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Optimizing Power Consumption in IoT Sensor Systems through Adaptive Duty Cycling with Intelligent Automated Switching

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

With the increasing demand for energy-efficient and automated sensing systems, the operation of DHT11 temperature and humidity sensors in different modes to optimize energy consumption has been explored. The experimental setup consists of a DHT11 sensor, INA219 current sensor, and IRLZ43N MOSFET relay, interfaced with a Raspberry Pi 4 to collect and upload data to the Adafruit

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IO cloud platform. Additionally, Google Assistant and IFTTT are used for voice-controlled sensor activation. The study evaluates three operational modes: continuous operation, code-controlled operation, and voice-controlled operation. In continuous operation, the sensor remains active for three hours, consuming 91.39 J of energy. In code-controlled mode, the sensor operates for a fixed time and is pushed in an idle state for the rest of the time. There is a significant reduction in energy consumption demonstrating a 99.8% energy saving as compared to continuous operation. The voice-controlled mode, which activates the sensor using voice commands, further optimizes power consumption, requiring only 0.147 J over three hours. However, a 20-30 second activation delay was observed due to the cloud-based processing of voice commands. The findings of this study highlight the potential of optimized duty cycling and intelligent automation in reducing energy consumption and improving sensor efficiency in IoT-based applications.

Keywords: DHT11 sensor; INA219 current sensor; IRLZ43N MOSFET relay; Raspberry Pi 4; Adafruit IO; IFTTT; automation.

1. INTRODUCTION

The most common measurement done on Earth is air temperature measurement. Temperature is an expression for denoting a physical condition of matter, just as the mass, dimensions, and time. Still, the idea of temperature is a relative one. Temperature is the measure of that heat, which is assumed to be in continuous motion present in the minute particles of the matter. For standardizing the temperature of objects under varying conditions, several scales have been devised such as Centigrade, Fahrenheit, and Kelvin. The International Practical Temperature Scale is the basis of the most present-day temperature measurements. The scale was first invented by an international commission in 1948 with a revision in 1960 (Liptak, 1995). The temperature range of the universe ranges from near zero of black space to billions of degrees in the nuclear fusion process deep within the stars. This is the wide range and no sensor could possibly cover this tremendous range. It is believed that Galileo invented the liquid-in-glass thermometer around 1592 the principle behind it was later discovered by Thomas Seebeck in 1821.

Measurement of any physical quantity is undertaken to ascertain and present the state, condition, or characteristic of a system in quantitative terms. Measurement is the first operation carried to reveal the performance of a physical or chemical system. The traditional thermal elements, used had range of -184 to 538oC which were used for limited applications such as heating, ventilation, and industrial applications. The traditional filled elements used such as wax and other solid filling materials have disappeared and mercury filling is not being favored due to its toxic characteristics. Similarly, gas filling is not used because of the requirement of large size bulbs and vapour filling can be a problem if the process temperature crosses through the ambient temperature. Liquid filling has problems with head effects such as limited capillary lengths and compensation (Liptak, 1995).

All living species are endowed with sensory organs and actuating mechanism for carrying out their routine activities. Similarly, in automation of the system, to gain knowledge and organize several activities, a large number of sensing systems are needed and they are known as transducers and lately as sensors. Diodes and integrated circuitry (IC) transistors have been readily available as temperature sensors. The silicon and germanium transistors are small and inexpensive but before they are used in sensing systems, they need to be packages in the form of IC. The readily available sensors when integrated with microprocessors results into smart sensors. Smart sensors are termed hybrid sensors as well as they employ a variety of components to deliver sensed information, in a convenient and comfortable way (Murty, 2018).

In traditional systems, sensors is specified by its sensitivity, input and output signal ranges, offsets, linearity, hysteresis. For compensating of some deficiencies involved and to ensure linearity between input and output, there is a provision of the signal processing unit. The micro-miniaturization of the single device along with the IC chip, is termed as smart sensor. Smart sensors linearize their own output, compensate for environment changes, include self-calibration and diagnostic functions for themselves and the system (Murty, 2018). In temperature measurements CMOS temperature sensor ICs are widely used. As theses CMOS are sensitive to temperature variations, any variation in temperature produces corresponding change in voltage. In self-calibrated mode, the voltage is converted into temperature and can be recorded or viewed with the assistance of micro-controller on the display device (Meijer et al., 2018). When the sensor is in an active mode of operation, it draws certain amount of power for its functioning. Prolonged use of temperature sensors for the recording use of temperature can lead to overheating and pre-mature damage to the device. Operation of temperature sensor only when required has to be designed so that extra wattage is not consumed and longetivity is ensured (Wei & Bao, 2018).

The term of Internet Things (IoT) has emerged over the past few years as one of the popular technology buzz terms. IoT refers to the interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data. The scope of IoT is not just limited to getting devices connected or networked, but rather it is more about the exchange of meaningful information from one device to another to acquire purposeful results. In the context of IoT, things refer to a variety of devices (Köylü et al., n.d.). At times even humans are the part of loop to become things. To fullfil the pre-requisite of being a thing, it requires the identity of its existence. The thing in a network can monitor or measure or can do both. As in the case of the temperature monitoring system, temperature sensor is being called as thing. Things are capable of exchanging data with other connected devices in the system. The data could be stored in a centralized server or cloud, processes there and a control action would be initiated (Yugank et al., 2022).

Revolution has taken place in the way technology interaction is being initiated due to the integration of voice-controlled switching of devices (Bansal et al., 2024). Voice controlled IoT systems allow the users to communicate with the devices using natural speech, eliminating the need for manual interfaces like keyboards or touchscreens. With the advent of low cost tiny micro-controller and variety of sensors available it is convenient to implement home automation using voice commands (Venkatraman et al., 2021). Traditional systems often require user interfaces to navigate through menus or type commands, which can be time-consuming. In contrast voice commands allows users to perform tasks with minimal effort quickly and straightforwardly. One of the most compelling aspects of voice-controlled IoT is the ability to seamlessly integrate with smart ecosystems. Smart home devices, for instance can be centrally controlled through voice assistants like Alexa or Google Assistant (Ekta et al., 2020).

