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IoT based energy consumption monitoring platform for industrial processes

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***Abstract*—Reducing the energy consumption is a major concern faced by industries worldwide to improve the economic performance while to reduce its CO2 footprint, and monitoring the energy usage at the component level is essential. This paper presents a design of an IoT (Internet of Things) based interactive system which combines non-invasive sensors and data acquisition apparatus, robust communication networks, clouds-based databases and web servers to achieve real-time monitoring of energy usage in industries. The collected energy consumption data are published to the data centre automatically through the wireless communication network using the MQTT protocol, while a web server driven by Apache is developed to provide a human-data interaction dashboard in B/S (Browser / Server) structure. The system can not only assist industrial energy management but also provide a platform to improve energy-saving, emission reduction, along with other potentials. The system has been implemented in a local bakery company, confirming its applicability for remote real-time monitoring of energy consumption in the industry.**

I. Introduction

The impact of global climate change, such as the rise of global temperature, shift of rainfall patterns, and extreme climate patterns, presents one of the most significant challenges for mankind. It is believed that these changes are linked to the substantial emissions of carbon dioxide and other greenhouse gases (GHG) [1]. Research shows that the excessive inefficient use of fossil resources is a key factor which leads to more GHG emissions. Governments worldwide have set ambitious targets to reduce GHG emissions. For example, the UK government has committed to reducing GHG emissions by at least 80 percent by 2050 with respect to 1990 levels [2]. Whilst, the Chinese government has committed to reducing its carbon intensity by roughly 60 to 65 percent from 2005 levels by 2030. Globally, industries account for 33% of the total GHG emotions. It is therefore imperative to improve the energy efficiency and reduce the total energy consumption in the industries in order to achieve lower GHG emissions [3].

To identify and monitor the most energy intensive components of a process is the first stage for taking further actions to improve the energy efficiency [4]. Complex industrial processes often have a large number of devices and components, each consuming different amount of energies and working in different states. To audit the energy usage in industry, in particular for SMEs where such information is often unavailable, or there is no technical support to help them acquire such insight in energy usage or such technical support is too expensive to deploy, it is imperative to develop a low-cost easy accessible platform for real-time energy monitoring at different level of system granularity [5]. The system should be able to collect, pre-process, transmit and store these data for further analysis, i.e. process maintenance, modelling and optimisation. Different from other applications, to install energy related sensors with wired communication network is unfeasible in industries, while conventional wireless communication networks are often subject to significant inferences emitted from machines. Furthermore, to enhance industrial acceptance, it is crucial to design the monitoring system to be minimal invasive, such that sensing, data acquisition and transmission cause little interruptions to the process [6].

To tackle the aforementioned challenges, an interactive system based on the Point Energy Technology for industrial energy monitoring was designed and developed. Non-intrusive sensors, such as the current transformers and smart power meters are used to measure the industry electricity usage, ultrasonic flow meters are employed for the gas and water usage. For processes where SCADA data is available, the acquired signals are directly used to calculate the energy usage [7]. To reduce the electromagnetic interference and to simplify the installation process, a MQTT protocol based LoRa communication network is used to transmit the on-site data to the data server which is driven by MySQL. Finally, a web-based dashboard connected to the data server is developed to provide both the historic and real-time energy usage information consumed by key components in the process. The remainder of this paper is organized as follows. Section II introduces the structure of the designed monitoring platform and a detail implementation of the platform is developed in section III. Section VI gives a brief analysis of the collected energy data. Finally, Section V concludes the paper.

II. System structure

The architecture of the developed IoT based industry energy consumption monitoring system consists of three layers, namely the perception layer which measure and acquire energy related process variables, the data transmission layer which sends the information to a cloud based server, the application which stores and displays the real-time on-site information data analysis for energy management is also included in this layer. Figure 1 is an illustration of the design structure of the developed system.

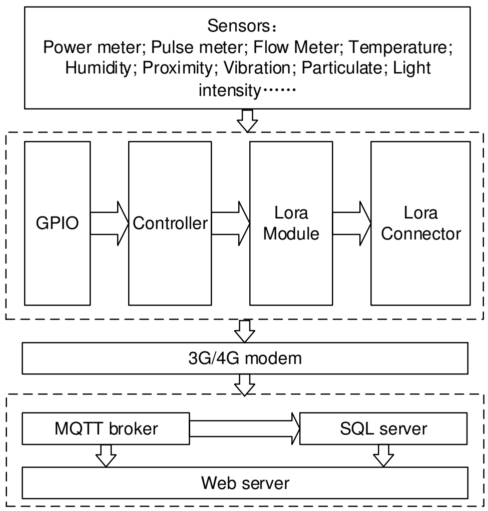

Fig. 1. System structure of the proposed interactive system

A. Perception layer

The Perception layer is directly linked to the industrial processes which mainly consists of various industrial sensors, such as smart power meters, current transformers, pulse meters, flow meters, temperature sensors, humidity sensors, etc. It also interfaces with SCADA system used in the industry if the protocol is available.

