Industrial Value Chain Research and Applications for Industry 4.0

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Abstract

In this paper, we present Industry 4.0 paradigm as a new business model that emerged from the GAFAM (Google-Apple- Facebook-Amazon-Microsoft) business model. As such, the main objectives of this new paradigm is internal and external customer empowerment and the creation of innovative collaborative applications. We discuss some applications that are ongoing research topics. We give two examples of industrial applications that are based on collaborative industrial-academic research partnership. We conclude by presenting some the opportunities, the challenges, recommendations and guidelines for industries and academia who are interested in implementing the Industry 4.0 paradigm.

Keywords
Industry 4.0, digital transformation, manufacturing, predictive maintenance, autonomous corrective action.

1. Introduction

Industry 4.0 is a paradigm that aims at taking advantage of the digital transformation in the manufacturing sector. Its focus is on creating an intelligent network of physical assets and processes through the deployment of information and communication technologies, and the exploitation of these technologies to serve internal and external customers (Guilhem 2018a). The basic concepts and technologies of Industry 4.0 are the Internet of Things (IoT), cloud computing, robotics, sensors, smart products, autonomous maintenance, autonomous machines, and autonomous processes of a cyber-physical system (CPS), in which peripherals and assets work together through a communication network . A diagram of this system is presented in Figure 1.
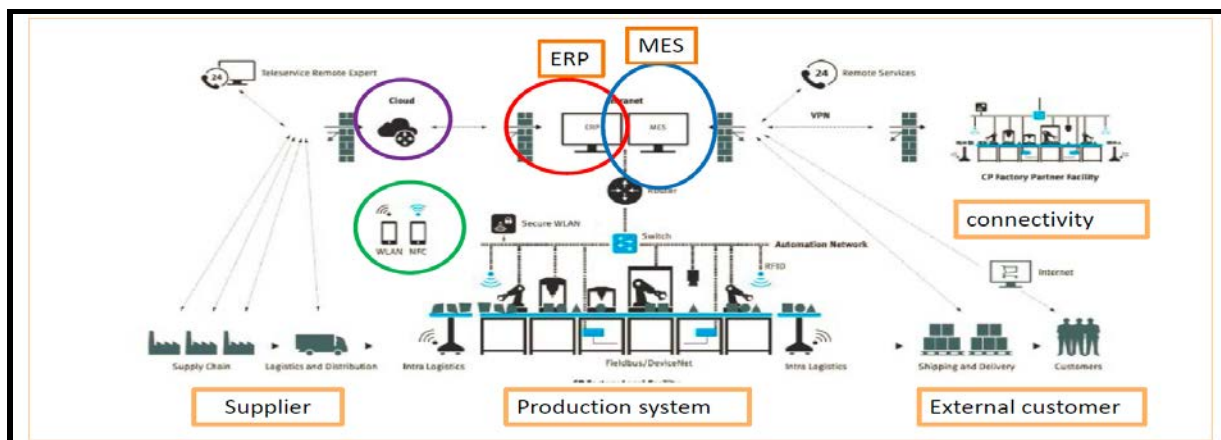

Figure 1. A cyber-physical system containing IoT, cloud, Enterprise Resource Planning system (ERP), and Manufacturing Execution System (MES).

In a cyber-physical system, the physical world, such as a production system, and the digitized cyber-world of data and information, are combined. This is the cornerstone of Industry 4.0. It is a network production facility for Industry 4.0. This installation combines the real world of production with the virtual world of information and communication technologies (Guilhem 2018b). As a result, traditional industrial processes are complemented and are represented in the digital world. This creates the basis for serial production of products with a higher level of quality, and processes with higher efficiency.

The idea of Industry 4.0 emerged after the vast adoption of the internet technology as a prime media of communication and for doing business. This technology was the cornerstone of the huge success of the giant enterprises, Google-Amazon-Facebook-Apple-and Microsoft (GAFAM). The business model of these enterprises has two main objectives of customer empowerment, and of collaborative problem solving. Figure 2 presents this basic idea of the GAFAM business model. Customer empowerment comes from the authority and power given to the customer to take action after receiving the necessary information. It is the process of becoming stronger and more confident, especially in controlling one's action and reaching to one's needs. As an example, with the services of Amazon, customers are empowered to search, analyze, chose, order and receive what they need, at their location and without the services of any intermediate agent. With the use of the internet services, customers learn to share their ideas to gain more information on their specific subject matters. As an example, customers describe their technical problems over the internet that diffuses the message, and a process of collaborative problem solving is created instantaneously. Other customers all over the world collaborate by suggesting and sharing their experience in solving similar problems (Nishioka, 2015).

