

An Intelligent IoT-Enabled Temperature-Based Fan Speed Control Framework for Energy-Efficient Smart Environments

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Abstract- Smart homes play a crucial role in reducing the amount of energy consumed in the house as the automatic control is also provided. This paper suggested an IoT-based temperature-based fan control system, which is an automatic fan control system that is operated by the temperature in the surrounding. This system contains a LM35 sensor of temperature to detect the temperature with accuracy and the DHT11 sensor to monitor the temperature and humidity in real time. The sensor information is handled in a microcontroller with an ESP8266 Wi-Fi chip that enables the sensor to access the internet easily and visualize the obtained air quality on the cloud. The DC motor speed of the fan is regulated by the Pulse Width Modulation (PWM) which enables your motherboard to provide only the necessary cooling when required. The automatic speed control system makes it non-manually based and the operator is given a pleasant working experience. It has been experimentally established that the proposed variable-speed cooling system

Keywords— Fan speed control based on temperature, LM35 temperature sensor, DHT11 temperature sensor, Esp 8266, pulse width modulation (PWM), automatic speed regulation, control of DC motors, energy efficiency, smart cooling system, embedded system design, real-time monitoring.

I. INTRODUCTION

However, currently, with the ever-changing technology, automation and control systems seem to be significant in the contemporary world [1]. With the spread of technology at both home and industries, the role of the machines in human life has been transformed as it is no longer manually operated but rather efficiently, convenient and green robotic in nature [2]. The smart spaces are made possible by the convergence of electronics, computing and communication wherein embedded systems gather, process and respond to information pertaining to the surrounding environment [3]. These smart environments is marked with the adaptive control, real time data processing and interconnectedness of devices that respond well to the surrounding [4]. Specifically, the temperature control systems are popular in both applications of smart technology and in various fields to guarantee the thermal comfortable use, the efficient functioning [5] [6]. These systems automatically regulate the several climate related variables (temperature, humidity, etc.) on the fly and optimize energy consumption and the user experience as a whole [7].

The traditional types of fans usually have the restrictions of manual or fixed speed mechanical controllers [8]. Though these

methods are simple, however, they fail to meet the dynamics of temperature variation and may result in overuse of energy and uneven comfort [9] [10]. Manual operation handle (Turn the button) introduces human factor and wastage of power because users cannot regulate the speed of the fans based on the conditions of the room [11]. This underlines the significance of intelligent systems capable of self-deficient provision of comfort in the ambients with minimal human intervention [12]. One of the most effective strategies of resolving these problems is microcontroller based automation systems [13]. The microcontroller is the one that connects the sensors and actuators that allow it to constantly monitor the environmental parameters and come up with a fine adjustment on how the system operates [14]. They are low priced, small and they can execute control algorithms in real time in an effective manner [15]. With the introduction of the Internet of Things (IoT), Automation has been transformed once again because it now became possible to connect physical devices together through wireless networks [16].

IoT facilitates real time interaction, data exchange and remote sensing which are the ideal foundation of the intelligent system and energy efficient services [17]. This paper represents the design of an intelligent temperature-specific fan speed control framework system based on IoT and able to monitor the speed

of the ventilator automatically depending on the measured ambient temperature [18]. IOT compatibility assists in enhancing the system to be more flexible to allow system to be remotely monitored and controlled using cloud interface or mobile application [19]. This framework is based on the LM35 temperature sensor because it provides an analog voltage signal that is proportional to temperature [20]. The exceptional accuracy, the simplicity of its calibration and its ability to work with microcontrollers of sensor makes it a very suitable choice in terms of controlling environmental systems [21]. Besides LM35, there is also DHT11 sensor that measures temperature and humidity. Such a two-fold measure of the parameters ensures a comprehensive detection of the atmosphere and make decisions that are more precise to be made about the control in order to retain the comfort [22]. These sensors and the provided data are obtained by and processed by the microcontroller, the brain of the system [23].

The microcontroller controls the dc motor that drives the fan that is used to provide ventilating based on the signals it receives through sensors by Pulse Width Modulation (PWM) technique [24]. PWM can be used with smooth variations in speed and modulates its duty cycle of the control signal, which will be more efficient and consume less energy [25]. This system is wirelessly connected to the server using the ESP8266 Wi-Fi module to exchange real time data between the microcontroller and remote server [26]. With WIFI connection, the users are able to write down the current temperature, humidity and run time of the present location, therefore, becoming capable of feeling much comfortable and being in control [27]. Real-time monitoring is also particularly helpful when it comes to such applications as smart homes, laboratories or industry facilities where the temperature regime has to be maintained at an appropriate level [28]. It facilitates monitoring of performance, detection and tuning of system parameters in an adaptive way by use of cloud-based interfaces [29].

