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# Development of an Industrial Internet of Things Suite for Smart Factory towards Re-industrialization

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**Abstract**

Re-industrialization, which supports industrial upgrading and transformation, promotes smart production and high value-added manufacturing processes and helps to create new momentum for the economic. Under the current situation, industrialists encounter several challenges to achieve re-industrialization. First, the cost and technical thresholds for industrialists to leverage emerging technologies are high. Second, there are huge quantities and numerous types of Internet of Things (IoT) devices in smart factories, warehouses and offices. The enormous extents of data exchange and communication, management, monitoring and control of IoT devices as well as the establishment and maintenance of a reliable cloud platform hinder industrialists to implement an integrated smart production management. Therefore, to achieve re-industrialization, an Industrial Internet of Things (IIoT) Suite consisting of a Micro-services-based IIoT Cloud Platform and IIoT-based Smart Hub is proposed, which helps to materialise re-industrialization and to conduct industrial upgrading and transformation to achieve smart production and high value-added manufacturing processes.

Keywords: Industrial Internet of things (IIoTs), Cloud platform, Micro-services-based, Industry 4.0, Re-industrialization

## 1. Introduction

Most of the countries are facing the challenge of shirking industries and diminishing production capability due to upward social mobility, the generation of improved quality in the manufacturing workplace and rising labour wage rates [1-4]. The phenomenon of de-industrialization causes considerable concern that affects the stability of the global economy, with the focus back from the fictitious economy to the real economy [5].Also, the unstable labour supply drives industrialists to increase automation so as to reduce reliance on labour and to attract customers by offering innovative solutions or value-added services [6]. The major challenge of finding the appropriate ways to achieve industrial upgrading and transformation as well as to move towards high-value added production has not yet been addressed. Advocating the reinvigorating the global economy and computerization in the manufacturing industry through Industry 4.0, the necessity of fundamental changes in the manufacturing models becomes the major driven hedging for re-industrialization [7]. To grasp the opportunities brought by re-industrialization, research in Big Data Analytics [8, 9], Cloud Computing [10, 11], Wireless Sensing Networks (WSN) [12-14], Robotics [15, 16], Augmented Reality [17] and IoT [10, 18-20] are the future directions to facilitate the development of industry 4.0 in smart manufacturing [21].

Industrial Internet of Things (IIoT) has been introduced recently as the adoption of IoT in manufacturing or industrial domains [22]. Because of the advanced development of IIoT, the industrial sector has undertaken a new paradigm shift from traditional manufacturing to contemporary industry 4.0 manufacturing with the support of Cyber-Physical Systems (CPS). However, industrialists encounter several challenges to achieve industry 4.0 manufacturing.

First, real time objects identification and their position in the manufacturing process remain a challenge [23]. The fundamental need for implementing CPS network is to assistant humans, machines and robots undertake collaboration by real-time tracking in manufacturing [23, 24]. The CPS network in manufacturing aims at providing automatic production in a dynamic environment, given that all the elements may not be in a fixed work position [25]. With the advancement of indoor positioning systems and object recognition, workplace optimisation and asset tracking can be visualized in the platform.

Second, the manufacturing processes and machine status can be extracted in real time or near time basis [12, 25]. The connection between physical objects in the warehouse and the network must be well established and able to react to real time communication. Although wireless communication sets offer connect-free monitoring in detecting activities and working procedures in the factory, the system architecture must be able to connect and transfer to the corresponding decision support system, to determine the machine status in detecting failure or any abnormal condition during production [26]. The Wireless Sensor and Actuator Network (WSAN) assists the CPS network to assess the industrial environment and can trigger an alarm in the event of an emergency [27]. The lack of IIoT architecture leads to a limited automatic power in managing real time scheduling and workforce management in Industry 4.0.

Third, the voluminous data exchange and communication, management, monitoring and control of IoT devices becomes challenging to industrialists due to inadequate technical knowledge and high start-up and maintenance costs [28, 29]. Moreover, using IoT devices, each with its individual management platform, without interconnection, makes it difficult for industrialists to manage, monitor and control various IoT devices [30]. A single and reliable cloud platform is preferred by industrialists. Beyond optimising the platform usage as well as conducting data analysis and reporting, the cloud platform is sustainable for future expansion and upgrades. Industrialists can also transfer useful statistical data or information from the platform to other Information Technology (IT) and/or Operation Technology (OT) systems for analysis so as to inform on risk management and process improvement for implementing smart production and high-value added production [31]. With the aim of facilitating the development of Industry 4.0, various IoT devices can be acquired and installed gradually so as to upgrade and transform existing processes. In addition, the IIoT framework must be able to handle huge quantities and numerous types of IoT devices in the smart factories, warehouses and offices.

