Development of a Compact Wireless Sensor for Analysing Building Energy Consumption: A Cost-Effective Approach

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Abstract. Construction significantly contributes to Greenhouse Gas Emissions (GHGe), accounting for 40% of the total. These emissions are either due to the embodied carbon in construction materials or due to their operational carbon (energy consumption during the service life of the building). Considering the current standards, the newly constructed building complies by the rules and regulations initiated by the government to meet the international energy standards. However, these standards were just a decade old and many of the old constructions do not fit into the current energy standards. Infact most of the buildings in Europe were constructed prior to 1990s and for their daily operation, they heavily rely on energy. While the electric meter provides overall measurements of the electricity consumption for the entire building, it is imperative to recognize that the electricity usage within individual sections of the floor often holds greater insights. Directly monitoring of the electricity usage of specific floor areas allows for a more precise analysis and targeted interventions to optimize energy usage and efficiency within those sections. Therefore, in this study, a wireless sensor node specifically designed for measuring the electricity consumption of the building floors is developed. This sensor is compact, and it integrates a current transformer, and a wireless microcontroller module. The sensor operates on the principle of electromagnetic induction and converts the high primary current into proportionally lower secondary current for measurements. Lightweight and with minimal latency, the developed instrumentation efficiently collects the energy data.

Keywords: construction, greenhouse gas emissions, electricity usage, wireless sensor node, minimal latency

1 Introduction

Internet of Things (IoT) is an emerging technology that could be used in our everyday lives. It is an embedded system which has things (sensors and machines) connected with a wireless computing machine that can be employed for automating the aspects of our daily routines. It can provide us with a detailed insights of diverse activities that a

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machine can implement, for the optimization of the resources. IoT is significant in number of applications and the acquired data from these applications could be used to add convenience in our daily routines as well as can assist companies to gain profits [1], [2], [3], [4].

In terms of the architectural perspective, IoT systems relates to various sensors and smart devices which are connected to a private, public or hybrid cloud platforms. There are several services like Azure IoT Development Platform [5],
[6] and Amazon Web Service's Kinesis [7], [8] introduced for the IoT devices for the data collection and data analysis purposes. In addition, the data analysis in the IoT devices could be performed by machine learning and deep learning algorithms that could be employed in edge computers. A few of those algorithms are Long Short-Term Memory, Kalman filter, Random Forest Regression, Regression and Time series forecasting [9], [10], [11].

The architecture of a standard IoT system consists of the three main layers, namely: a) the sensor layer, b) the software control layer and c) the application layer. The sensor layer includes the sensor and transducers that can measure the physical and derived parameters like temperature, humidity, acceleration, etc. These sensors are connected with the wireless microcontroller module, which has a unique identifier (MAC address) and are either connected with the network using the wired network or with the wireless network (Wi-Fi). After the sensors are being connected, a robust software is designed for controlling and analysing the data acquired from the sensor. The results and findings of the data (information) can then be displayed using the application layer.

With the advent of the IoT, there are new frameworks and directives introduced in form of Modern Methods of Construction (MMC), Industry 5.0 and Supply Chain 4.0. These frameworks encourage the usage of the IoT sensors and machine to machine communication (M2M). In MMC, there is a new concept of Net Zero Emission Building (NZEB) introduced for the reduction of the global CO_2 emissions. The NZEB focuses on the usage of the renewable sources to produce the electricity and promotes Climate Action Plan 2030 (CAP 2030) [12].

CAP 2030 states that the construction sector alone is accountable for producing approximately 40% of the Greenhouse Gas Emissions (GHGe). These GHGe are based on embodied carbon and operational carbon. While the embodied carbon defines the carbon emitted preconstruction of the building, whereas the operational carbon is the carbon emitted post construction of the building. The operation carbon is linked with the electricity consumption of the building which can be employed for analysing the building performance.

For determination of the operational carbon, it is essential to meet the requirements of the Climate Action Plan. Therefore, in this research, an IoT sensory system is developed that could contribute towards the enhancement of the building performance. This study focuses on the measurement of the electricity consumption and the instrumentation developed is in accordance with the Generation Data Protection Regulation (GDPR) and ISO 27001 compliance.

2 GDPR and ISO 27001

The application of the IoT sensors for the building energy management plays a significant role in monitoring of the building's energy usage. However, the deployment of the sensors in the building bring concern towards the data security towards the personal data of the occupants.

To make sure that this does not happen to any of the occupants, all the data collection and analysis must be in adherence with the ISO 27001 and General Data Protection Regulation (GDPR) [13]. The ISO 27001 provides a robust framework for managing the data security by emphasizing the risk assessment to control the data security in terms of building monitoring [14]. On the contrary, ISO 27001 complies on the developers of the IoT sensors for ensuring the data protection against unauthorised access, breaches, and other security threats.

In addition, the GDPR mandates strict guidelines for the management of the personal data of the individuals from the European Union's member states. GDPR encourages on the data minimization by ensuring that only the needed data is collected and analysed but for that, the consent from the individuals whose data is to be collected, is mandatory.