Controlling the operation of temperature sensors using voice commands is a significant step involved in power management. This kind of approach optimizes the functionality of the sensor, ensuring that it operates only when needed, thereby improving energy efficiency, and extending device lifespan (Qin et al., 2023). A major advantage of voice-controlled operation is its hands-free and remote accessibility. By integrating voice control feature with the regular temperature monitoring system it is possible to create complex workflows where action is triggered only when required. This means rather than keeping the sensor operational at all times, it can be programmed to wake up only when required, reducing the unnecessary data processing (Jawarkar et al., 2008). In agricultural applications, farmers can remotely activate the sensors and retrieve the necessary environmental data without physically visiting the location. This contributes to enhancing the efficiency of precision agriculture, where real-time data is crucial for making informed decisions about irrigation, ventilation and crop health (Nandurkar et al., 2014). Data-driven activation is crucial aspect of the voice-controlled operation of the temperature sensors. By switching the sensor into measurement mode, data collection only occurs when needed, reducing data storage and ensuring that only relevant data is processed.

Temperature measurement plays a crucial role in agriculture, it directly impacts plant growth, soil health and overall farm productivity. Different crops have specific temperature requirements for their growth and fruiting stage. Any deviations from the optimal conditions can lead to reduced yield and crop failure (Zhou et al., 2021). Soil temperature affects microbial activity, nutrient availability and decomposition rates which makes it essential for monitoring and maintaining appropriate conditions for sustainable farming (Lal, 2020). Fluctuations in temperature also affect pest and disease outbreaks, necessitating real time monitoring to enable the early intervention and effective pest management. Temperature sensors play a foundational role in precision agriculture by providing real-time data on ambient and soil temperatures. This vital information enables farmers to adjust their practices based on climatic conditions to micro level (Khanal et al., 2017). Voice-controlled sensor operation is an emerging technology that enhances agricultural automation, improving the efficiency and ease with which activities are carried out. It provides hands-free operation, allowing the farmers to control irrigation systems, and manage farm infrastructure using simple voice commands. Voice-controlled systems eliminate the need for manual intervention and complex programming. Farmers can activate or deactivate sensors using simple commands which makes technology more accessible even to non-technical users (O, 2022). This technique is particularly beneficial for large farms, and remote agricultural areas where direct physical access to control panels may be limited. Real-time monitoring and control through voice-activated systems enable farmers to respond promptly to environmental changes such as temperature fluctuations (Adewusi et al., 2024).

In this research article, the system is designed for controlling of the operation of temperature sensor according to the voice commands directed by the IoT platform and google voice assistant. The power consumption in continuous mode of operation and voice-controlled mode is measured and analysis is carried out in terms of power absorbed by the temperature sensor.

2. LITERATURE REVIEW

Several research articles have been recorded of the voice-controlled approach for operating the home appliances and operating the system from remote locations. In this section such systems are discussed briefly. Wireless home automation system (WHAS) was developed for providing an easy to use automation solution for elderly and disabled individuals, especially those living alone by enabling control of household appliances through voice commands (AlShu'eili et al., 2011). System is designed with Zigbee wireless communication module for low-power and cost-effective data transmission. The technology utilized for speech signal compression and decompression is Differential Pulse Code Modulation (DPCM). The system was tested with 35 participants with varying English accents and showed accuracy of 79.8%. The system facilitated controlling the lights and electrical appliances in homes or offices using voice commands. The highly sensitive, flexible and skin-attachable sensor is designed for accurate voice recognition to advance human-machine interaction, vocal healthcare monitoring and voice authentication (Su et al., 2022). The sensor integrates a pressure sensitive layer and a temperature sensitive layer. The system uses polyethylene terephthalate substrate with silver electrodes. A polydimethylsiloxane film embedded with single-walled carbon nanotubes for pressure sensing. A polyimide film with a patterned titanium thermistor for temperature sensing. The system can distinguish vocal fold vibrations corresponding to different spoken words with a recognition accuracy of 93.4%.

The system designed with the integration of soil moisture sensor and temperature sensors with Arduino focuses on integrating voice recognition technology with IoT to automate agricultural processes (Avinash et al., 2021). Voice commands are processed using speech recognition modules to control devices like water pumps and sprinklers. The innovation particularly benefits small-scale farmers by simplifying operations and improving resource management. IoT- based solution is designed for minimizing electricity consumption in office environments which saves power by 40%. (Abusukhon et al., 2021). The system uses the lecture time table to automate appliance control based on instructor's schedules. The system supports both manual control via voice commands and automatic control based on lecture time table data. IoT modules along with Artificial Intelligence and Deep Learning for controlling appliances and optimizing energy usage patterns respectively. It has been reported that electricity costs are significantly reduced by automating the management of lights, air conditioning. and other appliances. Intelligent lighting system that integrates voice commands, timer functionality, and human presence is designed using Arduino and PIR motion sensors (Lingayat, 2021). Speech recognition technology is used for turning LEDs on and off and adjust the brightness based on voice inputs. The system employs PIR sensor to detect human presence and automatically turn lights on and off, reducing unnecessary energy consumption. IoT based intelligent home automation system using IFTTT with Google Assistant explores the integration of IoT technologies with Google Assistant and IFTTT to create an intelligent home automation system (Bansal et al., 2024b). The system leverages IFTTT to create applets that link Google Assistant with IoT devices to enable conditional automation i.e. turning on lights when motion is detected. IFTTT applets offer customizable voice commands and compatibility with a wide range of smart devices. Switching of devices such as lights, fans and thermostats are enabled by IoT, temperature sensor, LDR and Arduino microcontroller.

Several research articles indicate that the system is designed for switching the devices ON and OFF using voice commands. Emphasis is given on home automation, controlling the operation of devices remotely. Study on operation of low-cost temperature sensor based on voice commands ensuring data access only when required is not been reported yet. The study is carried out by controlling the operation of the DHT11 temperature sensor according to the voice commands through Google Assistant and IFTTT. The study focuses on the comparison of power consumption during continuous mode of operation with the power consumption during voice-controlled mode.

3. MATERIALS AND METHODS

The experiment is carried out using DHT11 temperature sensor, INA219 current measuring sensor, and IRLZ34N relay. The current measured through the current measuring sensor is stored in the cloud platform through Raspberry Pi 4.0 module. The cloud platform used is Adafruit IO, the actuating voice commands are given through Google Assistant and IFTTT. Below is the block diagram representation of the experimental setup. Fig. 1. Represents the configuration used for the continuous mode and code-controlled mode of operation. Assembly illustrated in Fig. 2. is employed for voice-controlled mode, where the Raspberry Pi communicates with Adafruit IO cloud in two directions. In one direction it sends the data to cloud storage and in the other way it receives commands from cloud to control the operation of IRLZ43N MOSFET switch.