## 2. Related studies

### 2.1. Industry 4.0

Industry 4.0 has attracted numerous attentions from academic researchers and industrial practitioners ever since the German federal government announced industry 4.0 as one of the key initiatives of its high-tech strategy in 2011 [32]. The major focus of Industry 4.0 is to promote self-organized machines collaboration without human consciousness [33]. The information flow between material, sensors, machines, products, supply chain and demand chain, would be able to be connected independently and autonomously in response to the environmental changes and operational strategies [33]. Digitisation and automation of the manufacturing environment create a value chain to enhance the reliability of the production system and react under uncertainties in manufacturing by the smart and real-time analytics. Degradation of the machining processes and the occurrence of machine failure can be predicted beforehand with sensor-based machine health monitoring [29]. The smart factory in the context of industry 4.0 is becoming a new manufacturing pattern with the latest technologies. **Table 1** illustrates a comparison of today’s factory and Industry 4.0’s factory.

**Table 1**

A comparison of today's factory and industry 4.0's factory [9]

| | Attributes | Technologies |
|---|---|---|

| | | | |
|---|---|---|---|
| **Component sensor** | **Today's factory** | Precision | Smart sensors<br>Fault detection |
| | **Industry 4.0 factory** | Self-aware<br>Self-predict | Degradation monitoring<br>Remaining useful life prediction |
| **Machine controller** | **Today's factory** | Production rate<br>Performance | Condition-based monitoring & diagnostics |
| | **Industry 4.0 factory** | Self-aware<br>Self-predict<br>Self-compare | Up time with predictive health monitoring |
| **Production system and network system** | **Today's factory** | Productivity<br>OEE | Lean operations: work and waste reduction |
| | **Industry 4.0 factory** | Self-configure<br>Self-maintain<br>Self-organize | Worry-free Productivity |

### 2.2. Cyber Physical System

CPS relies on the newest and foreseeable further developments of Computer Science (CS), Information and Communication technologies (ICT) and Manufacturing Science and Technology (MST). There is increasing enthusiasm in exploiting the latest technologies for the CPS in order to enhance productivity and product quality, among which, IoT is the most essential and fundamental technology that enable the CPS. The application of CPS in manufacturing has been studies by numerous researchers. For example, Mikusz [34] regarded CPS as an industrial software-product-service system in view of the perspectives from solution, value chain and software part and proposed a structure of CPS as illustrated in **Fig. 1**. Monostori [35] introduced a Cyber-Physical Production Systems (CPPSs) considering the interplay between computer science, information and communication technology and manufacturing automation. Lee, et al. [36] introduced a 5C CPS structure to guide the development and deployment of CPS in manufacturing domain, which comprises smart connection, data-to-information conversion, cyber, cognition and configuration. Moreover, in the cyber level, they introduced a concept of time machine to conduct the Prognostic and Health Management (PHM), which consists of three steps, i.e., snapshot collection, similarity identification and synthesis optimised future operation.

