The Development of Utilization Rate and Energy Consumption Monitoring and Networking System for Old Machine

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Abstract

In this paper, we present a system based on a microcontroller unit (MCU) for measuring the utilization rate of traditional, non-networked machinery. This equipment is designed for use with older machines equipped with andon lights. It employs optocoupler circuits to capture the status of these lights and current transformers to measure their operating and standby currents. Data is transmitted to the server using the Hypertext Transfer Protocol (HTTP) in JavaScript Object Notation (JSON) format. On the server side, a Hypertext Preprocessor (PHP) interprets the data, connects to a Structured Query Language (SQL) database, and stores the data using SQL commands. Users can access graphical data through a web-based interface, using it to refine production processes, reduce production costs, and minimize carbon emissions.

Keywords: Utilization, Non-networked machinery, Andon lights, Current transformers.

1. Introduction

With the widespread adoption of Industry 4.0 concepts and the concurrent advancement of relevant technologies such as networking and microchips, the Internet of Things (IoT) has emerged as a globally esteemed paradigm. The internet of machines refers to the ability of machines and devices to interact with the internet without human intervention. Information from devices, including operational progress, work duration, production history, and more, is transmitted via the Internet to servers for recording and analysis. The data facilitates analyses such as production process and utilization rate, allowing enterprises to adjust production processes based on this data. However, these actions are typically limited to new generations of IoT-enabled devices, as traditional machinery lacks such capabilities.

On the other hand, environmental protection has become a topic of global concern in recent years. Nations worldwide recognize the severity of greenhouse gas emissions and the importance of reducing carbon footprints. Governments have initiated carbon fees and tax policies, with the European Union passing a Carbon Border Tax set to take effect in 2026 [1]. This policy targets high carbon-emitting industries, imposing restrictions and charges. For enterprises, maintaining or reducing carbon emissions has become a matter of heightened concern. The determination of product carbon footprints and the subsequent implementation of carbon reduction labels are tasks to be addressed in the future.

This paper aims to assist factories in recording changes in andon light signals and corresponding time-related variations in electrical currents without intrusively altering traditional machinery's existing hardware and software. This is achieved by incorporating IoT devices to facilitate the documentation of machine operating states, thereby reducing downtime and enhancing overall operational efficiency. In addition, it also provides relevant information on the product's carbon footprint, aligning with the demands of Industry 4.0 and the implementation of carbon taxes.

2. Related Work

2.1. *Utilization*

The production or manufacturing process involves transforming raw materials or components into finished products. In the industrial context, production lines can be categorized into three types: automated production lines, semi-automated production lines, and manual production lines. The nature of a production line depends on the complexity of the finished product, production qunatity, and costs. Enterprises can plan and lay out production lines based on their requirements [2].

As highlighted by both [2], [3], inefficient working hours on the production line primarily stem from machine waiting times for personnel handling, waiting for material changes, troubleshooting, and maintenance. The efficiency metric used is referred to as "utilization rate." The utilization rate indicates the percentage of the total working hours where the machine is under load during effective working hours. Effective personnel management plays a crucial role in improving the factory's utilization rate.

2.2. *Industry 4.0 and the Internet of Things (IoT)*

The term Industry 4.0 emerged in Germany in 2011, referring to the technology used in the manufacturing process to monitor processes and employ data-based techniques for predicting, correcting, and adaptively adjusting production strategies [4]. Its objective is to integrate various data, tools, and processes to analyze and reduce costs, mitigate risks, and enhance efficiency [5], [6], [7]. Unlike previous industrial revolutions, Industry 4.0 is not based on a single technology. Instead, it is a convergence of modern technologies such as Big Data, the Internet of Things (IoT), Cloud Computing, and Artificial Intelligence (AI) [5].

The Internet of Things (IoT) applications have deeply penetrated our lives, with interconnected IoT devices sharing vast amounts of information without human intervention. According to [8], global IoT devices online in 2020 totaled 9.76 billion, with application areas illustrated in Fig. 1. Of these, 22% were applied in the industrial sector, 15% in transportation, and 14% in energy. By 2026, the number of online devices is projected to reach 21.09 billion; by 2030, it is estimated to approach nearly 30 billion devices.