B. Data transmission layer

This layer mainly transmits the data acquired from various sensors and SCADA systems to the cloud sever. Data preprocessing methods such as filters and outlier detection and removal are embedded in the controller first, which can help to reduce the quantity of transmitted data, and thus the energy consumption of the communication nodes. After prepossessing, the data is transferred to the LoRa module or stored in the transmit queue depends on the data effectiveness time and data length. If the monitored industrial process changes fast, data can be sent to the LoRa module directly with the time stamp. The LoRa communication network is chosen to transmit data in the industrial sites due to a number of merits [8]:

- Lora uses 868 MHz/ 915 MHz ISM bands which is freely available world wide.
- Lora has a wide coverage range from 5 km in urban areas and 15 km in suburban areas, thus a single Lora gateway can cover most industrial sites.
- Lora has advantages in terms of battery lifetime due to lower working power compared to other wireless communications. Researches indicate that a Lora communication node can last up to 10 years on a single AA battery with 12 miles transmitting range [9]. This makes the Lora network particularly suitable for industry usage with less maintenance.
- Single LoRa Gateway device is designed to cover 1000 end devices and nodes. Thus one or two Lora gateways are sufficient to cover most industrial applications.
- Lora network is easy to install due to its simple architecture.
- Lora uses Adaptive Data Rate technique to vary output data rate/ Rf output of end devices. This helps to maximize the battery life as well as overall capacity of the LoRaWAN network. The data rate can vary from 0.3 kbps to 27 Kbps for the 125 KHz bandwidth.
- Lora is widely used for Machine to Machine (M2M) / IoT applications.

C. Application layer

Data can be published to remote MQTT broker directly through the internet from the LoRa gateway. MQTT is a lightweight messaging protocol designed for M2M (machine to machine) telemetry in low bandwidth environments, it has became one of the main protocols in IoT based deployment [10]. Even though MQTT uses an unsecured TCP, data are able to be encrypted using TLS/SSL which makes the data transmission more secure [11]. Another key feature which makes MQTT suitable for IoT applications is the Quality of Service (QoS). Three different level of QoS is defined in the MQTT protocol based on the importance of each message and the repetitiveness of the messages. Level 0 messages will be transmitted only once. Level 1 messages will be sent several times to ensure the message is received, and the receiver may receive the message more than once. Level 2 is the most secure level of message publication. This mechanism ensures the IoT based communication easier to implement in unreliable network environment as the protocol can handle the re-transmission and guarantee the successful delivery of messages.

To leverage the full potential of platform for effective energy management, a SQL data server is deployed to store all the industrial historic data. Finally, a web server is developed to host a dashboard based web application to present the visualization of data directly collected from the MQTT broker or retrieved from the SQL server. As the web server is published on the internet, the dashboard based web application is accessible anywhere and anytime using computers, laptops, tablets, mobile phones etc, enabling remote energy management by manufacturers.

III. Implementation

The developed system has been implemented to monitor the energy consumption of a local bakery company. The bakery sector produces approximate 2.5 million tons of baked goods every year in the UK and requires about 2000 gigawatt hours energy consumption equivalent to 570,000 tons of CO_2 emission [12]. A great potential of energy efficiency improvement can be expected through proper energy management in the bakery industry, making a significant contribution to the reduction of GHG emissions. Key equipment in a bakery process include mixers, dividers (bun and bread former), fermenters (proofing oven), bake oven, chiller units and boilers, and energy resources consumed in these processes often include electricity, steam and nature gas.

The energy monitoring system deployed in the bakery company include:

- ABB B24 digital power meter .
- HOBUT Split Core Current Transformer.
- Gas meter.
- Raspberry Pi2.
- LoRa node MTDOT-915-X1P-SMA-1.
- LoRa gateway MTCDT H5.
- 3G/4G router.

Combined with the current transformers, the three-phase voltage, current, power and power factors can be obtained simultaneously through a digital power meter.

In the bakery company, the installed gas meter generates 10 pulses for consuming every cubic meter gas, thus the gas usage can be calculated by counting the number of pulses. The gas consumption rate is also accessible based on the pulse rate. To collect the data from the gas meter and the digital power meter, a raspberry pi is adopted. To transmit the sensor data to the data server via the LoRa network, the LoRa module MTDOT-915-X1P-SMA is used which has a maximum transmission power of 19 dBm, a maximum receiver sensitivity of -137 dBm and a point to point link budget of 147 dB. For the LoRa gateway, Multiconnect Conduit (MTCDT H5) is adopted. The LoRa gateway is then connected to a 3G modem to send the data to the data centre through the internet. The hardware scheme provides the capability of collecting energy consumption data from multiple industrial devices and transmitting data to the data centre.