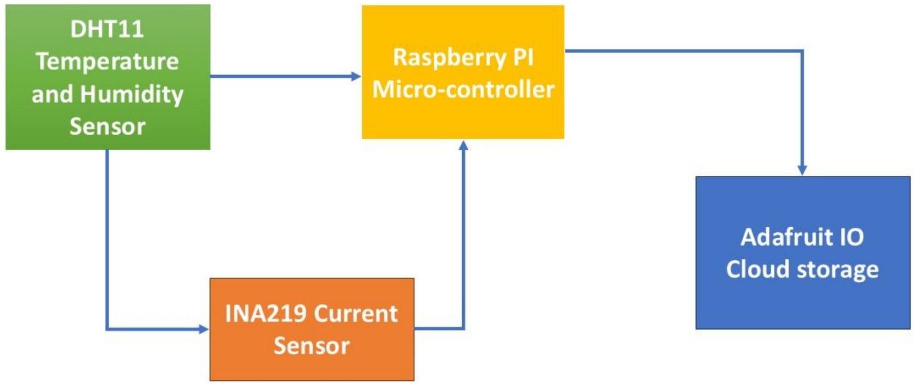

Fig. 1. Block diagram representation for experimental setup for continuous and code-controlled mode

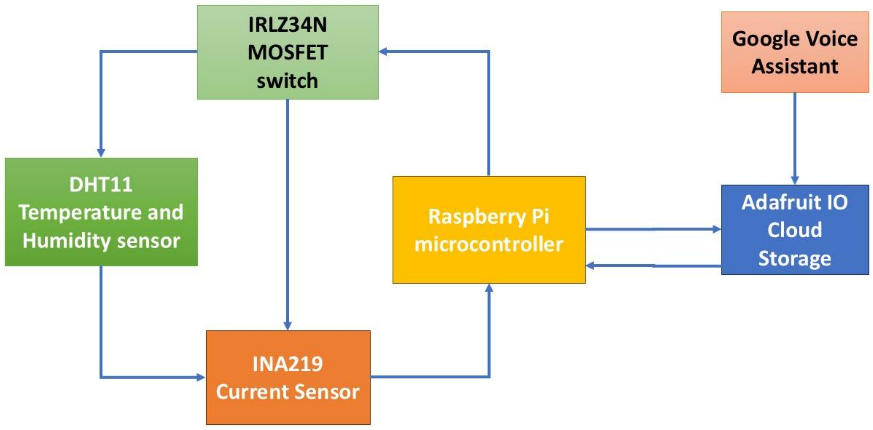

Fig. 2. Block diagram representation for the voice-controlled mode

4. RESULTS AND DISCUSSION

The DHT11 temperature sensor is a widely used low-cost digital sensor for measuring temperature and humidity in various applications from home automation to industrial systems. It is a basic digital sensor that combines a capacitive humidity sensor and a Negative Temperature Coefficient (NTC) thermistor for environment monitoring (Ethan & Author, 2023). It operates on a single wire communication protocol. Making it easier to interface with microcontrollers. Temperature and Humidity ranges that can be measured with minimal error are 0 to 50oC and 20 to 90% RH respectively. The humidity is measured by using a capacitive sensor with two electrodes separated by a moisture-absorbent substrate. Varying substrate's conductivity indicates the change in humidity, which alters the capacitance between electrodes (Ethan & Author, 2023). This change in capacitance is converted into a digital signal by an onboard microcontroller. Built in NTC thermistor measures the temperature by changing its electrical resistance in proportion to the change in temperature. The microcontroller converts this resistance change into digital temperature value (D-Robotics, 2018). The technical specifications of the DHT11 sensor are given in the Table 1 (Aosong, 2018).

The INA219 current sensor is to measure current, voltage and consequently power is a high precision, low-power device developed by Texas Instruments. The INA219 current sensor module is versatile tool for monitoring power in electronic circuits. It utilizes a shunt resistor to measure current and employs a 12-bit ADC for high resolution data acquisition. As the mode supports both I2C and SMBus interfaces, it is easier to integrate into microcontroller-based systems (Adrian et al., 2023). The INA219 operates by measuring the voltage drop across a precision shunt resistor (0.1 ohm with 1% tolerance). This voltage drop is proportional to the current flowing through the resistor. The onboard 12-bit ADC converts this analogue signal into digital data, which is then processed to calculate current, voltage, and power. It is commonly used in solar panel systems to monitor current flowing into batteries or loads, in battery operated devices like electric vehicles and portable electronics for tracking the charging and discharging currents to optimize performance and extend battery life (Lambert et al., 2021). The ability to measure currents up to 3.2A and voltages up to 26V makes it suitable for diverse applications. Technical specifications of the INA219 current sensor are given below (INA219, 2008).

During the voice-controlled mode of operation, the voice commands initiate the functioning of the DHT11 temperature humidity sensor with the actuating signal of the IRLZ34N MOSFET switch. When the voice command of START is fed to the Google Assistant, the switch turns on the supply to the DHT11 sensor and sensor is ready to measure the ambient temperature and humidity. When the voice command of STOP is input to the Google Assistant, the IRLZ34N turns off the supply with which DHT11 is powered turning it off. Power MOSFETs are essential components in modern electronics facilitating efficient power conversion and switching applications. The IRLZ34N, a logic-level MOSFET, is designed for applications requiring low gate drive voltages while delivering high power efficiency. The IRLZ34N operates at logic level of 5V. The IRLZ34N operates in enhancement mode, meaning it remains off when no voltage is applied to the gate terminal. Its structure consists of three terminals: Gate (G), Drain (D), and Source (S). The gate is insulated from the drain and source by a silicon dioxide layer, forming a metal-oxide-semiconductor (MOS) capacitor (Chen et al., 2024). When a positive voltage is applied to the gate relative to the source an electric field forms across the MOS capacitor. This field attracts electrons to the semiconductor surface between the drain and source, creating a conductive N-type channel. The current then flows from the drain to the source. Unlike standard MOSFETs which require 10V for activation, the IRLZ34N can operate between 3.3 to 5V, making it compatible with microcontrollers like Raspberry Pi without additional driver circuits (Yang et al., 2024). The IRLZ34N is housed in a TO-220AB package, which balances compactness with effective heat dissipation. Its maximum power dissipation is 56–68W, but prolonged high-current operation requires a heatsink to maintain temperatures below the 175°C limit(HEXFET ® Power MOSFET, 2018). The electrical characteristics and specifications are mentioned in the Table 3 given (HEXFET ® Power MOSFET, 2018).