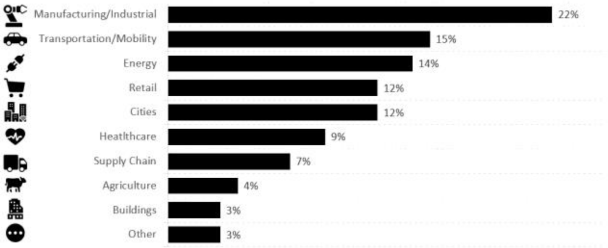

Fig. 1 The top 10 IoT application areas in 2020 [9]

This project aims to transform traditional machinery by further integrating it into the framework of Industry 4.0 to enhance machine utilization rates and production line efficiency. The referenced Internet of Machine Architecture model, as established in [10], [11], comprises five layers: the physical layer, sensor layer, connectivity layer, data layer, and application layer. The machinery transformation in line with Industry 4.0 primarily focuses on configuring the sensor, connectivity, and data layers. In the sensor layer, determining required machine states is crucial, involving establishing corresponding sensors and utilizing the production information provided by the machine. The connectivity layer deals with how the collected information is transmitted to the server for processing. The data layer emphasizes planning the format of machine data and storing it in a database for subsequent applications and analysis.

2.3. *Carbon credit issues*

With global industrialization and increased energy consumption, there is a significant increase in carbon dioxide emissions, contributing to climate challenges. Addressing these issues requires international cooperation to reduce and control carbon emissions. The European Parliament has taken legislative action this year, entering a transitional phase from October. They are implementing the European Union Carbon Border Adjustment Mechanism (CBAM), which restricts the import of high-carbon products such as steel, cement, and electricity. It will be mandatory for imported products falling into supervised categories to purchase CBAM certificates [1] after 2026.

3. System Architecture

In this project, the collaborating partners are concerned about the machinery's operational status and energy consumption. However, due to the large number of machines, totaling 27 units with over ten different models, some of the actual machine appearances are depicted in Fig. 2. Embedded systems, coupled with sensors, will be utilized to extract information on machine status and energy consumption. This data will be wirelessly transmitted to a server for storage, facilitating subsequent analysis and processing.

Fig. 2 The actual appearance of the machinery

As illustrated in Fig. 3, the network architecture primarily consists of an MCU and a server. When the sensor reads values and transmits data to the MCU, the MCU packages the data in a predefined format. Subsequently, using the built-in Wi-Fi module, the data is transmitted to the server. Specific PHP (Hypertext Preprocessor) programs perform data analysis within the server and upload it to the MySQL database. Upon completion of the upload, users can view all the data as of a webpage or export the data into reports through additional programming.

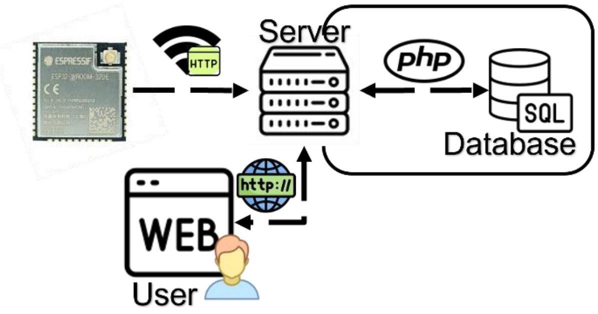

Fig. 3 The network architecture diagram

4. System Development

4.1. *Andon light status detection*

The core component of the Andon light status detection circuit is component U1 in Fig. 4, which is a optocoupler element. A optocoupler element is a device that uses light (such as visible light or infrared) as a medium to transmit electrical signals [12]. As previously mentioned, different machine models on the production line may use different electrical configurations for warning lights, distinguishing between AC and DC. Therefore, the PC814 bidirectional photocoupling element manufactured by Sharp, a Japanese electronics company, has been selected for development for this project. The main difference lies in the internal structure of the PC814, which includes a pair of light-emitting diodes — one forward and one reverse — enabling it to function in both directions of current flow. It elegantly resolved the compatibility issue between alternating current and direct current.