The Digital Transformation: a New Business Model

the 4th industrial revolution: The *digitization*

Results: Better digital communication (connectivity)

Empowerment of external and internal clients

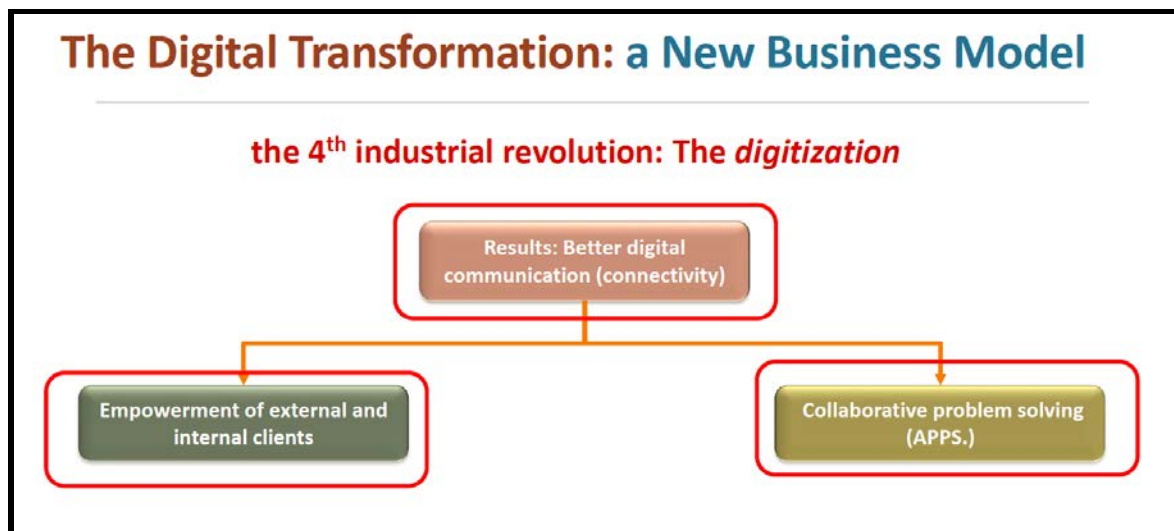Collaborative problem solving (APPS.)

Figure 2. Industry 4.0 as a new business model

From these two achievements of the new business model emerged the idea of the 4th industrial revolution that is based on industry's digitization in order to share knowledge, to empower customers, and to collaborative problem solving. This should lead to a process of democratization of knowledge, to more transparency, and to quicker and more efficient production process. In February 2017, Fujistu conducted a global digital transformation survey among business leaders. The survey's results indicated that 68% of business leaders acknowledged that their organizations are implementing, testing, or planning digital transformation (Sakai 2017). At the same year, Fujistu had already migrated 263 systems, approximately 30% of its 850 internal systems to cloud platform, and it had deployed 40 artificial intelligence projects. Respondents to the new 'Siemens Financial Services' believed that the "tipping point", defined as the time when 50% of players in the international manufacturing community will have substantially evolved into Industry production 4.0, will be achieved in 5-7 years for large manufacturers and in 9-11 years for manufacturers of SMEs (categorynet.com 2019). Financial Planning (2019) reported on a newly published report entitled 'Industry 4.0 Market', which has been apprehended by 'Verified Market' research in its repository. In this report, global Industry 4.0 market was valued at USD 66.72 billion in 2016, and it is projected to reach USD 227.29 billion by 2025, growing at a Compound Annual Growth Rate (CAGR) of 14.59% from 2017 to 2025.