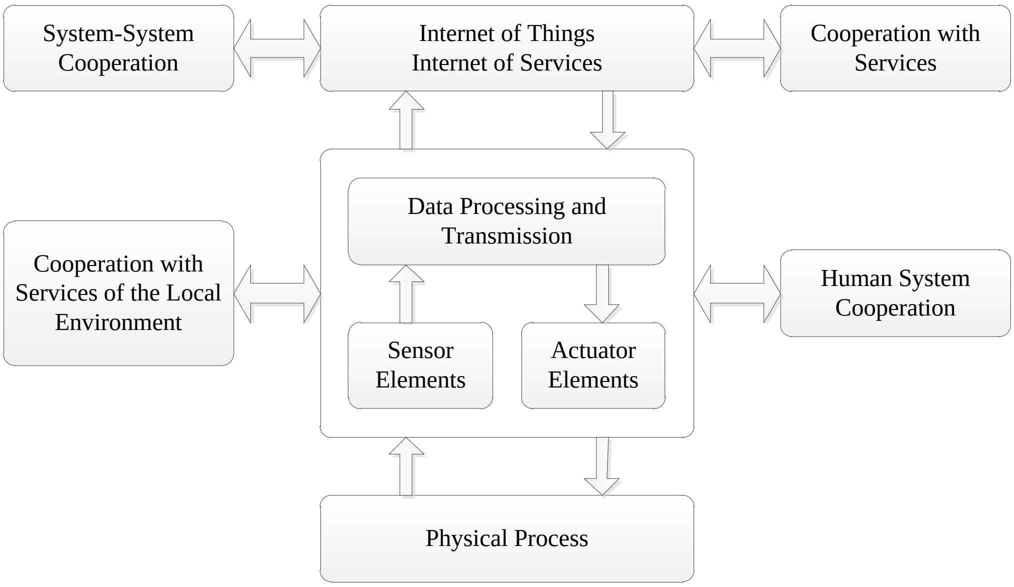


**Fig. 1** Structure of cyber-physical systems [34]

### 2.3. Application of IIoT in manufacturing systems

To step into the next generation of advanced manufacturing, IoT technology is regarded as a key enabler for the transformation from traditional to industry 4.0 manufacturing [31]. IoT architecture consists of four major layers: the sensing layer, networking layer, service layer and interface layer [19]. In the sensing layer, various techniques (RFID, sensors, actuators, Bluetooth, Wi-Fi, etc.) helps to obtain information from the physical environment. These data will transfer via the WLAN, WSN, Internet, Intranet, etc. to connect to the database in the network layer. After the data clearing process, the business logic can be applied to obtain knowledge by data mining in the service layer, and the result is presented in the interface layer. Although the applications in IoT are still at an early stage in the manufacturing sector, few successful IoT deployments in manufacturing have been discussed in the literature. Pang et al. [37] proposed IoT identification in healthcare systems to perform asset management and to evaluate performance measurement in decision making. Qiuping et al. [38] suggested that IoT deployment can prevent accidents in mining by sensing disaster signals from underground. Da Xu et al. [19] presented that IoT in transportation and logistics enables information to flow from the entire supply chain network so as to receive accurate information, such as inventory level, lead time and order tracking. Tao et al. [10] proposed cloud manufacturing in a global manufacturing context, given collaboration in manufacturing from different countries and regions. Enterprise resource management with IoT deployment facilitates the access of manufacturing resources and capacity management to resolve bottlenecks in the production chain.

In this research, in order to address the industrial challenges, achieve re-industrialization and future innovation and technology development, particularly in manufacturing and business processes, an IIoT Suite consisting of a Micro-services-based IIoT Cloud Platform and an IIoT-based Smart Hub is proposed. The IIoT Suite provides an information and operational infrastructure for industrialists to materialise re-industrialization in Hong Kong and to conduct industrial upgrading and transformation to achieve smart production and high value-added manufacturing processes.

After a brief overview of the challenges in re-industrialization in section 1 and the related study in industry 4.0, Cyber Physical System and IoT deployment in smart manufacturing, the remainder of the paper is organized as follows: Section 3 explains the main features of the IIoT suite in a real manufacturing scenario. Section 4 discusses the advantages and challenges for the application of IIoT Suite. Section 5 presents the conclusions and future direction of the field.

## 3. Key elements of the IIoT Suite

### 3.1. IIoT Suite

Nowadays IoT devices are ubiquitous, and these devices can be found in smart factories, warehouses, offices, etc. Intelligent and automated machines and equipment are examples of IoT devices which are used in manufacturing. The increased number and diversity of IoT devices, data exchange and communication as well as the need to manage different IoT devices present numerous challenges to the manufacturing industry. Therefore, we propose a conceptual design of the IIoT Suite, as shown in **Fig. 2**, so as to provide an information and operational infrastructure for industrialists to leverage emerging technologies, such as IIoT, so as to better manage, monitor and control existing and new IoT devices and to transform from traditional manufacturing, industrial and business processes to high-value-added production or services. The proposed IIoT Suite can also be adopted in existing smart factories to optimise the management of smart equipment and IoT devices and to improve production efficiency so as to provide customers with innovative and high value-added production or services.

