Development of cloud visualization a machining manufacturing system shop floor

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ABSTRACT

The industry is currently experiencing the fourth industrial revolution, characterized by the automation of cyber physical systems and advanced connectivity through the internet of things (IoT). This revolution enables real-time monitoring of machines status on the shop floor by leveraging cyber-physical and IoT technologies. This paper describes the results of research that develops IoT and cloud-based visualization for a machining manufacturing system shop floor. Our proposed solution involves an internet of things device equipped with two current sensors to detect machine and spindle current. The sensor connected to an Arduino Nano, which is then connected to Wemos D1 for wireless transmission of data to the cloud. The cloud has been developed to store data and provide visualization applications, in the form of machines layout map to monitor machines conditions in the form of machines ON, machines OFF, spindles ON and spindles OFF in real time.

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1. INTRODUCTION

Industry is currently undergoing the fourth industrial revolution, which has been propelled by the advancements in information and communication technology (ICT). This revolution is characterized by the automation of cyber physical systems (CPS), featuring decentralized control and enhanced connectivity through the internet of things (IoT). As a result of this technological evolution, traditional hierarchical automation systems in industrial production have been transformed into self-regulating cyber physical production systems. These systems enable the realization of flexible mass individual production and offer increased flexibility in production quantities [1], [2]. This transformative era is commonly referred to as industry 4.0.

The emergence of Industry 4.0 presents significant challenges for the industrial sector, as it requires adaptation to evolving market and consumer demands. A key aspect of Industry 4.0 is the growing importance of flexible and decentralized production, as well as the acquisition of advanced technologies [3]. This industrial paradigm is built upon the integration of business and manufacturing processes, as well as integration along the company's supply chain. To realize the vision of Industry 4.0, technical advancements such as CPS, IoT, and internet of service (IoS) are applied to industrial production lines [4], [5].

In Industry 4.0 factories, the machines employed are CPS, which integrate physical systems with ICT components. These CPS are autonomous systems capable of making independent decisions based on machine learning algorithms, real-time data capture, analytical insights, and records of successful past behavior. Programmable machines such as computer numerical control (CNC) and numerical control (NC) are extensively utilized in Industry 4.0 factories, with a significant portion of mobile agents and robots being self-regulating and optimization-oriented [6]. In the context of Industry 4.0, production elements go beyond their physical representation and also possess virtual identities. These virtual identities exist as data objects stored in the cloud. They encompass a wide range of information, including product-related data (ranging from documents to 3D models), individual identifiers, current status data, historical records, and measurement/testing data [7], [8].

Data collection, data processing and machining data storage of a manufacturing shop floor have been done using the MTConnect communication protocol [9]–[11] and open platform communications unified architecture (OPC UA) communication protocol [12], [13]. The MTConnect and OPC UA communication protocols connect CNC machine controllers and other software modules to process data from a specific CNC machine. The use of these communication protocols requires an adapter in the form of software or hardware that must match the type and version of the machine. Simple attempt to collect machine data on the shop floor have also been carried out by installing a current sensor on the machine [14]–[16]. By using one current sensor, for a CNC machine the ON and OFF machine and spindle conditions in real-time cannot be ascertained, because the current values change when the machine table moves or other machine activities occur. In addition, these studies are limited to data collection, data processing, and data storage, and do not display real-time machine status in graphical form. Considering these advancements, a small and medium-sized industrial company located in Cimahi, which specializes in the production of molds, dies, and precision components, has been utilizing the internet to collect and process data for its manufacturing enterprise resource planning system (ERP). The company wants to develop a system that can collect data from the shop floor, manual machines and CNC machines online. This online data collection system is expected to be able to support the ERP system and be able to display the status of machines on the shop floor in real-time. This paper describes the results of research that develops IoT devices and cloud shop floor visualization of machining manufacturing systems using machine layout plans. Through the website application (web app), users can view the status of each machine in real time.

