

# Design and development of an IoT-based web application for an intelligent remote SCADA system

Kuang-Chi Kao<sup>1\*</sup>, Wei-Hua Chieng<sup>1</sup> and Shyr-Long Jeng<sup>2</sup>

<sup>1</sup>National Chiao Tung University, Department of Mechanical Engineering, Hsinchu, Taiwan.

<sup>2</sup>Ta Hwa University of Science and Technology, Department of Electrical and Electronic Engineering, Hsinchu, Taiwan.

\*E-mail: chi1010860@gmail.com

**Abstract.** This paper presents a design of an intelligent remote electrical power supervisory control and data acquisition (SCADA) system based on the Internet of Things (IoT), with Internet Information Services (IIS) for setting up web servers, an ASP.NET model-view-controller (MVC) for establishing a remote electrical power monitoring and control system by using responsive web design (RWD), and a Microsoft SQL Server as the database. With the web browser connected to the Internet, the sensing data is sent to the client by using the TCP/IP protocol, which supports mobile devices with different screen sizes. The users can provide instructions immediately without being present to check the conditions, which considerably reduces labor and time costs. The developed system incorporates a remote measuring function by using a wireless sensor network and utilizes a visual interface to make the human-machine interface (HMI) more instinctive. Moreover, it contains an analog input/output and a basic digital input/output that can be applied to a motor driver and an inverter for integration with a remote SCADA system based on IoT, and thus achieve efficient power management.

## 1. Introduction

With the rapid development of the Internet in recent years, Internet-based applications such as remote monitoring systems are becoming increasingly popular in industry. Through the boundless Internet, a remote monitoring system allows the user to have remote real-time control of the situation in a factory by using a smartphone or computer.

In the future, factories will have different types of devices, which will need to be integrated in an intelligent manner. Wireless sensor networks (WSNs) are the base technology of the Internet of Things (IoT) [1]. A WSN is a network that uses intelligent sensors to transmit and receive data. The applications of WSN include health, environment, industrial, and traffic monitoring [2][3]. WSNs have not only contributed to the development of IoT [4] but also led to the development of devices and technologies that support the growth of the Internet, such as QR codes, intelligent phones, social networks, and cloud computing [5][6].

The applications of IoT can be divided into four categories, namely transportation and logistics, healthcare, smart environment (home, office, and plant), and personal and social [7]. Power supervision is important for not only factory power management but also home power monitoring [8]. Power line communication requires considerable power monitoring for factories, houses, or vehicles. However, power line communication has drawbacks such as large energy loss [9].



The development of Internet of Vehicles, IoT, and cloud computing technologies is expected to result in increasing demand for intelligent power monitoring systems and remote supervisory control and data acquisition (SCADA) systems [10][11].

Using an IoT-based SCADA system is a convenient and efficient way of remotely monitoring industrial equipment. Application of WSNs or wireless sensor and actuator networks to a SCADA system is beneficial because these networks are based on the well-developed TCP/IP and HTTP protocols for transferring data to a client from a server through a web application [12].

The open database connectivity (ODBC) method can be used for connecting and transferring the data, for example through Microsoft SQL Server. The web server must be established in order to provide a response to the client. Microsoft Internet Information Services (IIS) is a service for setting up the web server and delivering data to the client in Extensible Markup Language (XML) format [13]. In recent years, developers have replaced XML with JavaScript Object Notation (JSON) format to transfer data because JSON is a lightweight data interchange format that is easy for humans to read and write as well as easy for machines to parse and generate. JSON increases the decoding speed of a browser and improves the efficiency of a website. In addition, developers use a model–view–controller (MVC) architectural pattern to design a website because it provides a way to divide a given application into three interconnected parts. The MVC design pattern decouples these major components, enabling efficient code reuse and parallel development. The cloud-based vehicle toll payment system mentioned in [14] adopts the aforementioned strategy for the development of a web application.

A monitoring system can be divided into monitor tier, server tier, cloud tier, and client tier. Different tiers have different functions for using devices and software to achieve remote monitoring and data management [15].

A simple application for a remote monitoring system is a web oscilloscope. The web oscilloscope delivers acquisition data, which is stored in the database via TCP/IP and simulates a real oscilloscope to enable the user to easily observe the signal plot of an electrical circuit [16]. Other applications of remote monitoring include video surveillance, appliance testing, and ocean monitoring [17]. Because several studies have proposed that the graphical interfaces are more acceptable for users than using numerical tables as the interface, all these applications are designed with a friendly human–machine interface to enable users to supervise a situation [18][19].