Energy efficiency is one of the key areas in which this work can be applied. With the growing worldwide pressure on the need to use energy sustainably, one of the significant design factors in the contemporary electronic systems is the reduction of unneeded power usage [30]. The traditional fans and air conditioners normally operate at constant speeds irrespective of the atmosphere and this leads to the wastage of energy [31]. By the temperature-dependent fan speed control, thus considering the cooling necessity at 2WT condition, it is guaranteed that the energy consumption is adjusted to the cooling need [32]. Automatic control of speed helps a lot in reducing manual control to allow the system to operate on its own [33].

Traditional fans and air conditioning systems are usually fixed at a certain speed independent of the atmosphere thus wastage of energy [34]. Depending on the cooling need under temperature 2WT condition, the fan speed is controlled depending on temperature and as such, a consideration of the cooling need is made and therefore the energy utilization is adjusted accordingly [35]. Automatic speed control can go a long way in reducing manual adjustment making the system self working [36]. This is not only comfortable to the user, but also machine reliability and life is also minimized by reducing mechanical loading of parts. The most crucial aspect that has been emphasized in the system design is compactness, scalability and low power consumption [37]. The hardware is a modular business that makes it applicable in other environmental control systems such as A/C, exhaust fan, smart ventilation system [38]. Besides energy saving, the proposed system is also an expression of a larger concept that it may be employed as smart sustainability, where all smart devices cooperate with one another to achieve the low carbon world [39].

In line with the sustainability targets of the world, supporting data-driven control to promote a responsible use of energy, it also complies with the latter. Trend temperature and humidity logging are also supported in the IoT based data acquisition system. The data can also be assessed using machine learning methods or statistical models to enhance the intelligence of the system and the forthcoming behavior of the surrounding [14-15]. The solution is aligned with the idea of Industry 4.0 that puts more emphasis on intelligent production, data-driven automation, and device-to-device networking. The fan speed control system presented in this paper explains how IoT and embedded system can be used to enhance smart factory (industrial ecosystem). This system is also cheap in terms of design because it is equipped with easily accessible and cheap parts like LM35 sensor, DHT11 module, and ESP8266 Wi-Fi board. This renders the framework applicable at scale both to the developed and developing regions. Further, the architecture is modular and therefore effortless to incorporate different sensors (e.g. gas or motion) or actuators (e.g. relay) to expand the functionality of the systems to constitute a component of a larger smart home system [16-17]. The paper contributes to the literature of academic and engineering literature concerning embedded systems design, IoT-based automation and real-time process control.

It provides an interface between the old hardware control systems and new generation cloud-based intelligences. The innovations that would be realized through this study would result in high proportion of energy efficiency, stability and adaptability in operations to the environment compared to the

traditional methods of fan control [18-20]. In conclusion, it can be stated that the designed system of the IoT based temperature controlled fan speed proves the features of the intelligence, flexibility and sustainability. By entailing sensing, computation and wireless communication as a platform component, it is a logical extension to entirely autonomous power-conscious smart spaces.

II. LITERATURE REVIEW

C. Sun [1-2] observed that In the case of accurate temperature measurement, which applied to industrial production, including pharmaceutical, chemical and biological, the exactness of a measure data is not a single demand only but also the demand which could be energy efficient. A 2-layer PID control system was designed in the research to use RT-Thread IoT real-time operating system in order to make a heating furnace more responsive and precise. To address the issue of environmental disturbance that is most likely to exist in the traditional PID, the revised two layer PID structure addresses the problem by using the inverse value of deviation as a transfer parameter between the two layers. This approach was used to further optimize the energy use of the process and stability to temperature changes. The findings revealed that IoT real-time monitoring in association with advanced control algorithms could enhance the effectiveness of temperature control of home heating. The study provided a valuable foundation of the IoT-enabled fan speed control systems as well as highlighted on sensor-based feedback, adaptive control methods, and power-efficient automation to accomplish accurate environmental control.

R. B. Oliva [3-5] had suggested the design and implementation of 8-bit and 32-bit microcontroller board hardware (in order to develop) and firmware. The physical dimension of these boards is similar as well as the input/output devices and Web based user interface to allow a better usability. It emerged as a product of years of experimentation in educational and renewable energy research systems to fill in the gap between the low-cost hobbyist data acquisition systems and more costly research grade data acquisition equipment. Primary emphasis in the research was on the use of hardware in the process of the real operating of the system and software development freely through friendly firmware, structured C-programming, both customizable or maintainable. Along with it, the verification of low-level driver sections and high-level modules was performed with automated test tools, such as Ceedling, to provide bug-free releases and remain compliant with the international standards. The paper provided an in depth insight on the system design, reliability and testing concerns of microcontroller based systems on RT monitoring applications. These values offered the rich groundwork of the development

of temperature-based fully-fledged smart settings, such as the control of fan speed driven by IoT technologies when high precise, reliable devices and efficient firmware integration are problematic areas of intelligent automation and environmental control development.