2. LITERATURE REVIEW

There are four key components of Industry 4.0 technology: smart factories, CPS, IoT, and the IoS [17], [18]. The Industry 4.0 technology framework is built upon these four elements. Firstly, the IoT involves the integration of sensors and computing within the internet environment through wireless communication. Secondly, cloud services provide users with access to applications and information technology resources via the internet, eliminating the need for hardware. Thirdly, big data encompasses the collection of data from various systems and objects, such as sensor readings. Lastly, analytics, including data mining and machine learning, plays a crucial role in Industry 4.0 as it enables the generation of valuable information. By utilizing big data, a factory can create a data representation, while analytics allows for advanced predictions and the identification of events that may impact production [19]–[21]. The integration of big data and analytics offers substantial benefits in terms of production line management and decision-making processes across various business domains. By harnessing the power of big data and analytics, Industry 4.0 can optimize operations and enhance efficiency. IoT addresses communication challenges by facilitating seamless connectivity among objects and systems within a factory. Additionally, cloud services provide convenient access to information and services. The utilization of big data and analytics plays a crucial role in driving the advanced applications of Industry 4.0, as it relies on the accumulation of large volumes of big data and the application of sophisticated analytical techniques to enable system intelligence [22], [23].

The manufacturing system data life cycle encompasses three main components: IoT, communication network: big data, and information transmission: analytics [24]. The data life cycle involves several key activities: data sources, data collection, data processing, data storage, and applications. Data is sourced from various elements such as equipment, products, operators, information systems, and networks. Smart devices capable of communication are utilized to collect, transmit, and act upon the data. Different methods are employed to collect data from diverse sources, including historical data, real-time data, and web data. Historical data represents the storage of data over time, providing insights into the development or trends of specific events. Real-time data is generated by processing systems designed to handle dynamically changing workloads in real-time. Web data comprises a repository that stores substantial amounts of raw data in its original format, encompassing structured, semi-structured, and unstructured data. Data processing involves a series of operations performed to extract knowledge from the extensive data sets. The transformation of data into information and knowledge is essential for manufacturers to make informed and rational decisions [25], [26].

Data collection, processing and data storage on a machine on the shop floor have been carried out in previous studies: i) mnitoring CNC machines on the shop floor using the MTConnect communication protocol [9]–[11] and ii) monitoring CNC machines on the shop floor using the OPC UA communication protocol [12], [13]. A simple attempt to collect data online on small and medium manufacturing machining systems has been done by previous researchers using a current sensor [15]. The sensor is used to detect ON/OFF machine and ON/OFF spindles of manual machines [16]. Reading data from conventional machines on the production floor is stored in a database [14].

Geographical information system (GIS) is an information system specifically for managing data that has spatial information or spatial references. The development of IoT opens opportunities to integrate a device that can be monitored in real-time on the digital layer of a map or layout plan of a location [27]. Integration between IoT and GIS has been done in previous studies : i) smart water network monitoring [28] and ii) web-based management of public buildings [29]. Looking at previous research and this research, Table 1 shows a comparison of previous research and this research.

Table 1. State of the art

No	Title	author	Machine monitoring				Visualization on GIS in realtime
			CNC	Manual	Spindle status	Machine status	
1	Streaming machine generated data to enable a third-party ecosystem of digital manufacturing apps	Singh *et al.* [9]	✓	×	✓	✓	×
2	MTConnect-based cyber-physical machine tool: a case study	Liu *et al.* [11]	✓	×	✓	✓	×
3	MTConnect-based decision support system for local machine tool monitoring	Navas *et al.* [10]	✓	×	✓	✓	×
4	Developing an OPC UA server for CNC machines	Martins *et al.* [12]	✓	×	✓	✓	×
5	CNC machines integration in smart factories using OPCUA	Martins *et al.* [13]	✓	×	✓	✓	×
6	Development of a cost-effective cyber-physical production system for the make-to-order industry	Ma'ruf *et al.* [14]	?	✓	✓	✓	×
7	Real-time monitoring design for make-to-order industry	Adisasmito *et al.* [15]	×	✓	✓	✓	×
8	Development of internet of things cloud shop floor machining manufacturing system	Setiawan *et al.* [16]	×	✓	✓	✓	×
9	This research	Sulistyo *et al.*	✓	✓	✓	✓	✓

3. METHOD

The visualization model for the machining shop floor has been created, where data is gathered through IoT devices and transmitted to the cloud. The cloud infrastructure encompasses various components: data sources in the form of machines, data collection facilitated by specifically designed IoT devices, data processing, data storage, and applications within the internet domain of the cloud. In this context, the developed application focuses on visualizing the real-time status of machines operating on the shop floor. The stages in this research as a whole can be seen in Figure 1.

