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DEPLOYMENT OF SENSOR NETWORKS FOR EFFICIENT POWER CONSUMPTION MONITORING APPLICATION

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Abstract:

This paper presents a wireless monitoring system implemented using a wireless sensor network and the XCTU software. The existing monitoring systems for tracking alternating current utilization in various devices face limitations in terms of real-time data acquisition and seamless wireless transmission to a central computer for comprehensive analysis. This hinders the ability to accurately measure electric current consumption, impeding the development of efficient energy management strategies. Therefore, the primary focus of this monitoring system is to wirelessly track the utilization of alternating current in various devices. The wireless monitoring system relies on the integration of the XBEE device and the SCT 013 current sensor. The SCT 013 current sensor accurately measures electric current consumption, exhibiting a mere 0.03 variation, while the XBEE device is employed to transmit this data wirelessly to a computer for subsequent data analysis. In this configuration, the XBEE operates in AT mode for seamless data transfer to the computer.

Keywords:

Sensor Network, Power Consumption, XBEE, Monitoring System

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Introduction

The advent of electricity has transformed the world, ushering in an era of unprecedented advancement. In contemporary life, nearly all our devices, such as LED lights, water heaters, fans, and even essential equipment like WIFI routers, rely on electricity for their normal operation. The absence of electricity renders many aspects of daily life unfeasible, leaving us without WIFI for connectivity, fans for comfort, hot water for showers, and other conveniences. This underscores the profound importance of electricity in human existence. While every household is equipped with an electricity meter that tracks total monthly consumption, it falls short in distinguishing the individual contribution of each device to the overall electric consumption.

In this scenario, the wireless monitoring system utilizing the SCT 013 current sensor proves instrumental in addressing this challenge. The SCT 013 efficiently gauges the electrical consumption of a device, with the XBEE device facilitating seamless transmission of these measurements to a computer for in-depth analysis. This system empowers users to remotely monitor the status of their devices, thanks to the XBEE device's extensive radio frequency range, enabling data transfer across considerable distances.

To effectively address a problem, a strategic approach involves identifying its underlying cause and then implementing precise measures to mitigate that cause. In essence, this monitoring system serves as a powerful tool for pinpointing the most energy-intensive devices, enabling users to gain comprehensive control over their electrical consumption across various locations.

By identifying the device with the highest electricity consumption, this system empowers users to make informed decisions about more efficient energy management. When the monitoring system reveals significant electricity usage by a specific device, users can proactively seek ways to curtail that device's energy consumption. This proactive approach fosters improved energy efficiency and overall cost savings.

Related Work

Wireless Sensor Networks (WSNs) encompass an extensive network comprising numerous sensor nodes, each equipped with radio frequency capabilities for seamless communication (Alhmiedat T. et al. (2017); Kaur k. et al. (2014)). The primary purpose of WSNs is centered on monitoring, whether it be for physical or environmental observations. These sensor nodes are intelligently designed to be cost-effective and energy-efficient, facilitating widespread adoption and experimentation within the realm of WSNs. These sensor nodes play a multifaceted role, divided into three crucial components: sensing, computing, and communication. The sensing component is responsible for gathering data from the immediate surroundings. The computing aspect involves microcontrollers that process the collected data, while the communication part is tasked with transmitting this data to a central base station (Le M. et al. (2020)). The applications of WSNs are diverse, spanning both indoor and outdoor environments. In outdoor scenarios, WSNs are instrumental for tasks such as greenhouse surveillance, battlefield monitoring, military operations, environmental monitoring of small animals, and even forest fire detection (Saad A. M. et al. (2016)). Indoor monitoring, although typically requiring a fewer number of sensor nodes compared to outdoor settings, is valuable for overseeing different rooms and the conditions on various floors.

