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ORIGINAL PAPER

Implementation of cloud based IoT technology in manufacturing industry for smart control of manufacturing process

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Abstract

Internet of Things (IoT) and Cloud Computing are receiving a lot of attention lately because they can offer a new technique for smart sensing and connectivity from man-to-man, man-to-machine, and machine-to-machine, as well as on-demand usage and effective sharing of resources, alternately. For the Industrial IoT to function as an infrastructure for data collection of shop floor equipment, cloud computing is required; distributed computing would move to the edge due to speed requirements for real-time processing of massive data. The method describes the standard manufacturing system built on a private cloud system that gathers data in real time from smart technologies linked to shop-floor objects.The study aims to design a general structure for information and data acquisition, processing, and collection at the edges of massive production controllers, where the approach is determined by the collection of shop-floor objects. The implementation of a multi-criteria adaptive scheduling technique that conducts accurate and effective scheduling or rescheduling of production processes in real time while taking shop-floor data and condition-based services into consideration. To move towards the Internet of Things, the different parts of the created cyber-physical mechanism will be applied in a cloud setting. The entities are made up of industrial assets that embed work-in-progress on items throughout their production phase of Cyber-Physical Production Systems (CPPS), which work together intelligently in such systems to achieve and maintain the manufacturing process's optimum, manage disruptions, and adapt to changing circumstances.The CPPS architecture joins a system with the IoT nodes made up of IoT accesses, and instruments, including PC-style terminals holding the resource agents with such a private cloud service. The decentralized MES network of a semi-hierarchical cloud-based CPPS controlling system is comprised of both networks. The development of the manufacturing process, controlling, monitoring, including optimization, as well as the archiving of historical data, are the major functions of the management system. The assessment of power consumed is presented together with an implementation framework. The entire method is easy to apply in different kinds of businesses and yielded incredibly satisfying results.

Keywords Internet of things (IoT) · Cloud computing · Manufacturing industry · Smart control · Cyber-physical production systems (CPPS)

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1 Introduction

To obtain a new development engine, the manufacturing sector is currently seeking to increase competence through its integration with the most recent Information and communication technologies. The industrial revolution 4.0 transforms conventional production into a digital environment. With the adoption of different information and communication technologies and their incorporation with the current manufacturing technologies, smart manufacturing—the penultimate crisis in the manufacturing sector and a new platform —an accumulation of cutting-edge methodologies that supports precise and efficient decision-making on a real-time basis. A distinct collection of significant techniques for smart manufacturing, including Cyber-physical systems, big data, cloud manufacturing, smart sensors, IoT, energy efficiency, additive manufacturing, and augmented and virtual reality, were offered [1].

Additionally, the implementation of wireless sensor networks, intelligent sensory systems, and technological communication protocols would aid enterprises in introducing innovative ICT-based instruments or in converting current ICT-based manufacturingframeworks into adaptive ones. The essential perception of the state of the shop floor could be achieved through the interconnection of ICT-based technologies with detection models, which is important for the realization of flexible shop-floor control and scheduling [2]. As a platform for data collecting from shop-floor gadgets, edge computing is crucial for the modern IoT; distributed intelligence would move to the edge for speedconsiderations in the real-time processing of massive information.Data points found in large-scale production technologies have multiplied as a result of the digital transition and intelligent integration of shop floor equipment with control software [3]. The extent to which businesses can derive value from processing this informationthrough gathering valuable information from this serves as a differentiating factor for the short-term and medium-term advancement and improvement of the technologies that empower production activities.

In particular, two domains are taken into account: the domain associated with data processing to gain important information and the region associated with supporting the generation of physical value in production methods. The combination of enterprise resource planning systems (ERP), manufacturing execution systems (MES), and other software into a live performance of systems that are conscious of the present condition of every iteration of the value chain must be employed to accomplish it [4]. The IoT and its smart gadgets demonstrate how the operatingdegree of production control is connected to the real world.Real-time data inputs must be processed and analyzed to track assets and ongoing activities effectively. The MES uses distributed intelligence to handle the information that the agents including the 2 distinct kinds of shop floor elements, resources, and products, receive in real-time [5]. Cloud computing mostly corresponds to the digitalization of services like job scheduling, mixed batch planning, product traceability, resource allocation, and product tracking at the point of the manufacturing execution system (MES). The generic MES functions are standardized by the ISA-95.03 standard, even though MES deployments vary and rely on the physical infrastructure.

A cyber-physical production system is created when networked cyber-physical systems (CPS) are used for smart manufacturing (CPPS). In those kinds of systems, CPS work together intelligently to maintain and achieve the production process's maximum, handle disruptions, and respond to varying circumstances. Cyber-Physical Systems (CPS) and the Internet of Things play a significant part in this revolution [6].Advanced techniques like cloud computing, cyber-physical systems, and IoT, which enable automatic processes and communication in ways that were before impracticable give up new possibilities for industrial digitalization. This study proposes a cloud-based cyber-physical platform for shop-floor management, planning, and control that adheres to the IoT and fourth industrial revolution concepts to utilize advanced toolsconcerning the digitalization of advanced industrial processes. The suggested solution consists of a wireless sensor network-supported monitoring framework.

The following is a summary of the main contribution of the current paper,

- A multi-criteria adaptive scheduling method is introduced, which performs precise and efficient scheduling or rescheduling of production steps in real time while considering information from the shop- floor (operating workers, machines, etc.) and condition-based services
- The developed cyber-physical mechanism's various components will be implemented in a cloud environment to advance to the Internet of Things. Additionally, techniques for data processing and storage will be implemented, and the various modules (monitoring, planning, and servicing) will then be made available as solutions for further end-user requirements.
- A reasonably priced monitoring mechanism could collect data from many sources and broadcast it using a wireless sensor network and established communication protocols
- Processes for analyzing data that make it simple to determine the state of the shop floor and to compute essential Metrics in real-time

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- When compared to conventional methods, a whole system is simple to implement in various types of businesses and produced extremely satisfying outcomes.