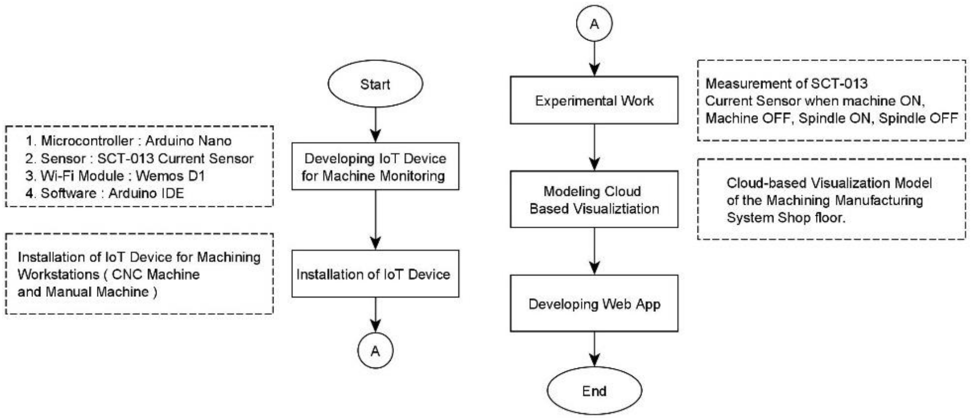


Figure 1. Flowchart of the research stage

3.1. IoT device for machining workstations

Basically, an IoT device consists of sensors/actuators, microcontrollers, and internet modules. An IoT device typically comprises three main components: sensors/actuators, microcontrollers, and internet modules such as wireless fidelity (WiFi) modules. In this study, the IoT device developed utilizes the following components: a current sensor for detecting machine activity, an Arduino Nano for data organization and processing, a Wemos D1 for internet connectivity, and a liquid crystal display (LCD) for displaying information. The sensors are responsible for detecting the activity of the manufacturing machines, while the Arduino Nano serves as the central processing unit for the IoT device. The Wemos D1 is connected to the internet through an access point/router, enabling data transmission to the cloud. The Arduino Nano processes the data and sends it to a cloud-based database, where it is stored. The LCD component provides visual feedback on the activities of the IoT device. The software used to program the Arduino Nano and Wemos D1 is the Arduino integrated development environment (IDE), while the programming languages used are C and C++. Figure 2 illustrates the components utilized in the IoT device for the machining workstation.

Figure 2. Components of IoT device for machining workstations

A schematic diagram of the developed IoT devices for machining workstations can be seen in Figure 3. The LCD is connected to the Wemos D1, while the spindle sensor and machine activity sensor are connected to the Arduino Nano. The 12 V input is used to supply the Arduino Nano and Wemos D1 connected to Vin. The description of the pins used in the devices is also shown in Table 2.

The developed machining workstation IoT device can be installed on manual machines or CNC machines. Installation of IoT devices is placed on the control panel of CNC machines and manual machines. The components installed in IoT devices on CNC and manual machines are current sensors installed on the spindle cable and power cable. Figure 4 illustrates the installation of a current sensor on a CNC machine, while Figure 5 depicts the installation of a current sensor on a manual machine.

