IoT-Enabled Air Conditioning Real-time Monitoring: An Arduino Uno R4 Approach for Indoor Temperature, Humidity, and Electrical Characteristics

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Abstract. This research focused on the monitoring of an air conditioning cooling system using an IoT platform. The IoT device used in this study was the Arduino Uno R4, along with the Arduino IoT Cloud for the online platform. The air conditioning system had a capacity of 2.5 kW and was equipped with an inverter, allowing for efficient energy use and temperature control. The results showed that the average temperature differential was 10°C between the inlet and outlet of the evaporator. Regarding the electrical results, it can be concluded that power consumption and electrical current were directly proportional. The higher the electrical current, the higher the power consumption. The average power consumption during monitoring was 388 W. Additionally, this research provides a smart solution for monitoring the performance of air conditioning systems using IoT devices. The monitoring also reflects the actual condition of the air conditioning system. By leveraging IoT technology, users can access real-time data and analytics and contribute to smart home technologies.

Keywords: Air Conditioning, Arduino Uno R4, IoT, Real-Time Monitoring

1 Introduction

The development of Internet of Things (IoT) technology is currently very rapid. This is because IoT has versatile capabilities such as automation and monitoring systems. The IoT role in air conditioning systems provides energy loads, indoor air quality (IAQ), and low-cost information (Negara et al., 2024). Adopting this technology allows the occupants to monitor their air conditioning system in actual conditions. In addition, IoT-driven sensor technology offers processing and data storage to maintain the air conditioning system (Meng et al., 2024).

The air conditioning system is one of the most vital systems for maintaining the indoor environment to secure the physical and mental health of residents. However, without using capable devices observing the specific parameters including room temperature, humidity levels as well as energy consumption is impossible (Liu et al., 2024). Therefore, the IoT-driven sensor technology is present to control and monitor each network-based parameter. This device is made based on smart sensors and

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integrated into each part (Nast et al., 2023). Several IoT devices have developed rapidly nowadays, such as the Arduino R4 microcontroller (Negara et al., 2023).

The R4 microcontroller is the latest variant of the microcontroller device from the previous series, the Arduino Uno R3. This microcontroller has a WiFi module in its chipset. Unlike the Arduino Uno R3, the Arduino Uno R4 is IoT based. The main advantage of this device is its capability for direct integration with the IoT ecosystem (Bohara et al., 2023). This is facilitated by the device's built-in WiFi module, which eliminates the need for additional shielding or external equipment to enable IoT connectivity (Nast et al., 2023). Moreover, the Arduino R4 offers extensive peripheral integration, enhanced signal processing capabilities, and the highest performance of the previous series of Arduino Uno (Erham & Inten, 2020).

This research focuses on monitoring parameters, including temperature, relative humidity, and electrical parameters of the air conditioning cooling system. This research aims to obtain real-time monitoring of the air conditioning cooling system under actual conditions. The monitoring applied in this study was integrated with IoT an IoT system. The Arduino Uno R4 microcontroller was used in this study for data logging and IoT integration.

2 Methodology

The air conditioning model that was applied in this research was a split wall 2.5 kW Inverter with R-410A. The technical data of the air conditioning can be seen in Table 1. The main instruments applied in this study include DS18B20, DHT22, and PZEM-004T. To monitor each parameter, the Arduino Uno R4 microcontroller was used in this study for data logging. This microcontroller was the latest variant provided by the ESP32-S3 Internet of Things (IoT) system. In addition, this microcontroller is capable of functioning as an IoT device and monitoring remotely without requiring additional components, unlike a conventional microcontroller. Technical details of Arduino Uno R4 can be seen in Table 2.

This microcontroller was integrated with Arduino IDE software for algorithm design according to the research objectives. DS18B20 sensors were installed on both the inlet and outlet sides of the evaporators. The DS18B20 sensor's measurement range is from −55°C to 125°C with a specific error of ±0.5% (Khairudin et al., 2021). The relative humidity sensor DHT22 was positioned similarly to the DS18B20 on both the inlet and outlet sides of the evaporator. Both the thermocouple and DHT22 work to monitor the temperature and relative humidity of the air conditioning system. The schematic of the research monitoring can be seen in Figure 1.

