Chapter

Remote Management of Autonomous Factory

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Abstract

In today's mass production era, the world is making things (products and systems) so quickly and systematically in huge volume. The demand for these products is very high and, at the same time, consumers are still in search for a need for making the production very personalized. Hence, the "one mold fits all" approach may not seem to be enough. The present approach is facing the lack of networking between the automation pyramid levels, that is, especially between enterprise resource planning (ERP) and manufacturing execution system (MES) layers and, in turn, communicating directly with the lower layers is not possible. This missing communication among the process equipment like machineries and field control systems like PLCs at the production shop floors implies that customization at the product layer for the consumer is still in progress in classical manufacturing. Mini-MES is a new concept being introduced here to solve the existing techniques reported in the literature and is followed by industry best practices. The novel mini-MES platform provides an avenue for the technology process level (the most bottom layer) to interplay interconnectivity and interoperability with its higher levels until the above pain points are addressed holistically. The chapter is going to focus mainly on the factory production of digital manufacturing and on describing the 3-Cs implementation plan, the enabling technology, and the achievable outcome ahead.

Keywords: factory cloud platform (FCP), autonomous factory, edge computing AI

1. Introduction

The smart manufacturing initiative from the industry transformation perspective is rapidly emerging in many parts of the world. Few notable smart manufacturing transformations leading the globe are the Chinese version of Made in China 2025, the German version of Industry 4.0, the United States version of Industrial Internet (Made in America), the Singaporean Smart Nation, and the UK/EU version of Future of Factory. Clearly, the global trend is pivoting toward the new era from the traditional mass ("Ford's") factory production, where a consumer-oriented low-volume, high-mixed demand and supply production would be the smarter way to build and make things [1].

In the factory, the manufacturing system is illustrated by the pyramid shown in **Figure 1**. At present, the production shop floor is already highly reconfigurable in its process level. This is possible, starting from the enterprise resource planning

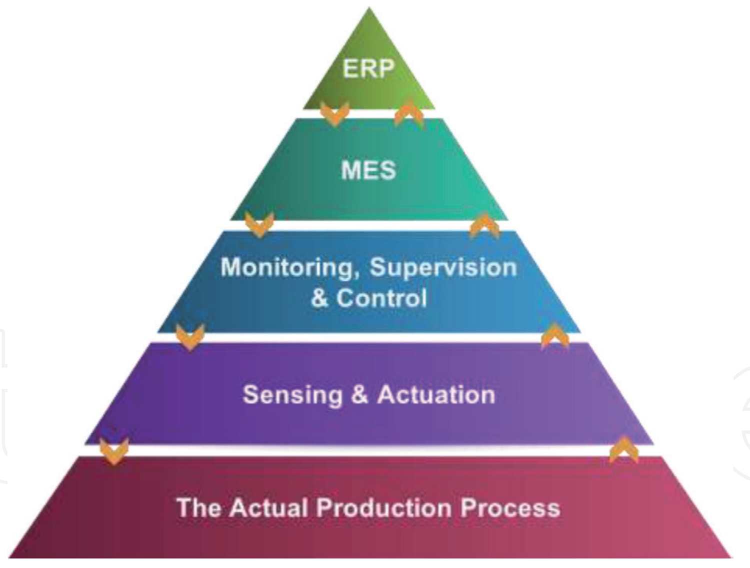

Figure 1.
The manufacturing pyramid—an overview of the existing production flow [2].

(ERP) layer, where process planning, operational management, etc. are interlinked. The manufacturing execution system (MES) layer is set to handle scheduling, dispatching production, etc. in a systematic manner. Monitoring, supervision, and control layer takes care of the real-time optimization and the advanced process controls. Sensing and actuation layer comprises the sensor readings' collection and manipulation of the production process. The final layer is where the actual production process exists.

In the above manufacturing pyramid diagram, few layers are already interconnected, but there are some layers which are independent silos. This is the pain point that is addressed through smart manufacturing, that is, introduction of the smart connectivity and interoperability throughout the layers. Various aspects need to be considered as it could be impossible to replace all the hardware in a manufacturing company to enable this. There could be some legacy systems as well which in itself would not be ideal to use in such an environment. By introducing the right cyber-physical tools and network connectivity, this can be achieved.

