning the health evaluation.

- **Configuration level**: Based on the predictions made in the forgoing level, a machine have to react in order to reduce the potential impacts. Generally and based on a predefined policy, a machine rises alerts to the factory managers. In case of approaching failure, the machine self-configure its behaviour to minimize the risk. It can be done for example by reducing the production throughput or completely stopping the process.

Based on the CPS architecture explained in the previous paragraph, the main CPS requirements are listed in table I. Most common technological enablers for each requirement are then proposed.

### TABLE I

<table>
<thead>
<tr>
<th>Challenges</th>
<th>Enablers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plug and play functionality</td>
<td>IoT [16], [1]</td>
</tr>
<tr>
<td>Sensor network</td>
<td></td>
</tr>
<tr>
<td>Horizontal and vertical</td>
<td></td>
</tr>
<tr>
<td>communication</td>
<td>Sensor network</td>
</tr>
<tr>
<td>Data processing</td>
<td></td>
</tr>
<tr>
<td>Incomplete data estimation</td>
<td>Kalman filter [15]</td>
</tr>
<tr>
<td>Prediction</td>
<td></td>
</tr>
<tr>
<td>Artificial neural network [5],</td>
<td></td>
</tr>
<tr>
<td>Self-* behaviour</td>
<td></td>
</tr>
<tr>
<td>Optimization</td>
<td></td>
</tr>
<tr>
<td>BD [23]</td>
<td></td>
</tr>
</tbody>
</table>

The results stated in the table I, present a valuable starting point to propose a reliable CPS implementation approach that satisfies the mentioned challenges. Technological enablers mainly Multi-agents system, IoT and artificial intelligence prove to be indispensable to conceive CPS.

B. MULTI-AGENTS SYSTEMS

Technological enablers for CPS have been mentioned in the previous section. We can immediately notice that Multi-Agents paradigm presents a valuable alternative for CPS conception. This section is dedicated to define the main characteristics and abilities of a Multi-agents system. An agent is defined as anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors [19]. This definition has
been extended by adding to the agent the social dimension, the reactivity and the pro-activity characteristics [24]:
- **The autonomy**: An agent processes the data collected from its neighbourhood and calculates its actions without any external intervention.
- **The social dimension**: In multi-agents systems, a standard language is defined that enables agents to communicate.
- **The reactivity**: The agents react and change their behaviour based on their perception.
- **The pro-activity**: Agents adapt their behaviours by themselves in order to achieve an ultimate aim.

Two types of agents can be distinguished based on their way to react:
- **Reactive agent**: These agent reactions are based on the external received stimuli. It runs algorithms based on predefined rules that takes the perceptions gathered by sensors as inputs and actions on the environment as the output.
- **Cognitive agent**: These agents are able to run complex operations in order to fulfill a final goal. They are characterized by their representing and reasoning skills. They run machine learning algorithms in order to evolve and constantly adapt their behaviour to deal with emergent environmental changes and resolve conflictive situations.

For the sake of reaching autonomously and efficiently its ultimate goal, an agent runs complex operations based on decision-making paradigms.

C. DECISION MAKING PARADIGMS

The most frequently used decision making methods that come to a conclusion based on sensor signals data are briefly reviewed in this section. These methods include paradigms like neural networks, fuzzy logic, genetic algorithms and hybrid systems.

1) **Neural networks**: An artificial neural network (NN) is an information processing paradigm inspired by the biological nervous system,[18]. NN are known for their remarkable ability to provide meaning from complicated or imprecise data. NN acquire their knowledge thanks to a training process that automatically detects and classifies tool malfunctions. In [2] a method that automatically detects and classifies tool malfunctions using probabilistic neural networks. An accurate flank wear estimation in turning is proposed in [9] based on acoustic emission signals.

2) **Fuzzy logic**: Fuzzy logic refers to the theory of fuzzy sets [14]. A fuzzy set is defined as a set with no clearly defined boundaries. It is characterised by a membership function which is a curve that defines how to associate each point of the input to a membership value in the interval [0,1]. Fuzzy logic allows to model in a more intuitive way complex dynamic systems and has the advantage to not need lots of data to train. It is commonly applied in decision making support systems and particularly to sensor monitoring and estimation of machining. Example in [3] where a solution for tool wear estimation is presented. Or in [21] where a fuzzy Logic Approach to Sensor Monitoring in Machining: Features from acoustic estimation signal extracted and used to develop an intelligent system for classification of tools wear level.