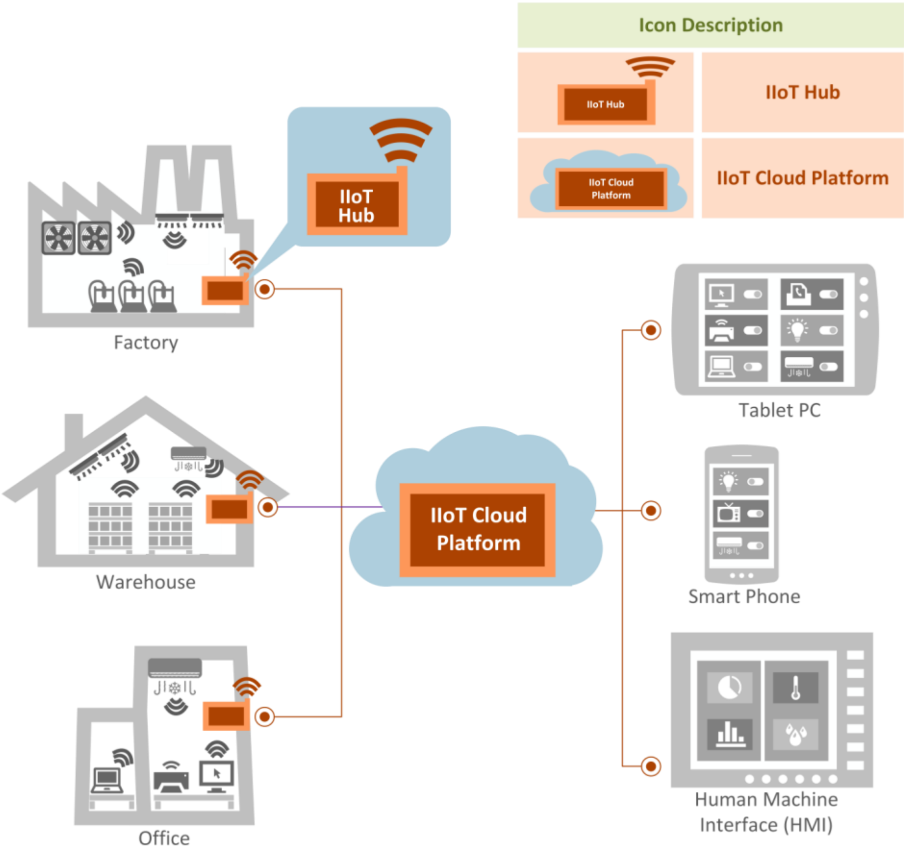


**Fig. 2** Conceptual design of IIoT Suite

The proposed IIoT suite is constructed based on multi-tier system architecture as shown in **Fig. 3**. Different IoT devices such as intelligent and automated machines, equipment, etc. are connected with the IIoT-based Smart Hub through device APIs (Application Program Interfaces).