2. Digital manufacturing transformation

2.1 Mass production era

In today's mass production era, the world is making things (products and systems) so quickly and systematically in huge volume. The demand for these products is very high and, at the same time, consumers are still in search for a need for making the production very personalized. Hence, the "one mold fits all" approach may not seem to be enough. The present approach is facing the lack of networking between the automation pyramid levels, that is, especially between ERP and MES layers and, in turn, communicating directly with the lower layers is not possible. This missing communication among the process equipment like machineries and field control systems like PLCs at the production shop floors implies that customization at the product layer for the consumer is still in progress in classical manufacturing [3].

Recently, there is a strong pull to shift from the classical manufacturing/automation pyramid to the horizontal and vertical networking and to achieve the cyber-physical production systems (CPPS) as illustrated in **Figure 2**.

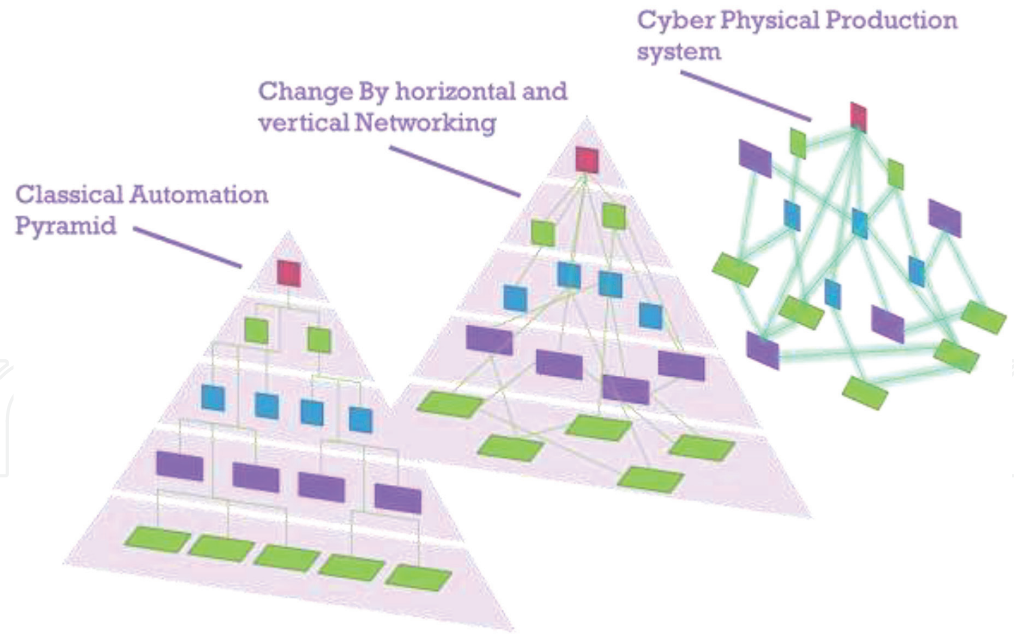

Figure 2.
The new paradigm of the manufacturing pyramid—an overview of the changed production flow.

The hierarchy arrangement of the automation pyramid is helpful for tracking the production status and for keeping proper process flow. Chaining the horizontal levels together adds value to the coordination and the vertical levels networks for more interconnection and cooperation. The full potential is attained when the boundaries are open. To reach this CPPS goal, one has to first identify and determine the associated pain points in order to enable the smooth transition:

1. Vast proprietary silos platforms/systems out there in the industrial systems.

2. Proper utilization of the available data.

3. Demand for higher response in terms of demand and supply of products in between the production line and the supply chain flow.

2.2 Digital manufacturing era

The CPPS is the backbone to the digital manufacturing era. The transition process from classical to digital manufacturing transformation requires a holistic platform of many Mini-MESs as shown in **Figure 3**. Mini-MES is a new concept being introduced by the authors to solve the existing techniques reported in the literature and is followed by industry best practices. The novel mini-MES platform provides an avenue for the technology process level (the most bottom layer) to interplay interconnectivity and interoperability with its higher levels until the above pain points are addressed holistically. There are four main aspects to be looked at and addressed, namely product, production, process management, and service manufacturing. This platform works hand in hand with the two upper layers to form the full CPPS as mentioned before in achieving the autonomous production factory. The rest of the chapter is going to focus mainly on the factory production of digital manufacturing and on describing the 3-Cs implementation plan, the enabling technology, and the achievable outcome ahead.