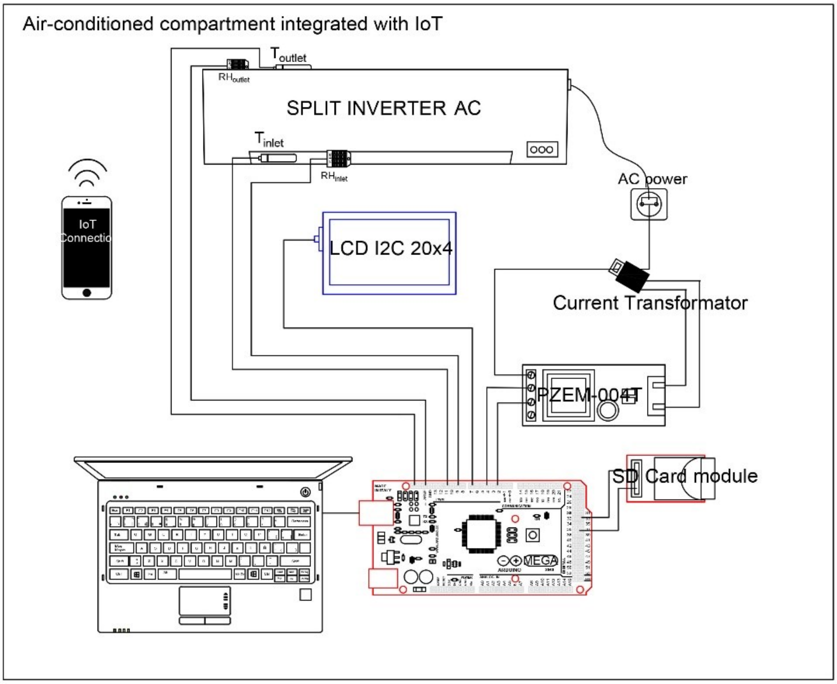

Figure 1. Schematic experimental design for an air conditioning system with integrated IoT

Table 1. In-depth details on the specifications of split inverter AC units

Model	Refrigerant: R-410A	
	Unit	Value
Heating input power	kW	0.58
Rated current	A	3
Maximum power	kW	2.06
Maximum current	A	9.5
Compressor speed range	RPM	600–3600
Cooling capacity	kW	3.2
Input power	kW	0.485
Rated current	A	2.7
Maximum power	kW	2.06
Maximum current	A	9.5
Compressor speed range	RPM	600–3600
Capacity	kW	2.5

Table 2. Comprehensive specifications of the Arduino Uno R4

Microcontroller	ARM Cortex-M4
Operating voltage	1.6 – 5.5V
Wifi module	ESP32-S3-Mini-1-N8
Input voltage	6-20V
Digital I/O pins	14 of which provide PWM output
Analog input pins	5
DC per I/O pins	20 mA
Flash memory	256 kB
SRAM	32 kB
EEPROM	4 kB
Clock speed	16 MHz

In addition, the PZEM-004T sensor was utilized in this study to monitor electrical parameters, including power consumption and electrical current. This sensor is connected to the power source of the air conditioning system. An SD card module is incorporated in this study to store monitoring data. Smartphones and PCs are used for remote monitoring as long as they are connected to a Wi-Fi network. The IoT platform used in this research was the Arduino IoT cloud. This platform provides an advanced interface to connect IoT applications. Arduino IoT cloud was selected in this study due to its reliability and validity.

This study was conducted in the Air Conditioning and Refrigeration Laboratory, Department of Mechanical Engineering, Bali State Polytechnic. The remote temperature of air conditioning was maintained at 16°C during monitoring. The room load was assumed to be constant throughout the monitoring period. This assumption implies that there were no significant variations in the thermal load during the study.

3 Result and Discussion

3.1 Indoor Monitoring

Indoor monitoring that investigated including temperature and relative humidity. Figure 2 shows the temperature variation between the temperature inlet and outlet of the evaporator. From the observation, the temperature outlet decreases significantly to 12°C at around 1500 s. Subsequently, the outlet temperature tends to be constant during monitoring. On the other hand, the inlet temperature was observed considerably higher than the outlet temperature. At 1500 s, the inlet temperature was found 24.5°C. However, throughout the monitoring, the inlet temperature of the evaporator was slightly decreased to 21°C. Figure 2 also shows the temperature differential between the temperature inlet and the outlet of the evaporator. It can be seen at around 200 s, the temperature differential reached up to 10°C. Furthermore, the temperature differential during the monitoring was within the range of 10°C -11°C. The temperature differential between the inlet and outlet of the evaporator is a key indicator of heat transfer efficiency (Chua et al., 2023). The larger the temperature differential, the more heat is being removed from the air passing through the evaporator.