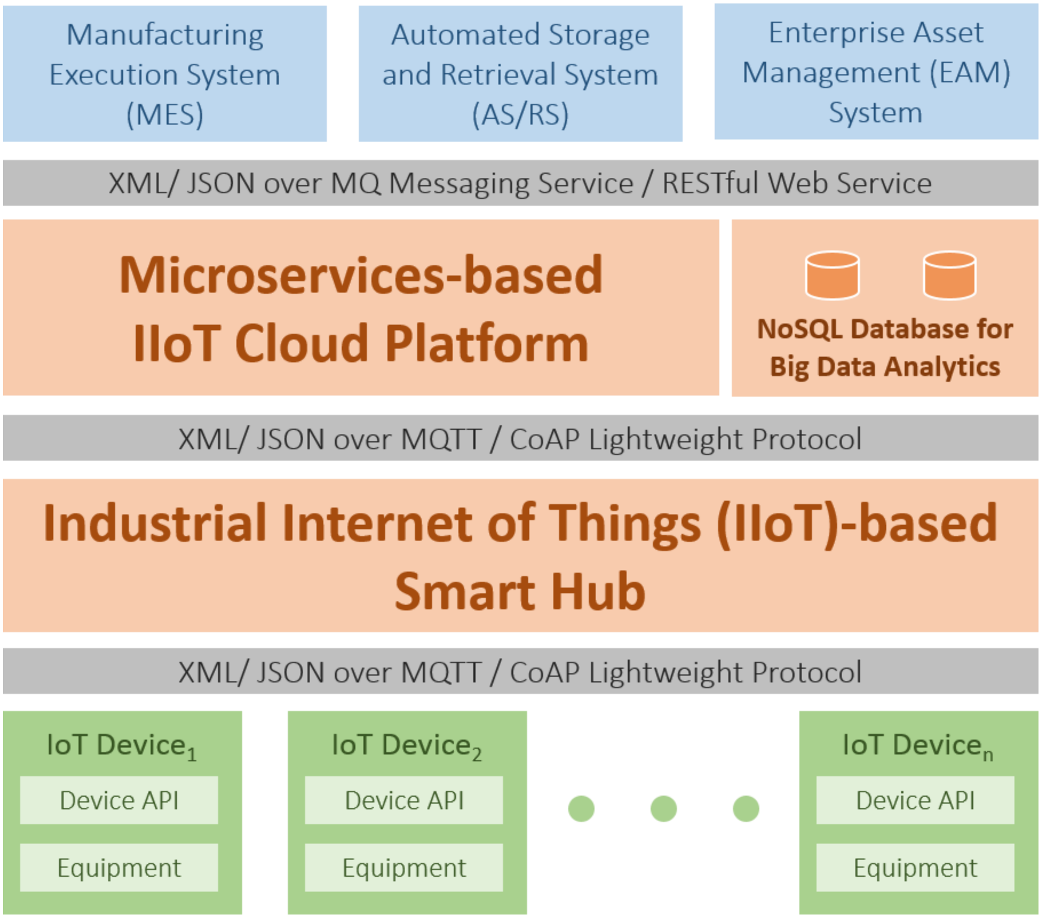


**Fig. 3** Schematic design of system architecture

The IIoT-based Smart Hub receives raw data from IoT devices; it then transfers the preprocessed data to the Micro-services-based IIoT Cloud Platform through XML/JSON over the MQTT/CoAP Lightweight Protocol. The Micro-services-based IIoT Cloud Platform consists of a variety of small and independent services. Each micro-service has its business logic and database, and each service can operate on its own independently. Micro-service can allocate and utilise resources for different job tasks in a dynamic and flexible way. The platform can transfer useful statistical data or information to other Information Technology (IT)/Operation Technology (OT) systems such as Manufacturing Execution System (MES), Automated Storage and Retrieval System (AS/RS) and Enterprise Asset Management (EAM) System through XML/JSON over MQ Message Service and/or RESTful Web Service to support risk and process management.

### 3.2. Smart Hub of Industrial Internet of Things

The IIoT-based Smart Hub is developed for managing IoT devices at distributed locations including smart factories, warehouses, and offices. In practical situations, wired communication is one of the reliable methods to transfer data to the backend platform. However, as different IoT devices may have their communication methods such as Wi-Fi, Bluetooth/BLE, ZigBee and Z-Wave; it is inefficient to connect various IoT devices to the backend platform directly. The most adopted solution is to collect data from IoT devices by using their communication methods and then transfer data through wired communication.

To address the above-mentioned problems, the IIoT-based Smart Hub is constructed, which can act as a gateway for existing IoT devices. The function of the IIoT-based Smart Hub is three-fold. First, it provides a simple and convenient method for data preprocessing, data exchange and communication between existing IoT devices and the backend platform, which means with the use of the IIoT-based Smart Hub, updates or enhancements of data exchange and communication channels can be realized. Second, it provides a sustainable solution to meet the challenges of future expansion of IoT devices. Third, the IIoT-based Smart Hub is designed to build a secure connection between the detected IoT devices and the Micro-services-based IIoT Cloud Platform.

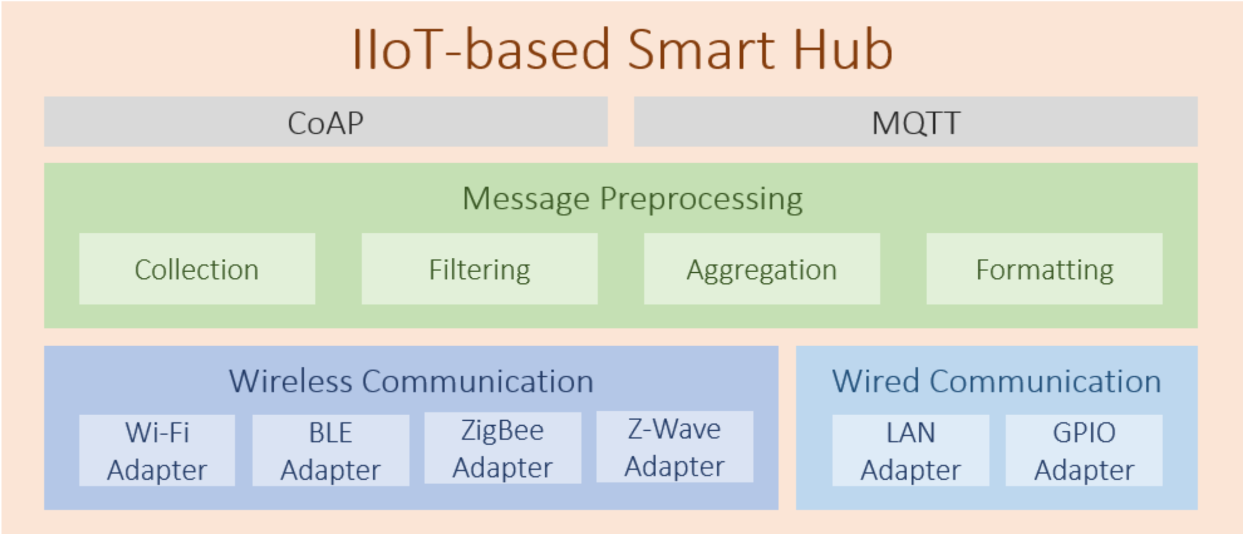


**Fig. 4** Main components of IIoT-based Smart Hub

**Fig. 4** shows the main components of IIoT-based Smart Hub. The IIoT-based Smart Hub is capable of communicating with IoT devices through wireless communications such as Wi-Fi, Bluetooth/BLE, ZigBee and Z-Wave or wired communications such as LAN and GPIO. Once the IIoT-based Smart Hub receives the data from IoT devices, it performs message preprocessing that includes data collection, filtering, aggregation and formatting. The IIoT-based Smart Hub transfers the preprocessed data to a Micro-services-based IIoT Cloud Platform through XML/JSON over the MQTT/CoAP Lightweight Protocol. Through establishing a secure connection between the IoT devices, the Micro-services-based IIoT Cloud Platform and IIoT-based Smart Hub, manufacturers and industrialists can simply select the relevant micro-services for the specific IoT devices on the platform.