The 3-Cs implementation plans can be divided into three main parts. First is connecting to enable remote monitoring and management [5]. To truly remotely

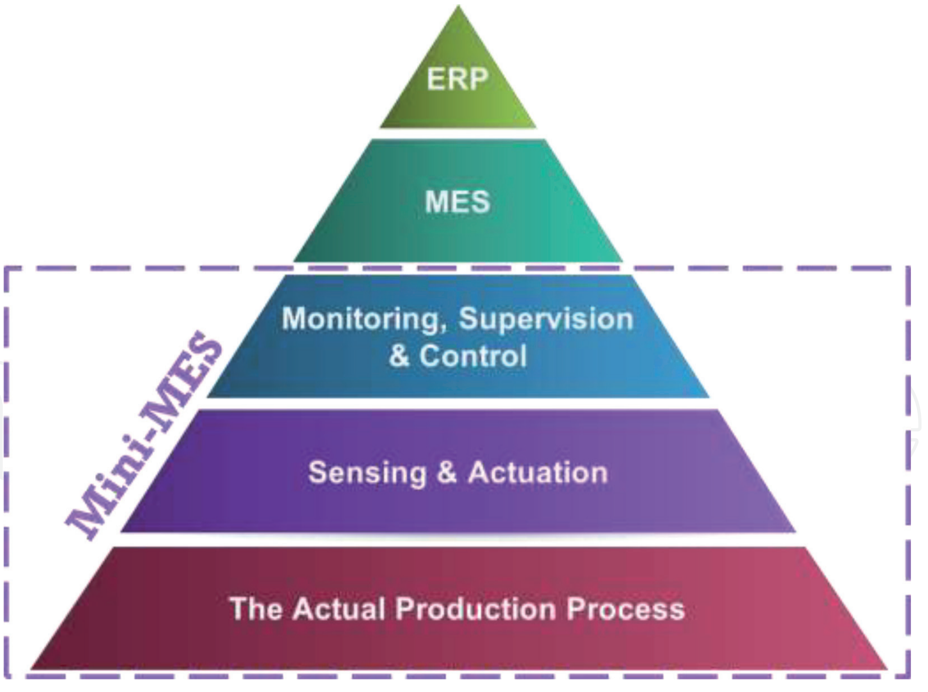

Figure 3.
Paradigm shift from classical automation toward interconnected smart systems [4].

manage the factory in real time, 5G technology has to be used since the specifications of 5G enable us to achieve a near real-time operation. The desired outcome is to achieve the large-scale deployment of remote autonomous control systems that are to be operated and managed seamlessly.

Second is computing at the edge. To implement as an aggregation point of the factory that holistically connects the dots of the individual levels of the automation pyramid and seamlessly control the communication protocols of devices and equipment of Siemens, Schneider Electric, ABB, etc. with a single common protocol. By doing so, any data point on the factory shop floor is available to the A.I. computation to develop the desired models and throughputs.

Third is collaborating/codeveloping with the domain experts. To leverage on the strong client records of experiences and add on to the implementation of the data platform to drive the traditional manufacturing market in a much faster and penetrable manner. Through the codevelopment process, the digital transformation of factory automation is going to accelerate tremendously while working closely back and forth with existing clients and leveraging on the existing manufacturing solution and the domain expertise.

3. Toward autonomous factory

As you may already realize, the global manufacturing trend is changing from the passive and reliant approach to a more demanding and intelligent way to manufacture produces. That is the smart factory (SF), which is rapidly growing and will be an anchor component of the digital manufacturing transformation journey. According to a financial report, it is expected that the SF market will continue to grow at a compound annual growth rate (CAGR) of 9.6% to reach around US$244.8 billion by 2024. In the case of the autonomous factory, it is projected to be one of the key enablers of these SFs for having the ability to be remotely operated and managed in the autonomous manner. Thanks to the data-driven platforms that are booming in from the digital space, the factory production can turn toward full automation and autonomy. It is expected to transform the traditional factory owners that produce in mass quantities with lots of manual workers into low-volume, high-mixture production with digital manufacturing technique.

The transformation will involve a set of digital technologies, including the Internet of Things (IoT), robotic and artificial intelligence (AI), into the implementation/upgrade for the factory modernization. With this, the new world of making things so agile in a flexible way, optimizing and integrating the system approach, and the great speed and accuracy are going to benefit and satisfy the fast consuming and highly personalized needs of the people (**Figure 4**).

Remote monitoring is a key aspect for an autonomous factory. For a manufacturing company to make money, it ultimately comes down to the number of products made. So, if there is an unscheduled downtime, the throughput of the production line reduces, and hence the company ends up making fewer products and thus loses money. We can overcome this by introducing a remote management solution. This would consist of a list of tools such as remote production monitoring, remote safety monitoring, machine learning, and artificial intelligence for predictive maintenance, which would address the problem even before they occur. As the solution is deployed, the owner will be able to see a reduction in operational costs and an increase in the equipment efficiency.