According to market research of browsers used in intelligent devices [20], people use browsers for browsing websites on devices such as smartphones, tablets, and laptops. Because devices can have different sizes, websites must be designed using responsive web design (RWD) to fit different devices. Therefore, a remote SCADA system is discussed in this paper [21].

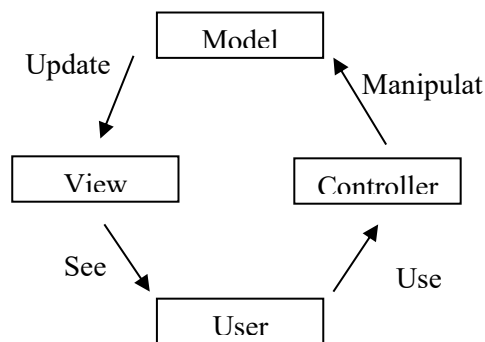
## **2. Concept of the System and Related Technologies**

This paper presents the design of a web application based on the ASP.NET framework using Visual Studio 2015. The coding languages used to establish the bridge between the server and client in the MVC structure were C#, SQL, JavaScript, HTML, and CSS. Some popular libraries, such as Razor and jQuery, and a common format for transferring data—JSON—were used in this project to implement the function of Asynchronous JavaScript and XML (AJAX).

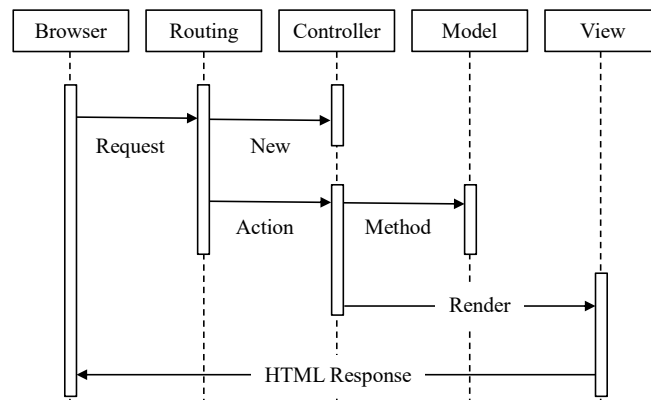
### *2.1. ASP.NET MVC architecture*

In this study, an MVC architecture was adopted to design the web application for a remote SCADA system. As shown in figure 1, the developer must divide an application into three types of components:

- (a) A model stores data that is then retrieved according to commands from the controllers. It includes business logic and all data used in a project.
- (b) A view presents the data from the controller based on changes in the model.
- (c) A controller decides the data flow and sends commands to the model and view.



**Figure 1.** MVC architecture.



**Figure 2.** Life cycle of an MVC.

Programming languages such as Java, C#, and PHP have popular MVC frameworks that are used in web application development. In this study, the ASP.NET MVC framework was applied to a remote SCADA system.

The life cycle of an MVC architecture is presented in figure 2. The entry point for every MVC application is URL routing. After the ASP.NET platform receives a request from a browser, a controller determines how it should be handled. The controller then determines the view and presents the view through URL routing.

## 2.2. Relational database

Microsoft SQL Server 2016 was adopted as a relational database management system to execute four basic functions of a database, namely create, read, update, and delete. Using a database to store data acquired with an analog-to-digital converter and establishing relations among each type of data is a common approach in industrial systems. To connect the web application to an SQL Server, Entity Framework should be used. Entity Framework can help a developer to relate the object in their code with a table in the database. This database technique is called “Code First” because developers initially design the objects and generate the code, and then implement the database. In this study, a view was created that presents the previous data acquired by the system to the users if required.

## 2.3. RWD

RWD was used in the IoT-based remote SCADA system to develop a friendly user interface. RWD is an approach of web designing aimed at allowing desktop webpages to be viewed in response to the size of the screen. For example, a website with a wide original template will be narrow when the pixels of the device screen are less than 400 px. An RWD website in different devices shows different UI templates. A website designed with RWD adapts the layout to the viewing environment by using fluid, proportion-based grids, and CSS3 media queries. The primary advantage of an RWD website is the reduction in user scrolling and zooming. Reading the data in an RWD website on smart devices makes supervision easier and more accurate than other websites without RWD. Moreover, it removes the problems of incorrectly touching buttons and improves the user scenarios considerably.

## 2.4. AJAX

Traditional websites must refresh continually to achieve dynamic updating. The users cannot efficiently browse a website because of the time required for waiting for the blank page to refresh before the content of the page appears.