The residual portion of the work is briefed as follows. Section 2 provides the recent literature regarding smart manufacturing control; section 3 provides the problem statement; section 4 gives a detailed explanation of IoT based smart manufacturing control process; section 5 provides the results and evaluation outcomes of the developed framework and last, the conclusion part is provided in section 6.

2 Literature survey

The core idea behind cloud manufacturing is the coordination of distributed cloud production resources to deliver on-demand production services to end customers worldwide. This concept significantly reduces the number of additional tiers in the conventional value chain by allowing users to communicate straightforwardly with resource suppliers through application providers. In [7], a generic framework focused on big data analytics and cyber-physical manufacturing framework is presented for cloud-based production equipment. This makes it possible to connect manufacturing machinery to the cloud and make it accessible for the delivery of production services on demand. The created method could successfully support firms looking to convert old production technology into cloud-based cyber-physical manufacturing technologies, and on-demand manufacturing services provided through the Internet. It lacks adaptability and is unsustainable for social applications since it lacks any intelligent or smart mechanisms.

Chao Liu et al. suggested remote control of cyber-physical production systems and web-based digital twin modeling [8]. The rise of CPPS, which might open the door to investigating new smart manufacturing processes, is facilitated by the quick growth of the current generation of information technology. From the perspective of industry 4.0, DT serves as the technological foundation for CPPS. A significant research requirement is the creation of a convenient and simplistic DT-based CPPS. This study integrates CPS, DT modeling technology, web technologies, and event-driven dispersed cooperation mechanisms, to present a systemic framework to give directions for quick configuration and easy running of DT-based CPPS. The integration of the semantic information models, the 3D geometric design, and the functional modules create the idea of the CPS nodes for manufacturing resources. Utilizing dynamic resource registrations and binding techniques, several CPSNs are coordinated as independent CPPS. Event-driven dispersed collaboration between web-based remote control of CPPS and CPSNs are presented, respectively, to facilitate simple runtime of DT-based CPPS. Lastly, a model of DT-based CPPS is developed, on which an illustrative case is constructed, to confirm the viability of the suggested framework. Conventional centralized control architecture could not accommodate dynamic business requirements in the runtime phase of DT-based CPPS and would severely restrict the CPPS made up of numerous collaborative CPS nodes.

In [9], a semi-hierarchical industrial control system based on a private cloud architecture is explored. This system gathers information in real time from smart gadgets linked to shop-floor units. The cloud-based shared database used to build the proposed control system manages operation synchronization and manufacturing control logic. By using this technique, the data could be processed directly on the embedded system as well as in the cloud because the latency enables this decision.The key characteristics of the evolved control system are the simplicity with which production information from different sources could be integrated into a cloud platform utilizing a multi-agent structure spread over field agencies and on the cloud, less error-prone and increased availability of the MES global applications centralized at MES stage, operating on cloud, configurability in running real production time-exhaustiveprocessing applications in the cloud, and viability of shop-floor.

Yuqian Lu and Xun Xu suggested integrating big data analytics and cloud-based manufacturing equipment to provide on-demand manufacturing services [10]. In the framework of Industry 4.0, the quick setup of tenuously connected production machines to create highly personalized goods is the disruptive paradigm that can help businesses attain essential business flexibility. The study presented in the paper aims to close the gap that exists in the lack of a workable solution for cloud-based manufacturing machinery that can offer online on-demand manufacturing services. The discussion centers on the enabling technologies as well as the technical difficulties in establishing cloud-based manufacturing equipment. Manufacturing equipment may be associated with the cloud and made accessible for the production of on-demand product manufacturing according to a generic system architecture that is presented which is focused on cyber-physical production technologies and big data analytics. The proposed system design for cloud-based manufacturing equipment has successfully enabled on-demand manufacturing facilities supplied via the Internet, and it can be lengthened to companies attempting to convert legacy production systems into cloud-based cyber-physical production systems, according to an industry implementation in the largest providers of machinery solutions. Real-time machine control over the Internet, however, is not possible with the system design and implementation in place today; even though this is seen to be a crucial step in the development of dispersed smart factories and intelligent manufacturing.

The Cloud Manufacturing framework with widespread robotic systems for product customization was proposed by Zhang Zhinan et al. Conventional manufacturing facilities must change into smart factories with cyber-physical product development systems in the current frontier of Industry 4.0. One of these systems' essential components is thought to be robots. The study outlines an infrastructure for the smart manufacture of bespoke products employing accessible, cloud-based robotic systems. The purpose, design, and behavior of a URS are created as part of a paradigm for creating a cloud-based URS. The creation of this type of URS is then given with a technique. The development of cloud-based URS demonstrates, in the end, that the suggested strategy can accomplish the objective of smart manufacturing of customized products. This is demonstrated by the integration of a cloud-based URS for smart production and the construction of a customized product. But many of the technologies needed by the system aren't yet developed enough to meet the demands [11].

Wernher Behrendt and Violeta Damjanovic-Behrendt suggested using an open-source methodology to develop and implement digital twinning for smart manufacturing [12]. The architecture of a Digital Twin demonstration for Smart Manufacturing is covered in the paper, with an open-source implementation strategy. Open-source technologies can include hardware, software, and hybrid solutions, all of which are used today to power smart manufacturing. Open-source technology has the greatest promise for Smart Manufacturing in facilitating interoperability and lowering the upfront expenses associated with developing and deploying innovative manufacturing solutions. Researchers first discuss why they chose to create a DT demonstrator using an open-source method before identifying the key implementation needs for DTs and Smart Cyber-Physical Systems. Three technical parts for the construction of a DT have been identified, together with a conceptualization of the essential elements of a DT demonstrator. These technological building blocks contain elements for model, data, and service management. Researchers created a high-level micro-services framework from the DT demonstrator conceptual model and offered study architecture for the execution of the DT demonstration based on readily accessible open-source technologies. But a thorough set of useful strategies and validation metrics must be included in the DT demonstration.