Remote management and monitoring had been available as a technology for the past decade or so, but somehow, the breakout year was never seen by the experts and observers. However, the situation is poised to change in today's scenario, with the new economic trends, transformed man power needs, and the availability of new technologies. During the global financial crisis, a lot of companies turned to lean staffing models. There is a certain lack of design and maintenance talents in many companies because of this. Coupling together with this is the retirement of the baby boomer workforce [6], who are extremely hardworking, which eventually led to a change in the demography of a factory floor. The new staff severely lack the decades of hands-on experience on the aging legacy equipment. They are also put under tremendous pressure to deliver a better throughput and more uptime and hence forcing the companies to remote monitoring and management.

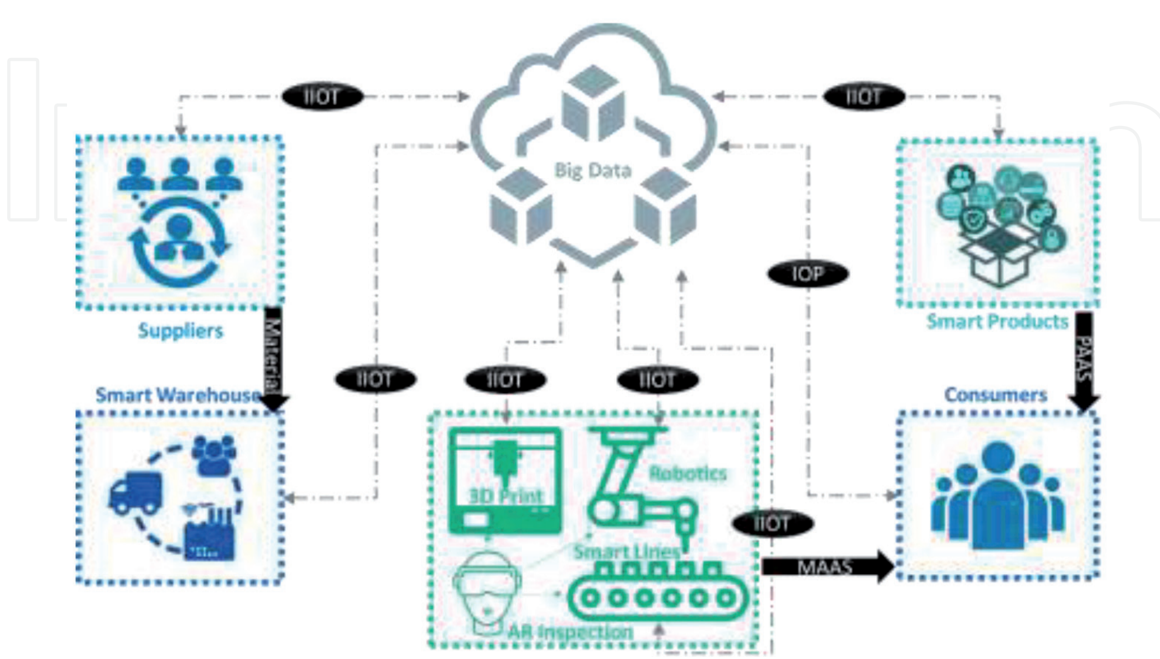

Figure 4.
Autonomous factory flow.

Another challenge we all know well is that the present manufacturing ecosystem is highly dependent on China, where most of the factories are located. China has a very strong fire wall, since they need to ensure their cyberspace is well protected, which is understandable. There is a great need for an IT platform that is equipped with the ability to capture true value creation from opening up the interrelationship between the nations like Singapore and China. The data exchange channel link has to be interlinked with minimum latency to empower an autonomous factory to interact on a real-time basis with its clients throughout day and night for 365 days without fail and to report machine health, process flow rate, and production status to the health diagnostic center for close and constant tracking outside China. Take for an example, there is this possibility with the use of the newly built Singapore and China data connectivity infrastructure of less than 60 ms latency between countries to enable online live communicating and producing of productions. This powerful data transmission exchange infrastructure will definitely enable an autonomous factory to work in a well-protected network environment.