AJAX is a new technique that enables a web application to send and receive data from a server asynchronously. With AJAX, a web page can change content dynamically without needing to reload

the entire page. In practice, modern implementations commonly substitute JSON for XML because of the advantages of being native to JavaScript.

AJAX is not a single technology but rather a group of technologies. HTML, CSS, and JavaScript may be used synchronously in a project.

In this study, the AJAX technique was used with the jQuery library in JavaScript to develop the numerical and graphical interfaces for displaying the measurement data. figure 3. (a) shows the practical code for implementing the AJAX function. The red box in figure 3. (b) indicates the area that is dynamically updated with the AJAX technique.



**Figure 3.** AJAX monitoring interface of mobile browser: (a) AJAX function with jQuery code. (b) Interface of a smartphone.

### 2.5. Communication

A system comprising a server PC, an inverter, a WSN module, and a client device was established. Communication between these pieces of hardware is a critical problem. The server PC and inverter are connected through the Modbus protocol and with RS-485 as the electrical interface. Therefore, a USB-RS-485 converter (National Instruments, USA) was used in this study. To transmit data from a Wi-Fi data acquisition (DAQ) device to the server PC, the IEEE 802.11 standard is required. The DAQ device and the server PC can be connected using a Wi-Fi router. Finally, the server PC uses the TCP/IP protocol to connect to the client devices because this system is based on the Internet.

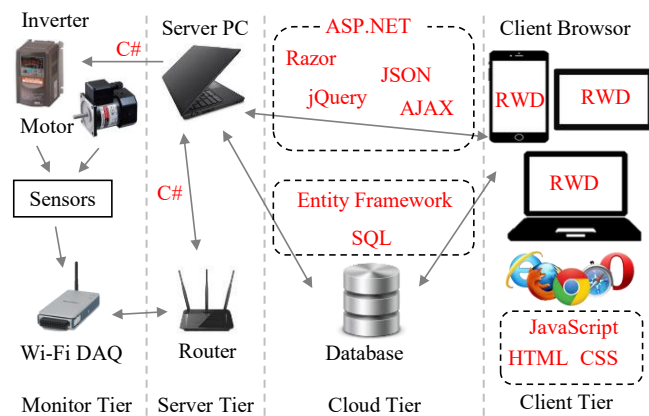
## 3. Implementation of the IoT-based SCADA System

### 3.1. Architecture of a remote SCADA system

The system was divided into monitor, server, cloud, and client tiers. The architecture shown in figure 4 shows that the system comprises sensors, a Wi-Fi DAQ device, an inverter, and a motor as the monitor tier; a wireless router and a PC server as the server tier; a database as the cloud tier; and a laptop, a tablet, and a smartphone as the client tier. With this architecture, the system can be practically and structurally implemented and the data flow of the entire system can be confirmed.

### 3.2. Wireless sensor network with a Wi-Fi DAQ device

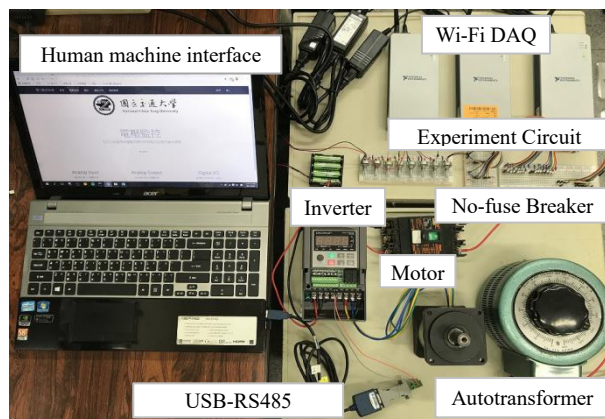
This paper presents a structure with a Wi-Fi DAQ device for supervising the voltage and current of the inverter to control the motor. The Wi-Fi DAQ device (cDAQ series; National Instruments) was selected because this device is based on the .NET Framework. Developers can apply this device to their project using a C#-based API and easily connect the application to Microsoft IIS and SQL Server database. Therefore, functions including analog input/output and digital input/output using the browser are presented.



**Figure 4.** Architecture of a remote monitoring system.

### 3.3. Hardware structure of the SCADA system

The hardware structure of the system is as shown in figure 5. The structure can be simply divided into two parts, namely the wireless monitor and inverter control. The components of the wireless monitor include the Wi-Fi DAQ device, potential meters as the substitute of the sensors, and a simple experimental circuit for testing the analog input/output and digital input/output. The components of the inverter control include an inverter (Rich tech), a USB-RS485 converter, a 1.5-kW motor, a no-fuse breaker, and a 220-V autotransformer. To present the performance of this system, a laptop was used to connect the Wi-Fi DAQ device and inverter. In addition, it was established as a server and presented the scenario in which users attempt to browse the web application of the remote SCADA system.