So far, Industry 4.0 is still a very technical subject. In addition to the technology that is constantly changing, research's results concerning economic, social and organizational perspectives of Industry 4.0 are scarce. The added-value of this new value network remains a research subject's. In a cyber-physical factory, human traditional work will not be eliminated, but work patterns will change. Consequently, more important and original interactive human- machines, robots and software actions are expected. Research in this area is still at its early stages all over the world (Netherler 2017). In order to be adopted quickly by the industrial world, Industry 4.0 paradigm must demonstrate potential and substantial gains in productivity and resource utilization's efficiency across the value network. At the current state of Industry 4.0, companies are still struggling to implement the existing technologies. The new technologies in the production process, such as communication between machines, computers and people via the Internet (Internet of Things, IoT), and the connection of the virtual world of information and data to the real world by cyber-physical systems, remain subjects of research that require substantial investment in infrastructure. Present existing experiences lack recommendations for the implementation processes as too little is known about the key success factors underlying the adoption processes. The incentives for implementation and the benefits of this new business model remain to be demonstrated. Value network research, implementation strategies and implementation opportunities, in addition to technological innovations, are needed. Moreover, the socio-technical perspectives of Industry 4.0 allowing the integration of human, social and organizational factors into the design of the system need to be emphasized. Research in these areas could lead to quick acceptance of the underlying technologies (Thoben et al 2017).

In this paper, we first present some areas of research and applications related to Industry 4.0 paradigm. We then introduce two examples of collaborative research applications. We conclude the paper with some opportunities, challenges and recommendations of researches in industries and academia that are building Industry 4.0 infrastructure.

2. Applications for Industry 4.0

Although the infrastructure and technologies that are needed to apply the paradigm of Industry 4.0 are known and available, the value- added applications, which are supposed to lead to higher productivity and efficient resources' utilization, as well as social, environmental, economical, and health impacts, are still in their early stages of development. The following are descriptions of some of those applications:

2.1 Production planning

This area of research aims to obtain, analyze, and exploit real-time data that is available in an Enterprise Resource Planning system (ERP), and a Warehouse Management System (WMS) to decrease the response time for sudden changes. The ERP controls all the data, which is related to the logistical planning of physical internal and external resources, in order to satisfy the customers' requirements, while the WMS manages the stock of material that is needed to implement the optimal resource planning.   The integration of these two systems, and the exploitation of data in real-time is implemented in a Manufacturing Execution System (MES). This system is a production steering tool that works in two directions. In one direction, it collects and analyzes all data necessary to guide the resource planning in real time by capturing production data in real time from automata, sensors or manual input systems' workshop, and then to forward them to the ERP. In the other direction, it executes the resource planning that is sent by the ERP. In doing so, the MES gathers the information available in all the data of the production chain, from raw materials to shipping, and if intelligence is added to it, optimal resource utilization may be obtained. The main gain associated with the implementation of this software is the capacity of analyzing large volume of heterogeneous data in real-time, and the quick reactivity to any production's disturbance. It significantly reduces the administrative tasks of the operators and the compilation of data related to productivity. Its acquisition is justified by better resources management, process management, and product's quality management, which will lead to quicker response to changes, reduction in downtime of the machines, reduction of rejections and start-up times, and by an increase in overall quality and productivity. Such a tool allows the company and its managers to stop to be simple operators, with downstream work, short-term vision, obsolete information analysis, and frequent crisis, to become strategic operators, with upstream work, planning, control and analysis in real time, which allows them to react promptly to situations in the short, medium and long term. Figure 3 emphasizes the importance of the MES. An important area of research stems from the fact that the cyber-physical platform, which includes all the above-mentioned systems, will need the addition of a layer of artificial intelligence and optimization techniques and algorithms. Future Market (2017) predicted smart factories will make US$215 billion by 2025. According to General Electric, the smart factory concept could be worth $ 10-15 trillion to Global Gross Domestic Product (GDP) over the next 20 years.

Figure 3. The Manufacturing execution System (MES) at work.