The way things are bought and sold is going to change. It will go, way beyond buying from ecommerce platforms to making the products directly for the consumers. Take for an example, a production factory based somewhere in the middle part of China, in a city called Henan province, where there are a large varieties of machining/processing tools on the actual manufacturing shop floor. The digital manufacturing technology made by Printed Power (PP) Pvt. Ltd. (a company based in Singapore focusing on IoT and smart manufacturing) for the plant is an IoT-cloud platform that allows the remote manning, from the other parts of China or even from Singapore, of the Henan's factory production and maintenance as well as interconnecting the local resource planning ERP with the manufacturing execution system. The power of mini-MES (as illustrated in **Figure 3**) autonomous factory platform is to do away with: (1) restricted remote connectivity for the manufacturing solution to provide access to their local factory floor within China and (2) limited 24 × 7 real-time domain experts' monitoring and resource planning and managing of the factory production system.

In short, this proposed mini-MES autonomous factory platform is one of the first types of deployment in the world that compasses IoT-cloud cum edge computing technology to upskill the local manufacturing solution providers in serving their end manufacturing factory clients more effectively and efficiently. The autonomous factory software platform is performing three key functions: (1) to allow the manufacturing solution provider/system integrator to upgrade the traditional factory to be remotely access and control and (2) to support the manufacturing process/operation with the at-the-edge computers to do data compression for fast speed production and for onsite decision and execution for real-time factory throughput.

4. Technology enablers for autonomous factory

In this section, we will discuss the key technology enablers of an autonomous factory system. The discussion is going to surround on the digitalization tools, namely, the Internet of Things (IoT) hardware, the AI machine learning software, and the application design thinking/innovation needs. **Figure 5** illustrates an overview of the various technology enabling modules that apply to the autonomous factory context.

Among the many, the middleware or the firmware and operating system layers are the most important for the distributed edge computer network with AI processing at the cloud edge. As so, the edge computer becomes a crucial