Raspberry Pi is used as microcontroller for interfacing of sensors with the IoT platform. The Raspberry Pi 4 model B with 4GB RAM is used in this case. It is the latest iteration of the Raspberry Pi series which offers significant improvements in processing power, memory and connectivity. Designed as credit-card sized computer, it offers wide range of applications (Ghael et al., 2008). It features a powerful Broadcom BCM2711 quad-core Cortex-A72 processor and up to 8GB of LPDDR4 RAM. It has enhanced connectivity options which include Gigabit Ethernet and USB 3.0 ports, making it suitable for modern computing tasks. The device supports dual 4K monitors via micro-HDMI ports and offers improved graphics performance with the VideoCore VI GPU (Wai Zhao et al., 2023). Raspberry Pi 4 supports dual-band Wi-Fi and Bluetooth 5.0 BLE to ensure seamless wireless communication. With its improved CPU, GPU and memory options, the Raspberry Pi 4 can function as a low-cost desktop PC for web browsing, office tasks and media playback when paired with a keyboard, mouse and monitor. The recommended operating system for the Raspberry Pi 4 is Raspbian, a Debian-based Linux distribution optimized for the Raspberry Pi hardware. The operating system can be installed using the Raspberry Pi imager tool simplifying the process of preparing microSD card with the desired OS. The technical specifications of the Raspberry Pi 4 are given in the Table 4 (Raspberry Pi 4 Model B, 2024).

The measured instantaneous values of current consumed by the DHT11 sensor, and MOSFET switch are uploaded on the IoT cloud platform with minimum delay. The cloud platform used in this regard is Adafruit IO. Adafruit IO is a cloud-based platform designed for IoT projects, enabling users to collect, visualize and interact with data from sensors, devices and other data sources. It provides a user-friendly interface, robust APIs and seamless integration with Adafruit hardware, making it an ideal choice for prototyping and deploying IoT solutions (Mishra et al., 2022). Adafruit IO allows users to connect IoT devices, store data and create dashboards for real-time visualization. It is part of the Adafruit ecosystem, which includes hardware components like microcontrollers, sensors and actuators as well as software tools and libraries. Automated responses based on data thresholds can be set up using Adafruit IO. It facilitates connecting third-party services like IFTTT, Google Sheets (Yusuf et al., 2022). Adafruit IO is built on a client-server architecture, where IoT devices acting as clients send data to the Adafruit IO cloud server. The server processes and stores the data, making it accessible through dashboards, APIs and integrations. Adafruit IO uses MQTT and HTTP/REST protocols which are lightweight messaging protocols for optimizing for low-bandwidth, high-latency networks (Dinmohammadi et al., 2025).

In the voice-controlled mode of the operation of the switching of the DHT11 sensor, IFTTT (If This Then That) and Google Assistant are used. IFTTT and Google Assistant are two powerful tools for automating tasks and controlling smart devices. IFTTT serves as a platform that connects apps, devices and services through automation workflows, while Google Assistant is a voice-activated AI assistant that integrates with smart home ecosystems (Orange Technologies (ICOT), 2014 IEEE International Conference On, 2014). IFTTT is a cloud-based automation platform founded in 2010 that allows users to create applets which is a customized workflow. These applets follow a simple logic of “If this happens then do that” (Kumer et al., 2021). Google Assistant, launched in 2016, is a conversational AI assistant that uses natural language processing to execute voice commands. It integrates with Google’s ecosystem and third-party devices to perform tasks like setting reminders, controlling smart home devices and retrieving information (Torres-Maldonado et al., 2023). When combined IFTTT and Google Assistant enable users to automate complex tasks and control IoT systems using voice commands. The specifications of IFTTT are given (Alaa et al., 2017). Features of Google Assistant are given in Table 6 (Torres-Maldonado et al., 2023).

Table 1. Technical specifications of DHT11 temperature and humidity sensor

Parameter	Value
Operating Voltage	3.3V–5.5V
Current Consumption	0.3mA (active), 60μA (standby)
Temperature Range	0°C to 50°C (±1–2°C accuracy)
Humidity Range	20–90% RH (±1–5% accuracy)
Sampling Rate	1Hz (1 reading per second)
Output	Digital signal (single-wire)

Table 2. Technical specifications of INA219 current sensor

Parameter	Value
Operating Voltage	3V–5.5V
Shunt Resistor Value	0.1 ohm (1% tolerance)
Current Sensing Range	±3.2A with ±0.8mA resolution
ADC Resolution	12-bit
Power Consumption	<2 micro A (low-power mode)

Table 3. Technical specifications of IRLZ34N MOSFET

Parameter	Value
Drain-Source Voltage	55V
Continuous Drain Current	30A
Gate threshold voltage	1 to 2V
Gate source voltage	16V
On-Resistance	35m-ohm
Total gate charge	67nC
Rise time	60ns
Fall time	45ns

Table 4. Technical specifications of Raspberry Pi 4 Model B

Component	Specification
Processor (CPU)	Broadcom BCM2711, Quad-core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz
Memory (RAM)	1GB, 2GB, 4GB, or 8GB LPDDR4-3200 SDRAM
Graphics (GPU)	Broadcom VideoCore VI, supporting OpenGL ES 3.1 and Vulkan 1.0
Networking	Gigabit Ethernet
Wireless	2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE
USB Ports	2 × USB 3.0 ports, 2 × USB 2.0 ports
Display Outputs	2 × micro-HDMI ports
Camera Interface	2-lane MIPI CSI camera port
Display Interface	2-lane MIPI DSI display port
Audio/Video Output	4-pole stereo audio and composite video port
Storage	Micro-SD card slot for loading operating system and data storage
GPIO	Raspberry Pi standard 40 pin GPIO
Power Supply	5V DC via USB-C connector
Operating Temperature	0 – 50 degrees C ambient

Table 5. Technical specifications of IFTTT

Feature	Details
Platform Type	Cloud-based automation platform
Founded	2010
Supported Services	Over 900 apps and devices
Core Functions	Triggers, actions, applets
Programming Model	No-code interface
Subscription Plans	Free (limited applets), Pro (unlimited applets with advanced features)
Mobile App Availability	iOS and Android