3 Problem statement

In the recent decade, there has been a significant number of studies focused on improving production by making it more flexible, intelligent, and service-oriented. One of the areas of focus that stands out is cloud manufacturing, which denotes a flexible network of production services that could be rapidly customized to meet product development needs. The core idea behind cloud manufacturing is the online delivery of on-demand manufacturing services to customers through a dispersed network of cloud manufacturing resources.A viable solution for cloud-based manufacturing equipment that could offer online, on-demand manufacturing services are lacking in several systems. While integrating manufacturing equipment to the cloud, privacy, and security continue to be major concerns. Identification of a machine's identity through a secured communication channel presents a problem in this area.The majority of scientific literature discusses individual, highly specific issues with developing and implementing CPPS, and though they rarely discuss the broad range of necessary enabling technologies for an effective implementation, which renders it difficult for practitioners in particular to begin the appropriate strategies and measures. Because the main loop's execution in a separate thread in some systems samples is also missed while utilizing the intelligent system. As a result, there is a latency between the signal that was measured directly and the information that was recorded utilizing the smart system.

4 Proposed methodology for smart control of the manufacturing process

4.1 Cloud computing in IoT

Several ideas have emerged in recent years to connect informational and physical items. From a chronological perspective, the Internet came first, allowing programs to link and facilitate effective communication. Then, as physical devices began to be interconnected, they became smarter and more productive as a result of information sharing with peer and cloud networks. Process controls were carried out differently throughout this second phase. The term "Internet of Things" (IoT) [13] refers to a new idea that brings types of machinery with practices of the digital network towards the real domain. Cloud computing is crucial for IoT because it provides a structure for the dataset from shop floor equipment; dispersed intelligence would move to the edge for real-time processing of massive data due to speed considerations. Some activities will be carried out near the IoT system as well as the application, thus it is the edge of the system or the endpoint, rather than transferring each data through the system by processing it, such, as within the centralized cloud-based MES. By directly combining intelligence and processing capabilities into compact edge devices, and IoT gateways, a fresh viewpoint is transported toward the industrial IoT environment. Instead of mailing every collection to the secured cloud for processing, an application is necessary to access information right on decentralized, small-footprint edge equipment. Such technology helps to reduce latency as well as makes data transfer between the centralized aspect of the MES with the decentralized part of the MES. The study's objective is to provide a basic structure for data with information collection, and analysis, including the edge of massive production control structures; the edge is characterized using the collection of identified shop floor objects towards which CPPS [14] is applied. Data availability in an OT system is improved through OT and IT synchronization within the IoT framework, which is supported by a reliable and fault-tolerant IT architecture. Without affecting the current Supervisory Control and Information Collection network, cloud computing enables the collection of large amounts of higher-quality data from the operational side. The framework scheduling algorithm, machine learning as well as prediction-generating techniques in the MES, controlling unusual situations, real-time resource reconfiguring using digital configurations of mechanisms and assets uncontaminated by features, and resource functioning within the latest IT secured protocol can be transferred from manufacturing floor data centers to the cloud with the support of cloud and configuration management technologies [15].

The essential functions are carried out by the suggested cloud-based manufacturing control architecture. Configuration of the resource collection, batch scheduling, planning procedures for goods, resource assignment to activities, energy usage forecast, and anomaly detection using machine learning, cell, and production surveillance. For batch requests that are approved and processed on the higher MES level deployed on a private cloud platform, these activities would be completed.Product routing and batch transaction processing are managed automatically, and online rescheduling in the event of disruption is accomplished by order agents cooperating at the decentralized MES layer. The significant inputs from the lower MES control level to the System Scheduler in the cloud are concerned withthe designation, behavior, energy usage, and CPPS performed at the termination of any operation on products currently being executed also the acquiring of anticipated and unexpected happenings.

The effective management of batch processes with heterarchical, decentralized management of product implementation combined with hierarchical, centralized optimizing of mixing batch planning as well as product scheduling [16]. As long as the characteristics of the resource are not changed, the originally generated optimal schedule is used as a recommendation. Performing in the cloud optimization programs on various time horizons up to the furthest one makes it possible to implement this double management topology with online switching modes and real-time rescheduled. A suitable timing should be chosen to continually monitor resource behavior and capability evolution, spot efficiency deterioration, foresee unforeseen occurrences and energy consumption levels, as well as to modify ideal schedules. No important event should go unnoticed, and the global control system shouldn't become excessively tense.An appropriate timing strategy might be to update the assets' status, and KPIs, including energy consumption every time an activity on products, is complete, while also updating the appropriate production scheduling every time a product's performance is complete. The MES order agents as well as the cloud System Scheduler work together to rearrange the products now being run [17]. The cloud System Scheduler adjusts the best order for the remaining goods to be performed at this time.

An optimization approach that was first calculated in the cloud may be updated and rerun with specific timing in to maintain the optimal global batch estimation methods by gathering in real-time the status of the resources, the CPPS performed, as well as the energy used. Throughout this study, the cost is made up of the overall manufacturing time and the energy used; with makespan having an impact on energy consumption.In the experimental stage, tests were performed for the updated instantaneous energy and power operations. Two types of events might affect the calculated optimum schedule: harsh changes to the resource's state, and soft changes to the resource's state.Based on experience and experimentation, the events are first configured in the cloud; throughout manufacturing, these are identified by the resource holons which interact with the order holons. Hard changes might well be identified at any time and result in automatic resource team reconfiguration and operations scheduling in the cloud for the batch's unfinished goods, and theoperations rescheduling in the MES by collective judgments of the MES of order agents. Soft changes have been assessed whenever a product is completed and the rise in the selected soft change measurement exceeds a predefined threshold, which might result in centralized operations in the cloud being rescheduled for the goods that haven't yet been executed.

