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PWM Precision Flight Controller Cooling System for UAV in Pineapple Plantation

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Abstract: PWM selection is to provide the required operating signal for the flight controller. During the flight, drone technology advances, flight times and distances escalate. The flight controller will become more susceptible to damage, complicating the distance and tasks that the drone will perform—the likelihood of causing high maintenance costs. The appropriate PWM to maintain the cooling system, safeguard to extensive usage of operating signal might be useful to minimize mechanical damage and extend flight longevity. The aim is to develop a cooling system to subside thermal heat in order to raise a UAV's flight time. The study was carried out in a closed environment with room temperature at 32ºC. A flight controller prototype was designed and operated with PWM, and fan revolution speed with temperature was recorded every 15 seconds for 1 minute. The thermal heat reduces by 6ºC from the baseline (40ºC), the fan speed remains constant at 3000-3500 rpm at 45-60 secs during PWM 25%. Whereby, thermal heat reduces by 10ºC from the baseline, the fan speed remains 4000 - 5000 rpm at 45-60 secs during PWM 75%,100%. The linearity between the duty cycle of PWM is 98% with fan speed. However, the appropriate duty cycle of PWM set at 50%; the temperature is considerably below 30ºC beginning at 45 secs shows positivity towards cooling systems. Thus, the operating signal is overused during PWM 75% and 100% for 15 secs. The basic concept behind this project is to turn on the DC motor fan when the temperature threshold value of 40ºC.

Keywords: Pulse Width Modulation (PWM), cooling system, temperature

1. Introduction

Automation is the key concern in agriculture and the world's new trend. UAV use has already begun in developing countries agriculture, photogrammetry, and remote sensing in their accuracy. UAV dependability, like maintenance and safety issues [1], has grown increasingly crucial in recent years: engines have gotten more durable, avionics must be at peak performance, and so on. 45% of accidents to involve material failure alone, and their paper was studied aiming at the criticality of maintenance [2]. However, as drone technology advances and flight times and distances escalate, flight controllers will become more susceptible to damage, complicating the distance and tasks that the drone will perform. The likelihood of a cooling system being able to extend a UAV's flight time. Sophisticated UAV systems have an overall failure rate of 25% [3]. Pulse width modulation (PWM) is a technique of modulation which produces variable width pulses representing the amplitude of analog input signals. For a high-amplitude signal, the output transistor is longer, and a low-amplitude signal more time. Additionally, the flight controller will become more susceptible to damage, complicating the distance and tasks that the drone will perform—the likelihood of causing high maintenance costs.

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Researchers showed another Unmanned Air Vehicle (UAV) accuracy sprayer Pulse Width Modulation (PWM) controller for agriculture with TL494 a fixed-recurrency beat width modulator along with details on the board and programming developed [4]. Besides spraying, the UAV is also used to aggregate thermal, measuring water stress [5]. Moreover, UAV manages investigation related to complexities of using useful ICT services that enhance the efficiency of agrochemical products [6]. The various usage may involve high maintenance costs in long run. Thus, ambient temperature is useful to stabilize the cooling system to prevent overheating. Excessive heating is caused by a cooling system failure, according to researchers [7]. The appropriate PWM to maintain the cooling system, safeguard to extensive usage of operating signal might be useful to minimize mechanical damage and extend flight longevity. There is a gap between the present technology in PWM of TL494 PIC controller and the statistical output of Arduino Nano AT Mega 328 in time of fan speed.

A study on ‘Temperature based automatic fan speed controller’ that the team had automatically adjusted revolution of fan following the environmental temperature using entire hardware design, aimed the temperature sensor circuit that senses the change of ambient temperature for a computer [8]. Thus, this study will focus on PWM in transmitting a signal on the drone for precision temperature.

2. Materials and Methods

The Movement Control Order (MCO) to flatten the curve to diminish the Covid-19 pandemic turned the researcher's maneuver to test the drone on the ground. As a result, the researcher employed fundamental prototyping techniques to conduct cooling tests on the drone in a room environment. Moreover, the design of the experiment is a methodology that guides the users through experimental tests while developing models using a minimal expenditure of resources.