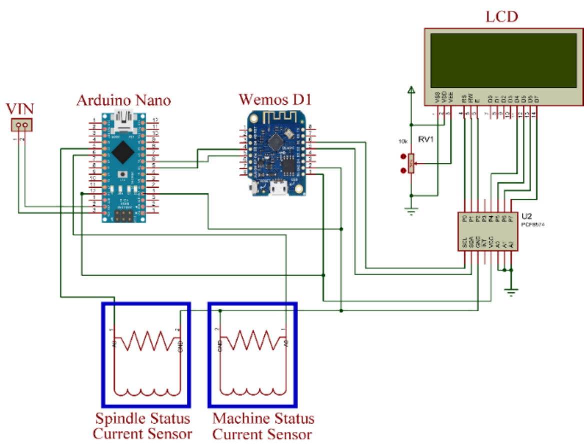


Figure 3. The scheme of IoT device for machining workstations

Table 2. Arduino Nano and Wemos D1 pin connection

No	LCD	Wemos D1
1	SDA	D2
2	SCL	D1
3	VCC	3,3V
4	GND	GND
No	Machine status sensor SCT 013	Arduino Nano
1	L	GND
2	K	A1
No	Spindle status sensor SCT 013	Arduino Nano
1	L	GND
2	K	A2
No	DC Input	Arduino Nano
1	12 V	Vin
2	GND	GND
No	Nano	Wemos
1	D6 (RX)	D5 (RX)
2	D5 (TX)	D6 (TX)

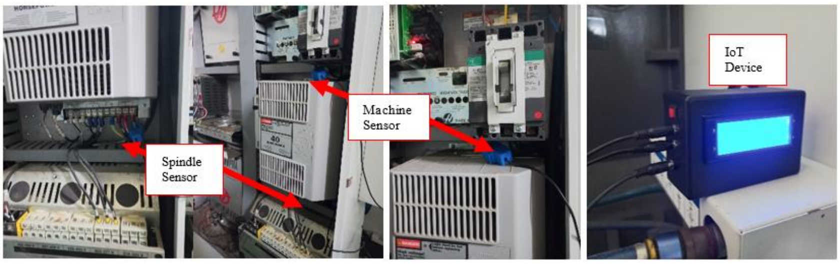


Figure 4. Installation of current sensor on CNC machine

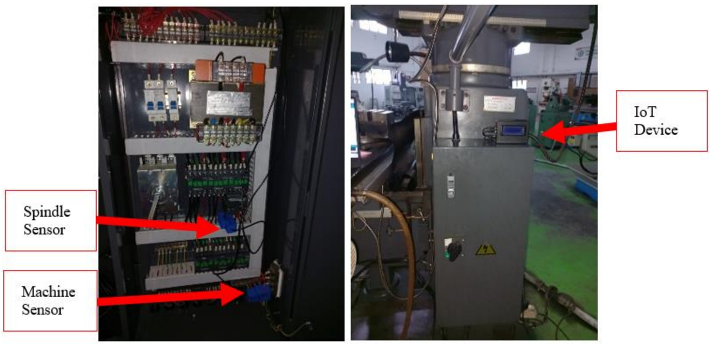


Figure 5. Installation of current sensor on manual machine

3.2. Experimental work

To determine the status of the machine (ON/OFF), a current sensor is attached to one of the phase cables of the machine ON/OFF switch of a manual machine or a CNC machine. To determine the status of the spindle (ON/OFF), a current sensor is attached to one of the phase cables of the spindle controller of the machine. By reading the current value through the sensor, the condition of the machine and spindle can be identified. It is essential to ensure that the device accurately determines the condition or status of the monitored machine. Sensor calibration plays a vital role in achieving this accuracy, as it aligns the sensor readings with the desired indicators. Sensor calibration is performed by comparing the current values obtained from the IoT sensor, as displayed on the Arduino serial monitor, with the measurements taken using the Metraclip Gossen 66 Metrawatt measuring instrument. The error values are calculated using (1) and (2).

$$Error = Sensor\ Reading\ Value - Measuring\ Instrument\ Value \quad (1)$$

$$Error = \frac{Sensor\ Value - Measuring\ Instrument\ Value}{Measuring\ Instrument\ Value}\ x\ 100\ \% \quad (2)$$

The sensor readings for the spindle can be seen in Table 3, while the sensor readings for the machine can be seen in Table 4. The machine and spindle sensor readings presented in Tables 3 and 4 allow for the determination of the machine status, including machine ON, machine OFF, spindle ON, and spindle OFF, based on the recorded sensor values. The flowchart in Figure 6 illustrates the process of converting the current measurements into machine status. The pseudocode for programming the conversion of the current read by the SCT-013 sensor into machine status on the Arduino Nano can be seen in Algorithm 1.