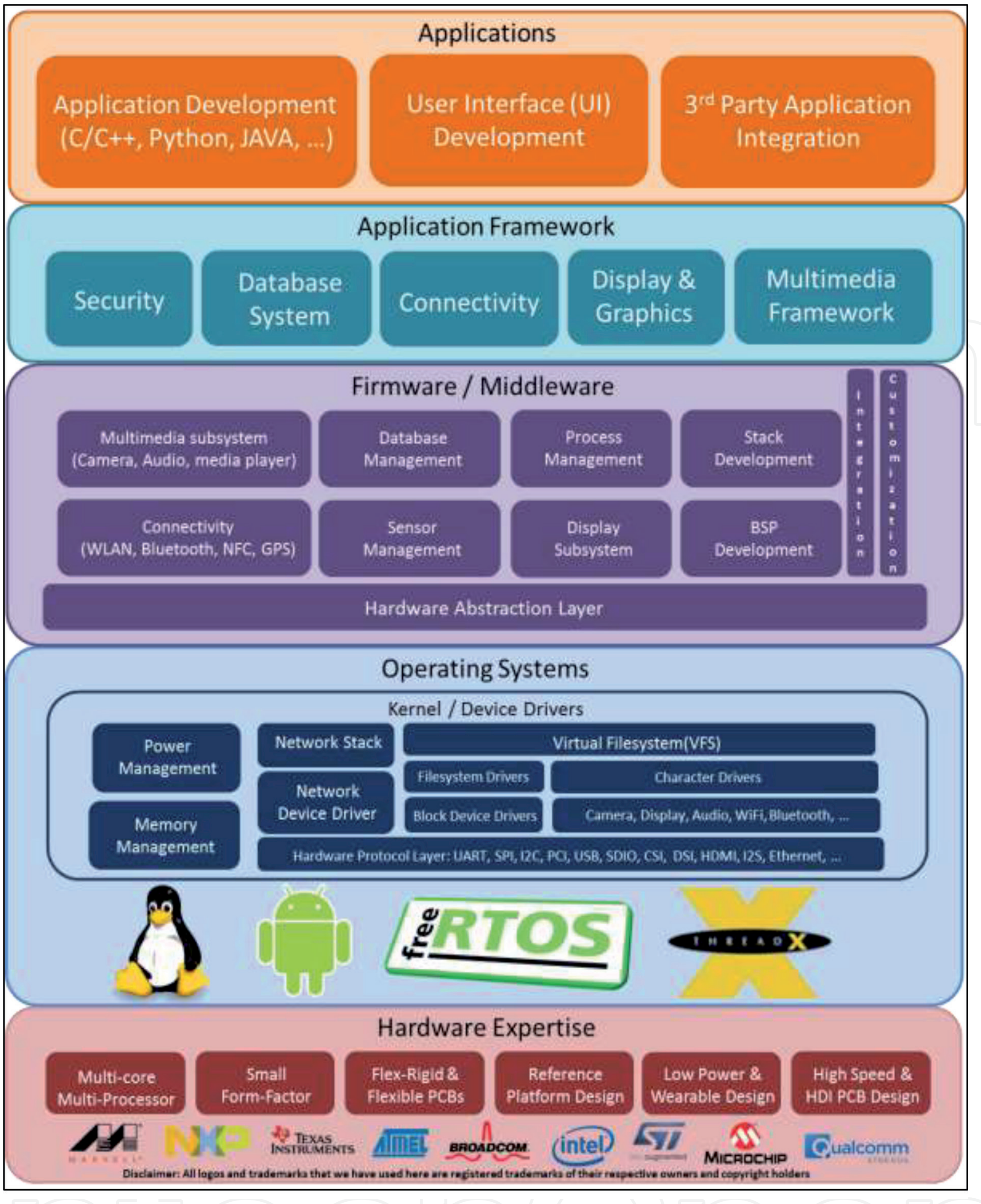

Figure 5.
Technology enablers (reference to https://volansys.com/product-engineering-services/).

technological enabler to the transformation of mass manufacturing into low-volume, high-mixed production. The discussion will focus on the product and system of edge computing and its underlying features as well as its association with manufacturing application and solution. As a reference, some of the tools used by Printed Power will be discussed.

4.1 Printed Power PowerEdge™

Printed Power has developed an IoT edge gateway product as shown in **Figure 6**, which is a powerful hardware platform with multiple protocol support for wired and wireless communication systems. Edge gateway product supports Android, Linux, and Ubuntu operating systems out of the box and can run a multitude of "apps" for each platform. It is a compact industrial PC combined with a powerful IoT gateway.

Figure 6.
Printed power PowerEdge™ hardware specification.

The PowerEdge™ product consists of RK3399 SOC, wireless radios, power modules, multiple GPIO and USB ports, and camera ports enclosed in a weather-proof enclosure with the following:

a. Light-weight operating system (OS): quick booting time and selected services running to reduce the dynamic memory consumption. The OS is based on the trimmed-down version of Android, Linux, or Ubuntu.

b. Embedded device driver development: able to support third party IoT devices interfaced over wired or wireless connectivity. Device drivers are dependent on the current OS running on the platform.

c. Embedded hardware development: able to install add-on hardware for the edge gateway to support IoT devices which operate at different power levels or nonstandard protocol.

d. OTA update support: allow updatable library packages inside the edge gateway for easier firmware upgrade which is completely wireless based.

On top of that, the Printed Power edge-cloud platform depicted in **Figure 7** allows the edge devices that are distributed throughout the factory shop floor and interconnected with the various machineries to gather at one place for monitoring and controlling. The cloud runs machine learning algorithm, makes java class image for download into the edge devices, and interoperates between the cyber cloud and the physical factory seamlessly.

4.2 Digital manufacturing application and solution

Let us first take a look at what a manufacturing production floor looks like and the kind of stuffs they do. A factory, manufacturing plant, or a production plant is an industrial site usually consisting of buildings and machinery, or more commonly a complex having several buildings, where workers manufacture goods or operate machines processing one product into another [4]. The area in a manufacturing facility is where the assembly or production is carried out either by an automated system or by workers or by a combination of both. The shop floor may include equipment, inventory, and storage areas. The basis of manufacturing [7] can be described in the following areas:

1. Assembly line: defines the progression and synchronization of work. The Ford example is typical of manufacturing, where there is a specific sequence of events which must be followed in order to produce the desired work product in a timely manner.

2. Division of labor: breaks the production process into separate tasks performed by specialists or craftsmen. Subdividing the process down into smaller increments provides the means to employ common workers as opposed to developing a dependence on highly skilled craftsmen which may add to the cost to the work product.

3. Precision tooling: provides mechanical leverage in the assembly line, the need for using the most technologically advanced tools, something that requires constant monitoring and upgrading.

Machines and the people are both working together in the shop floor and they operate with each other simultaneously. The machines are controlled by PLC logic and humans are controlled by themselves or by the company process. It is thus important that the two systems of their own talk with each other. **Figure 8(i)** is a snapshot of how this has being designed for an autonomous factory and it illustrates the architecture of such a platform design.

Referring to **Figure 8(ii)**, the robotic automation system of the autonomous factory consists of the arm performing pick and place, the moving robot to convey materials and products inside the factory, and the pressing and heating machine to treat and mold the made products. In order for the machines to communicate by themselves within the horizontal level of the manufacturing pyramid as discussed before, one has to first make a common communication language translator that allows cross talk among the machine systems. Printed Power PowerEdge™ fits in to provide the hardware connectivity as well as the firmware language translation.