Table 6. Features of google assistant

Feature	Details
Platform Type	AI-powered virtual assistant
Launched	2016
Supported Devices	Smartphones, smart speakers (Google Nest), Android Auto, Wear OS
Core Functions	Voice recognition, contextual queries, smart home control
Integration Services	Google Home ecosystem, IFTTT, third-party APIs
Languages Supported	Over 30 languages
AI Technologies Used	Natural Language Processing (NLP), Machine Learning

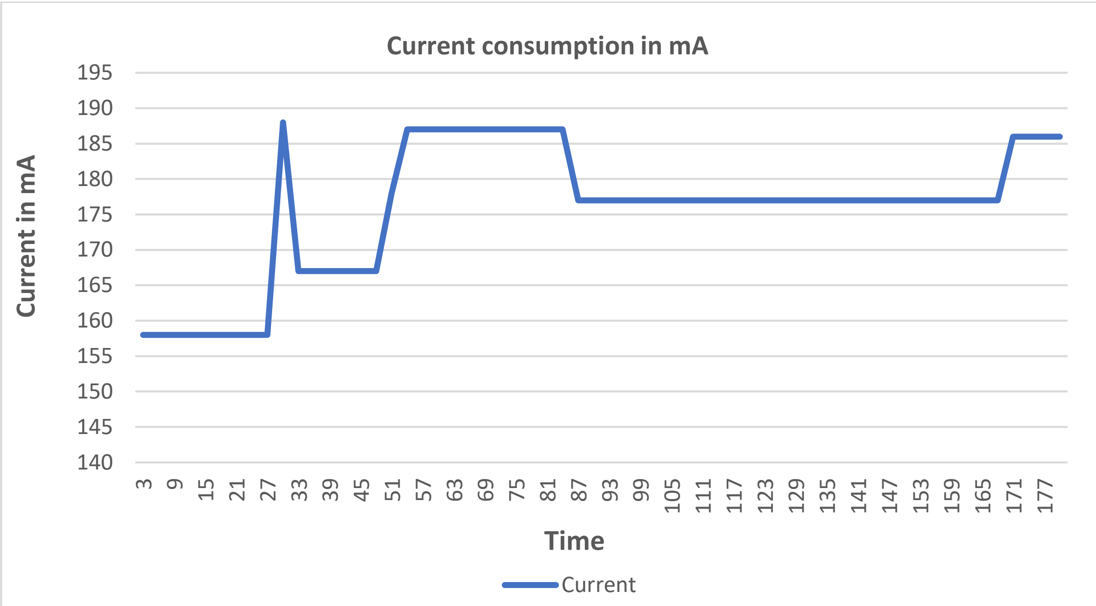

Fig. 3. Current consumption of DHT11 sensor in continuous operation

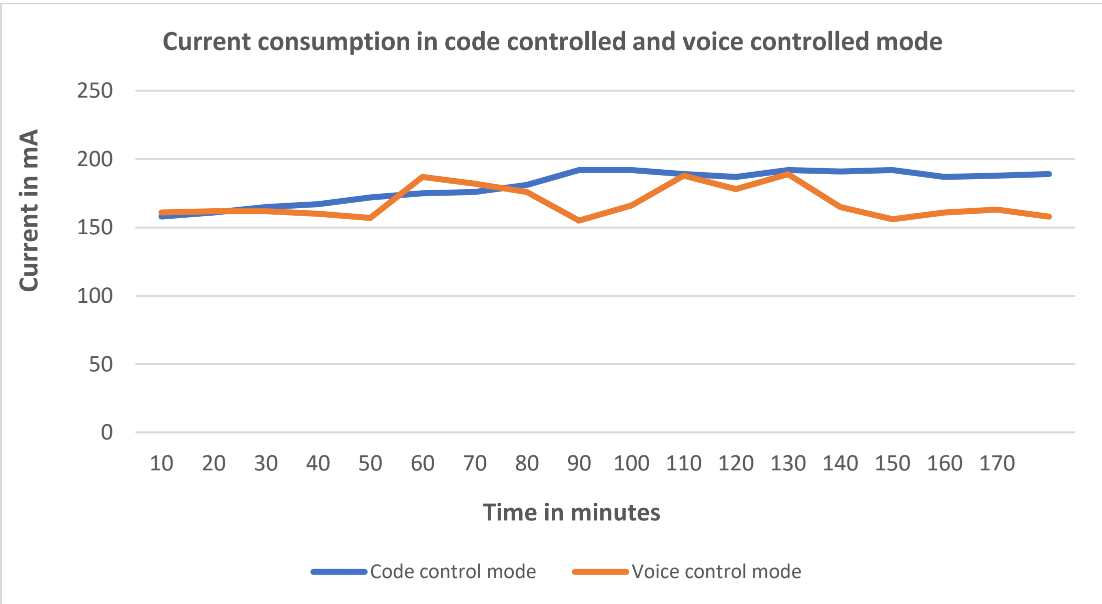

Fig. 4. Current consumption of DHT11 sensor in code-controlled and voice-controlled mode of operation

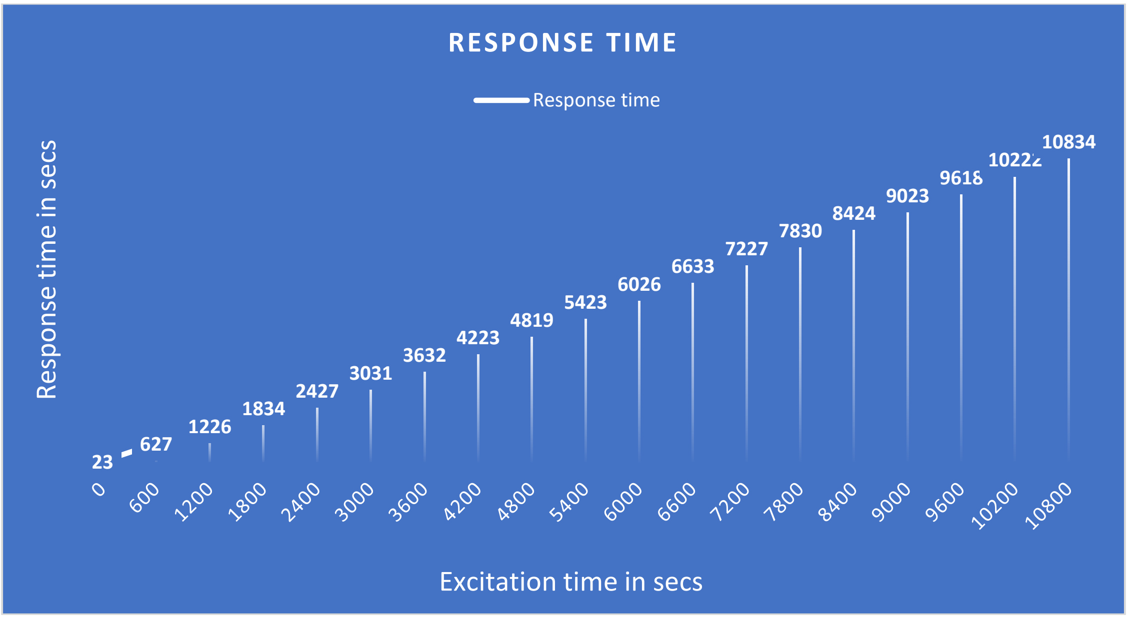

Fig. 5. Time delay between excitation and response of DHT11 sensor in voice-controlled mode