**Figure 5.** Hardware architecture of the SCADA system.



**Figure 6.** Data visualization for real-time monitoring.

### 3.4. Data visualization

The data transmission flows in two directions: from database to the client tier and from the monitor tier to the client tier without the database. Both situations are presented using a graphical interface with the AJAX technique to present the data to users.

Without a graphical interface for monitoring, the users cannot read and understand the data easily. Designing a graphical interface for a SCADA system is necessary because it makes users know what happens exactly in the supervision. Compared with the conventional method of using the graphical monitoring interface, AJAX is a much faster approach that does not require refreshing the web page. The advantage is that the data can be visualized considerably more clearly than with a numerical data demonstration. Users can observe the data immediately because data is transmitted to the client

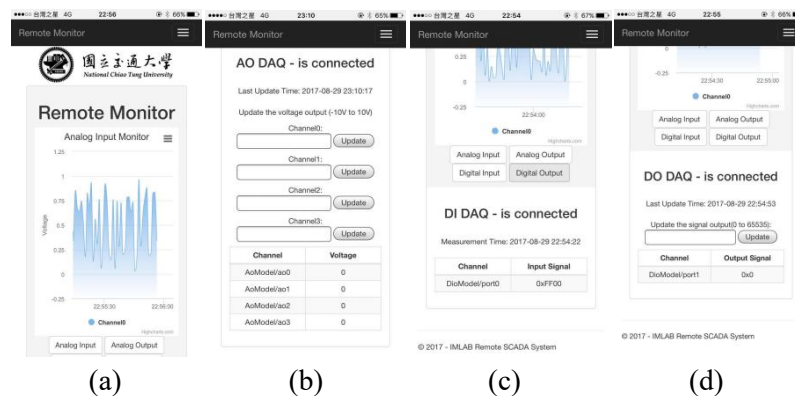


directly without waiting for writing and reading of the database. The real-time dynamic monitoring interface is shown in figure 6. The JavaScript library jQuery is used to enable the user read the data more easily and intuitively.

### 3.5. Remote control of inverter

The system developed in this study not only enables monitoring but also provides remote control. Several basic functions were developed to control the voltage and frequency of the inverter via RS-485 as the physical layer of the Modbus protocol. They can be divided into four main functions which are Analog input (AI), Analog output (AO), Digital input (DI), Digital output (DO) and shown in figure 7.

This paper presents several simple functions of remote control to demonstrate how users can control a system using their smartphones. Using the web application presented in this paper, users can send commands in case of any emergency from wherever they are without being actually present at the location. They can also use any intelligent device that can connect to a wireless network.



**Figure 7.** Implementation analog input/output and digital input/output functions with a smart phone.

## 4. Conclusions

With the development of IoT, the need for a bridge between things and the Internet is growing. This paper presents a practical IoT-based web application for an intelligent remote electrical power SCADA system. It includes a wireless sensor network for acquiring signal data and receiving information from things that people are interested in to the world through the Internet. This system enables communication with intelligent devices. Users can remotely control and monitor the system by using a browser on their PC or intelligent device.

This system was applied for remote inverter control and monitoring with basic functions. Although the system is incomplete, it has substantial potential for incorporating more functions. This system can be applied in transportation vehicles such as intelligent yachts, autonomous cars, and personal rapid transit and supervise power usage in the future. The measurement data is stored in the database to achieve efficient power management.

## References

- [1] L. D. Xu, W. He and S. Li, "Internet of Things in Industries: A Survey," in *IEEE Transactions on Industrial Informatics*, vol. **10**, no. 4, pp. 2233-43, Nov. 2014.
- [2] S. Li, L. Xu, and X. Wang, "Compressed sensing signal and data acquisition in wireless sensor networks and internet of things," *IEEE Trans. Ind. Informat.* vol. **9**, no. 4, pp. 2177-86, Nov. 2013.
- [3] W. He and L. Xu, "Integration of distributed enterprise applications: A survey," *IEEE Trans. Ind. Informat.* vol. **10**, no. 1, pp. 35-42, Feb. 2014.