4.2 Architecture for cyber-physical manufacturing system implementation

A conceptual framework for CPPS based on three-tier architecture is created for the above-mentioned significance that logically divides the network's nodes into three "tiers" according to their requirement specification and communication requirements. The "edge tier" at the lower level is given, which works directly with the physical environment and carries out lower-level control functions. The "platform tier" puts functionalities into place to make the hardware operational and to gather data from every CPPS instance, resulting in high-level analytics and information about the entire system. The functionality of data analytics with high-level decision-making is implemented at the "enterprise tier." The three-tier structure suggests a certain network type for every tier that is appropriate for the specific computerized signal that is located on that tier. Each character in a CPPS consists of nodes as well as a holon with a digitized portion

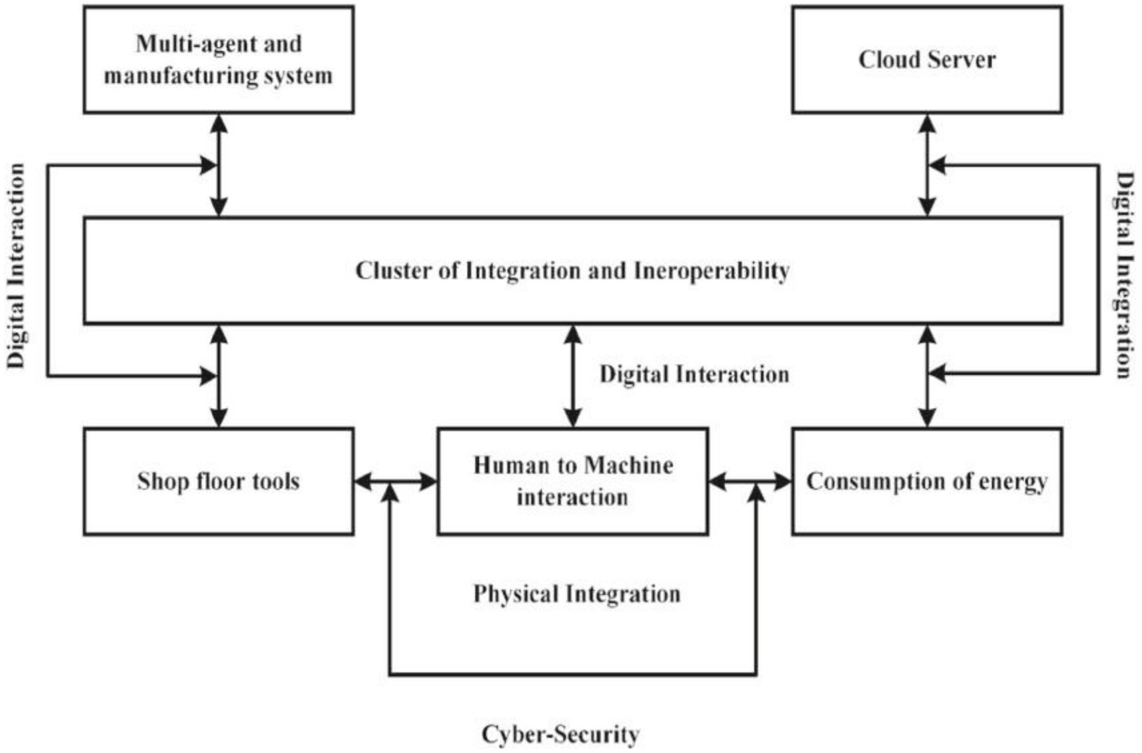


Figure 1 Structure of cyber-physical production system

for every node. Every tier is distinguished by the presence of qualitatively unique holons. Nearly every holon at the edge tier contains a physical component, or a CPPS, which makes it possible to produce physical value by implementing OT. The majorities of the holons at the lower tiers only include a digital component that uses IT to process data and gathers important information for top-level decision-making. The structure of CPPS is given in Fig. 1.

The interaction between IoT with control systems makes CPPS practical. In reality, it is given that a control system is required to decide which series of actions would lead a machine to the desired outcome, it is obvious that IoT would improve the accuracy of such selections because information about the system and its environment would be widely available. According to this theory, the traditional function of centralized control and management systems is replaced by the evolving behavior of smart agents because of the Internet of Things, which makes it possible to do away with the requirement of centralized monitoring as well as action planning processes. Additionally, IoT would connect technologies at the operations as well as field control level (edge tier) with management, business, and platform technologies (platform and enterprise tiers), using a seamless as well as homogenous communication architecture and plug-and-play capabilities. Because of this uniformity, it is feasible to join several digital systems to conduct control actions at every point along the value chain, even from a distance, while taking into consideration every component of the entire system. Every actor in the CPPS can access and exchange information due to the integration and interoperability cluster's role as an abstraction network. Since every cluster is connected to this network, all its constituent parts could access and exchange data that serves as the foundation for intelligent behavior. The design and implementation of the characteristics that every node's software layer needs to achieve intelligent behavior through interaction with its peers are addressed by the conceptual grouping of multi-agent systems as well as colonic production. A special class of holon called a human requires an interface layer to be incorporated into the network. Underneath the conceptual cluster of human-machine interaction is this layer.

The cloud presents as a unique node that can partially enclose a layer or a particular operation of another layer carried out via the internet. At every digital occurrence, a certain type of data processing is undertaken. The platform layer and enterprise tier are where big data and complex data analysis are carried out. In the meanwhile, only real-time data processing is carried out at the edge tier. The security feature is also cross-layer to all other layers. Only locally focused information gathering, and action-taking are possible for autonomous agents. Due to their worldwide connection capabilities, the IoT components of the CPPS would offer a channel of communication that enables the development of intelligence. Thus, the interaction between the control infrastructures installed into the CPPS with IoT is what makes this generation of smart production systems viable. Based on experience and research, the occurrences are first configured in the cloud; during manufacturing, they are recognized through the source agents, who interact with the sequence agents. Complex alteration might well be identified at any time as result, which is automatic source group reconfiguration with the process of rescheduling within the cloud for the batch's unfinished items; and activities reschedule within the dMES by collective judgments of ordering agents.

4.3 MES layer network

The decentralized MES network of equipment is integrated with the suggested CPPS structure for the acquisition of data and smart processing:

The dataset is processed by agents living upon smart technologies inserted on product carters over a system of IoT gateway devices. While a task is complete and then leaves the shop floor, the IoT access tool on the carrier obtains the data from the PLC overseeing product sequencing for use through the order agent of the following product that would be gradually built at the accessible carrier. The amount of IoT tools is equivalent to the number of products that are being executed simultaneously; the residing ordering agents and source agents interact when rescheduling processes for the n products that are currently being performed due to the complex alteration in the position of a single asset. Every order agent which is incorporated into a CPPS framework with WiFi connectivity works together to make this rescheduling; order agents communicate information about the ongoing job to the cloud.