The first experiment involves operating the DHT11 sensor for continuous 3 hours. It involves measuring and uploading the current and voltage consumed by DHT sensor to the Adafruit IO cloud every 3 minutes for 3 hours. The data is collected using an INA219 current sensor interfaced with a Raspberry Pi and then sent to Adafruit IO for analysis. The software components used are Python programming language for data acquisition and upload. Adafruit IO library is used to send sensor data to Adafruit IO. Python Library of INA219 sensor interfaces the INA219 with Raspberry Pi. Adafruit IO is a cloud-based IoT platform that allows users to share, monitor and visualize sensor data. For storing the current and voltage values separate feeds are created. Feeds are created on Adafruit IO in stepwise manner.

1. Visit https://io.adafruit.com/ login or create a new account
2. Go to the “Feeds” section and click on create new feed.
3. Create Voltage feed and Current feed by clicking on to create button.
4. Copy the key of both feeds to include in the code which is written in Raspberry Pi to ensure data is sent to corresponding feed.

In the second experiment which is code-controlled mode, the DHT11 sensor is programmed to operate efficiently by reducing its active time. The DHT 11 sensor is activated for only 1 second every 10 minutes, during which it measures temperature and humidity. Once the measurement is complete, the sensor remains in an idle state for the next 599 seconds. This cycle is repeated 18 times, covering total the duration of 3 hours. During each measurement cycle, the voltage and current consumed by the DHT11 sensor are recorded using the INA219 current sensor, and the data is then uploaded to Adafruit IO for remote monitoring and analysis. The Python script is structured to ensure the controlled operation of the DHT11 sensor. The Raspberry Pi communicates with the INA219 sensor over the I2C bus to obtain voltage and current readings. The script is designed to follow a loop that runs for 18 cycles, ensuring that data is collected and uploaded every 10 minutes. The Python script allows for measurement mode of 1 second as well as pushing the DHT11 sensor into the idle state for 599 seconds. The data is uploaded on separate “Voltage” and “Current” feeds by the same procedure followed for the first experiment.

In the third experiment, Google Assistant, IFTTT and Adafruit Io are used to control the switching on and off of the DHT11 sensor’s power supply via an ILZ34N MOSFET. This method enables voice-controlled activation and deactivation of the sensor. The process involves the following steps:

1. Google Assistant receives a voice command from the user e.g. “Start the sensor” or “Stop the sensor”.
2. The IFTTT applet is triggered, sending a web request to Adafruit IO.

3. Adafruit IO toggles a feed value that is on or off.
4. Raspberry Pi reads the feed value from Adafruit IO and controls the IRLZ43N MOSFET accordingly.
5. IRLZ43N MOSFET acts as a switch, controlling power to the DHT11 sensor.

Google Assistant serves as the input trigger that activates the applets in IFTTT. IFTTT is used to link Google Assistant with Adafruit IO enabling remote switching of the DHT11 sensor. An IFTTT applet consists of a trigger and an action. The first applet will turn ON the DHT11 sensor when the user says, “Start the sensor”. Following steps are followed to create trigger and action.

1. Click on “If This” and select Google Assistant.
2. Choose “Say a simple phrase”.
3. Enter the command phrase e.g. “Start the sensor”
4. Click “Create trigger”.
5. Click on “Then That” and select Webhooks which is used to send data to Adafruit IO.
6. Choose “Make a web request”
7. Click “Create action” and then “Finish”.
8. Use the phrase “Stop the sensor” and change the body line in further steps.

For configuring Adafruit IO to receive commands for controlling the switching of DHT11 sensor following steps are involved.

1. Log in to Adafruit IO.
2. Go to Feeds > New Feed.
3. Name the feed sensor-control
4. Click “Create”

This feed will store ON or OFF values based on Google Assistant commands. Once the sensor-control feed updates, the Raspberry Pi reads the value and controls the IRLZ34N MOSFET to switch the sensor ON or OFF. When the user says “Start the sensor”, Google Assistant triggers IFTTT. IFTTT sends a request to Adafruit IO, updating the sensor-control feed with ON. Raspberry Pi reads the feed, detects ON, and sets GPIO (Raspberry PI pins which are connected to sensor pins). MOSFET switches ON, allowing current to flow and power the DHT11 sensor.

Summery:

The experiment is carried out for continuous three hours and with three setups. The basic equation which determines the power consumption is given below (Svensson & Wikner, 2010).

Power (P) = Voltage (V) X Current (I).
Energy (E) = Power X Time (t)
Units of measurement:
Power = Watts (W)
Voltage = Volts (V)
Current = Ampere (A)
Time = seconds (s)
Energy = Joule (J)

From the voltage, and csurrent data uploaded on the cloud platform for the three modes of operation following things are noted.

1. In the continuous mode of operation of the DHT11 sensor, the voltage and current values are measured by the INA219 current sensor for continuous three hours and data is uploaded on Adafruit IO cloud platform for every 3 minutes. 60 set of values of voltage and current consumed are available on the cloud platform.
2. The voltage supply to DHT11 sensor varies from 4.77V to 5 V. The current consumed by the sensor ranges from 158 mA to 186 mA. The power consumption for every minute is around 1.43 J.
3. The cumulative sum of the power consumed for 180 minutes is 91.39 J.
4. In the second set of experiments where the DHT11 sensor is operated in measurement mode for 1 second and pushed in an idle state for 599 seconds. For every 10 minutes data is uploaded on cloud. 18 such data points are available for energy consumption calculation.
5. The expression used in this mode of operation is given as:

Energy consumption = (V X $I_{\text{measurement mode}}$ X 1) + (V X $I_{\text{idle state}}$ X 599)

V = Voltage supply

$I_{\text{measurement mode}}$ = Current in measurement mode

$I_{\text{idle state}}$ = Current in idle mode.