Presently, a typical cyber-physical system does not necessarily includes artificial intelligence tools that leads to learning and automatic problem solving. It rather acts as an available source of data, which is gathered from all equipment and other sources in a manufacturing plant and redistributed to shareholders and users. The inclusion of artificial intelligence tools and techniques is a necessary step toward the exploitation of data and the creation of applications that should lead to efficient use of plant's resources despite sudden changes in plans, and in response to instantaneous disturbance. As such, these applications are the source of improvement and of value-added to the new value network. Moreover, as a result of the increased connectivity, and the creation of a value-added network, well-designed tests and scenarios, as well as a SWOT analysis (Strengths, Weaknesses, opportunities, Threats), is needed to gain greater understanding of this network, the suggestions for improvement, and the optimal way of operating it. A diagram of this intelligent cyber-physical system, with its two pillars of artificial intelligence and applications, is given in Figure 4.
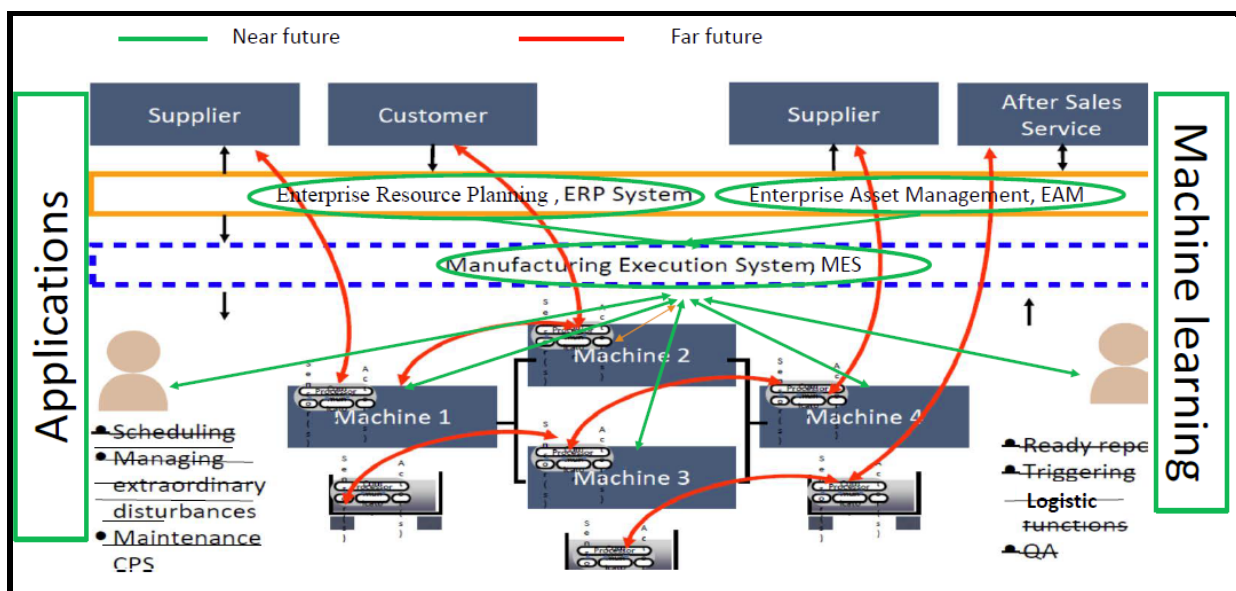

Figure 4. Intelligent cyber-physical system and applications

2.2 Human-machine interface in manufacturing

The increased use of robots allows manufacturing companies to put into practice a Flexible Production System (FMS) bringing gains of quality and productivity. In particular, collaborative robotics have experienced impressive growth in recent years, and they have penetrated many markets. Collaborative robots, which are called cobots, have as main characteristic to be able to work close to humans without putting them in danger. These robots have built-in limitations in their speeds and forces, which are specified by a demanding ISO standard, to ensure that any accidental collision with an operator has no impact on the operator. Operators and mechanics interact with cobots for adjustments, start-up, learning and tool changes. Their security must be ensured. Health and safety research is needed to study the contact forces between machines and humans, and to study different configurations, limitations and specificities that prevent accidents at work while ensuring a level of productivity in the company.

2.3 Research in connectivity and networking

All digital technologies depend on a communication network to exchange the generated data. This data comes from a Radio Frequency Identification Device (RFID) or other readers, access points, and identifiers such as memory chips. Research into reader's reliability and chip quality, even in harsh environments is needed to improve connectivity. Moreover, the lack of interoperability between the technologies developed for the Internet of Things (IoT) and the challenges of their integration constitute an important research topic. Another research topic emerges from the multitude of data origins and systems in the Industry 4.0 plant. This situation highlights the importance of the computer security aspect. The open structural design of the IoT architecture and the extensive use of the paradigm cause conventional security issues for existing network technologies. In addition, collaboration creates challenges as new security challenges can disrupt normal system functionality and operations. The commercialization of the IoT has raised a number of public safety concerns, including threats of cyber-attacks, privacy issues and organized crime. All these topics need to be addressed in a structured research.