The resource agents are housed on a network of aggregating nodes made up of sensors, PC-style workstations, and Arduino ETH boards (IoT gateways). The computer processes data directly from assets in real-time for the purposes described in point 1 as depicted in Fig. 2. For instance, the actual-time set is gathered then the operation is applied for acquiring the electrical output, that is consumed towards the cloud dataset and for upgrading the energy record, and for the appropriate resource agent located in the PC for determining the power consumption for an accomplished process.

The monitoring system's gathered data is examined and utilized for energy consumption forecasting as well as predictive maintenance scheduling taking into account the machine tools' accessible time windows. The immediate power is delivered straight to the cloud that used an HTTP POST request towards PHP/MySQL software that is hosted in the cloud. The sequence of data is as follows: the source holon gets a procedure execution request from an ordering agent; the holon reads the present power consumption from the Arduino board as well as issues a start procedure signal towards the source; the source implements the procedure in the last indicators the accomplishment towards the agent; the agent reads the current power consumption again then through removing the first power value. Fig. 3 shows the order of data in the CPPS agent executing on the IoT node.

The resource agent could keep an eye on characteristics related to the resource, including heat, the energy source for a drive with positioning error, CPU boards, and the effectiveness of object identification, among others. ODBC is used to write this data on cloud storage. Towards the upgrade processing of execution information and applying decisions made at hierarchical and heterarchical phases within production, both IoT device networks connect with the cloud.

5 Result and discussion

5.1 MES aggregation level

The IoT device systems have indeed been developed and put into practice for a shop floor with types of equipment, including four fully automated component construction workstations (two of which contain CNC machines for micromachining), one robotized pallet for good or service I/O workstation, and one automatized part space workplace). Devices for 2D vision are used by robots. The Omron automated robotic Adept eCobra has been used in experiments to compare several methods for gathering criteria and internal factors from resources and raw materials: a) utilizing the proprietary programming tool Adept ACE; b) using an archive provided by Adept to read factors from external programs; and c) using a set of software programs running both with the automaton and on the aggregation PC node that communicate over TCP. This final option is a component of the aggregate node and consists of a PC program that may connect to manufacturing equipment to read information and to a database on the cloud server MES to send data [18]. These techniques were used to gather the following information from robotic sources mentioned in Fig. 4.

Data collection: Data obtained from the robot includes input signal, processor board temperature, encoder, and amplifier temperature levels, joints motor torque multiplication, and positioning inaccuracies
Information retrieved from belt whose encoders are linked to the robotic platform belt speed, instance frequency, instances/minute, or faults
Process information: Methods work, including processing speed, idle time, parts per minute, and processed or unprocessed parts

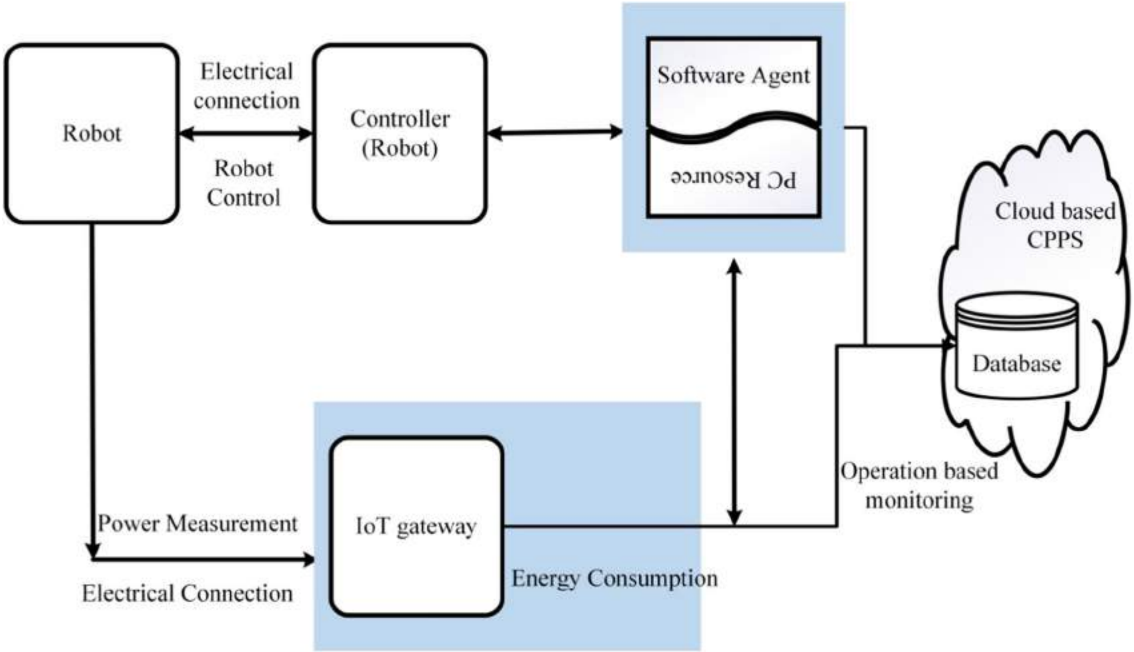


Figure 2 Integration and interoperability process on CPPS

Data on the tracked parameters, including the status of digitized outputs and input robot variables (such as speed), and program state. These variables represent the Cartesian locations and joints

Furthermore, data from the robot environmental sensor is gathered utilizing Arduino IoT gateways and delivered to the PC-based aggregation node for aggregation. The aggregation program, which is responsible for coordinating and adding entries to the databases, receives all the data collected from the robot through into the earlier sources (ACE implementation and TCP/IP interface) as plaintext. Production variable data is collected and sent to a private IBM CloudBurst cloud platform for archiving. Investigations utilizing various information-gathering techniques employing low- and high-level communication protocols make up the validation situation. The primary communication interfaces include publicly release communication technologies on top of the TCP/IP stack like MQTT, network access techniques like UDP and TCP, application-level algorithms like HTTP requests, and so on. Using data received from a database server (time.nist.gov) and 100 messages each having a single timestamp, a situation consisting of 100 communications was run to assess the database updating rate, communications delay, and information leakage [5]. The following Table 1 shows the comparative analysis of IoT gateway devices using cloud communication protocols.