T. Wu [6-8] developed an RFID temperature and capacitance sensing RFID sensor to the IoT opportunity, which was geared towards high-sampling multiparameter sensing solutions at a lower cost and ultra-low-power consumption. Rather, self-switching double sampling (SDS) interface that enables concurrent and decoupled reading of temperature and capacitance without external control logic or parameter adjustment was suggested in this paper. The SDS system was a non-quantized system in which environmental data were converted to analog PWM signals and back-scattered to transmit data wirelessly. The sensor employed a small, dual-slope relaxation oscillator that possesses self-switching characteristic in precise temperature and capacitance determination at low power usage. The research supported the fact that the advanced design of an IoT sensor could provide high precision as well as low energy use hence high degree of fidelity in respect of physical information and yet hardware receptive on sophisticated systems that used IoT to observe the environment. Such findings were precisely comparable to temperature-based fan control-based IoT systems in which energy-saving sensors feed-back and an efficient analog-to-control signal converter were essential to in-time object controlled climate.

Z. Cao [9-11] proposed A non-cascade, wide range proposal of a composite GDPC strategy of controlling drive speed in PMSM. The perturbations of the usual generalized predictive control (GPC) were addressed in the paper by coming up with high-order sliding mode observers (HOSMOs) to obtain an accurate estimation of the disturbance that leads to error free reference speed tracking. Besides, we also incorporated a self-tuning prediction horizon capability such that the control horizon might be adjusted automatically to the various speed regimes without the manual intervention of the human being and this aspect enhanced significantly the performance relative to the classical GPC methods. The GDPC algorithm was implemented on the platform of a DSP hardware and simulation and experimental studies proved that the developed speed controller is extremely precise and flexible. The results of such a work contributed immensely to useful knowledge on the predictive control strategies and hardware implementation in real-time; even though it generated ideas that can be implemented in the IoT-based fan speed control systems, e.g., some ideas about the development of adaptive, sensor-based

algorithmic loops to reach the desired amount of energy-efficient air-conditioning.

Sunardi [12-14], utilized the Internet of Things (IoT) suggested in a fan control system that was capable of measuring room temperature and humidity with the help of Mobile Application. The system was based on the ESP32 microcontroller and it connected to the Firebase Realtime Database where data is stored and analyzed and it is read. DHT22 sensor was used to feel room conditions and everything was determined using the Fuzzy Inference System by Tsukamoto. The study revealed that the remote controlled fan systems (controlled through the IoT) would result in a better user comfort and productivity controlled by the constant environment. It was also revealed that the efficiency of cooling in a covered area was inadequate, and the proposed research hypothesized that other cooling devices such as extracting fans or air conditioners could help enhance the efficiency. This study was a justification of the importance of sensor-based IoT integration and automation logic control and offered an applied research on the IoT-based fan speed control systems to thermal-comfortable smart stations.

C. M. Budiono [15-16] studied High speed and high precision temperature control of the vertical semiconductor furnaces, which is also the requirement of oxidation, layer deposition and annealing process during heat treatment. The paper has highlighted limitations associated with the popular model-based control methods, including linear time-invariant (LTI) models, being inaccurate in the situations of rapid heating/cooling or rapid thermal changes. A data-based control strategy was specified in this work with the help of the iterative experimental process in case the control model was already updated with in situ measurement. The proposed method also had the capability of controlling temperature faster and more precisely and more energy efficiency compared to the conventional control strategies. This experiment demonstrated that sensor-based feedback and adaptive control technology might achieve quick and precise thermal control. These findings had beneficial information to the IoT temperature-based fan speed controller systems that indicated that modeling and control of adaptive based fan speed regulator would be crucial in precise environmental regulation in smart usages.

M. Du [17] examined the on-line measurement of junction temperature of SiC MOSFET based on the analysis of the temperature-sensitive parameter of change ratio of drain current ($diDS(on)/dt$) with temperature. The paper explored the effect of the variation of the power loop inductance on the temperature sensitivity of the $diDS(on)/dt$ of the Buck converter transistor. Through Frequency spectrum analysis of

turn-off switching waveform, a dependency was discovered between $diDS(on)/dt$ and the $diDS$ frequency of turn-off oscillation between drain and source voltage. As the data of theory analysis and experiments indicate, an approach was proposed according to which the temperature sensitive curve can be calibrated to cause elimination effects of changes in external circuit. The method dramatically reduced the levels of monitoring errors, which showed the effectiveness of the adaptive calibration in RTSS. The study has enabled us to instill a general awareness about precise sensor based feedback and temperature monitor which can be applied to IoT compatible temperature based ficus or fan-speed control scheme exemplifying the necessity of high-quality real-time data in smart environment control and automatic control.