### 3.3. Cloud Platform of Industrial Internet of Things

The Micro-services-based IIoT Cloud Platform, acting as the brain for the IIoT Suite, is the most important output, which is designed based on small and independent services, named micro-services. Each micro-service has its business logic and database, and it can operate individually. The micro-services architecture allows users to control a single application rather than a whole platform. The micro-services architecture has many advantages over the traditional monolithic architecture. On the one hand, the use of various IoT devices is increasing exponentially; it becomes difficult to forecast the number and variety of IoT devices. When a traditional monolithic architecture platform is used, the whole platform has to be suspended for maintenance or upgrade. On the other hand, the micro-services architecture allows users to add, delete, update or enhance a particular service without affecting the operation performance of the whole platform which is beneficial for the maintenance processes. Moreover, it is also capable of optimising platform usage and maintaining reliable platform performance. With the support from micro-services, the Micro-services-based IIoT Cloud Platform can offer a single platform with Graphical User Interfaces (GUI) for industrialists to communicate, manage, monitor and control IoT devices remotely in a simple, efficient and convenient way.

**Fig. 5** shows the main components of a Micro-services-based IIoT Cloud Platform. Examples of the micro-services include Identity and Access Management (IAM), load balancing, devices/services discovery, devices configuration, routeing/rule engine, monitoring and control. These services can communicate with each other through messaging channels, and they perform small tasks independently. Due to various types and functions of the micro-services, each micro-service is allocated to an individual NoSQL (non-relational) database for data storage.

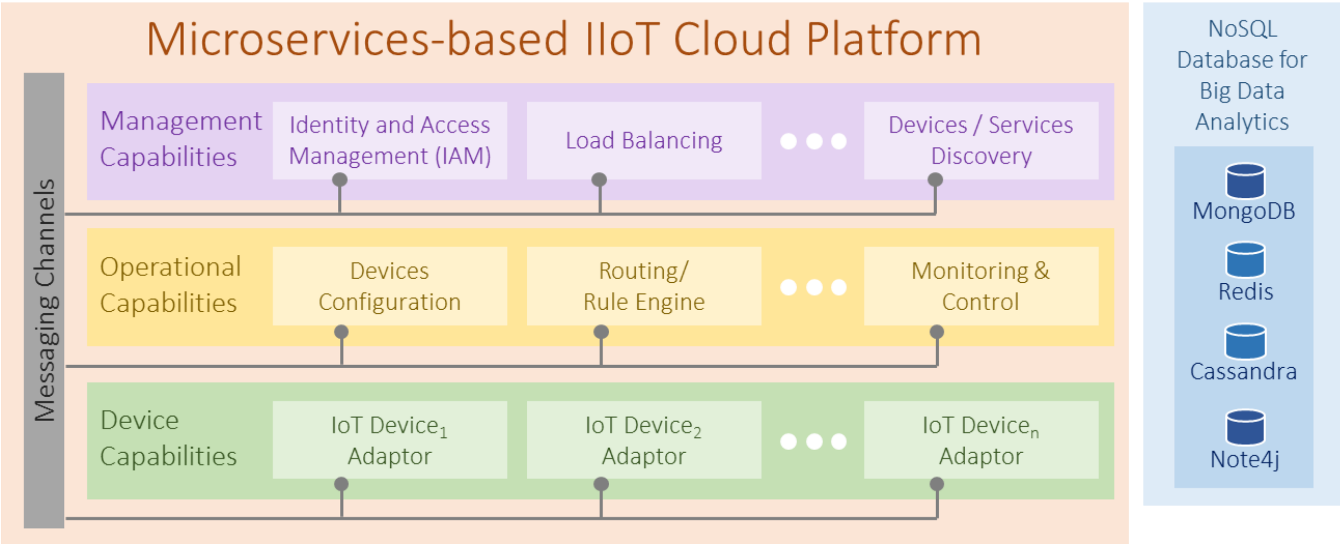


**Fig. 5** Main components of IIoT cloud platform

The application scenarios of the Micro-services-based IIoT Cloud Platform can be described as follows. When a user would like to configure an IoT Device, the platform will check the user identity first by using the IAM micro-service. The requested micro-service can be performed only if the user has the appropriate permission. If a large number of users are requesting the same micro-service, not only the identities and permissions of these users are examined, the loading of the micro-service will also be checked. If the micro-service is overloaded, the micro-services architecture can allow the platform to replicate one or more instances of that micro-service instance to share the workload of the overloaded tasks. Once the loading of the micro-service is back to normal, the platform will kill excess micro-services. The micro-services architecture can allow the platform to optimise its usage according to the actual pattern of demand.