6. The current consumption by the DHT11 sensor is from 158 mA to 192 mA in measurement mode. In idle mode of operation, the current is drawn in the range of 158 to 195 micro A.
7. The energy consumption for every 10 minutes of operation is 0.01 J. The

cumulative sum of energy consumption for 3 hours is 0.21 J.

8. In the third type of experiment where voice commands control the switching of the DHT11 sensor, it is observed that there is a time lag of 20 to 30 seconds from the time START command is instructed and the actual operation of the sensor begins.
9. The current drained in this type of operation is in the range of 158mA to 188 mA. The power of relay is constant throughout the operation which is 36 micro W. The energy consumption calculated in this mode is given by

Energy consumption = (V X $I_{\text{measurement mode}}$ X 1) + (Power of IRLZ34N X 625)

V = Voltage supply

$I_{\text{measurement mode}}$ = Current in measurement mode

On monitoring it is observed that for every cycle of 10 minutes IRLZ34N MOSFET remains on for 625 seconds.

10. The energy consumption for every 10 minutes cycle is 0.008 J. The total energy requirement of the voice-controlled mode for three hours is 0.147 J.

5. CONCLUSION

Operating the DHT11 sensor continuously for three hours results in a total energy consumption of 91.39 J, with power consumption per minute averaging 1.43 J. This is the indication of high power-requirement due to the continuous operation without any power-saving measures. By implementing measurement then idle state (1s active, 599s idle), the energy consumption significantly drops to 0.21 J over three hours. The code-controlled demonstrates that duty cycling effectively reduces energy consumption by nearly 99.8% compared to continuous mode. While voice-controlled operation further optimizes energy usage, a 20-30 second delay is observed between the command and sensor activation. The total energy consumption for three hours is 0.147 J, slightly lower than the code-controlled mode. However, the IRLZ43N MOSFET remains ON for on an average of 625 seconds per cycle, consuming a small but constant power. The current consumption in all the three modes of operation is nearly same but the time for which the sensor is in measurement mode is crucial factor in energy requirement of the circuit.

It can be further deduced that code-controlled and voice-controlled modes are highly energy efficient alternatives to continuous operation. The voice-controlled mode offers highly lower power consumption than the code-controlled mode but introduces time delay due to network-based activation. For real time applications requiring immediate sensor response voice-controlled mode can be preferred due to its predictable operation although it introduces latency. It can be used where remote operation is essential, but time lag should be considered when designing real-time systems.

6. FUTURE SCOPE

One of the key challenges in implementing voice-controlled sensor systems is the 20-30 second delay in sensor activation, which occurs due to dependance on cloud based services for voice processing. This delay can be significantly reduced by employing AI-based voice processing, where voice recognition and command execution take place on the edge device itself. Edge computing solutions can further enhance response times by processing sensor data locally before sending only necessary updates to the cloud. For improving the sustainability of the sensor system, solar energy integration can be explored to make it self-powered and energy efficient. This kind of approach not only makes the system more environmentally friendly but also enhances its long-term usability by minimizing energy costs and ensuring uninterrupted operation even in areas without stable electricity access.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Abusukhon, A., Hawashin, B., & Lafi, M. (2021). An efficient system for reducing the power consumption in offices using the Internet of Things. *International Journal of Advanced Soft Computing and Applications*, 13(1).

Adewusi, A. O., Asuzu, O. F., Olorunsogo, T., Olorunsogo, T., Adaga, E., & Daraojimba, D. O. (2024). AI in precision agriculture: A review of technologies for sustainable farming practices. *World Journal of Advanced Research and Reviews*, 1, 2276–2285. https://doi.org/10.30574/wjarr.2024.21.1.0314

Adrian, M., Constantin, G., Girjob, C., Chicea, L., Maroșan, A., GÎRJOB, E., CHICEA, L., & Crenganiș, M. (2023). Real-time data acquisition of low-cost current sensors ACS712-05 and INA219 using Raspberry Pi, DAQCPlate, and Node-RED. *Proceedings in Manufacturing Systems*, 18(2), 51–59. https://www.researchgate.net/publication/382143349

Alaa, M., Zaidan, A. A., Zaidan, B. B., Talal, M., & Kiah, M. L. M. (2017). A review of smart home applications based on the Internet of Things. *Journal of Network and Computer Applications*, 97, 48–65. https://doi.org/10.1016/j.jnca.2017.08.017

AlShu'eili, H., Gupta, G. S., & Mukhopadhyay, S. (2011). Voice recognition based wireless home automation system. *2011 4th International Conference on Mechatronics (ICOM)*, 1–6. https://doi.org/10.1109/ICOM.2011.5937116

Aosong. (2018). *Temperature and humidity module DHT11 product manual*. Retrieved from www.aosong.com

Avinash, Y., Sagar, N. R., & Chinnadurai, S. (2021). Voice automation agricultural systems using IoT. *2021 12th International Conference on Computing Communication and Networking Technologies (ICCCNT)*, 1–4. https://doi.org/10.1109/ICCCNT51525.2021.9579842

Bansal, M., Sharma, R., Yadav, A., & Krishna. (2024). IoT-based intelligent home automation system using IFTTT with Google Assistant (pp. 97–119). https://doi.org/10.1007/978-981-97-5718-3_6

Chen, R., Fan, J., Yu, C., & Gao, W. (2024). Digitized phase-change material heterostack for transmissive diffractive optical neural network. *Advanced Photonics Research*. https://doi.org/10.1002/adpr.202400201

Dinmohammadi, F., Farook, A. M., & Shafiee, M. (2025). Improving energy efficiency in buildings with an IoT-based smart monitoring system. *Energies*, 18(5), 1269. https://doi.org/10.3390/en18051269

D-Robotics. (2018). *DHT11 Humidity & Temperature Sensor*.