Two IoT device systems were used to effectively evaluate the edge computing solution for information collecting, intelligence technology, and aggregation from shop floor assets and items with smart technology. The aggregation node, which gathers data from various sources and adds entries to a database on cloud infrastructure, is the main component of the system. The MQTT protocol is the greatest option for transmitting data from embedding devices to the cloud, according to the results of the studies that were conducted. This is a result of its publish/subscribe capabilities, which enable the development of networks capable of many-to-many communication [19].

5.2 Evaluation of energy consumption

In this segment, researchers present an experiential assessment of the MES product's data collection procedure, which collects data from embedded systems on manufacturing employment (machinery, robotics), and transfers it to the cloud for centralized activities. Measuring energy utilization is part of the prototype process utilized to verify the technology. Two cases are examined for this intent: first, the connection among embedded devices monitoring instantaneous power and the cloud-based MES databases; second, the real-time component of data gathered from assets [20]. The "Instantaneous power chart," which tracks the power requirements used by each component, is linked to the first situation. The effectiveness of the network connection among the embedded systems dispersed around the shop floor and the cloud is key in this situation. To get a thorough energy usage graph, a high-frequency updating rate and reduced latency are required. The second scenario is linked to the "Operational processes on Resources List," which tracks

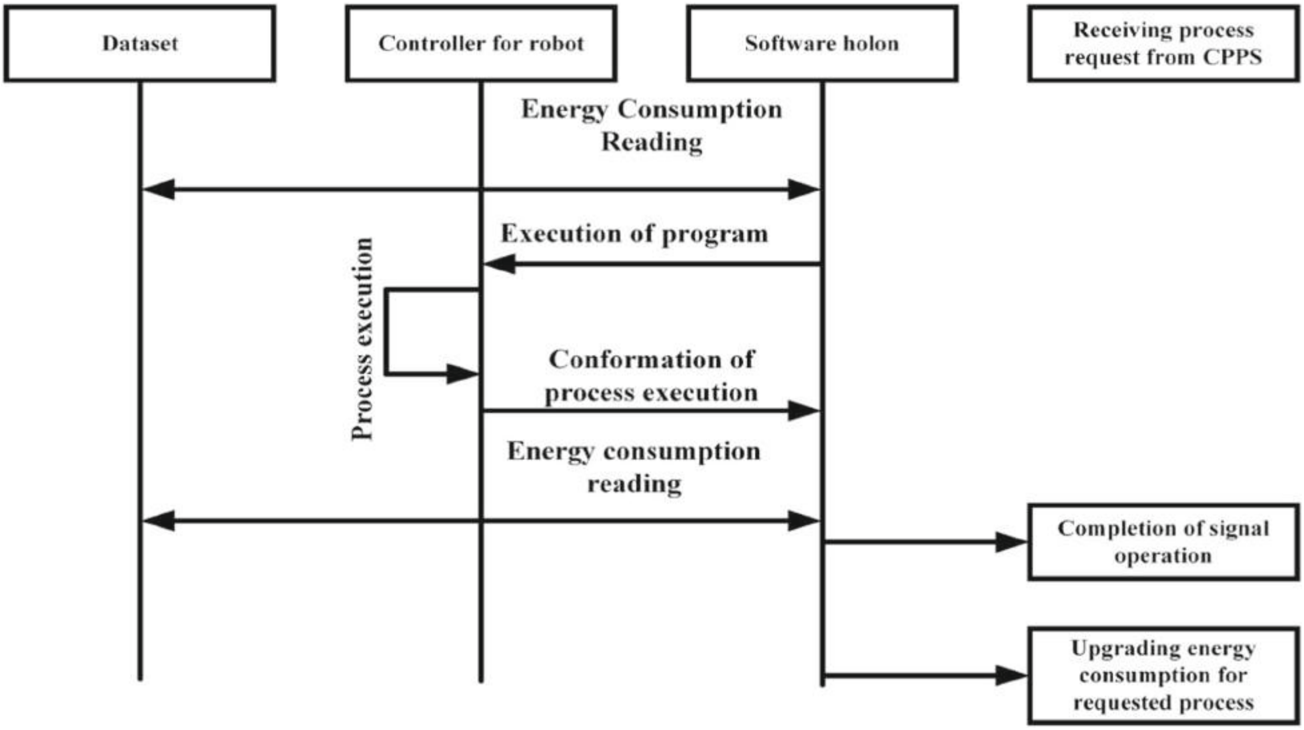


Figure 3 Order of data in CPPS agent executing on IoT node

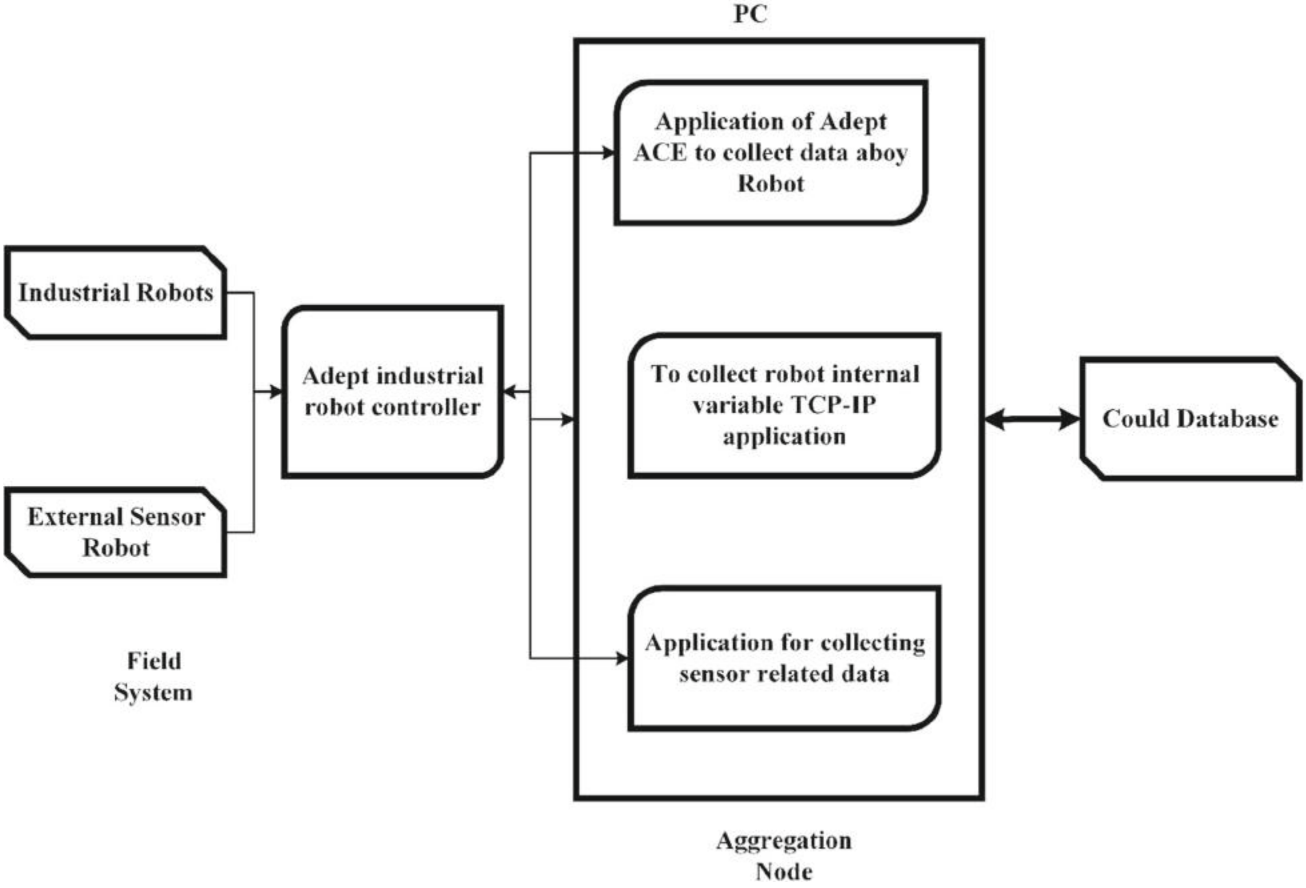


Figure 4 dMES level

Table 1 Comparative analysis

Type	Transmitted text	Recipient text	Average delay	Average rate (msg/S)	Observation
User datagram protocol	100	100	0.69	19	Edge to edge
Transmission control protocol	100	100	0.66	14	Edge to edge
Hypertext transfer protocol	100	100	1.3	9	Edge to edge
Message queuing telemetry transport	100	100	0.55	19	Many to many

energy use for each commodity at the operational level. The way the embedded devices store and time-integrate independent power measurements is crucial in this situation. The following information has been recorded as a result of research using a standard picking and placing automated robotic operation to evaluate the proposed situations:

5.2.1 Latency

The measurement of latency lag among a signal's transmitting from an embedded system and its updating in a cloud-based database. To execute this research, a cloud-based server and an embedded device were both employed, and the time and date of messages transmission and receiving were examined. The embedded operating loop time, transmission delay, and computerized information upgrade delay all contribute to the instantaneous power's aggregate report regularly of 1.24 s. On a private cloud connected to the production shop floor within the same network, communications tests have been performed. The operational databases in the cloud can be updated in real-time using this data [20].