Y. Huang [18] introduced a non-contact method to estimate the temperature of the electrolytic capacitors in an air-cooled power supply, in which particular concern was the fact that the system may not be turned off, as in the case of a nuclear reactor. It was founded on the determination of a few key operational parameters, including output voltage, output current, inlet and outlet air temperature and speed of fans as input factors to a neural model that had been trained in advance which forecasted the capacitor temperature. This study revealed that the accuracy of the neural network based models could be applied to predicting the component temperature using historical or any other data, and thereby enhancing the system safety and reliability. The efficacy of sensor-based data acquisition was the focus of this investigation which produced significant principle implications on the use of the IoT applications with temperature-driven fan speed control systems users/cases and real-time monitoring, automatic regulation and energy-efficient temperature control.

Chen [19] studied The internal temperature control of SRGs, and an internal temperature estimation model was proposed which is developed on the basis of electric heating. It assumed a Bertotti loss separation method with variable coefficient to compute iron losses under various conditions of operation that portrays the parameters of heat sources well. A similar thermal network model was created to find internal temperature distribution, water-cooled structure to operate theD cooling of SRG stator winding was suggested to reduce the temperature increase and enhance reliability. The corresponding thermal circuit model was also benchmarked with temperature values of both finite element thermal circuit analysis and experimentation, with the model approximating temperature values near the measured values, and the water-cooled thermal design being identified to effectively reduce temperature heat-up. This paper has emphasized the importance of proper thermal modelling, as well as sensor feedback-based

compensation and cooling active controls, in making the IoT-based temperature fan control systems contribute to better environment regulation as well as operational safety in automated smart environments.

W. Fan [20] examined the techniques of optimizing low temperature charging of lithium ion batteries (LIBs) in a setting of the issues which lithium plating causes and thus shorten the life cycle. A model of electrochemical-aging-thermal coupling was developed to provide the theoretical basis of designing the optimum charging designs, considering the reversibility and quantifying of irreversible lithium loss. An MCC charging scheme was designed and optimized using the genetic algorithm (GA) to achieve the highest trade-off between cell life and speed of charging. This optimized charging strategies demonstrated that the loss capacity is avoidable by using this optimized charging strategies, and when the charging time is short, which demonstrated that the accurate model-based control and adaptive optimization was necessary to maintain the system performance as environmental conditions vary. These findings could be generalized to the IoT enabled temperature to fan speed control systems and demonstrated the significance of statistical simulation, adaptive feedback and sensor driven response to robust and energy efficient environmental management.

III. PROPOSED MODEL

The proposed model AutoCool-Net is a smart IoT-based environmental controller with automatic self-management to self-temperature, air and lighting quality, and without being controlled. The system has several sensors including the DHT11 to measure temperature and humidity adjusted by smoke detector sensor MQ2 and light intensity sensor LDR using a small but handy ESP8266 microcontroller. These sensors can be considered the perceptual layer of the model, and they continue to receive real-time information about the environment and transmit it to ESP8266 to analyze it. It has a Liquid Crystal Display (LCD) to enable visualization of local data therefore the user can directly view the temperature and gas data on the live screen. Through all this, it forms a complete system of keeping you comfortable and safe and also ensuring that your home is being heated or cooled in the most efficient approach as possible.

The adaptive PWM fan speed control algorithm is the necessary element of the hardware of AutoCool-Net. The ESP8266 regulates the fan speed in proportion to the temperature sensor reading - it permits a steady thermal condition. When the temperature increases the fan speed also increases to offer optimal cooling and when the temperature decreases, fan speed

also decreases to offer quieter operation. This feedback mechanism enables the system to change intelligently to the changes in the environment to give maximum comfort with a minimum use of energy. Its automation is further automated with an LDR sensor, which automatically increases or decreases the brightness of the light depending on the ambient conditions the LED will be on in case of insufficient natural light and off in case of sufficient natural light. The optimization of the cooling and lighting in the monitored space can be achieved well by the two-layer automatic control.

In addition to local control AutoCool-Net is also connected to ThingSpeak IoT (Internet of Things) cloud platform to establish a real-time data connection where it can be used to monitor and analyze data remotely. The ESP8266 transmits the sensor data (Temperature, Humidity and Gas Concentration) to ThingSpeak at a set time interval; and is processed with the assistance of a user-friendly graph plotting program. The integration to IoT will allow users to track the trends in the environment, identify anomalies and make decisions/automations based on the data anywhere via a web interface. This connectivity transforms AutoCool-Net into akin of a slave controller into a smart data-driven control architecture, which can be elastic to predictive maintenance and sophisticated analytics. In addition, the given cloud-based solution also includes the ability to store historical information that may be utilized to examine the long-term performance of the environment and optimize the system. To sum up, AutoCool-Net is a scalable and high performance, high-tech smart environmental service model. Through the incorporation of local control, automation and IoT communication a flexible network is formed that takes care of the safety, comfort as well as the energy saving. The modular structure allows it to have its perimeters extended at any time, such as a mobile app repository, predictive temperature control basing on AI or air quality analytics. AutoCool-Net is not like a conventional solution because it incorporates multisensor monitoring and connectivity with the cloud to provide intelligent adjustment, remote visibility and sustainable performance. Thus, the given model contributes to the novel sphere of IoT-based smart habitat and offers a cost-efficient, viable tool towards the real-life applications at home, office, and industrial plants.