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XBEE, also referred to as ZIGBEE in some contexts, stands as a radiofrequency module device recognized for its prowess in wireless data transmission. Operating within the realm of radiofrequency, XBEE is a linchpin in the domain of Wireless Personal Area Networks (WPANs). A WPAN comprises a dynamic ensemble of components, including end devices, coordinators, and routers. The coordinator holds a pivotal role, serving as the bridge that connects the XBEE network to various other types of networks through the use of specialized communication mediums. Meanwhile, routers operate as key enablers in linking end devices to the coordinator. In essence, a single router can foster connections with multiple end devices, mirroring a cascading effect, while coordinators can also be hierarchically connected to a higher-level coordinator. XBEE harnesses diverse network topologies, adapting to specific communication needs. These topologies encompass mesh, star, and cluster tree configurations (Alhmiedat T. et al. (2017); Kamarudin N.H. et all (2015)). Comparing XBEE to other wireless counterparts like Wi-Fi and Bluetooth, it excels in multiple facets. XBEE boasts an impressive communication range of up to 200 meters, dwarfing Bluetooth's 10-meter range and outstripping Wi-Fi's 100-meter reach. Additionally, XBEE shines in the realm of energy efficiency, consuming considerably less power compared with the high-power consumption of Wi-Fi and Bluetooth devices (Kumar V. et al. (2019); Kamarudin N.H. et al (2017)).

The SCT 013 current sensor is a specific type of current transformer renowned for its invasive characteristics, primarily employed in measuring energy consumption. This sensor operates on the fundamental principle of gauging the electromagnetic induction generated by electric current. It quantifies this induction effect by dividing the measured value by the number of coils within the current transformer. The SCT 013 current sensor comes in various model numbers, each tailored to measure specific ranges of electric current. For instance, the SCT013-100A is designed to measure currents up to 100A, while the SCT013-50A is optimized for currents up to 50A, and so forth (Sowmya K. V., et al. (2021). Notably, research has demonstrated that the SCT 013 current sensor exhibits an impressive accuracy level of 98% and maintains a minimal precision margin of 0.04, underscoring its reliability and utility in practical applications (Usrah I. et al. (2019)).

Azevedo et al. (2021) proposed a method for power home monitoring systems using controlled battery charging. Relays are used to control the battery charging process. The collecting and monitoring data from a home monitoring system using a coordinator connected to a Raspberry Pi, a local MySQL database server, and a simple webpage developed using PHP. The data is exported via MySQL files to a web cloud according to a pre-established periodicity to minimize the problem of SD card corruption. Another script is running on a desktop computer to import this data into another database when it is powered on.

Other works by Utami et al. (2018), they are present an electrical power monitoring system implemented via wireless sensor network and Internet of Things (IoT). The electrical power consumption level of any electrical devices or areas like offices, classrooms, or houses can be monitored via the internet. Sownya et al. (2021) presents the utilization of various negative coefficient sensors to obtain power consumption optimization and home automation. The sensors used were LDRs, thermistors, humidity sensors, and gas sensors to obtain information such as light intensity, temperature, humidity, and harmful gases, respectively. The data was transmitted to the GSM from the controller with the help of Max232 IC. Zigbee wireless sensor network was initially used to monitor and control the system, but due to its limitations, GSM system was used in the extension part of the project.

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Cowlyn et al. (2016) proposed A wireless sensor network for collecting electrical energy consumption and power quality monitoring within an industrial environment is proposed. The purpose of the proposed WSN is to monitor energy consumption effectively using inexpensive sensors and data can be acquired, without disruption of production, in order to determine energy usage between different stages and lines of production and more accurately grade customer pricing per part produced.

Table 1. These Papers Discuss Various Aspects Of Power Consumption Monitoring Applications.