The software development includes the storage, analysis and visualization of energy consumption data. The development environment includes:

- Ubuntu operating system.
- Mosquitto MQTT broker.
- MySql database.
- Apache.
- Django 2.02.
- Python 3.0.

The mosquitto MQTT is a lightweight open source message broker that implements the MQTT protocol and it is embedded in an Ubuntu server. However, it does not support the WebSocket protocol by default, hence the connection to a web browser is not allowed. To overcome this shortfall to enable the design and development of a web-based interactive system for remote monitoring, it is necessary to make a connection from the web APIs to deliver the real-time display of industrial data. To enable WebSocket support in the mosquitto broker, configurations was modified to add an listener port and associated protocol. Once this was completed, tables in the SQL server were created to store data, the database ER diagram is shown in figure 2. The 'ElectricityUsage' and 'GasUsage' tables store all the electricity and gas usage in the bakery company. 'Pi', 'Ii' and 'Vi' (i = 1, 2, 3) are the power, current and voltage in each power phase. 'PF' is the power factor. 'Hz' is the power frequency. As different devices and processes may consume different type of energy, each table is assigned a field named 'DeviceID' to distinguish the exact energy consumption of each device and process. Besides, customer information table is designed to store the login information to ensure the secure access of the data. Finally, an Apache based web server was deployed to host the web application which is designed in a dashboard style for remote monitoring. The web server gains the access to both the real-time energy data through the MQTT broker and the historic data through SQL server at the same time. By appropriate authentication and access control, only authorised users and industry administrators can access to the dashboard display of the process data using computers, laptops, tablets or smart phones any time any place. Figures 3 and 4 are snapshots of the designed web page for monitoring the electricity and gas usages in the bakery industry.