Next, some form of intelligence is gathered from the data sets collected from the operations and maintenance to derive with the AI learning models for the control and automating of the manufacturing process. The AI learning is supported by both the online cloud-based engine as well as the offline edge Printed Power PowerEdge™ executable controls. GPU is part of this ball game to power up the AI engine and speed up the entire manufacturing process.

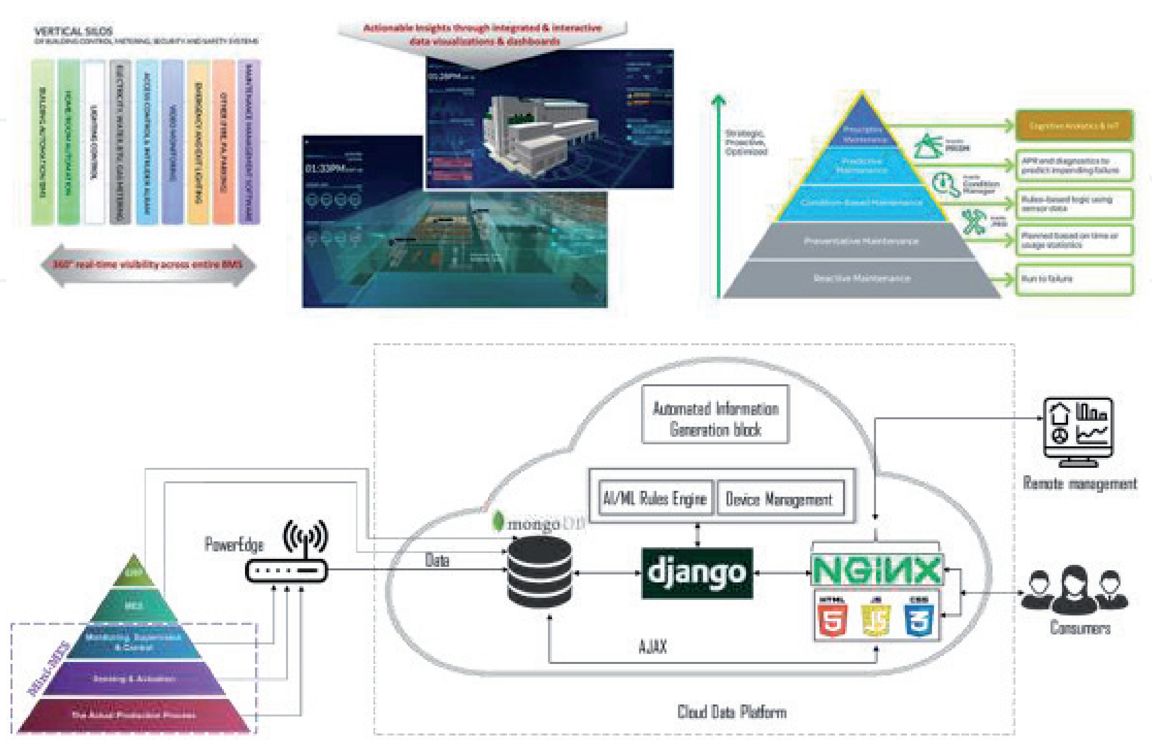

Figure 7.
Printed Power edge-cloud platform. (i) Description of platform components. (ii) Application of edge-cloud.