Author (year)	Objective	Method
Aziz et al. (2023)	Analysis and Monitoring Energy Consumption in Basic Electric Bills	The value detected by the sensor is sent to the LCD and Blynk to display current, voltage, power, and kWh.
Somantri et al. (2020)	Electrical Consumption Monitoring and Controlling System Based on IoT and Mobile Application	IoT based electronic devices or via the internet where electricity consumption data is stored in the Firebase real time database using the ACS712 current sensor, ZMPT101B voltage sensor, an Arduino microcontroller, and NodeMCU V3. The tool sends current, voltage, and wattage data into the database, and then it is converted into kWh. The system can monitor electricity consumption for 4 electronic devices and control electronic devices using a relay module, which functions as an electric switch to turn on and off electronic devices controlled via an Android device.
Zoni et al. (2018)	PowerTap: All-digital power meter modeling for run-time power monitoring	The contribution of the work is PowerTap, a methodology to design an all-digital power monitoring infrastructure for generic RTL descriptions encompassing both the RTL level power modelling and the feasibility issues.
Thaung et al. (2016)	Electric Utilization Monitoring and Usage Optimization with Mobile Application	The methodology used in the project includes current sensing and power factor measurement approach to capture the characteristic of appliances and teach machine to learn and classify it. The power measurement implements current and voltage transformer to obtain the phase shift and hall effect current sensors were used to capture the current flow. The combination of these 2 parameters contributes to the real power calculation

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Methodology

In Figure 1, the component on the transmitter side is connected to a hairdryer for the purpose of measuring its energy consumption and subsequently transmitting this data to the receiver. Although the receiver side is not depicted, it is, in fact, situated on the right side of the computer. To validate the accuracy of the current sensor's measurements, a clamp digital AC meter is employed. This meter is utilized to cross-reference and confirm the readings obtained from the current sensor, ensuring the precision of the measured values. Figure 2 provides the flowchart outlining the project's design for monitoring power consumption.

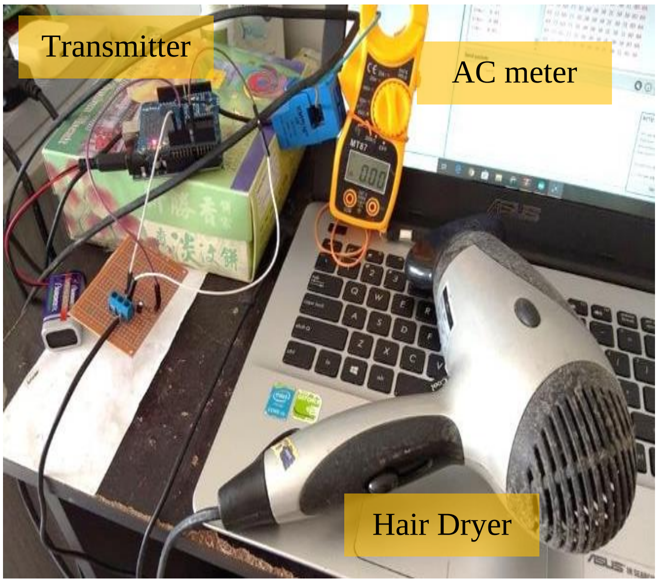

Figure 1: Overall Diagram of the Project.

The circuit depicted on the circular board in Figure 3 serves the crucial function of processing data sourced from the SCT013 current sensor and transmitting it to the Arduino UNO microcontroller. This circuit is composed of two 10K resistors and a single 10µF capacitor. The pairing of two resistors arranged in series is designed to create a voltage divider within the board. The primary objective of this voltage divider is to reduce the supplied 5V voltage originating from the Arduino to a lower value, specifically 2.5V. This reduced voltage, often referred to as a new reference voltage or offset voltage, plays a pivotal role in signal processing. The capacitor integrated into this circuit, contrary to serving as a filter, serves as a low-impedance pathway connecting to ground for the AC signal. The data extracted from the SCT013 sensor is transmitted to the Arduino UNO through its analog pin A0. Figure 3 visually illustrates the circuit configuration on the circuit board.

