An IoT-based Smart Electric Heating Control System: Design and Implementation

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***Abstract*—This paper presents the design and realization of an IoT-based smart electric heating control system for homes, offices, schools, community centres, and the like. The architecture proposed provides a gateway to the IoT cloud for the control system through a Data Transfer Unit (DTU) which sends the sensor data to an IoT centre via a TCP server over a GPRS/Wi-Fi wireless interface and receives energy telecommands for the controllers, which thus switch off, on or adjust electric heating operation. The hardware and software descriptions set out here are from a small pilot system which was successfully designed and implemented.**

***Keywords*—Internet of Things (IoT); Electric Heating Control System; Data Transfer Unit (DTU); Smart Home; Hadoop.**

I. Introduction

China is an example of a country where the Government is actively fostering a move from coal-burning heating to electric heating. The drive has arisen because of the significant contribution to air pollution of coal-burning, especially of airborne ash particles and sulfur dioxide pollution, [1]. The extent of the pollution helps to understand the massive need to move to electric heating, and thus also the importance of planning for economies and efficiencies from the beginning in this changeover.

In Beijing, the incentives are good to make the switch, e.g., for homes or schools, the Government covers electric heating equipment and installation costs fully [2]. In addition, the energy cost to the user is only 0.1 Yuan (0.0014 Euro) per kilowatt-hour (kWh). The government's goal is to reduce the Air Quality Index (AQI) value in Beijing to less than 100 in the winter.

In the west, and worldwide, making the electric heating systems smarter is an ongoing area of R&D. Intel and RealValue have developed a Smart Electric Thermal Storage Systems (SETS) [3, 4], as part of a 15.5M European energy storage project, the RealValue, funded by the EU Horizon 2020 research program [5]. The field trial includes 800 smart electric thermal storage systems to be installed in Irish homes. Each of these systems will be fully controlled by the owner of the house, based on a timer. There is no Internet of Things (IoT) dimension to this project. However, an IoT environment has potential to add value, and more flexible and smart solutions. This paper reports on the development of such a smart control system operating as part of a central electric heating system, which is integrated into a generic IoT architecture conceived for smart cities. The designed system enables smart control of home/school and such like heating systems, based on consumers' profiles, which could include allowances for developing the potential to exploit energy economies mentioned above. Default heating settings can be stored in the supporting cloud, and be easily changed or overridden by means of a convenient mobile app, installed on the consumers' mobile devices.

II. System Architecture

A schematic for the IoT smart electric heating control system described here is shown in Figure 1, consisting of smart controllers, which include relevant sensors, Data Transfer Units (DTUs) with supporting TCP infrastructure [6], and a cloud platform.

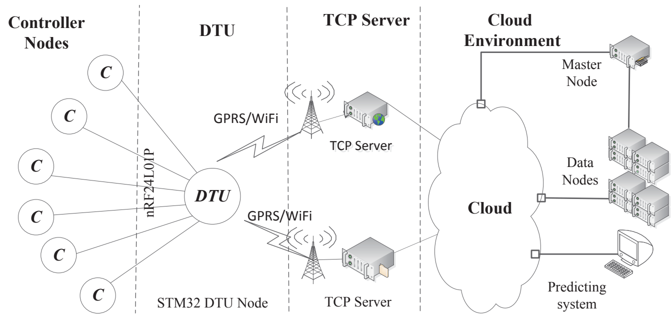


Fig. 1. The Smart Electric Heating Control System Architecture.

The key knowledge required for smart control in any location is the present temperature and presence of people / relevant activity in that location. For these, a temperature sensor such as the Maxim DS18B20 and a people presence detector, such as a HC-SR501 infrared sensor, would suffice, e.g., to support control of a number of electric heaters within a particular area, such as four 1.5kW electric heaters within an school classroom area of 60 square meters accommodating 40 students. The actual control may be by means of on-off relays and/or silicon controlled rectifiers (SCR) [7] . The controllers communicate with a DTU. A variety of solutions are possible for this, depending on the context; e.g., wireless using for instance a NordicSemi nRF24L01P a highly integrated, ultra