5.2.2 Signal reproduction

Using an industrial robot can perform pick-and-place tasks, the observed instantaneous energy was transmitted to the cloud and saved in the "Instantaneous power table." The initial signal from the distribution transformer was observed using an extra oscilloscope. Information from the two main sources is contrasted by employing the same timer in two of the visuals shown in Fig. 5 [21].

The same pick-and-place action from the second scenario was carried out, however, this time the power was monitored and incorporated utilizing the embedded system, and then the instantaneous energy was transferred to the cloud. Signal integration on the embedded system connected with the resources. This information is crucial to the forecasting and scheduling paradigm and goes into the operational processes on resource tables. The primary loop of the embedded system has four phases: the instantaneous power quantitative determination and absorbed power upgrade (this is the most time-consuming part because it uses sample data to calculate instantaneous power), the time information, the PHP script request for dataset update with the instantaneous value, and the TCP server connectedness required to accurately from outside investigate the total consumption of power (this is utilized by the resource agent to precisely track the energy used by a certain operation) [22].

The loop takes 370 milliseconds to complete on average, with 260 of those milliseconds being used to calculate the instantaneous power. The embedded system detected 1137Ws as the amount of energy used to complete the pick-and-place activity (robot motion is capped at 50% maximum velocity). Figure 6 displays the measurement outcome. In conjunction with the object relocation tests, energy consumption assessments were started and completed. The data was collected every second, the accumulated results were shown, and the Wh unit of consumption was utilized (Watt-hour). The outcome is also the average across all investigations, with a 96% standard error. Figure 7 compares energy consumption before and following the repair. The overall energy consumed before the conversion was 2.21 Wh, and afterward, it was 1.65 Wh, a 25% reduction in usage brought about by the replacement of the robot controller [23].

It is essential to note that the CPPS Retrofitting is designed to introduce the same perks into manufacturing machinery of different types and designs than that introduced in the prototype, in addition to enhancements in assets, interaction in time real, and the energetic obtain of the technology demonstrator after the realization of the CPPS Retrofitting.

The main advantages of the proposed platform and its application are:

1. Increased awareness of both machine and shop-floor level conditions.
2. Effective and accurate maintenance of machine tools.
3. Accurate decisions through condition-based maintenance and adaptive scheduling.
4. Increased interoperability and communication among the different systems in the company.
5. Increased automation will support companies to shift towards Industry 4.0 environment.