2.4 Research on Value-Added Services

With the Industry 4.0 plant's cyber-physical platform, product's vendors make their data and product parameters available to members of the value network. Based on all this data, new services will emerge, such as standalone and autonomous maintenance. With a cyber-physical system, maintenance activities are expected to change dramatically. Decision-makers will be able to track the health of an equipment in real time and build an adaptable schedule of interventions. The cyber-physical plant collects, analyzes, and processes data to provide customized, tailored services, such as optimized maintenance at the right time. Moreover, a non-configured equipment will be introduced in production, for example to quickly replace another defective one. The equipment are individualized and parameterized due to the information contained in the software components. In the future, the equipment will be able to perform maintenance autonomously by changing the values of some controlled parameters in response to changes in operating conditions. A simulation of these scenarios needs to be developed.

3. Examples of applications

In the following two examples, we present two collaborative research projects that are implemented at industrial partners' facilities. Both applications incorporate state-of- the art methods and algorithms of data science, artificial intelligence and operations research. The first application is concerned with health monitoring and state characterization, while the second implements autonomous predictive and prescriptive actions.

3.1 Adaptive health monitoring and prognostic models for remaining useful life estimation

In this application, we develop real-time, self-learning techniques, for adaptive prognosis of the state of health of an industrial equipment. Supervised, semi supervised, and unsupervised techniques, which in real-time, combine sensors' data from a manufacturing equipment, as well as historical maintenance records and failure data, are used to construct failure prediction models and an adaptive estimate of the remaining useful life of the equipment (Elsheik et al 2018). This knowledge is combined to available maintenance actions to define the optimal strategy online and in real-time. The self-learning supervised technique is based on an adaptive version of LAD approach. In this version, time-series data is analyzed online, and hidden events are characterized by special patterns that identify the state of the equipment

over time. Statistical knowledge is combined to data-driven machine-learning techniques to predict the remaining useful life based on the most recently collected data. Figure 5 presents a schematic description of the self-learning and adaptation steps, where knowledge is acquired incrementally over time at predefined inspection periods. The results of this incremental learning is shown in Figure 6, where an autonomous-learning stratification process is performed to predict the remaining useful life based on similar past events. This process update the previous learning once new data is collected. New self-adapted survival curves are constructed in real-time and online. The area under the survival curves are used to estimate the remaining useful life and to update this estimation based on the most recent acquired knowledge.
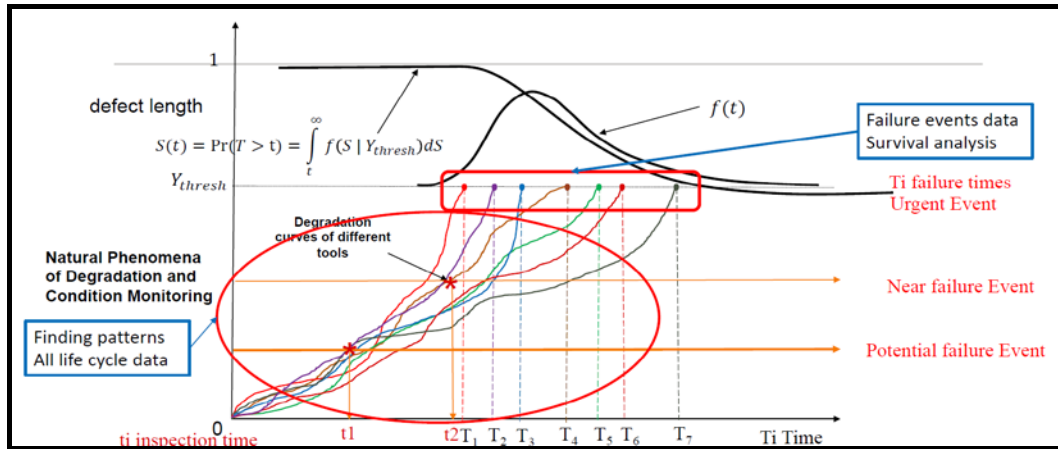