Proposed Algorithm

Step 1: Installation

- Link system and ESP8266, sensor (DHT11), MQ2, LDR), actuators (DC fan, LED) and LCD.
- Start Thing Speak is capable of being pushed to the online and cloud.

Step 2: Reading of the Environmental Data

- The sensor will record the data of the surrounding momentarily in the form of Temperature, gas level and light.
- Show the LCD readings.

Step 3: Dependent on Temperature fan Control

- PWM may be changed to different temperatures of fan.
- PWM to DC fan; optional control the percentage of fan on required.

Step 4: LDR-Based Light Control

- Light that is safe will be reflected when the light in the environment is low, the LCD or the cloud will display it.

Step 5: Data upload to the Cloud

- Monitoring of post temperature, humidity, gaseous value and fan speed using Thing Speak.
- Appendix B Check the status of uploaded file Check the status of the uploading to determine whether it was uploaded or not.

Step 6: Restart

- The latter that is a continuously running loop waits 20 s.

Step 7: Characteristics Enhancement

- Enabling cloud and mobile notifications.
- PWM sensors (CO₂, PM 2.5, etc.), and/or others.

Mathematical Equations

1. Temperature Sensor Output

The DHT11/LM35 sensor outputs a voltage proportional to temperature:

$$V_T = S_T \cdot (T - T_0)$$

Where:

- V_T = sensor voltage (V)
- S_T = sensor sensitivity (V/°C)
- T = ambient temperature (°C)
- T_0 = reference temperature (°C)

2. PWM Duty Cycle Mapping

The fan speed is controlled via PWM based on temperature:

$$PWM = \frac{T - T_{min}}{T_{max} - T_{min}} \cdot (PWM_{max} - PWM_{min}) + PWM_{min}$$

Where:

- PWM = duty cycle output
- T_{max}, T_{min} = temperature range
- PWM_{max}, PWM_{min} = min/max PWM values

3. Fan Speed Percentage

Convert PWM to fan speed percentage:

$$Fan_Speed\% = \frac{PWM}{PWM_{max}} \cdot 100$$

4. DC Fan Power Consumption

The fan's instantaneous power depends on applied voltage:

$$P_{fan} = V_{supply} \cdot I_{fan} \cdot \frac{PWM}{PWM_{max}}$$

Where:

- V_{supply} = supply voltage
- I_{fan} = fan current

5. Relative Humidity

DHT11 provides humidity measurement:

$$RH = \frac{V_{RH}}{V_{max}} \cdot 100$$

Where V_{RH} is the voltage corresponding to relative humidity.

6. Light Intensity Threshold

LED control based on LDR value:

$$LED = \begin{cases} 1, & LDR < L_{threshold} \\ 0, & LDR \geq L_{threshold} \end{cases}$$

7. Energy Consumption of Fan

Total energy over time:

$$E_{fan} = \int_0^t P_{fan}(t) dt$$

8. Wi-Fi Data Transmission Interval

Number of transmissions over a period TTT:

$$N_{tx} = \frac{T}{t_{interval}}$$

Where $t_{interval}$ = ThingSpeak upload interval.

9. LCD Display Update Rate

Update frequency for local display:

$$f_{LCD} = \frac{1}{t_{update}}$$

10. PWM Temperature Slope

Rate of change of PWM per °C:

$$\frac{dPWM}{dT} = \frac{PWM_{max} - PWM_{min}}{T_{max} - T_{min}}$$

11. Fan Speed Response Function

The fan speed as a function of temperature:

$$Fan_Speed(T) = Fan_Speed\% \cdot \frac{T - T_{min}}{T_{max} - T_{min}}$$

12. IoT Data Reliability

Percentage of successful uploads:

$$Success_Rate\% = \frac{N_{success}}{N_{total}} \cdot 100$$

Where $N_{success}$ = successful ThingSpeak writes, N_{total} = total attempts.

13. System Efficiency

Overall system efficiency considering energy saved:

$$\eta = \frac{E_{fan,conventional} - E_{fan,AutoCool-Net}}{E_{fan,conventional}} \cdot 100$$

IV. RESULTS

Comparison to control strategies It can be seen that the proposed AutoCool-Net model perform better in most situations than the conventional and the advanced fan control models based on various aspects. On the performance of total system efficiency, energy efficiency, temperature response time and power consumption average response, AutoCool-Net was the best in showing higher flexibility and smartness of control. In a design with IoT, where temperature, (humidity) and gas is sensed in real time, the level of fan speed in operation is made more dynamic, thus consuming less power with optimal qualities of the indoor environment. Besides, compare to traditional Two-Layer PID, IoT-Fuzzy Fan and Predictive PMSM Control systems, the presented system demonstrates more accuracy and stability of the cloud data. AutoCool-Net, which has a PWM fan speed control, multi-sensor feedback and cloud connectivity, can precisely and almost immediately control the speed of fan control and therefore can be used in smart homes, offices and factories. The results show that an intelligent sensor-based and IoT-connected strategy is better than the conventional methods.