Table 3. Spindle sensor readings

No	Status	Spindle sensor	Metraclip Gossen	Error
1	Spindle ON	4.33 A	4.05 A	6.46%
2	Spindle OFF	0.00 A	0.00 A	0%

Table 4. Machine sensor readings

No	Status	Machine sensor	Metraclip Gossen	Error
1	Machine ON	0.56 A	0.49 A	14.28%
2	Machine OFF	0.00 A	0.00 A	0%

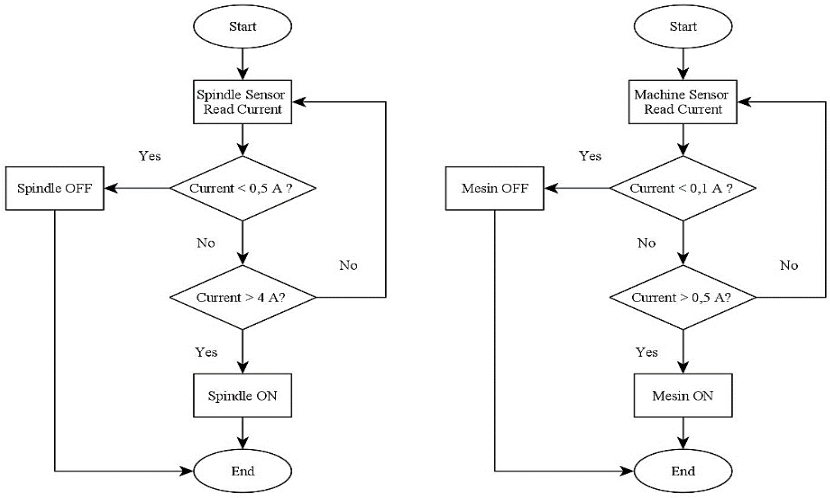


Figure 6. The flowchart of current to machine status conversion

Algoritm 1. Pseudocode conversion of current to machine status is as follows

```
Procedure status_machine()
BEGIN
call Procedure machine_current_sensor_reading();
if(machine_current<0,1)
THEN st_machine=machine_OFF;status=0
ENDIF
END
ELSE if (machine_current>0,5)
THEN st_machine=machine_ON;status=1
ENDIF
END

Procedure status_spindle()
BEGIN
call Procedure spindle_current_sensor_reading();
IF(spindle_current<0,5)
IF(spindle_current<0,5)
Then st_spindle=spindle_OFF;status=2;
ENDIF
ELSE if (spindle_current>4)
THEN st_spindle=spindle_ON;status=3;
ENDIF
END
```

3.2. Cloud-based visualization model of the machining manufacturing system shop floor

The cloud system functions as a server within the internet domain, enabling data storage and processing. Users can connect to the internet and access applications that store, process, and display information. The cloud model of the shop floor visualization of the machining manufacturing system is shown in Figure 7.

The data collected by the IoT device at the machining workstation is transmitted and stored in a database. Figure 8 illustrates the schematic of the cloud-based shop floor mechanism for the machining manufacturing system. The obtained data is uploaded to the shop-act.pilm.ac.id domain using the hypertext transfer protocol (HTTP) protocol through a network that utilizes a router or access point. Subsequently, a hypertext preprocessor (PHP) script called post-mc_st_stat.php manages the data, ensuring its storage in the MySQL database. Codeigniter is used to generate visualizations such as photo or machines layout map. To better understand the http posting of IoT machining stations (Arduino Nano and Wemos D1) to the database, it can be seen in Algorithm 2.