Ekta, M., Kumar, V., & Sandeep, M. (2020). Design and implementation of IoT based smart controlling application for LED scrolling text display with integration of Google Assistant. *International Research Journal of Engineering and Technology*. www.irjet.net

Ethan, S., & Author, C. (2023). Understanding the DHT11 temperature sensor: Principles and applications. *Journal of Electrical Engineering and Electronic Technology Short Communication*, 12(2). https://doi.org/10.4172/2325-9838.1000945

Ghael, D., Solanki, L., Sahu, G., & Professor, A. (2008). A review paper on Raspberry Pi and its applications. *International Journal of Advances in Engineering and Management*, 2, 225. https://doi.org/10.35629/5252-0212225227

HEXFET® Power MOSFET. (2018).

INA219. (2008). www.ti.com

Jawarkar, N. P., Ahmed, V., & Ladhake, S. A. (2008). Microcontroller-based remote monitoring using mobile through spoken commands.

Khanal, S., Fulton, J., & Shearer, S. (2017). An overview of current and potential applications of thermal remote sensing in precision agriculture. *Computers and Electronics in Agriculture*, 139, 22–32. https://doi.org/10.1016/j.compag.2017.05.001

Köylü, F., Sabriye, M. M., Ali, A. O., Osman, A. A., Abdullah, Q., Hassan, M. M., & Hilal, A. A. (n.d.). Review of Internet of Things (IoT) security threats and challenges.

Kumer, S. V. A., Kanakaraja, P., Teja, A. P., Sree, T. H., & Tejaswni, T. (2021). Smart home automation using IFTTT and Google Assistant. *Materials Today: Proceedings*, 46, 4070–4076. https://doi.org/10.1016/j.matpr.2021.02.610

Lal, R. (2020). Managing soils for negative feedback to climate change and positive impact on food and nutritional security. *Soil Science and Plant Nutrition*, 66(1), 1–9.

https://doi.org/10.1080/00380768.2020.1718548

Lambert, J., Monahan, R., & Casey, K. (2021). Power consumption profiling of a lightweight development board: Sensing with the INA219 and Teensy 4.0 microcontroller. *Electronics*, 10(7), 775. https://doi.org/10.3390/electronics10070775

Lingayat, V. M. (2021). Controlling LED by voice command, timer, and human presence detection. *International Journal for Research in Applied Science and Engineering Technology*, 9(8), 2143–2150. https://doi.org/10.22214/ijraset.2021.37535

Liptak, B. G. (1995). *Process measurement and analysis* (3rd ed.). Butterworth.

Meijer, G. C. M., Wang, G., & Heidary, A. (2018). Smart temperature sensors and temperature sensor systems. In *Smart Sensors and MEMs* (pp. 57–85). https://doi.org/10.1016/B978-0-08-102055-5.00003-6

Mishra, D., Yadav, P., Yadav, V., Srivastava, R., Agrawal, K. K., & Yadav, R. S. (2022). Adafruit IO-based smart irrigation system using MQTT protocol for urban farming. *Journal of Computer Science*, 18(5), 374–381. https://doi.org/10.3844/jcssp.2022.374.381

Murty, D. V. S. (2018). *Transducers and instrumentation* (2nd ed.). PHI Learning Private Limited.

Nandurkar, S. R., Thool, V. R., & Thool, R. C. (2014). Design and development of precision agriculture system using wireless sensor network. *2014 First International Conference on Automation, Control, Energy and Systems (ACES)*, 1–6. https://doi.org/10.1109/ACES.2014.6808017

O, J. S. (2022). Voice controlled agribot. www.ijert.org

Orange Technologies (ICOT), 2014 IEEE International Conference on. (2014). [Publisher not identified].

Qin, T., Li, X., Yang, A., Wu, M., Yu, L., Zeng, H., & Han, L. (2023). Nanomaterials-enhanced, stretchable, self-healing, temperature-tolerant, and adhesive tough organohydrogels with long-term durability as flexible sensors for intelligent motion-speech recognition. *Chemical Engineering Journal*, 461, 141905. https://doi.org/10.1016/j.cej.2023.141905

Raspberry Pi 4 Model B. (2024).

Su, Y., Ma, K., Zhang, X., & Liu, M. (2022). Neural network-enabled flexible pressure and temperature sensor with honeycomb-like architecture for voice recognition. *Sensors, 22*(3), 759. https://doi.org/10.3390/s22030759

Svensson, C., & Wikner, J. J. (2010). Power consumption of analog circuits: A tutorial. *Analog Integrated Circuits and Signal Processing, 65*(2), 171–184. https://doi.org/10.1007/s10470-010-9491-7

Torres-Maldonado, S. Y., Tinoco-Varela, D., Dalí Cruz-Morales, R., Hedain López-Mera, G., Sánchez-García, D., & Axel Padilla-García, E. (2023). Design and implementation of a voice assistant to be used in an IoT home automation environment. *2023 27th International Conference on Circuits, Systems, Communications and Computers (CSCC)*, 1–8. https://doi.org/10.1109/CSCC58962.2023.00027

Venkatraman, S., Overmars, A., & Thong, M. (2021). Smart home automation—Use cases of a secure and integrated voice-control system. *Systems, 9*(4), 77. https://doi.org/10.3390/systems9040077

Wai Zhao, C., Jegatheesan, J., & Chee Loon, S. (2023). Exploring IoT application using Raspberry Pi. *International Journal of Computer Networks and Applications, 2*(1). Retrieved from http://www.digi.com

Wei, R., & Bao, X. (2018). A low power energy-efficient precision CMOS temperature sensor. *Micromachines, 9*(6), 257. https://doi.org/10.3390/mi9060257

Yang, Z., Rupavatharam, S., Burns, A., Lee, D., Howard, R., & Isler, V. (2024). Low-cost refrigerator frost detection using piezoelectric sensors.

Yugank, H. K., Sharma, R., & Gupta, S. H. (2022). An approach to analyse energy consumption of an IoT system. *International Journal of Information Technology, 14*(5), 2549–2558. https://doi.org/10.1007/s41870-022-00954-5

Yusuf, M. M., Sahrani, S., Saad, M. H., Sarker, M., & Samah, M. Z. (2022). Design and development of an Internet of Things (IoT) based real-time monitoring and control system for smart indoor hydroponic vertical farming system with ESP32 and Adafruit IO. *Journal of Information System and Technology Management, 7*(28), 155–163. https://doi.org/10.35631/JISTM.728010

Zhou, Y., Xu, L., Xu, Y., Xi, M., Tu, D., Chen, J., & Wu, W. (2021). A meta-analysis of the effects of global warming on rice and wheat yields in a rice–wheat rotation system. *Food and Energy Security, 10*(4). https://doi.org/10.1002/fes3.316

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