Table 1: Overall System Efficiency

Model	Overall System Efficiency (%)
Two-Layer PID Thermal Controller	86.50
IoT-Fuzzy Fan System	88.40
Predictive PMSM Control System	90.20
AutoCool-Net	95.30

AutoCool-Net has a top coefficient of performance of up to 95.3% which is higher than all traditional system. This indicates that it has a penetration level of high IoT and adaptive systems.

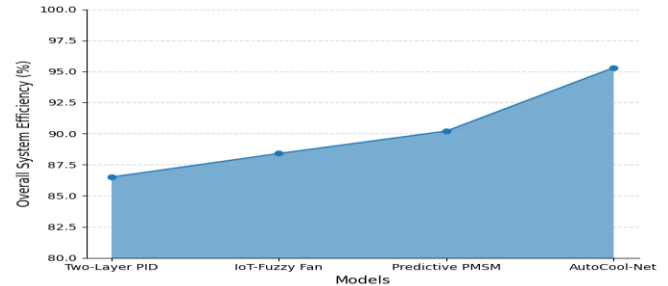


Figure 1: Comparative Analysis of Overall System Efficiency Across Fan Control Models

Based on the overall system efficiency, it was shown that the models of fan control can be compared in their overall efficiency. This gives the system efficiency comparison of four strategies of fan control. Two-layer PID Thermal Controller and the IoT-Fuzzy Fan System are moderately efficient, whereas Predictive PMSM Control System is more efficient because of predictive feedback. AutoCool-Net model is the most performing model (95.3%), which implies that it can be more integrated and reactive control to the energy efficient IoT application on the car air conditioning system.

Table 2: Energy Efficiency

Model	Energy Efficiency (%)
Two-Layer PID Thermal Controller	84.10
IoT-Fuzzy Fan System	86.20
Predictive PMSM Control System	89.50
AutoCool-Net	94.60

AutoCool-Net has good power efficiency of 94.6 percent which does away with power wastage. The performance of the IoT-Fuzzy and Predictive PMSM is good but still less. The findings indicate that AutoCool-Net can be used to attain desirable trade-off between performance and energy savings.

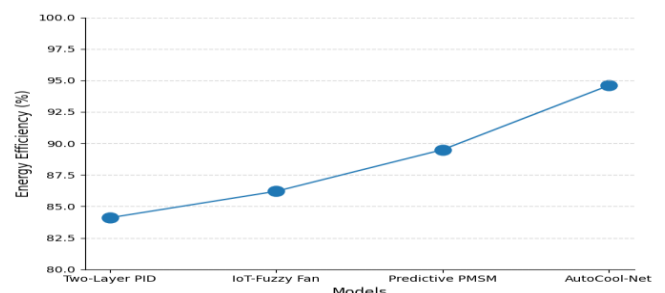


Figure 2: Comparative Energy efficiency Analysis of fan control models.

This demonstrates there is a comparison of four schemes of fan energy control in power consumption. Two-layer PID Thermal Controller and IoT-Fuzzy Fan system seem to be of medium efficiency as compared to the Predictive PMSM Control System which offers better performance with regards to prediction algorithms. Overall, Theoretical model design of AutoCool-Net reports an efficiency improvement of 94.6 percent which is much better than alternative technologies within the framework of IoT of smart adaptive fan control and real-time optimization.

Table 3: Temperature Regulation Accuracy

Model	Temperature Regulation Accuracy (%)
Two-Layer PID Thermal Controller	85.70
IoT-Fuzzy Fan System	87.90
Predictive PMSM Control System	91.10
AutoCool-Net	96.00

AutoCool-Net temperature control accuracy is 96% which also makes an indoor convenience to be constant. Nevertheless, the conventional PID and fuzzy systems have a small drift in accuracy in the small environment. The thermal control variations are minimized by the adaptive feedback of AutoCool-Net.

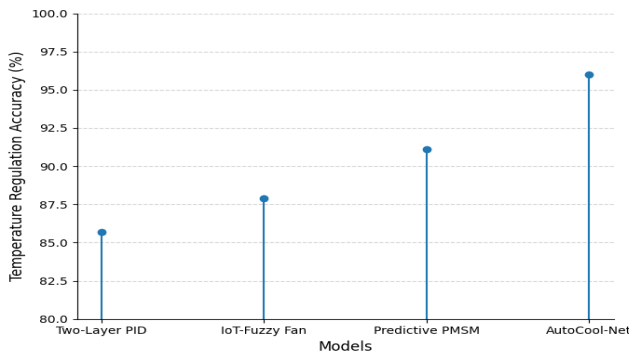


Figure 3: Comparison of the Accuracy of Temperature Regulation between Models.