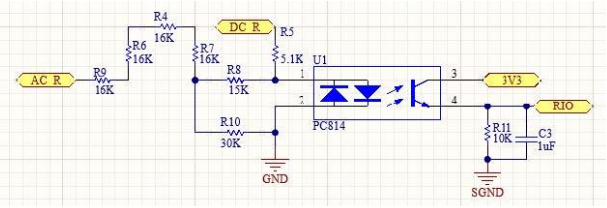

Fig. 4 Andon light status detection circuit diagram (detection part)

4.2. *Current Measurement*

This project utilized the SCT013 split-core current transformer manufactured by YHDC to avoid damaging the original power wiring. The circuit structure employed is illustrated in Fig. 5 with the calculation method for the burden resistor according to Eq. (1).

$$\text{Burden Resistor}(\Omega) = \frac{V_{AREF} * CT\ TURNS}{2\sqrt{2} * I_{pm}} \qquad (1)$$

Where V_{AREF} denotes analog reference voltage, CT TURNS represents the current transformer turns ratio, and I_{pm} denotes the maximum current on the primary side. By generating a voltage across the burden resistor through the secondary side current, the capacitor in Fig. 5 can accurately represent the direction and magnitude of the current. This information is acquired through the MCU's Analog-to-Digital Converter (ADC).

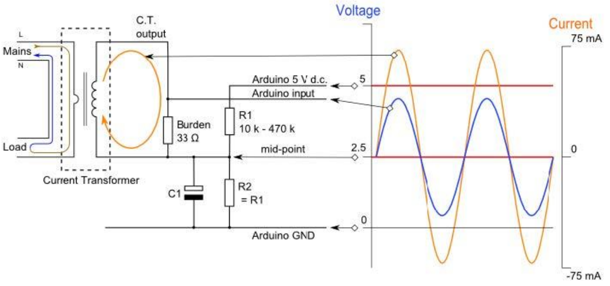

Fig. 5 Current measurement circuit diagram (measurement part) [13]

4.3. *Data format and transmission*

Upon receiving the status and data from peripheral devices, the MCU must analyze and upload the information to the server. The transmitted data should include details such as machine ID, data type, and timestamp. JSON (JavaScript Object Notation) can be employed as the data packaging format. JSON is a lightweight data interchange format supported by most programming languages, often with additional libraries for convenient packaging and parsing. The specific packaging format for this project is illustrated in Fig. 6.

```
{
   "id": 99,
   "type": "light",
   "data": [
      {
         "data": "Red",
         "time": "16809965626701"
      },
      {
         "data": "Yellow",
         "time": "1680966155194"
      },
         ⋮
   ]
}
```

```
{
   "id": 99,
   "type":  “current",
   "data": [
      {
         "data":  “5231",
         "time": "16809965626701"
      },
      {
         "data":  “4859",
         "time": "1680966155194"
      },
         ⋮
   ]
}
```

Fig. 6 Data format

The data, transmitted through HTTP request by the MCU with Wi-Fi functionality, undergoes analysis on the server side using PHP. PHP also responds to the HTTP request and uploads the data to the database for storage. The server-side data transfer path is illustrated in Fig. 7.

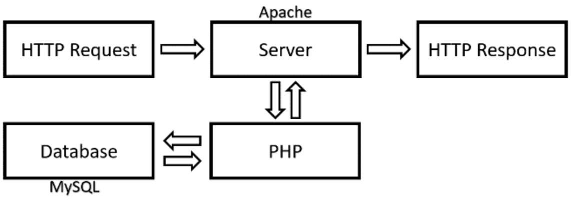

Fig. 7 The server-side data transfer path

5. Result

This paper uses the ESP32 series MCU, which Espressif Systems developed as the core for edge-side development. Its advantages lie in its cost-effectiveness and the integration of network modules with basic microprocessors. This MCU is commonly employed in the development of IoT applications.

After collecting data, present it to users in a graphical format for more straightforward interpretation and analysis. The system is developed as a Web App to avoid the need for different applications on various devices and the authentication thresholds of mobile applications. The advantages of a Web App lie in its accessibility—any internet-connected device with basic browser functionality can use it. The web page is coded using HTML (Hypertext Markup Language) for interface design. JavaScript is employed for real-time content updates and user interaction. PHP serves as an intermediary between JavaScript and the database for data requests.