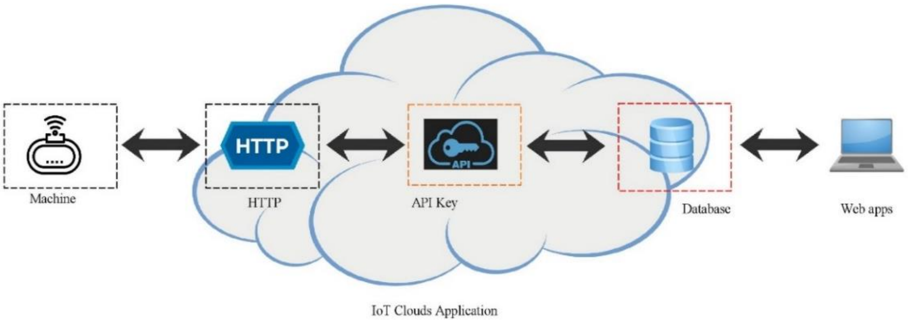


Figure 7. Cloud-based visualization model of the machining manufacturing system shop floor

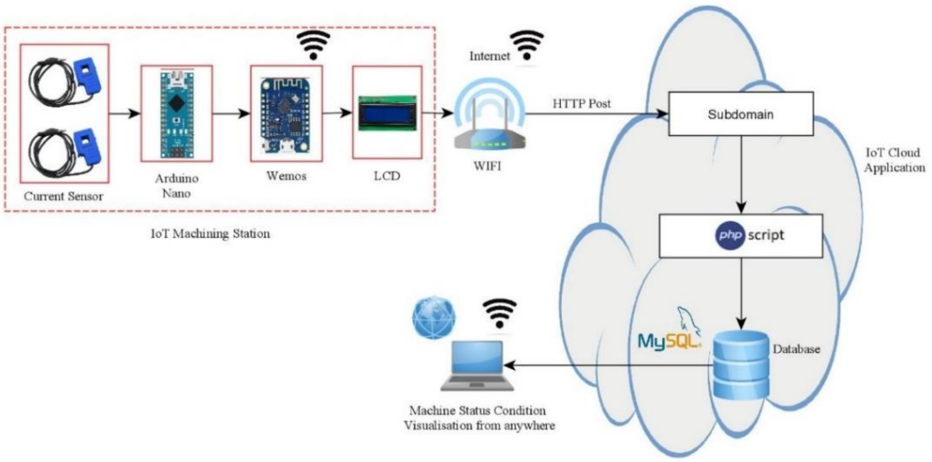


Figure 8. Schema of data acquisition, storage, and processing for visualization of machining manufacturing system shop floor

Algoritm 2. Pseudocode http posting

```
Http posting has two algorithms, each of which is handled by Arduino Nano and Wemos D1.
```

Algorithm 2.1 is an algorithm contained in the Arduino Nano which handles reading data from the SCT-013 sensor according to algorithm 1. If the machine status is successfully read by the Arduino Nano, then the Arduino Nano will send serial data to Wemos D1. Algorithm 2.2 is an algorithm found in Wemos D1. After Wemos D1 receives serial data from Arduino Nano, Wemos D1 will make an HTTP post to the database.

Algoritm 2.1. Pseudocode Arduino Nano

```
Intilize Machine_ID;
Intilize Serial_Communication pin RX,TX;
Intilize Sensor_Current pin Analog Input;
```

```
BEGIN
Call Procedure status_spindle();
Call Procedure status_machine();
IF (st_machine change)
THEN Serial.print((‘*’+Machine_ID+','+st_machine+’,’+status+’#’);
END IF
IF (st_spindle change)
THEN Serial.print((‘*’+Machine_ID+','+st_spindle+’,’+status+’#’);
END IF
```

Algoritm 2.2. Pseucode Wemos D1

```
Initilize ESP8266 HTTP Client;
Initilize ESP8266 Wifi;
Initilze NTP Client date/time;
Intilize Serial_Communication pin RX,TX;
BEGIN
Connecting to Wifi;
IF(Serial Available from Arduino Nano)
THEN parsing data(Machine_ID,st_spindle/st_machine,status);
httpRequestData(api_key+date+time+Machine_ID+st_spindle/st_machine+total_duration+status);
http.POST(httpRequestData);
ENDIF
END
```

3.3. Web app development

The shop floor of the manufacturing system is visualized through a web app developed using the codeigniter framework. The web app utilizes machines layout map or photographs to represent the shop floor, with the display implemented using leaflet.css. The main objective of this web app is to monitor the real-time activities of the machines by IoT. The flowchart algorithm for the web app as shown in Figure 9.