3 The IoT Architecture

The architecture of the developed instrumentation is illustrated in the figure 1, and it consists of three main layers namely:

i. Sensor Layer: In which the current transformer is connected. ii.
Software Control Layer: It is comprised of network layer and data processing layer. In the network layer, the credentials are to be required for establishing a connection with the network.
Credentials like user ID (SSID), password, API key, API URL and the MAC address of the sensor. Whereas in the data processing layer, the data acquired from the sensor (Current Transformer) must be calibrated.
iii. Application Layer: The data acquired from the wireless microcontroller, can be visualised in form of graphical representation using an IoT development Cloud platform (like Thingspeak).

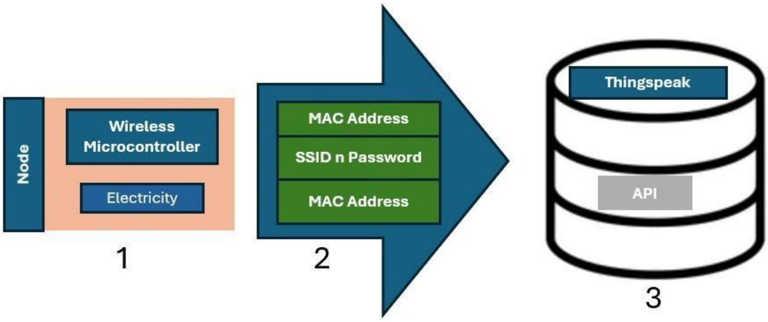

Fig. 1. Proposed IoT architecture

4 Development of the Wireless Node

For the development of the wireless node to measure the electrical consumption of the main electric line, the two main components are: i. Current Transformer and ii. Wireless microcontroller.

The selection of these components is mentioned in the following sub-sections below:

4.1 Selection of the Sensor

The selection of the wireless microcontroller is critical as it will be responsible for sending the data to the IoT cloud platform. Along with that its power rating, it is essential for a wireless microcontroller to have less latency. For this study, the Adafruit Huzzah ESP8266 is considered because it is a balance between cost, performance and ease of use. In comparison to ESP32 and Arduino + WiFi shield, it is less power hungry, compact and less expensive.

For the measurement of the electric consumption in this study, current transformer (CT) is considered. CT consists of two windings. The primary winding creates a magnetic field around the conductor whereas the secondary winding consists of many turns around the magnetic core. Such that when the primary winding carries a current, it creates magnetic field which induces a current in the secondary winding proportional to the current in the primary winding.

The induced current in the secondary winding is a scaled down version of the primary current, which can be easily measured with standard instrumentation like data acquisition system.

In this study, the output of the CT is fed to Adafruit Huzzah ESP8266 as shown in the figure 2.

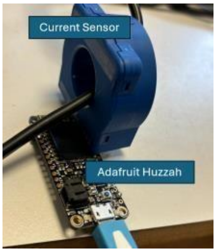

Fig. 2. Huzzah ESP8266 with Current Transformer

4.2 Programming Connection with the Network

For establishing the connection with the network, the SSID (the username of the network), network password, API URL and the API key are needed for connecting the wireless microcontroller with IoT cloud platform (as shown in figure 3).

```
const char* ssid = "Ali";
const char* password =[redacted];
const char* apiKey = "[redacted]";

const char* server = "api.thingspeak.com";
```

Fig. 3. Network Credentials

For acquiring the data of the CT, the CT pin must be connected to the analogue pin of the wireless microcontroller or with the analogue to digital converter (ADC).

Integration with IoT Cloud Platform

The IoT cloud platform selected for this study is Thingspeak. It is a platform developed by the Mathswork that connects the sensor with the cloud platform for making the data accessible for the user, remotely.

The data collected can be visualise in form graphical representation. For that, a channel must be made. The channel made for the developed prototype has the current value in the Y- axis and the time at which the sensor was taking the reading were represented in the X – axis. The graphical representation of the acquired readings from the current sensor can be seen in figure 4.

Fig. 4. Visualisation in IoT Cloud Platform

For the testing purpose, the readings of a heater were collected. The developed instrumentation was successfully connected with the IoT cloud platform, indicating towards the successful deployment of the developed instrumentation.

5 Conclusions and Future Works

The implementation of the IoT in the construction sector have been instrumental in assessing the building lifecycle and circularity. Moreover, it can play a substantial role in enhancing the building performance by optimizing the usage of the electricity. This study provides a solution to the analysis of the electricity consumption in the confined spaces of the building by developing an instrumentation that could contribute to the data collection and processing. The developed instrumentation can provide the update on the energy usage to the stakeholders or the building occupants so that they could take informed decisions for the optimization of the building energy usage.

The developed instrumentation is equipped with a wireless microcontroller that establishes connection with the IoT cloud platform. The data acquired in the cloud could further be use for the data analysis so that valuable insights for the data could be acquired.

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