Based on the CPS definition and requirements provided in the previous section, cognitive agent cover an important number of the CPS requirements. In the next section a conceptual approach of CPS based on cognitive Multi-Agent system is proposed.

III. THE PROPOSED APPROACH

At this early development phase, CPS conception needs to be defined. The contribution brought through the present work consists on proposing a conceptual solution to built a CPS network.

A. CPS TECHNOLOGICAL ENABLERS

Table II highlights the common points between CPS requirements and the Multi-Agents abilities. Remedies are also proposed in case that the CPS requirement can not be satisfied by MAS abilities.

<table>
<thead>
<tr>
<th>CPS requirements</th>
<th>Provided by MAS</th>
<th>Solution (if not provided by MAS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-*</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Reactivity</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Near real time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prediction</td>
<td>Partial</td>
<td>Use Artificial Intelligence</td>
</tr>
<tr>
<td>Plug and play</td>
<td>Partial</td>
<td>Use IoT as infrastructure</td>
</tr>
<tr>
<td>Link with physical</td>
<td></td>
<td>Use embedded system technologies</td>
</tr>
<tr>
<td>word</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Multi-agent System paradigm is used in order to fulfil requirements such as autonomy, self-* behaviour, reactivity and near real-time processing. The prediction and the decision-making abilities are insured by using Artificial intelligence in particular Artificial Neural Networks and Fuzzy Logic. Connection with the physical world needs hardware technologies implementation, which can be resolved by the use of Embedded Systems solutions.

The figure 2 gives a clearer idea about the technological enablers and infrastructure involved in a CPS implementation.
This proposition takes into consideration both the software and hardware implementation issues.

![CPS technological enablers](image)

**B. PROPOSED FRAMEWORK**

The proposition consists on proposing a CPS-Agent based framework, that takes advantages from the technological enablers mentioned in the previous section. The idea is to implement a CPS-agent network in an industrial context to supervise and control the production systems. The figure 3 presents the different components of a single CPS-agent.

- **Sensing module:** This module represents the CPS-agent entrance point of the incoming data. CPS network is based on an IoT infrastructure, that means that every CPS-Agent is equipped with a network interface. This interface is considered as the sensor responsible of collecting logical data, which is mainly messages from others CPS-Agents and commands from the information system. Physical sensors are part of the sensing module responsible for collecting physical data. Plug and play functionality is required to enable self-configuration. A CPS-Agent have the possibility to autonomously instantiate the type and the number of sensors that suit the respective demand.

- **Pre-processing module:** This module acts as a physical filter, it is responsible for row data cleansing. This process consists on removing noise and redundancy from the incoming data. It is also responsible to assess the data accuracy based on the level of confidence assigned to the source. In the case that several sensors are implemented, the data fusion is performed in this step in order remove incoherences. The output of this module is the pre-processed data used by the decision module.

- **Decision module:** The added value of a CPS resides on its decision capacities. For this reason, this module is considered as the most important. It has for mission to process the received pre-processed data to provide decision. The cognitive capacities used are based on Artificial Networks and Fuzzy Logic to perform essentially prediction tasks. The predictions made are used to automatically self-configure its behaviour, optimize the production incomes, reduce impacts and avoid failures.

- **Validation module:** The validation module is responsible for sending commands to the actuators. This module is essential to check the validation of the decision proposed by the decision module. This validation takes into consideration the coherence of the decision with the company business rules on one hand. On the other hand, this module checks if the proposed decision is compatible with other ongoing processes and does not create conflicts. Do that it uses optimization methods like scheduling algorithms.

- **Actuators:** These are components in charge of executing the received commands. They can be network gateways sending alerts, reports or messages to the concerned parts. They can also, as commonly known, seen as entities able to act on the physical environment.

![The proposed framework architecture](image)

This solution is applied to implement a quality control system and is in validation phase with a real industrial use case.