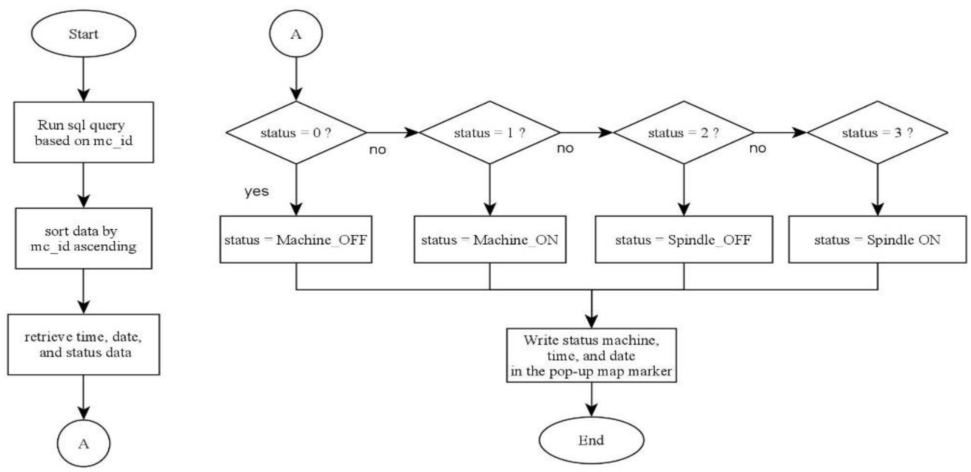


Figure 9. Flowchart of the web app algorithm

4. RESULTS AND DISCUSSION

The process of posting data to the database is handled by the Wemos D1. Once the Arduino Nano processes the machine status based on the sensor readings, it sends the machine status data to the Wemos D1 through serial communication. The data sent from the Arduino Nano to the Wemos D1 includes the machine name, machine status, and machine status code. Upon receiving the data from the Arduino Nano, the Wemos D1 completes the information by adding an application programming interface (API) key, date, time, machine name, machine status, total duration, and machine status code. Figure 10 illustrates the HTTP request data packet sent to the cloud. The HTTP response code indicates whether the data has been successfully handled.

The Wemos D1 utilizes the http extension and an API key as a verifier to access PHP files in the cloud. One of these PHP files, post-mc_st_stat.php, is responsible for handling the POST request to store the data in the database. To ensure successful data posting to the database, the link http://shop-act.pilm.ac.id/IoT/post-mc_st_stat.php can be accessed. Figure 11 depicts the various statuses of data transmission, including successful data transmission to the database, failed data transmission to the database, an idle condition indicating no data has been sent, and an incorrect API key condition. If a new record is created successfully, the data have been successfully sent to the database. The structure of the database can be seen in Figure 12.

The machine activities are the machine status conditions such as machine OFF, machine ON, spindle OFF, spindle ON, date and time represented through pop-up map markers. The date and time displayed on the pop-up markers show the date and time of the latest updated data on the condition of the machine. Updated data on the web app is synchronized in real-time with the database. The developed web app is accessible via http://shop-act.pilm.ac.id/ and as shown in Figure 13.