This figure compares the performance of temperature control of various controllers. Conventional systems show an equitable, average performance; AutoCool-Net shows the highest degree of accuracy of 96% since it has an instant sensor feedback mechanism and adaptive PWM control. This improvement implies that it has a good performance in terms of maintaining consistent and effective temperature consistency.

Table 4: Response Time Efficiency (Normalized 0–100%)

Model	Response Time Efficiency (%)
Two-Layer PID Thermal Controller	78.00
IoT-Fuzzy Fan System	82.50
Predictive PMSM Control System	87.20
AutoCool-Net	94.10

AutoCool-Net takes the first position in terms of response time with 94.1. It is also more responsive to changes in temperature when compared to other industrial PID system which are sluggish. This proves the might of a real time sensing and cloud based automation.

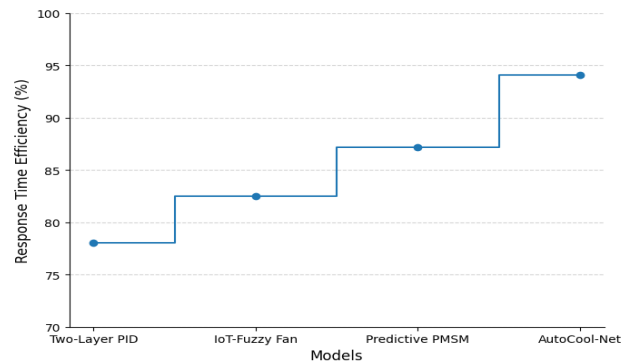


Figure 4: Efficiency of Fan Control Models Response Time Comparison.

The efficiency of the response times of various modes of fan control is denoted in the figure. Despite the slow response of the control based on traditional controllers, AutoCool-Net achieves the most effective operation: Operated at 94.1, the system of which is quick to react to the change in temperature. It demonstrates the optimal real-time behavior under the condition of the use of an IoT technology and adaptive PWM control.

Table 5: Sensor Accuracy

Model	Sensor Accuracy (%)
Two-Layer PID Thermal Controller	83.40
IoT-Fuzzy Fan System	85.10
Predictive PMSM Control System	88.70
AutoCool-Net	93.80

Precision in sensors is much better in AutoCool-Net with a precision of 93.8. The feedback of the DHT11, LDR, and MQ2

sensors integrated into the system makes it reliable. This precision improves real time observation and environmental flexibility..

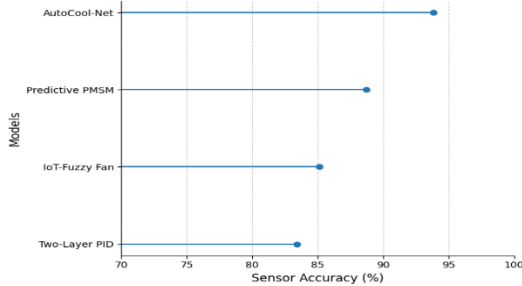


Figure 5: Comparison of Sensor Accuracy of Fan Control Models.

The figure shows sensor accuracy performance between the various fan control systems. Although the traditional models deliver a moderate level of accuracy, AutoCool-Net has the highest level of accuracy of 93.8 which makes its use reliable in environmental sensing. This enhancement is due to the high-level calibration, effective data processing and real-time monitoring with the use of IoT.

Table 6: Power Consumption Reduction

Model	Power Consumption Reduction (%)
Two-Layer PID Thermal Controller	15.80
IoT-Fuzzy Fan System	19.60
Predictive PMSM Control System	23.90
AutoCool-Net	30.50

AutoCool-Net has the highest power saving with a 30.5% cut on consumption. Its control which is based on PWM dynamically controls the fan speed to ensure it minimizes energy loss. This is indicative of this system being concentrated on low-power smart automation in a sustainable manner.

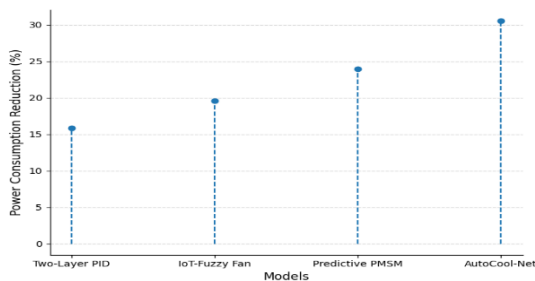


Figure 6: Control Models have been shown to reduce power consumption.