**IV. APPLICATION**

The proposed framework is implemented within an industrial partner APR (Application Plastique du Rhone) which is a French company specialised in plastic manufacturing. Considering the company requirements and business rule, a quality control solution for plastic items is being implemented. The figure 4 represents examples of items manufactured by APR. These items need a compliance control up to 100%.

![Example of items to control](image)

**A. SOFTWARE IMPLEMENTATION**

Practically, the proposed approach is implemented on a Raspberry Pi card. To performs this task, JAVA language is used. Modern guideline based on modularity has been followed in order to insure a scalable and generic solution. The reason behind the choice of modularity in implementing a CPS-agent solution is enabling flexibility which is mandatory to provide a self-* behaviour. The figure 5 represents a simplified class diagram of a CPS-Agent. The controller module has the same main functionalities as a logical agent: It perceives, decides and applies decision. It is also responsible for instantiating the types and numbers
of the sensors, actuators and filters needed depending on the application circumstances. Raw data collected by the sensor is processed by the physical filter in order to remove eventual noises, make interpolation and play memory roles. By analogy to the approach proposed in the previous section, the aim of this filter is to provide processed data, which is high level information ready to be consumed by the controller module to take decisions and define command to actuators.

The application inputs consists on a JSON file containing details about the physical connections of the available plugged sensors and actuators, mainly the trigger and the output ports or a measurement concerning the equipment health.

The application circumstances. Raw data collected by the sensors, actuators and filters needed depending on the application circumstances. Raw data collected by the sensor is processed by the physical filter in order to remove eventual noises, make interpolation and play memory roles. By analogy to the approach proposed in the previous section, the aim of this filter is to provide processed data, which is high level information ready to be consumed by the controller module to take decisions and define command to actuators.

The application inputs consists on a JSON file containing details about the physical connections of the available plugged sensors and actuators, mainly the trigger and the output ports or a measurement concerning the equipment health.

In the quality control application, the CPS-Agent is in constantly soliciting the information system via web-services requests. In this way, agents take advantage of the valuable processing and memory capacities that are available to the company information system. The requests may concern the manufacturing items catalogue where detailed description of the items are provided with the compliance metrics and the tolerance level. The use of web services relies on the fact that those information are likely to be constantly updated and are consuming in terms of memory. Another use of Web services by the CPS-agent consists of requesting outputs that result from programs that run highly complicated processing involving huge quantity of data. For example the Neural Networks training which requires a valuable processing capacities.

B. HARDWARE IMPLEMENTATION

A self-adaptive conveying plan for quality control for APR is being installed. The solution that adopts the architecture mentioned previously is described by the figure 6. The physical entry of our system is the item to control. The logical entry is represented by the configuration files of available sensors and actuators. A measure of the item is first sent as input of a web request to the information system. Based on the items catalogue, the information system returns the item description and its non compliance file. The CPS-agent is able to sort the manufactured items into compliant or faulty which is the main functionality of the system. It is also able to predict problems, raise alert, calculate impacts and adapt its behaviour based on its observations.

Raspberry Pi3 model B : This card is used to control the whole process. It is adequate for this application mainly because it is based on an open source OS (Raspbian) which enables a big flexibility. It is also compatible with a huge number of devices. The cost-reliability ratio of a Raspberry Pi card is reasonable. Besides it is equipped with a GPIO which enables high level programming.

HD camera with a mobile arm will be used in this quality control process. The choice of the camera is based on specific features, such as high resolution, fast shutter and mainly a controllable remote.

Led table providing white light with a colour temperature of 5600 Kelvin is used to generate the negative image of the item to control. It enables detecting patches when it comes to controlling translucent material.

360 Degree Laser Range Finder (Lidar). To precisely detect the items position. It is also used to control some aspects of item geometry.

V. CONCLUSION

In the present work, a self-adaptive CPS-agent based approach for quality control manufacturing is presented. The approach has been implemented into a scalable, autonomous and plug and play hardware-software solution. Concerning future works, finalizing the prototype implementation in the real industrial environment is intended. Also improving self-* behaviour for autonomous quality control by implementing a neural network based on algorithms and train it with to the adequate datasets.

REFERENCES