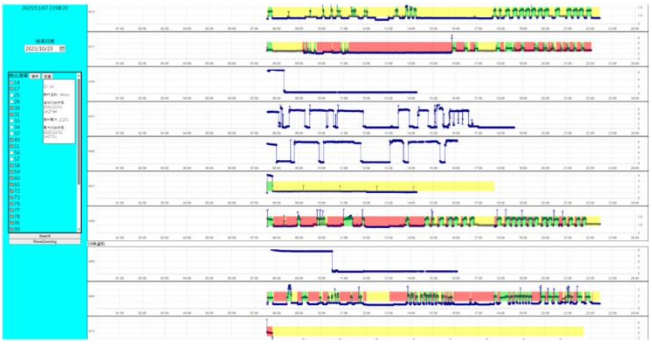

Fig. 8 Web App

Fig. 8 shows the interface displayed in the web app, divided into two main sections. Users can choose the machine number and time of interest on the left-hand side in the blue area. After selection, the data for the chosen machine will be displayed on the right-hand side in the white area. Each row in the chart on the right represents the data for a single machine on a given day. The various colored blocks represent the machine's status (indicator lights) during specific time intervals, while the lines depict the machine's current consumption. Analyzing this data assists factories in power consumption statistics, emission calculations, and formulating strategies for emission reduction. Aligns with national and international carbon policies, helping to minimize carbon-related costs and reduce unnecessary energy consumption during idle times.

6. Conclusion

This article utilizes a microcontroller with wireless connectivity, sensors, and electronic components to create a non-invasive device. Combined with a web app, factory administrators can swiftly gather production information to analyze and adjust production strategies.

References

[1] European Commission, Carbon Border Adjustment Mechanism, Taxation and Customs Union, https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en (accessed Nov. 15, 2023).

[2] SKAL Subramaniam, Siti Huzaimah Binti Husin, Yusmarnita Binti Yusop, and Abdul Hamid Bin Hamidon, Machine efficiency and man power utilization on production lines, in WSEAS International Conference. Proceedings. Mathematics and Computers in Science and Engineering, vol. 7, 2008, World Scientific and Engineering Academy and Society.

[3] Y. Y. Wang, J. Lionel, Case Study of the Machine Utilization on the Turning Process," in Industrial Science and Management Journal, Mar. 31, 2008.

[4] T. Ainsworth, J. Brake, P. Gonzalez, D. Toma, and A. F. Browne, A comprehensive survey of Industry 4.0, IIoT, and areas of implementation, SoutheastCon 2021*, pp. 1-6, 2021, IEEE.

[5] H. Khujamatov, E. Reypnazarov, D. Khasanov, and N. Akhmedov, IoT, IIoT, and cyber-physical systems integration, in Emergence of Cyber Physical System and IoT in Smart Automation and Robotics: Computer Engineering in Automation, Springer, 2021, pp. 31-50.

[6] K. Wójcicki, M. Biegańska, B. Paliwoda, and J. Górna, Internet of Things in Industry: Research Profiling, Application, Challenges and Opportunities—A Review, Energies, vol. 15, no. 5, p. 1806, 2022, MDPI.

[7] R. Y. Zhong, X. Xu, E. Klotz, and S. T. Newman, Intelligent manufacturing in the context of Industry 4.0: a review, Engineering, vol. 3, no. 5, pp. 616-630, 2017, Elsevier.

[8] L. S. Vailshery, IOT connected devices worldwide 2019-2030, Statista, https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/ (accessed Jun. 15, 2023).)

[9] M. H. Alsharif, A. Jahid, A. H. Kelechi, and R. Kannadasan, Green IoT: A Review and Future Research Directions, in Symmetry, 2023, vol. 15, p. 757.

[10] D. Jaspert, M. Ebel, A. Eckhardt, and J. Poeppelbuss, Smart retrofitting in manufacturing: A systematic review, Journal of Cleaner Production, vol. 312, p. 127555, 2021, Elsevier.

[11] P. Zheng, Z. Wang, C.-H. Chen, and L. P. Khoo, A survey of smart product-service systems: Key aspects, challenges and future perspectives, Advanced Engineering Informatics, vol. 42, p. 100973, 2019, Elsevier.

[12] Opto-Isolator, Wikipedia, https://en.wikipedia.org/wiki/Opto-isolator (accessed Dec. 4, 2023).

[13] CT sensors - interfacing with an arduino, CT Sensors - Interfacing with an Arduino - OpenEnergyMonitor 0.0.1 documentation, https://docs.openenergymonitor.org/electricity-monitoring/ct-sensors/interface-with-arduino.html (accessed Dec. 4, 2023).

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