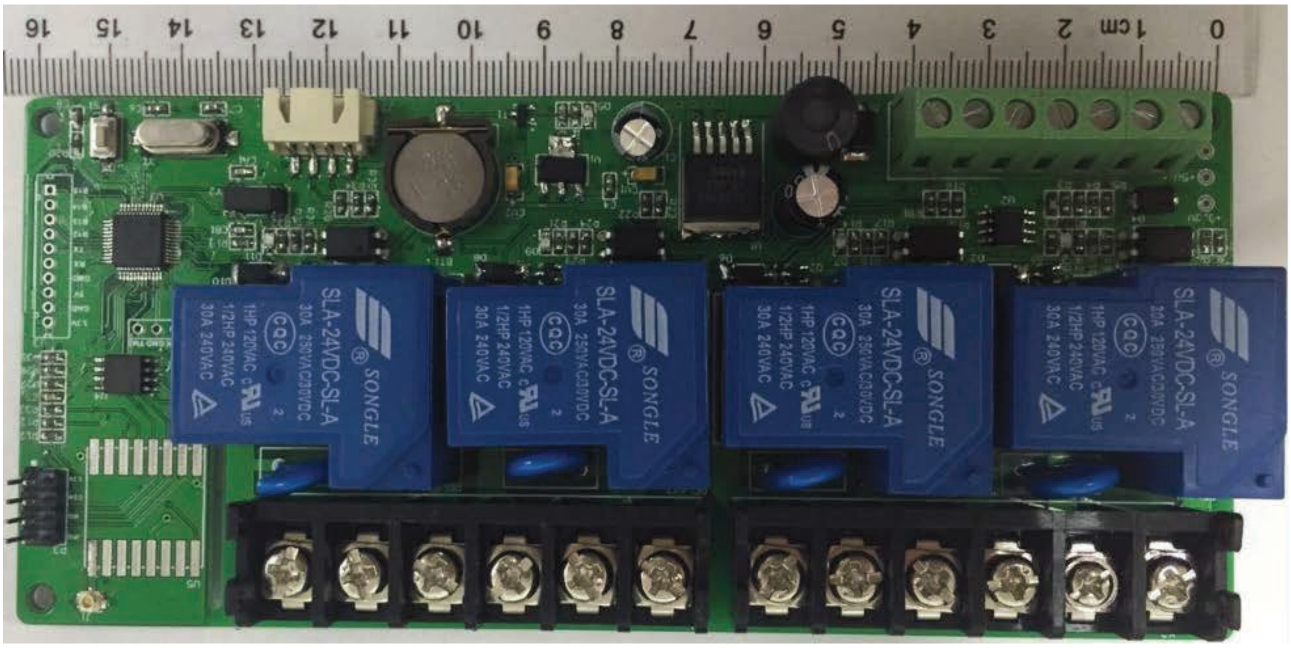


Fig. 2. The controller's hardware.

low power (ULP) 2Mbps RF transceiver IC for the 2.4GHz ISM (Industrial, Scientific and Medical) band or a Wi-Fi transceiver module, or wired where that might be feasible, e.g., by a RS/TIA-485 cable. In addition, the DTU is equipped with a low-cost General Packet Radio Service (GPRS) module for communication with a TCP server and, through it, with the cloud.

III. Design and Implementation

A. Smart Controller

The smart controller is the core unit in the electric heating control system. A picture of a typical controller hardware system configuration for a 6kW heating system, consisting of four electric heaters such as might be installed in a house or a classroom, is shown in Figure 2, and the principle diagram is shown on Figure 3. Each heater can be switched on/off by a SLA-24VDC-SL relay. When on, the input voltage level, and hence heating level, is controlled by an SCR. With the controller directed by policies, schedules or remote users, one can designate the heater as 'smart'.

In regard to seeking a low-cost design, this controller's design is based on the 1 STMicroelectronics STM32F103 32-bit MCU, which has 48 pins, 128KB flash memory, 72MHz CPU, motor control, USB and CAN support. The software was designed with the Free Real Time Operating System (FreeRTOS) . A brief summary of software aspects is provided below, while full detail of the key software components will be described in a later paper.

B. DTU

The DTU acts as a bridge between the Internet and the controller. It has a GPRS module to communicate with