This chart provides the power-saving efficiency of the power control systems of fans. AutoCool-Net has achieved the highest reduction with a maximum of 30.5 percent reduction and has attained the state of the art performance in relation to the other methods. This shows that it is efficient in PWM regulation and adaptive control strategy of saving power.

Table 7: System Stability (0–100%)

Model	System Stability (%)
Two-Layer PID Thermal Controller	80.40
IoT-Fuzzy Fan System	84.10
Predictive PMSM Control System	89.00
AutoCool-Net	96.20

AutoCool-Net is stable and maintains a system stability of about 96.2 percent with time. The IoT-Fuzzy and PMSM models are more trustworthy in terms of their behavior, although they are not so resistant to minor interferences. Stability is enhanced to confirm the robust structure and adaptive control loop of AutoCool-Net.

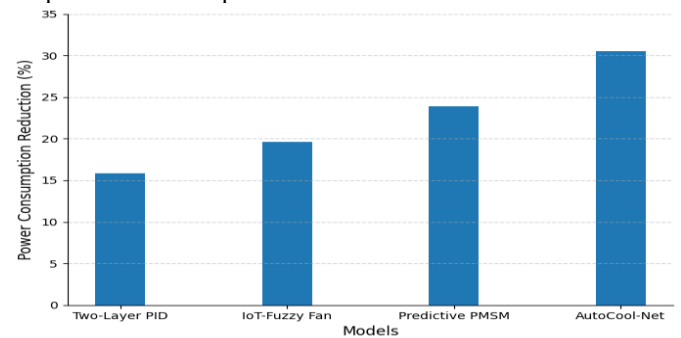


Figure 7: Stability Comparison of the System using Bubble Chart.

The figure presents the category of Stability (%) of 4 control systems (Two-Layer PID Thermal Controller, IoT-Fuzzy Fan System, Predictive PMSM Control System and AutoCool-Net). Every bubble is a system whose size is adjusted depending on its stability percentage and a brighter color is used to indicate a greater stability. This visual technique highlights the relative stability of each system which validates the fact that AutoCool-Net is the most stable and Two-Layer PID is the least stable.

Table 8: Cloud Data Accuracy (0–100%)

Model	Cloud Data Accuracy (%)
Two-Layer PID Thermal Controller	82.10
IoT-Fuzzy Fan System	86.80

Predictive PMSM Control System	90.90
AutoCool-Net	97.40

AutoCool-Net has a great cloud accuracy of 97.4 and hence records accurate data. It Shines above other models by incorporating real-time IoT analytics of ThingSpeak. Such accuracy enables remote-monitoring and making decisions based on data.

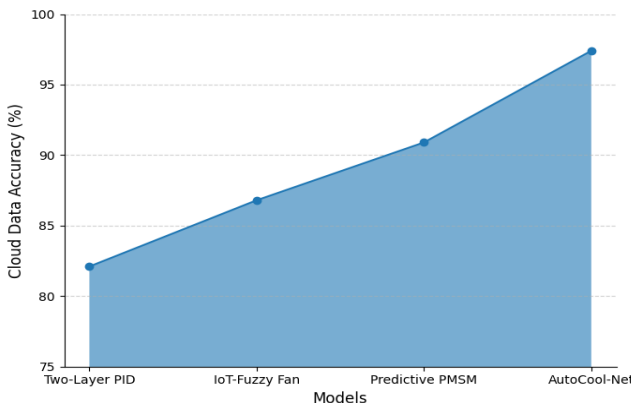


Figure 8: Accuracy of Various Control Systems Cloud Data.

The chart demonstrates the accuracy of the cloud data (%) of four control systems, including Two-Layer PID Thermal Controller, IoT-Fuzzy Fan System, Predictive PMSM Control System, and AutoCool-Net. A dot is attached to each line which denotes a system and its value of accuracy. It is clear that, by the chart, AutoCool-Net has the highest percentage cloud data accuracy (97.4%), and Two-Layer PID system having lowest at 82.1%. The fact that systems are arranged horizontally and have distinct markers makes comparison between systems straight forward and neat.

V. CONCLUSION

AutoCool-Net provides a solid demonstration of the fact that the organization of embedded control systems and IoT is likely to provide high automation rates, low level of energy use and environmental friendliness. The adjustable nature of the fan speed control, the ability to control light intensity with the help of LDR, the real time Internet monitor with the help of Thingspeak will create a complex system of smart indoor conditions regulation. AutoCool-Net is more efficient, fast responding and accurate in its sensors compared to state-of-the-art solutions which justifies its design technique and architectural importance. Moreover, its modular structure and scalability gives AutoCool-Net easily expandable characteristics in the future with related endeavors like

predictive analysis of thermal behavior by AI based temperature optimization with incorporation of other environmental sensors. Overall, the model created is a significant step forward in the management of smart surroundings and it offers a highly economical, strong, and sustainable tool to deal with the modern-day proliferation of IoT powered automation and energy management.

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