Figure 5. Combined statistical and machine learning knowledge of the equipment's state.
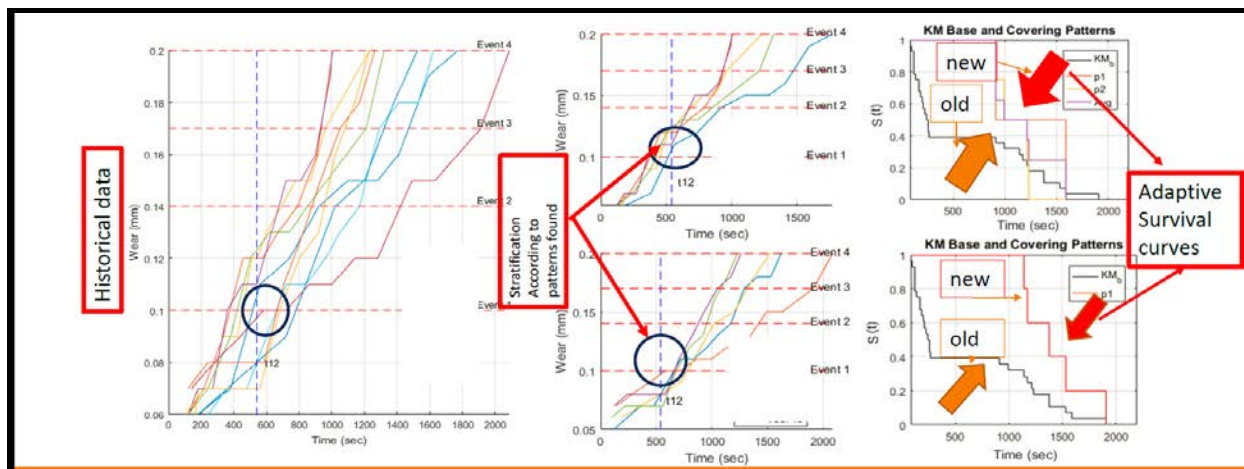

Figure 6. The stratification process and the updated survival curves

3.2 Autonomous corrective actions based on anomaly detection and diagnosis

One of the main advantages of adding machine-learning capabilities to a cyber- physical infrastructure is the ability to implement autonomous corrective actions in abnormal situations. This should lead to decreasing downtimes due to machine failures and abnormal shutdown, and to increasing production efficiency. It should also lead to saving energy and raw material that are consumed while producing defective products. In this collaborative industry-academia partnership project, the objective is to implement an autonomous process control technique that is based on machine learning and patterns' recognition. Machine learning techniques are applied to classify the machining conditions and to evaluate the quality and the geometric profile of the machined part. Sensors record the uncontrollable machining

conditions, which are used to generate patterns that describe the machining operation. The controllable machining conditions are used to control part accuracy and quality. We use pattern recognition technique that detects characteristic patterns, and use them to control the quality of a machined part by adjusting the controllable machining conditions in response to sensors' readings of the uncontrollable conditions (Shaban et al. 2017). Figure 7 shows the sequences of autonomous operations that are taken places.
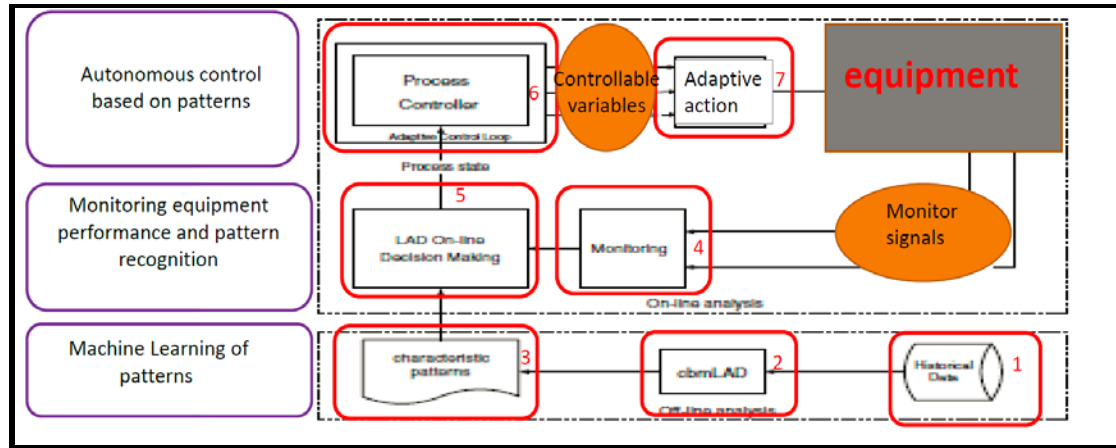