Figure 5 Comparison of signal reproduction

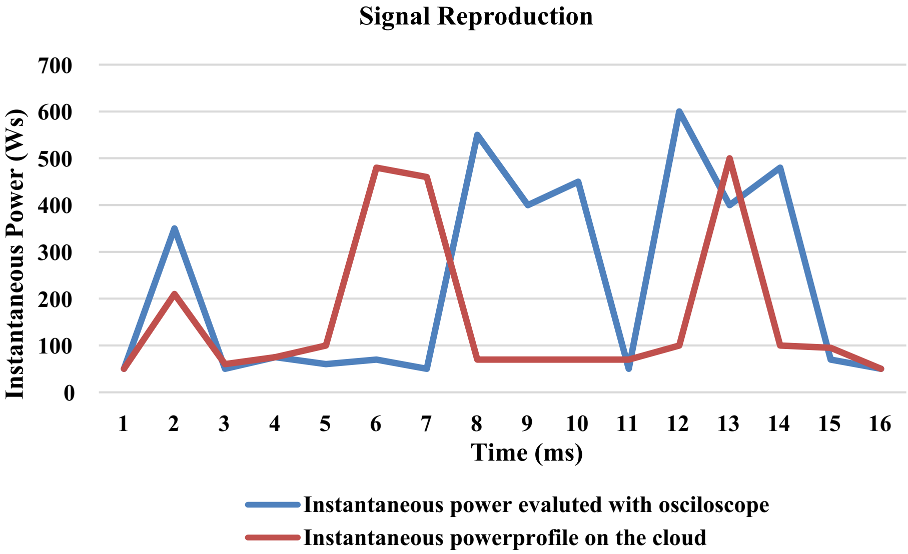


Figure 6 Comparison of signal on cloud

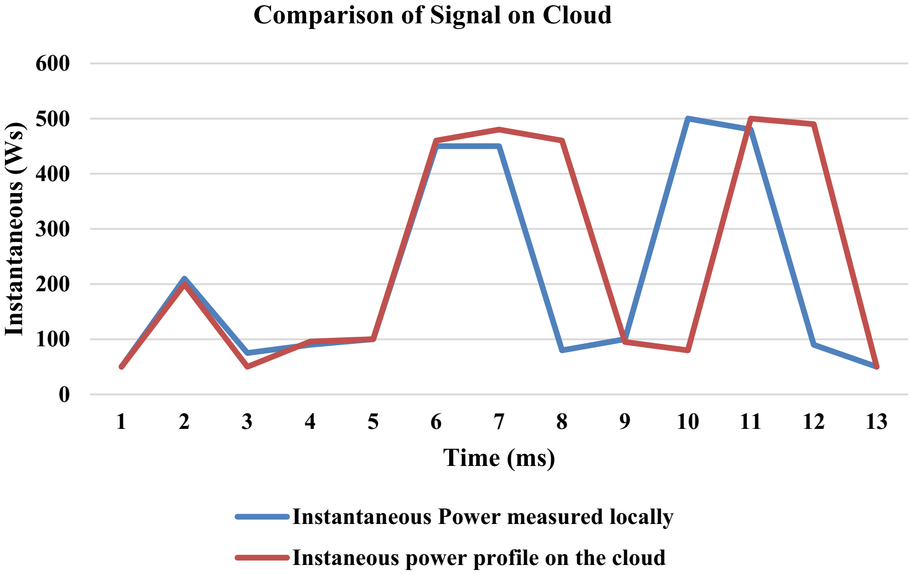
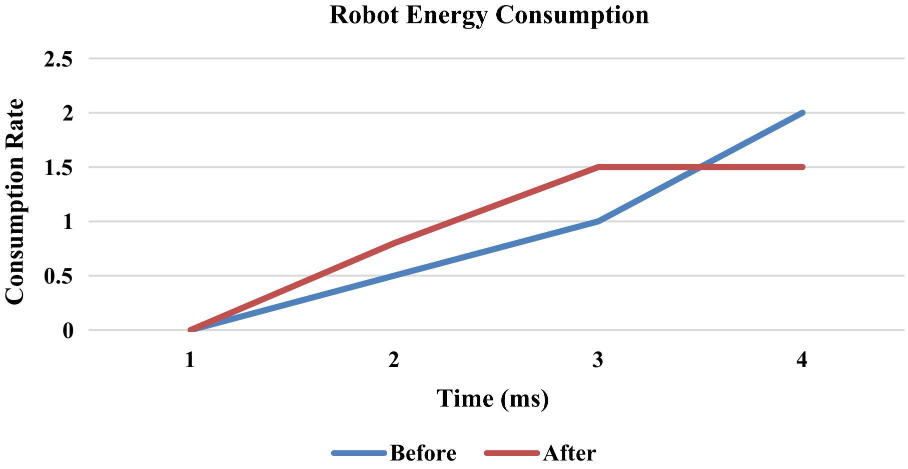


Figure 7 Robot energy consumption



6 Conclusion

IoT and CC are getting a lot of attention right now as they provide a new method for smart sensing and connectivity from man to man, man to machine, and machine to machine, as well as on-demand utilization and efficient sharing of resources, alternatively. Cloud computing is necessary for the Industrial IoT to serve as the backbone for data gathering from shop floor equipment; decentralized computing would shift towards the edge due to the requirements for real-time processing of huge data. Several IoT device systems were used to effectively evaluate the cloud-computing solution for information collecting, intelligent processing, and aggregation from shop floor supplies and items with smart sensors. The aggregation nodes, which gather information from various sources as well as add entries to a database on a private cloud, are the main component of the system. The protocol is the greatest option for transmitting data from smart devices to the cloud, according to the results of the studies that were conducted. This results from the following qualities: It is a publish/subscribe approach that enables the creation of infrastructures capable of many-to-many communication. The entities are made up of industrial assets that include ongoing work on products into Cyber-Physical Production Systems (CPPS), which collaborate intelligently in such systems to optimize and sustain the manufacturing process, handle interruptions, and adapt to changing conditions. The CPPS design integrates such secured cloud service along a system of IoT nodes made up of IoT accesses, devices, as well as PC-style terminals holding the source holons. Therefore, the results of the study not only serve as a foundation for the scientific advancement of CPPS but also provide practitioners with an insight into the enablers that must be taken into account when implementing CPPS in future smart manufacturing industries.

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