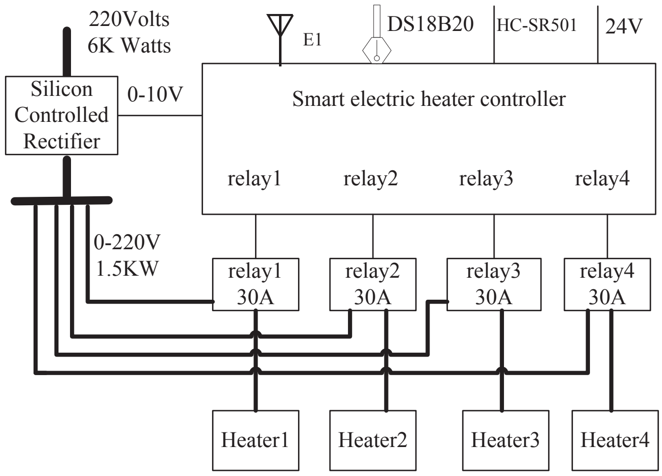
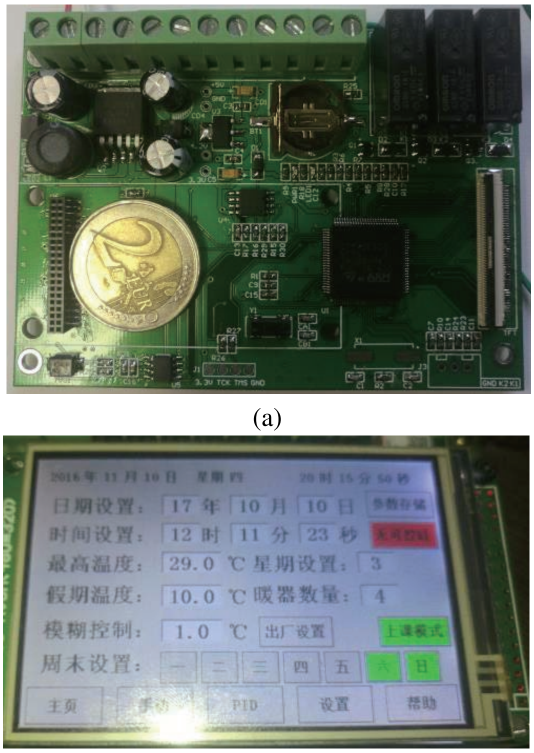


Fig. 3. An example of controller hardware system configuration.

the TCP server(s) in a real time. The STMicroelectronics STM32F103VCT6 was selected for this design. Pictures of the DTU are shown in Figure 4. It mainly includes a 3.5TFT touchable screen, a RS-485 port, a NordicSemi nRF24L01P, and a Wi-Fi and a GPRS wireless communication modules.

The software running inside the DTU was developed with the FreeRTOS. The system includes four tasks: (i) the USART data task, whose main functions are SendRecvDataToDeal and ComDataToSendGSM. The first function is used for processing the received COMMAND dataset, and the second - for the RS485 port transparent transmission; (ii) the Short Messaging Service (SMS) task for controlling the smart heater and updating parameters by sending a SMS; (iii) the networking



(a) (b)

Fig. 4. The DTU hardware implementation: (a) Main PCB; (b) 3.5 TFT GUI.

task, whose focus is on the setting up TCP/IP connections between the DTU and the TCP server over GPRS using the GPRS AT functions; (iv) the heater data task for collecting data from DTU input ports.

C. Server Side and Cloud platform

Two TCP servers are used. The first one acts as a prime server and the other as a backup. Each TCP server needs to run in a stable mode and provide data transparent transmission. The Microsoft .NET framework was used as a fast development solutions platform for designing the two required multi-thread applications, combined into a DD server, viz., (1) a TCP/IP server, designed as a Windows service that automatically starts with the operation system; (2) a GUI, a screen capture example of which is shown in Figure 5 (the numbers 1127 and 1035 (bottom rows of the upper screen) are used for the smart heating DTUs.

The distributed Apache Hadoop [8] framework was utilized for the design of the cloud as it provides an efficient Hadoop Distributed File System (HDFS) for data storing and a Hadoop MapReduce for 'big data' processing [9]. In order to improve the performance of the cloud platform, a set of software components for providing efficient data services along with a highly efficient interface for the smart heating control service were developed.

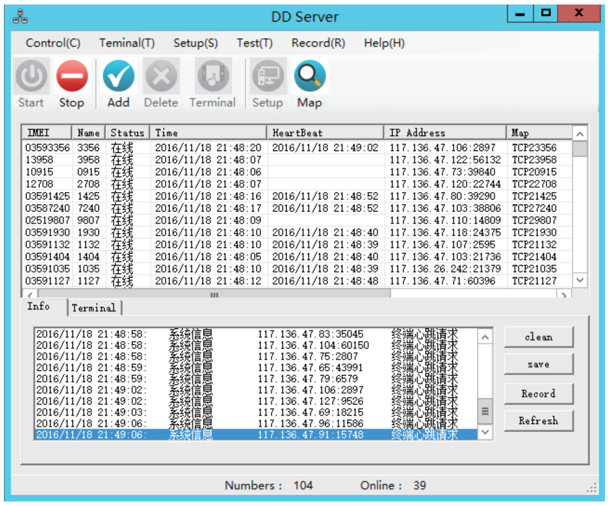


Fig. 5. The DD server's GUI.

IV. Conclusion

A new inexpensive, wireless-based, Internet of Things (IoT) smart domestic electric heating control system (for homes/schools) has been presented in this paper. The system includes smart controllers, data transfer units (DTUs), Transmission Control Protocol (TCP) servers, and a cloud platform. The system architecture, design and implementation have been outlined. A pilot test has been successfully trialed. The next phase is to roll out a fully scaled up version for a large-city deployment.

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