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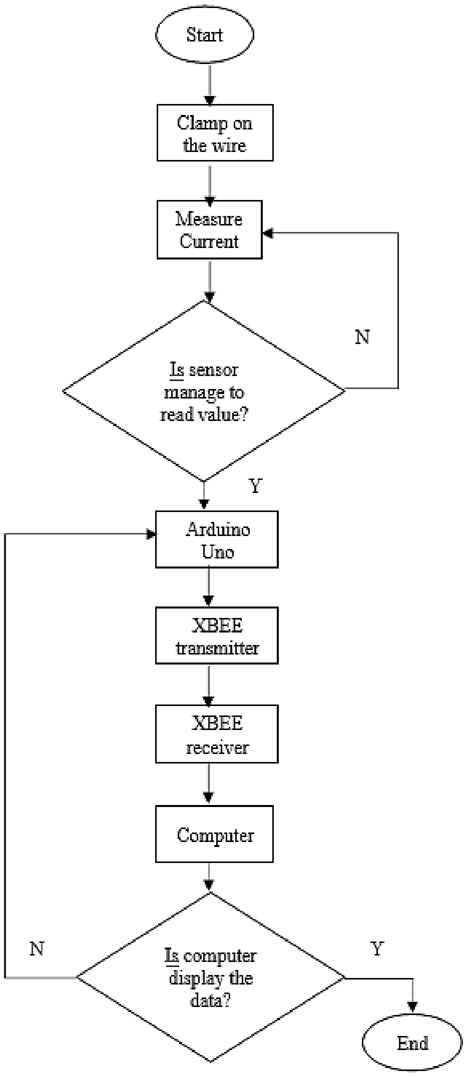

Figure 2: Flowchart of the Project.

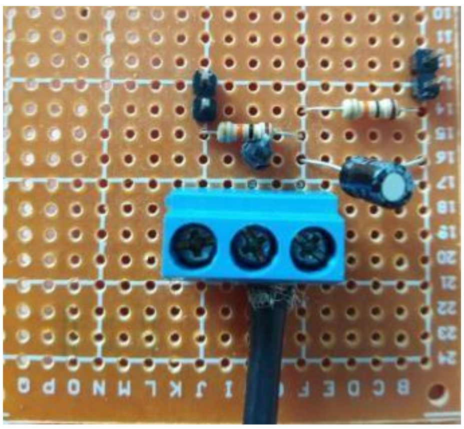

Figure 3: A Circuit With A Voltage Divider

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The battery serves as the power source, facilitating the normal operation of the Arduino UNO. Subsequently, the SCT 013 current sensor undertakes the task of measurement and data collection before forwarding this information to the Arduino UNO microcontroller. Within the circuit, the voltage divider plays a pivotal role by converting the voltage into an offset voltage. This transformation enables the Arduino UNO to effectively receive and interpret the data sourced from the current sensor. The XBEE, in collaboration with the XBEE shield connected to the Arduino UNO, then facilitates the transmission of the measured data. The receiving end of the XBEE device on the other side acts as the recipient, finalizing the data transfer process.

On the receiver side, the setup comprises an XBEE USB adapter and an XBEE device. The XBEE device, stationed as a coordinator, plays a vital role in gathering data transmitted from the XBEE end device located on the transmitter side. The XBEE USB adapter serves a dual purpose, as it not only enables the configuration of the XBEE device but, notably in this project, also functions as the interface for the XCTU software. Through the XBEE USB adapter, the coordinator XBEE device efficiently receives the data, presenting it within the XCTU software interface.

Result

The outcomes of this project can be categorized into two distinct parts. In Part A, we observe the values obtained directly from the SCT 013 current sensor, without any involvement of the XBEE device. In Part B, we examine the data displayed on the computer, which is achieved with the aid of the XBEE wireless device.