Figure 7. Autonomous corrective actions based on anomaly detection and diagnosis

4. Discussion and Conclusions

In this paper, we introduced the Industry 4.0 paradigm as a new business model that stemmed from the GAFAM business model. We emphasized the idea that this new revolution should lead to customer empowerment and to collaborative problem solving culture, which is based on more transparency and sharing of knowledge. We presented areas of opportunities for collaborative industry-academia research topics, and we gave two examples of implementation of Industry 4.0 paradigm that are based on the existence of data and artificial intelligence techniques. For the manufacturers who are looking for embracing the new paradigm, the opportunities are as follows (Andrews, 2017):

- An opportunity to tackle the complex problem of rapid changes of customers' requirements and the obligation to answer to these requirements in a short time interval, and with high product's quality. The use of information technologies and the internet has been proven highly efficient in all aspects of our lives. It is thus logical to expect the same result of efficiency when large volume of heterogeneous information is rapidly gathered from all the processes of an industrial network, then smartly analyzed to support smart the decision making.

- The cost and the variety of the available information technology are more affordable than ever, whether it is the cloud-based services, the open-source artificial intelligence tools, or the sensors that can track the tools and equipment states around the factory.

- Many governments and coalitions are alerted to the importance of this change of paradigm, and are willing to invest for upgrading their industries. For example, the German government invested 500 million Euros to encourage research into Industry 4.0. In the USA, technology firms, manufactures, suppliers, government agencies and universities have formed the Smart Manufacturing Leadership Coalition, a not-for-profit-organization funded by 140 million $ of public and private investments. In the UK, the government had announced that 4.7 billion pounds would be available for research and development into areas such as robotics, artificial intelligence, 5G mobile and smart energy.

However, the new paradigm of Industry 4.0 presents some challenges for the Industry (Andrews, 2017):

- Since Industry 4.0 is a disruptive concept by nature, and people usually resist any changes, it is expected that some high and middle management officers and employees will adopt a conservative attitude, and express concerns about the required changes.

- It is already clear that it is hard to find people having the required qualifications and digital skills to run the new systems, and to adapt them to the future technologies.

- It is not clear yet whether the manufacturers, their suppliers and theirs customers will accept to adopt smart communication systems and to exchange data and information openly and with little constraints.
- There is an obvious need for standardization, which is not fully available yet.
- It is important for historically different teams, such as the IT, the Engineering, and the Production teams to work closer to provide support for the new paradigm within a common IoT strategy.
- Finally, the cybersecurity stems as a major challenge for Industry 4.0, since many believe that the risk of security breaches by the hackers, through the IoT, will increase.

We conclude with the following recommendations to industries who plan to invest in building a cyber-physical infrastructure, which is needed to implement the Industry 4.0 paradigm:

- Combining manufacturing and information technologies and take initiatives collaboratively;
- Reforming the company's data architecture;
- Building the Digital Value Network Architecture (DVNA) to create value;
- Creating active knowledge and network business model to capture innovation;
- Driving a culture of collaboration through digitalization and IoT;
- Creating value through innovation in a collaborative industry-academia research, as well as industry-industry mode. Some information should be ready to share to achieve mutual gain;
- Interoperability means to operate correctly as a whole when connecting and using different sources. Here it means the state where data can be mutually used between digital platforms;
- Encouraging data utilization in a customer-oriented manner;
- Investing in human capital and development programs that promote new digital collaborative thinking;
- Identifying opportunities to deepen collaboration and understanding of sharing-economy platforms and use of Cloud capabilities;
- Standardization of operation means more future opportunities of collaborative problem solving.

For future research, more migration toward industry 4.0 paradigm, will mean adaptation of old tools and techniques to exploit the new capabilities of a cyber-physical factory, and the development of new applications to satisfy and empower the customer.

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Biography

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