- [4] L. Wang, L. Xu, Z. Bi, and Y. Xu, "Data filtering for RFID and WSN integration," *IEEE Trans. Ind. Informat.* vol. **10**, no. 1, pp. 408–18, Feb. 2014.
- [5] F. Tao, Y. Laili, L. Xu, and L. Zhang, "FC-PACO-RM: A parallel method for service composition optimal-selection in cloud manufacturing system," *IEEE Trans. Ind. Informat.*, vol. **9**, no. 4, pp. 2023–33, Nov. 2013.
- [6] D. Bandyopadhyay and J. Sen, "Internet of things: Applications and challenges in technology and standardization," *Wireless Pers. Commun.*, vol. **58**, no. 1, pp. 49–69, 2011.
- [7] L. Atzori, A. Iera, and G. Morabito, "The internet of things: A survey," *Comput. Netw.* vol. **54**, no. 15, pp. 2787–805, 2010.
- [8] L. M. L. Oliveira, J. Reis, J. J. P. C. Rodrigues, A. F. de Sousa, "IoT based solution for home power energy monitoring and actuating," *IEEE, 13th Int. Conf. Industrial Informatics (INDIN)*, Jul. 2015.
- [9] Y. Huo, W. Tu, Z. Sheng and C.M. Leung, "A survey of in-vehicle communications: Requirements, solutions and opportunities in IoT," *IEEE Conf. 2nd World Forum on Internet of Things (WF-IoT)*, pp.132–37, 2015.
- [10] A. Fachechi, L. Mainetti, L. Palano, L. Patrono, M. L. Stefanizzi, R. Vergallo, P. Chu, R. Gadh, "A new vehicle-to-grid system for battery charging exploiting IoT protocols," *IEEE Int. Conf. Industrial Technology (ICIT)*, 2015.
- [11] Z. Ding, B. Yang, R. H. Guting and Y. Li, "Network-Matched Trajectory-Based Moving-Object Database: Models and Applications," *IEEE Trans. Intell. Transp. Syst.*, vol. **16**, no. 4, pp.1918–28, Aug. 2015.
- [12] A. M. Grilo, J. Chen, M. Diaz, D. Garrido, A. Casaca, "An Integrated WSN and SCADA System for Monitoring a Critical Infrastructure," *IEEE Transactions on Industrial Informatics*, vol. **10**, no. 3, Aug. 2014.
- [13] A. Lipnickas, R. Rutkauskas, R. Cerkauskas, "A resource oriented architecture for Web-integrated SCADA applications," *IEEE World Conference on Factory Communication Systems (WFCS)*, May. 2015.
- [14] B. Cvijic, D. Bundalo, D. Pasalic, Z. Bundalo, "Cloud based web application supporting vehicle toll payment system," *IEEE, 5th Mediterranean Conference on Embedded Computing (MECO)*, Jun. 2016
- [15] E. Kanagaraj, L. M. Kamarudin, A. Zakaria, R. Gunasagaran, A. Y. M. Shakaff, "Cloud-based Remote Environmental Monitoring System with Distributed WSN Weather Stations," *IEEE Sensors*, Nov. 2015.
- [16] R. Marques, J. Rocha, S. Rafael, J. F. Martins, "Design and Implementation of a Reconfigurable Remote Laboratory, Using Oscilloscope or PLC Network for WWW Access", *IEEE Transactions on Industrial Electronics*, vol. **55**, no. 6, Jun. 2008.
- [17] C. Liu, Z. Guo, Y. Feng, F. Hong, W. Jing, "CPCA: The Cloud Platform of Complex Virtual Instruments System Architecture," *IEEE Access*, vol. **5**, pp. 4350-4360, Mar. 2017.
- [18] P. Chynal, J. Sobecki, "Eyetracking Evaluation of Different Chart Types Used for Web-Based System Data Visualization," *IEEE Conf. Network Intelligence Conference (ENIC)*, Jul. 2016.
- [19] P. Radunovic, T. Vujicic, A. Balota, "Web application for lightning activity monitoring system (LAMS)," *IEEE Conf. Information System and Technologies (CISTI)*, Jun. 2017.
- [20] W. Peng, Y. Zhou, "The Design and Research of Responsive Web Supporting Mobile Learning Devices," *IEEE Conf. Educational Technology (ISET)*, Jul. 2015.
- [21] M. A. Moyeen, G. G. Md. Nawaz Ali, Peter Han Joo Chong, "An automatic layout faults detection technique in responsive web pages considering JavaScript defined dynamic layouts," *IEEE Conf. Electrical Engineering and Information Communication Technology (ICEEICT)*, Sep. 2016.