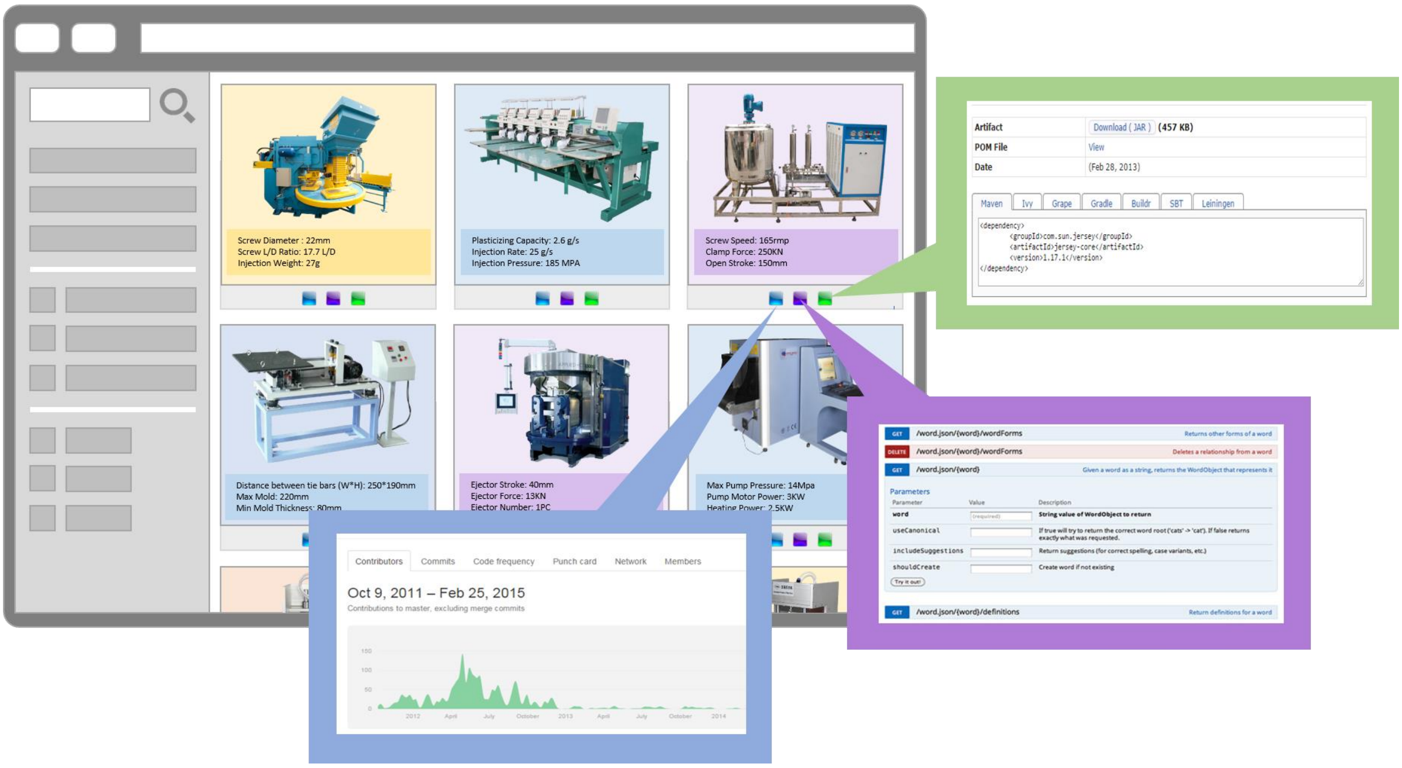


**Fig. 6** Graphical user interface of IIoT cloud platform

The GUI between the Micro-services-based IIoT Cloud Platform and users is illustrated in **Fig. 6**. The platform provides a graphical presentation layout that can facilitate manufacturers and industrialists to manage, monitor and control the connected IoT devices located in different smart factories, warehouses and offices. Once a new IoT Device adaptor (e.g. IoT Device) is established on the Micro-services-based IIoT Cloud Platform, and a new IoT device (e.g. a machine) are connected through the IIoT-based Smart Hub, the platform is able to propose appropriate services for the identified IoT devices by using the devices/service discovery micro-service. According to the nature of the machine, appropriate sensors are attached to obtain time-series sensory data for content-awareness maintenance management. The machine health condition assessment can be performed by continuously evaluating the anomalies processes. This provides aid for practitioners to determine the anomalies event and remaining useful lifetime of a machine [29]. GUI centralise the machine performance and historical data via an interactive dashboard to enable machine health analysis [39]. The user or other third party applications can further execute or control the identified IoT device through the platform, the IIoT-based Smart Hub and appropriate IoT Device adapter (e.g. IoT Device).