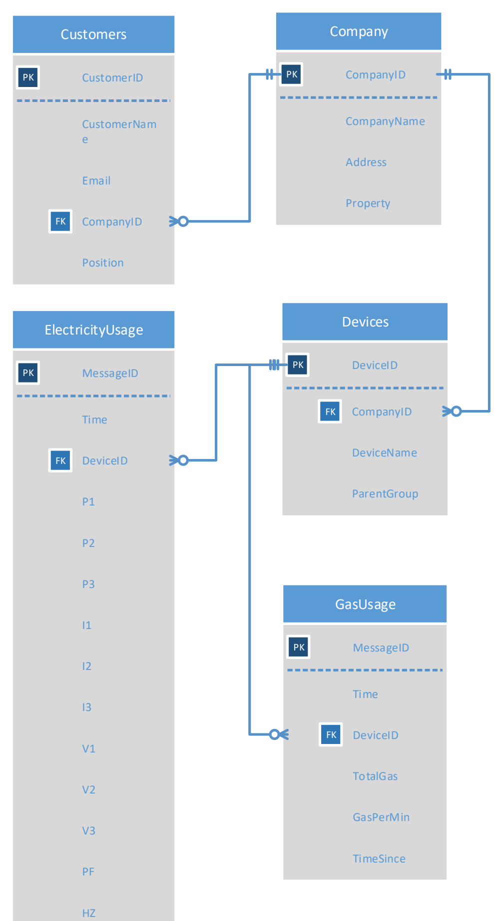

Fig. 2. Data table relationship

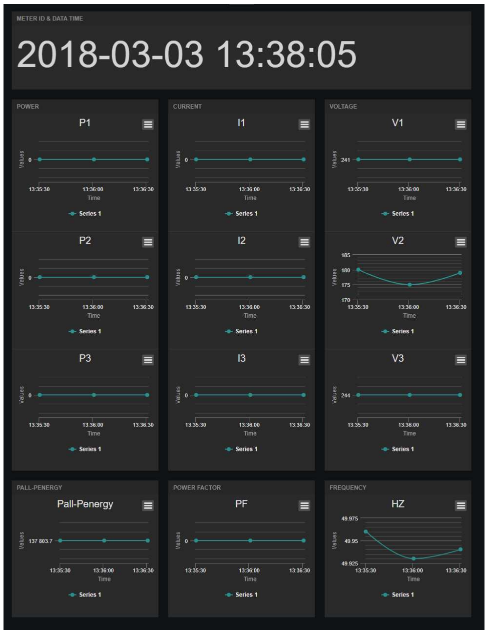

Fig. 3. The electricity consumption display interface

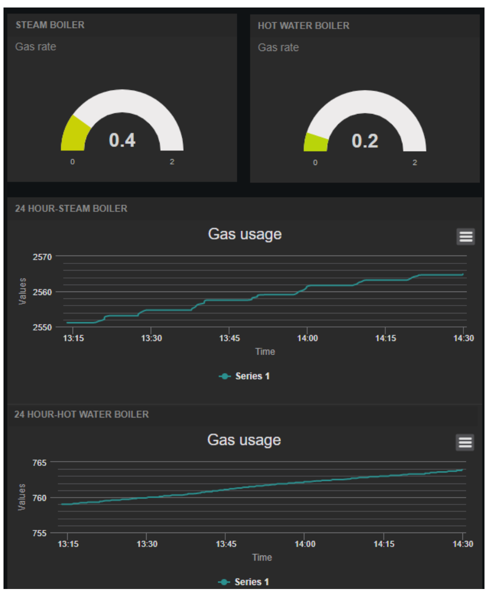

Fig. 4. The gas usage monitoring in the industrial process

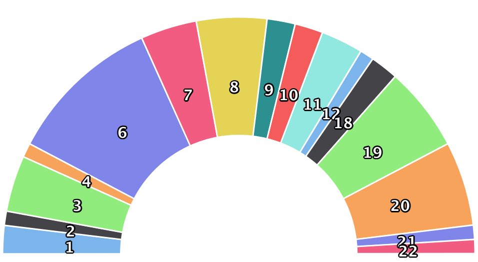

Fig. 5. The hourly power-on rate of the bakery mixer in 24 hours of a particular date

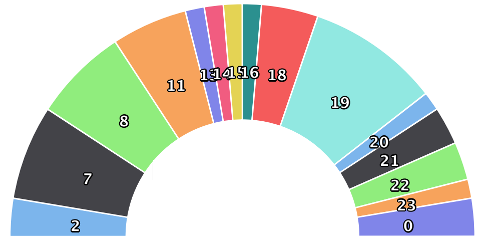

Fig. 6. The hourly power-off rate of the bakery mixer in 24 hours of a particular date

IV. Data analysis

Analysis of the collected energy consumption data can help to gain insights of the processes, such as the patterns of energy usages in the process, and potential faults hidden in the process, etc. Figures 5 and 6 are the distributions of the power-on and power-off time of a mixer from 0 am to 24 pm. It is clear that the mixer was powered on at most hours of the day except for 0 am, 5 am, 13 pm, 14 pm, 15pm, 16 pm, 17pm and 23 pm. Likewise, the Mixer was also turned off at most of the hours of the day. A simple statistics show that the hourly power-on probability of the mixer at 6:00 am and 20:00 pm are 23.1% and 16.2% respectively. The most likely time to turn off the mixer is 7 am, 8 am and 19 pm with more than 50% probability.

Fig. 7. The hourly power consumption monitoring of the device from 26th February to 25th March 2018

The detailed energy consumption of the mixer from 26th Feb. 2018 to 25th Mar. 2018 is shown in figure 7. It is obvious that the peak power of the mixer was between 20 kilowatts to 30 kilowatts, the average daily energy consumption of the mixer was 302.9 kilowatts, and the most energy intensive day was 27 February which consumed 426 kilowatts while on 10 March, only 80 kilowatts were used. The working hour of the mixer can also be intuitively inferred from figure 7 by analysing the energy consumption data. The average daily working time of the mixer was 279 minutes, the longest working time of the mixer was 412 minutes on 21 March while the shortest working time was 84 minutes on 10 March, It is also shown that the longest working time did not necessarily result in the most energy usage. This is because the energy consumption of the mixer is related to both the working time and the working power, figure 8 confirms that the energy consumption of the mixer was strongly correlated to the working time, however they were not exactly linearly correlated.

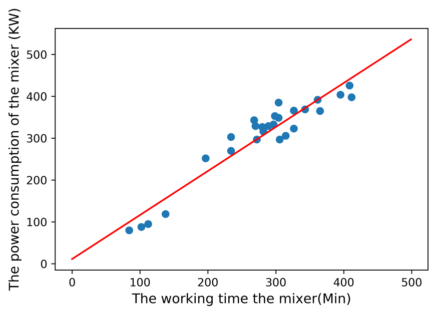

Fig. 8. The linear regression of the energy consumption with working time

V. Conclusion

This paper has presented an energy consumption monitoring system which integrates the capability of IoT and cloud-based technologies to achieve noninvasive remote monitoring of the industrial process. Through experimental analysis, we have shown that the developed system is scalable and easy to install in industrial sites.

Through the analysis of the monitoring data, the working status of the industrial processes is intuitively inferrable. An example to analyze the mixer data has been made and the result confirms that the energy consumption of the mixer was strongly correlated to the working time, but not exactly linearly correlated.

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