The Result Without The Connection Of XBEE Device

Part A entails the monitoring system without the inclusion of the XBEE wireless device. The SCT 013 current sensor is clamped onto either the live or neutral wire of the hairdryer, while the circuit on the circular board connects the SCT 013 current sensor to the Arduino, which, in turn, interfaces with the computer. The Arduino UNO microcontroller requires the Arduino IDE software for verifying and uploading the coding, also referred to as a sketch. A sketch is essentially a set of instructions provided by the user, guiding the Arduino UNO in executing specific tasks. The results of these actions are then displayed on the serial monitor. The project's sketch commences by configuring the Emonlib. This Arduino library encompasses comprehensive information about the current sensor, including its calculation methodology. Subsequently, the Arduino UNO is set up with a baud rate of 9600, enabling it to relay messages to the serial monitor at a rate of 9600 bits per second.

The sketch then focuses on the input pin and calibration. Calibration assumes critical importance within this project, and the calibration value is determined through the equation: Calibration value = IP / VS. While the calibration value serves as a reference point, it necessitates manual calibration by the user to achieve a more precise measurement. In this project, the calibration value is initially set at 30, with the student subsequently adjusting it downward to gauge its impact on result accuracy. Ultimately, the calibration value is fine-tuned to 27, as it yields the most accurate readings when compared with those from the AC clamp meter. The subsequent lines in the sketch pertain to the calculation method contained within the Emonlib, followed by the printing of results derived from Emonlib calculations.

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current_only_1 | Arduino 1.8.11

File Edit Sketch Tools Help

current_only_1

```
// EmonLibrary examples openenergymonitor.org, Licence GNU GPL V3

#include "EmonLib.h"                   // Include Emon Library
EnergyMonitor emon1;                   // Create an instance

void setup()
{
  Serial.begin(9600);

  emon1.current(0, 27);             // Current: input pin, calibration.
}

void loop()
{


  double Irms = emon1.calcIrms(1480);  // Calculate Irms only

  Serial.print("Irms= ");
  Serial.print(" ");
  Serial.println(Irms);          // Irms
}
```

Figure 4: The Sketch Of The Project

The hairdryer functions with two distinct spinning speeds during its operation. Speed 1 represents the lower speed, generating a modest airflow, while Speed 2 operates at a faster pace, resulting in a more substantial airflow. It's worth noting that the choice of operating speed directly impacts the energy consumption of the hairdryer. In Figure 5, we observe the values measured by the SCT 013 current sensor and display measurements obtained from the AC clamp meter. This comparative analysis is essential to gauge the accuracy and consistency of the two measurement methods.

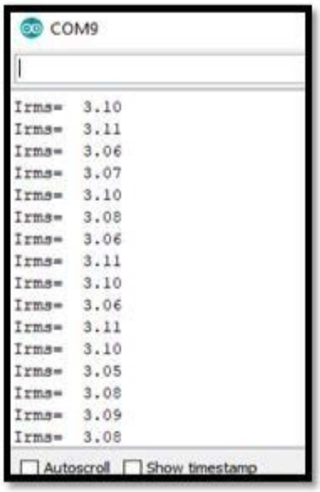

Figure 5: SCT 013 and AC Clamp Meter Value Measurement

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In Figure 6, we find the values obtained via the SCT 013 current sensor and illustrate measurements captured by the AC clamp meter. Comparing the results in Figure 6 with those in Figure 5, a clear pattern emerges where a discernible increase in electric current usage occurs when the user switches the hairdryer to a higher spinning speed.

Figure 6: SCT 013 and AC Clamp Meter Value Measurement When The Speed Is Switched.

The Result With The Connection Of XBEE Wireless Device

In this context, another essential software application for managing the XBEE wireless device is XCTU. Since the Arduino UNO connects to the computer wirelessly, the Arduino IDE isn't applicable, making XCTU the preferred choice for displaying the measured values. XCTU possesses the capability to identify neighboring XBEE devices, as demonstrated in Figure 7. For this project, the XBEE wireless device operates in AT mode, also known as transparent mode. This mode successfully facilitates wireless data transfer to the computer, as attested by the project's success. To verify the correctness and accuracy of the measured values, an additional tool is employed: a clamp digital AC meter. This meter is positioned at the same location as the current sensor, enabling it to provide precise readings of the hairdryer's energy usage. The values recorded are illustrated in Figure 8 and Figure 9. Both figures reveal minimal discrepancies between the AC clamp meter's readings and those obtained using the SCT 013 current sensor. The disparity is typically within a narrow range of plus or minus 0.02, indicative of the high accuracy associated with the SCT 013's measurements.