### 3.4. Case Study

The case company is a paper production and printing company. With the complexity of machines and moulds for printing production, the case company encounters difficulties in managing printing machine health condition and maintenance schedules. The selection of the IIoT sensors is determined by the critical components of the machine and domain knowledge in machine reliability. In general, three sensors are usually included in most of the printing machines in the case company. These include 3-axis accelerometer, thermometer and flow switch. The digital accelerometer is a 3-axis accelerometer, which is able to determine the motion performance of a machine. In two-sided printing, matrix rolling and anti-curl machines are the alternative to turn a stack of paper from another slide. Based on the moisture level, thickness and the materials of the paper, the printing processes may cause curling instead of lying flat when the paper passes through the fuser to perform the flip-over process. However, the adoption of matrix rolling machine requires monitoring on the compression process to flip over a stack of paper. Therefore, we adopt a motion sensor *ANALOG DEVICE ADXL345* to ensure that the matrix is rolling machine work properly. Another IIoT sensor is considered in our application is a thermometer. The abnormal operation may induce heat during production. Hence, we adopt *MAXIM DS18B20* 1-wire digital thermometer as the sensor provides a wide operation temperature range and simple wired connection. As aforementioned, compression operation usually occurred in the printing process. Pneumatic press machine provides kinetic power to perform compression. One phenomenon using air compression is that the inspection on the leaking location of the air compressor is not easily determined without sensor application. Leaking of the air compressor causes an extra-cost on printing production. Hence, the flow sensors *RoHS PFM710S-C6* are attached to the pipe to measure the flowing rate. All IIoT sensors are connected to *Raspberry Pi* as an IIoT smart hub to monitor the machine using wireless network configuration.

## 4. Key advantages and challenges of IIoT

The emergence of the IIoT smart hub provides a new research direction to consolidate the various IoT devices in a sensing layer. The utilisation of IoT sensing data enables obtaining of real time information of the physical environment and machine status [40]. Predictive maintenance helps to improve the transparency of the system and the machine health condition in order to enhance the reliability of the production system [29]. Also, the transparent manufacturing processes and machine status can benefit industrialists in accessing intrinsic knowledge to improve decision making. The IIoT cloud platform allows a global view of points in manufacturing processes between humans/machines and machines. This creates a bridge to allow self-adjustment of the manufacturing processes in a virtual layer [41, 42]. Moreover, the IIoT Suite allows unlimited connection to the cloud system compared with hard wired systems via programmable logic controllers. The decision making of the business logic and sensing data extraction from the sensing layer are designed with a decentralised approach [43]. It allows high-speed data collection in the IIoT Suite and transfers the data to the cloud platform for further processing. However, there are still challenges remaining for the implementation of the IIoT Suite. The volume of the sensing data from the IIoT suite may dramatically boost the data volume in the databases [29]. The storage capability may not be satisfied with the high velocity of automatic data retrieval systems from the IIoT Suite. Therefore, the speed of data processing from Big Data must be as expeditious as possible to meet the fast data flow.

## 5. Conclusions and Future work

To deal with rising labour wage rates and a severe shortage of labour in China, an information and operational infrastructure, called IIoT Suite, is proposed, aiming to accomplish re-industrialization of Hong Kong and to upgrade or transform industrial operations so as to implement smart production and run high value-added manufacturing processes. In the IIoT Suite, the IIoT-based Smart Hub is developed as a gateway to simplify connection and communication with various IoT devices (e.g. intelligent and automated machines and equipment) so as to facilitate efficient data exchange and communication between IoT devices and the Micro-services-based IIoT Cloud Platform. The Micro-services-based IIoT Cloud Platform provides a reliable and convenient way for industrialists to communicate, manage, monitor and control IoT devices at distributed locations such as smart factories, warehouses and offices. The IIoT Suite presents a straightforward and convenient way to exchange data amongst existing or forthcoming IoT devices. It also provides a single platform for manufacturers and industrialists to manage, monitor and control of various connected IoT devices more effectively. Furthermore, the proposed IIoT Suite is capable of transferring useful statistics from the platform to other information and operating systems for further investigation and analysis.


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