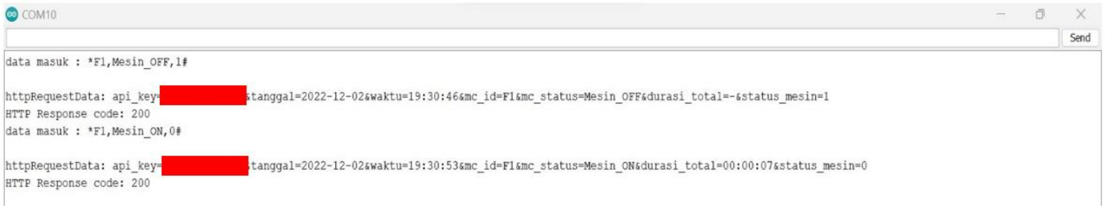


Figure 10. Data package sent to the cloud

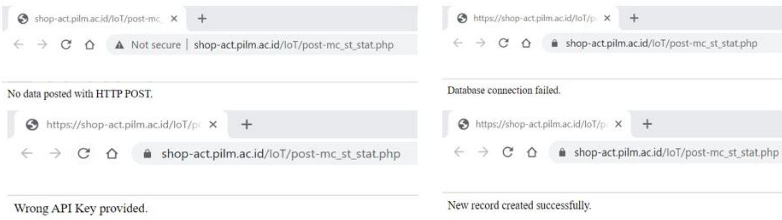
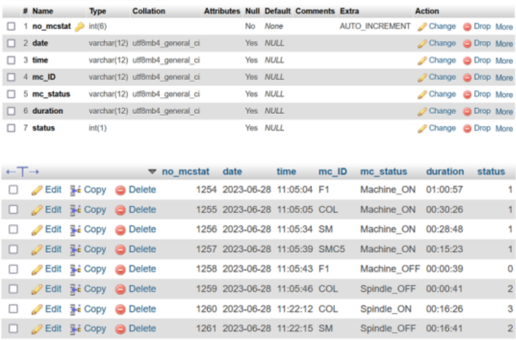


Figure 11. Data transmission status to the database



#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
1	no_mcstat	int(6)			No	None		AUTO_INCREMENT	Change Drop More
2	date	varchar(12)	utf8mb4_general_ci		Yes	NULL			Change Drop More
3	time	varchar(12)	utf8mb4_general_ci		Yes	NULL			Change Drop More
4	mc_ID	varchar(12)	utf8mb4_general_ci		Yes	NULL			Change Drop More
5	mc_status	varchar(12)	utf8mb4_general_ci		Yes	NULL			Change Drop More
6	duration	varchar(12)	utf8mb4_general_ci		Yes	NULL			Change Drop More
7	status	int(1)			Yes	NULL			Change Drop More

←T→	no_mcstat	date	time	mc_ID	mc_status	duration	status
Edit Copy Delete	1254	2023-06-28	11:05:04	F1	Machine_ON	01:00:57	1
Edit Copy Delete	1255	2023-06-28	11:05:05	COL	Machine_ON	00:30:26	1
Edit Copy Delete	1256	2023-06-28	11:05:34	SM	Machine_ON	00:28:48	1
Edit Copy Delete	1257	2023-06-28	11:05:39	SMC5	Machine_ON	00:15:23	1
Edit Copy Delete	1258	2023-06-28	11:05:43	F1	Machine_OFF	00:00:39	0
Edit Copy Delete	1259	2023-06-28	11:05:46	COL	Spindle_OFF	00:00:41	2
Edit Copy Delete	1260	2023-06-28	11:22:12	COL	Spindle_ON	00:16:26	3
Edit Copy Delete	1261	2023-06-28	11:22:15	SM	Spindle_OFF	00:16:41	2

Figure 12. Database structure

Figure 13. Web app machine activities on the shop floor

5. CONCLUSION

This paper focuses on the development of an IoT and cloud-based shop floor visualization of a machining manufacturing system. The IoT device is developed using Arduino Nano and Wemos D1. It monitors the machine conditions, such as machine ON, machine OFF, spindle ON, and spindle OFF, by detecting changes in the current of the machines and spindles. The data traffic generated by the IoT device is managed by PHP scripts located in the cloud. A web app is also developed to visualize the layout of the machines on the shop floor. By accessing the web app, users can view the real-time condition of each machine, including the time, date, and machine status.

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