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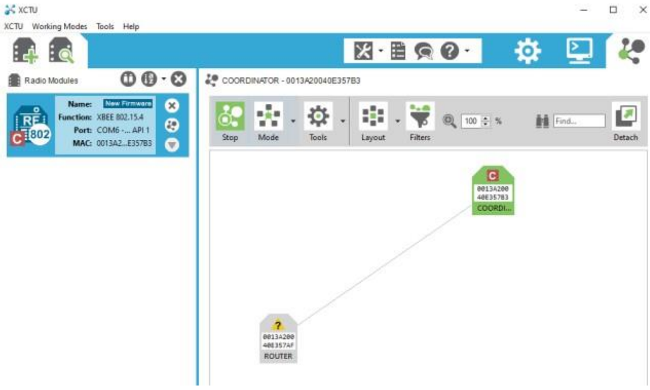

Figure 7: XCTU Software That Can Detect Other XBEE Devices In The Surrounding Area.

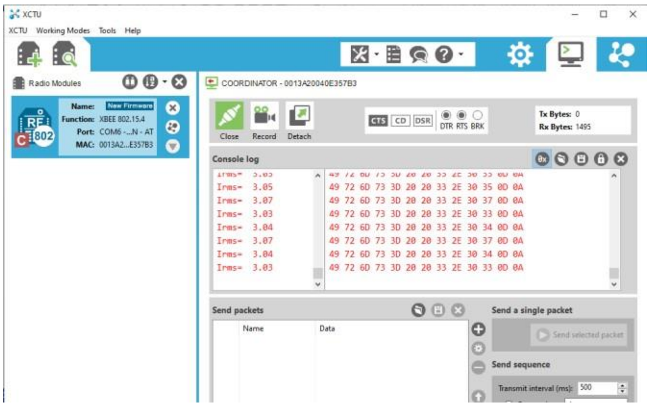

Figure 8: Display For The Measured Result At Speed 1

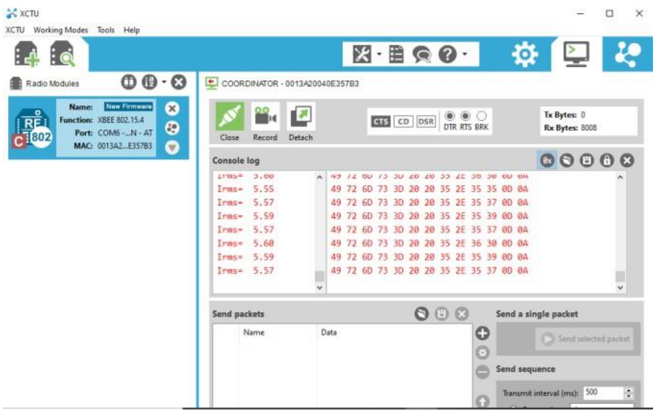

Figure 9: Display For The Measured Result At Speed 2

Conclusion

To sum up, the SCT 013 current sensor demonstrates remarkable precision in gauging a device's energy consumption, exhibiting a mere 0.03 variation in comparison to the AC clamp meter's readings. Furthermore, the XBEE device, functioning seamlessly in AT mode, adeptly conveys these measurements to the computer interface wirelessly.

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This wireless monitoring system finds its niche in educational institutions, serving as a versatile solution for the remote oversight of energy consumption across diverse classrooms. It not only furnishes crucial insights into energy utilization but also empowers informed decision-making in resource management, contributing to enhanced sustainability and operational efficiency within educational environments.

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