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Internet-of-Things Enabled Real-Time Monitoring of Energy Efficiency on Manufacturing Shop Floors

Yee Shee Tan[a,]* , Yen Ting Ng[a], Jonathan Sze Choong Low[a]

[a]*Singapore Institute of Manufacturing Technology, 2 Fusionopolis Way, Singapore 138634*

* Corresponding author. Tel.: +65 6319 4451; fax: +65 6250 3659. *E-mail address:* tanys@simtech.a-star.edu.sg

Abstract

Energy efficiency (EE) has become an important indicator in manufacturing industry due the rising concerns about climate change and tightening of environmental regulations. However, most manufacturing companies today are only able to monitor aggregated energy consumption and lack the real-time visibility of EE on the shop floors. The ability to access energy information and effectively analyze such real-time data to extract key indicators is a crucial factor for successful energy management. Therefore, in this paper, we introduce an internet-of-things (IoT) enabled software application for real-time monitoring of EE on manufacturing shop floors. While enabling real-time monitoring of EE, it also applies data envelopment analysis (DEA) technique to detect abnormal energy consumption patterns and quantify energy efficiency gaps. Through a case study of a microfluidic device manufacturing line, we demonstrate how the application can assist energy managers in embedding best energy management practices in their day-to-day operations and improve EE by eliminating possible energy wastages on manufacturing shop floors.

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Keywords: Energy Efficiency; Real-Time Monitoring; Data Envelopment Analysis; Best Practices; Internet-of-Things

1. Introduction

Nowadays, efficient usage of energy is becoming more of priority due to the rising concerns about climate change and regulatory requirements. Among all end-user sectors that are targeted for achieving energy efficiency (EE) improvement, manufacturing industry is deemed one of the high potentials as it is the largest consumers among all end-user sectors. According to Singapore's energy statistics, the energy consumption by industry sector was 42.6% of total energy consumed, followed by the commercial and household sectors, which are 36.5% and 14.9%, respectively in 2015 [1].

To improve EE, the role of energy management has greatly expanded in manufacturing industry as it has also resulted in reducing operating costs in long term. As defined by ISO 50001:2011, energy management is a comprehensive and systematic approach for energy conservation efforts in an industry. It is judicious and effective use of energy to maximize profits and to enhance competitive positions through industrial measures and optimization of EE in the process. For energy management, the first step is usually the energy monitoring. Industry can only manage their energy when they initiate to measure and understand their current energy performance. However, industry today is only able to monitor aggregated energy consumption, but unable to visualize real-time EE at shop floor. The ability to access energy information and effectively analyze such real-time data to extract key indicators is a crucial factor for successful energy management.

The new emerging technology, Internet-of-Things (IoT), which connects physical objects using electronic sensors and internet is drawing attention nowadays. IoT technology promotes the heightened level of awareness about the world and a platform from which to monitor changing conditions and react to those changes [2]. IoT is expanding to many other interesting application domains while energy is one of the

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application areas where IoT technology plays a major role [3]. Energy management is integrated with IoT technology to provide the ideal solution for monitoring real-time energy consumption while providing the level of awareness of energy performance [4][5]. With the support of IoT technology, i.e. energy sensor, energy consumption data can be collected in real-time at different levels, such as machine, production line or facility level [6]. However, collection of these data without the production or operating data will not be sufficient to understand EE [7][8].

Thus, this paper aims to bridge the gap by introducing an approach that uses both the energy and production data for EE assessment. Coupled with the IoT technology, the approach is able to provide real-time EE monitoring in manufacturing shop floors. Besides, data envelopment analysis (DEA) technique is applied to identify abnormal energy consumption patterns and quantify energy efficiency gaps. Through a case study of a microfluidic device manufacturing line, we demonstrate how the application can assist energy managers in embedding best energy management practices in their day-to-day operations and improve EE by eliminating possible energy wastages on manufacturing shop floors.

2. Internet-of-Things enabled software application for real-time energy efficiency monitoring

2.1. Concept Overview

The proposed IoT enabled software application helps energy managers in achieving better EE by understanding both the energy consumption patterns and production data while eliminating possible energy wastages in the manufacturing operation. It works in a simple manner as shown in Fig. 1. The application users, e.g. energy manager, monitor the energy performance for each machine at shop floor using tablet while data such as power consumption and process operating parameters, e.g. temperature, pressure, etc. are captured via sensor or controller. Production data are provided by existing software such as manufacturing execution system, work order tracking system, etc. The server stores the data as well as the energy performance status and respective analysis results in the common repository. The three components, i.e. data acquisition, server and energy manager, interact with each other via wireless network.

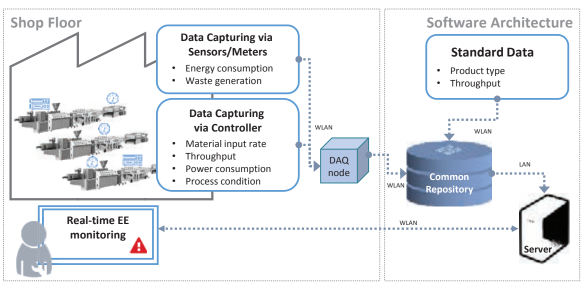

Fig. 1. Concept overview of Internet-of-Things enabled software application

2.2. Software application architecture

A software application is developed and structured as a multi-layered application consisting of user experience, business logic and data layers [9]. As Fig. 2 illustrates, it consists of

(1) Presentation layer

This layer contains the components that implement and display the user interface and manage user interaction. A set of user interface components such as the dashboard, notification pages and reports are design to provide a way for users to interact with the application. User interface can make use of controllers to communicate with the back-end and to navigate or process the interface components.

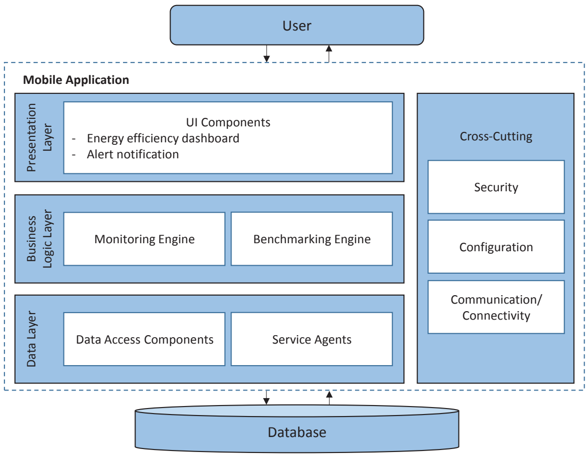

Fig. 2. Software application structure for real-time EE monitoring

(2) Business logic layer

This is the layer where all the engines in the application reside. It contains all the processing logic to make the application possible. The application consists of two parts, i.e. a) monitoring algorithm and b) benchmarking engine.

a) Monitoring algorithm

Monitoring is a process for metering the energy consumption and collecting real-time energy data. Data collected from monitoring is served as a basis to understand current level of energy use. With the basis, we can identify patterns and obtain information that can further be used to implement corrective and preventive action. However, as mentioned, in order to improve EE, integrating energy and production data is important. The algorithm flow chart to show how we correlate energy and production data is presented as Fig. 3. Inputs considered are 1) power consumption data (P) captured via sensor or controller and 2) production data (PV) tracked by production monitoring software, such as work order tracking system. The interval data (i) comes in increments of 1-minute granularity. With the acquired data, the energy consumption and production volume involved with respect to different reporting period r,