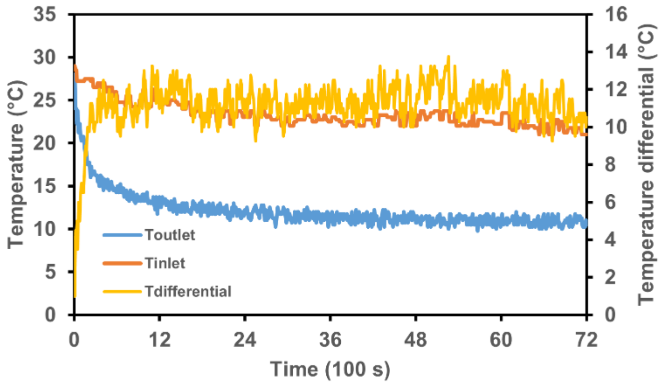

Figure 2. Variation in temperature from the inlet and the outlet of the evaporator

Figure 3 shows the relative humidity variations between the inlet and outlet of the evaporator. It can be seen the relative humidity on the outlet of the evaporator sharply increases to 90% at approximately 200 s and is relatively constant during monitoring. This is due to the evaporation process occurring within the evaporator (Randazzo et al., 2023; Raunima et al., 2023). In contrast, the relative humidity on the inlet of the evaporator was decreased. At around 3600 s the relative humidity was found 60% and slight fluctuated over 7200 s investigation. The stabilization of the inlet relative humidity at around 60% suggests that the system has reached a steady state, where the rate of moisture removal from the air is balanced by the rate of moisture addition from the environment.

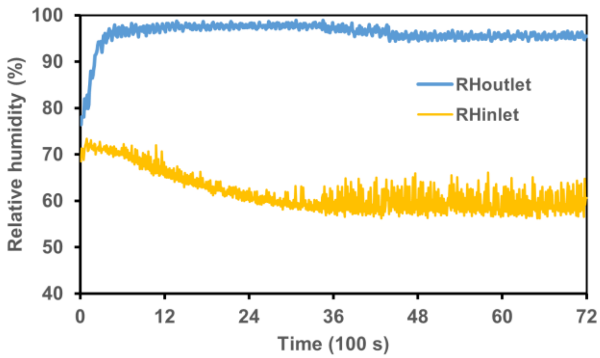

Figure 3. Variation in relative humidity from the inlet to the outlet of the evaporator

3.2 Electrical Monitoring

The electrical parameters monitored in this research include power and electrical current as shown in Figure 4. From Figure 4, both power and electrical current sharply increase at around 200 s. The average power consumption is 388 W and remains relatively stable throughout the monitoring period. This stability is due to the air conditioning system equipped with inverter technology, which allows the compressor to operate more slowly than in a conventional air conditioning system. The inverter technology utilizes a variable frequency drive (VFD) that modulates the compressor's speed to match the cooling demand (Bohara et al., 2023). This modulation is accomplished by altering the frequency of the electrical supply to the compressor motor, thereby changing its rotational speed. In addition, the inverter reduces the binary on/off cycle of the compressor, resulting in increased energy efficiency. Furthermore, the electrical current measured 2.23 A at 200 s and slightly increased to 2.33 A around 400 s. Figure 4 also shows that both power consumption and electrical current are directly proportional. The higher the power consumption, the higher the electrical current. The inverter technology maintains this relationship while optimizing the overall energy consumption by adjusting the compressor's speed and, consequently, its power draw to match the cooling requirements more precisely than traditional on/off systems.

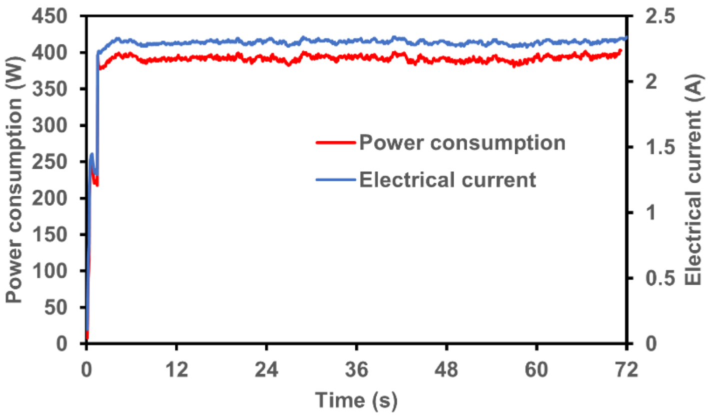

Figure 4. Variation in power consumption and electrical current of the air conditioning

4 Conclusion

The 2.5 kW inverter air conditioning system has been monitored in this research using an IoT platform. The parameters that were monitored included temperature, relative humidity, power consumption as well as electrical current. The IoT platform used was the Arduino IoT Cloud. This platform allows users to monitor various interesting interfaces. The monitored temperatures indicated an average temperature differential of 10°C between the inlet and outlet of the evaporator. This result indicates that the air conditioning system is efficient. Furthermore, the electrical results show that power consumption and electrical current are directly proportional. In addition, this study provides a remarkable solution for monitoring the performance of air conditioning based on IoT. The IoT can reflect the actual condition of the air conditioning system.

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