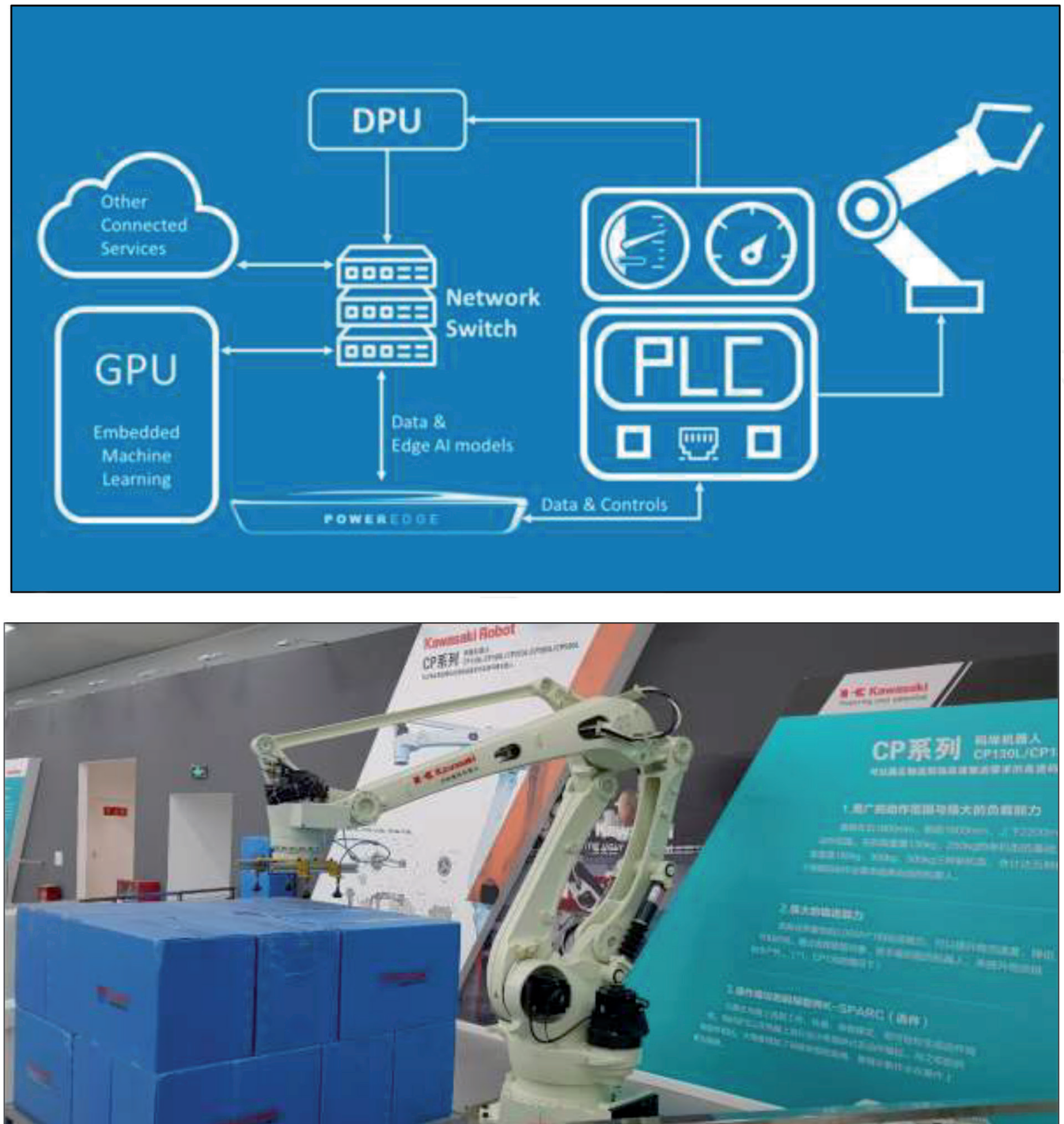

Figure 8.
Autonomous factory platform. (i) Printed Power digital manufacturing architecture. (ii) Robotic automation system.

Lastly, the remote manning and controlling of the entire autonomous factory platform is achieved via the dashboard at the command and control center. With the manufacturing and production status, the business owner is able to make a holistic and accurate decision with the sales figures, logistic and supply chain availability, demand and supply status, etc. Hence, this is a crucial part of the manufacturing application and solution.

The entire platform is undergoing development and installation at the site. It is expected to deliver its desired outcomes of being able to remotely access and control via the designed mini-MES platform with its backend housed on the AWS cloud. The autonomous factory should operate at its highest efficiency with the installed PowerEdge™ edge data compression for fast speed production and for onsite decision and execution for the real-time factory throughput.

5. Conclusion

Smart manufacturing initiative or movement from the industry transformation perspective is rapidly emerging in many parts of the world. Today, mass production is making things (products and systems) in a gigantic way that everyone is consuming them not at their preferences. The made from the "one mold fits all" approach does not seem to work for the consumers. The new world of making things is going to be so agile, so optimized and integrated, and so fast in speed and precise in accuracy to benefit and satisfy the fast consuming and highly personalized needs of the people.

To address this, the chapter discusses the digital manufacturing technology made by a Singaporean company, Printed Power, for the plant to be remotely manned and controlled by a press of a button. This autonomous factory software platform which is being developed allows for: (1) the remote connectivity for the manufacturing solution to access their local factory floor within China and (2) the 24 × 7 real-time outside China monitoring and managing of the factory production system.

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