2.1 Materials

2.1.1 Hardware Description

a) Arduino Nano ATMega 328 microcontroller - The Arduino Nano High Performance, Low Power AVR® 8-Bit Microcontroller. Advanced RISC Architecture. 131 Powerful Instructions - Most Single Clock Cycle Execution Six PWM Channels. 6-channel 10-bit ADC in PDIP Package. Programmable Serial USART Master/Slave SPI Serial Interface.
b) Axial fan - to receive PWM signal from sender side, transfer the spinning speed to the microcontroller.
c) Battery pack - lithium batteries for power sources.
d) Digital multimeter - to check the DMM functions AC/DC voltage, capacitance, continuity, diode, frequency, resistance with 3.75 digits. The max voltage measure AC dan DC is 600V.
e) Digital oscilloscope - A unique characteristic of analog oscilloscopes is that they present reference value and time information in 'near real-time"; that is, the demonstration is generated immediately as real calculated value versus the time events.
f) Thermal sensor (DS18B20) - measure the temperature in Celsius, connects with a central CPU using a 1-Wire bus.
g) Digital Tachometer - to measure the speed of axial fan spinning, able to notify 1 to 99,999 rpm.
h) Motor drive L298N as a high power motor driver module for driving DC and Stepper Motors.
i) Thermometer to detects temperature translating into a numerical number.
j) Resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element.
k) Burner and metal sheet - burner to provide fire that heats the metal sheet to transfer heat to the flight controller.

Fig. 1 shows the overall system setup concerning the axial fan into the prototype UAV system to activate the cooling mechanism for the flight controller. Fig. 2 shows a block diagram followed by an electrical schematic diagram (Fig. 3) concerning the axial fan into the prototype UAV system to activate the cooling mechanism for the flight controller. A 12V battery is used to power the circuit. Next, the breadboard is connected to the input of L298N positive and negative ends. The output of 5V from L298N is connected to the input of 5V pin Arduino nano to power up. Followed by that thermal sensor DS18B20 positive wire is connected to 5V Arduino input and negative wire connected to power supply battery. The 4.7K ohm resistor is linked to the thermal sensor data supply wire D9 digital pin and the 5V input pin of the Arduino nano, and from the other end of the L298N ENA pin is connected to the D3 digital pin to get control of PWM, the IN1 & IN2 is connected to D6 and D7 digital pin to on and off the axial fan. From motor A, out 1 is connected to negative, and out 2 it is connected to the positive wire of the axial fan. The tech wire from the axial fan is connected to the D2 digital pin of the Arduino Nano ATMega 328 microcontroller.

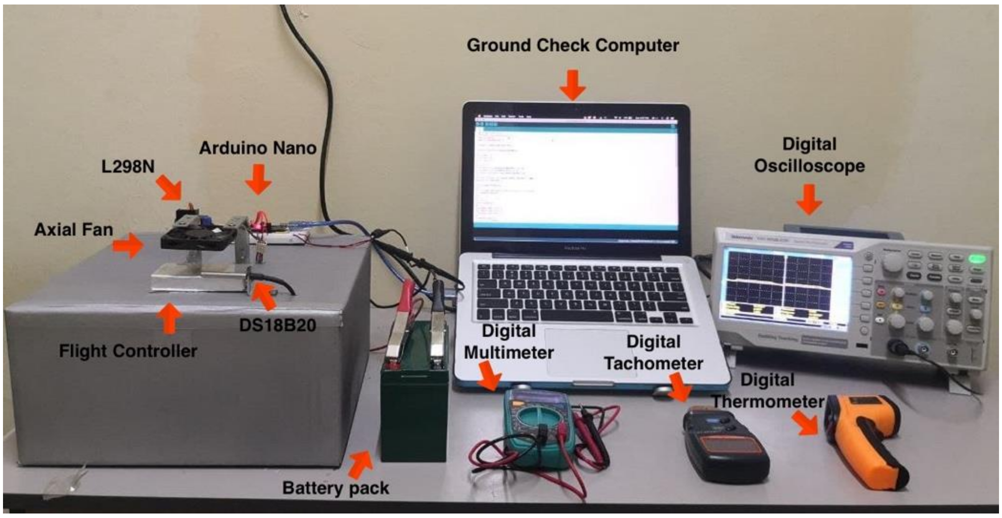

Fig.1 - Overall system setup

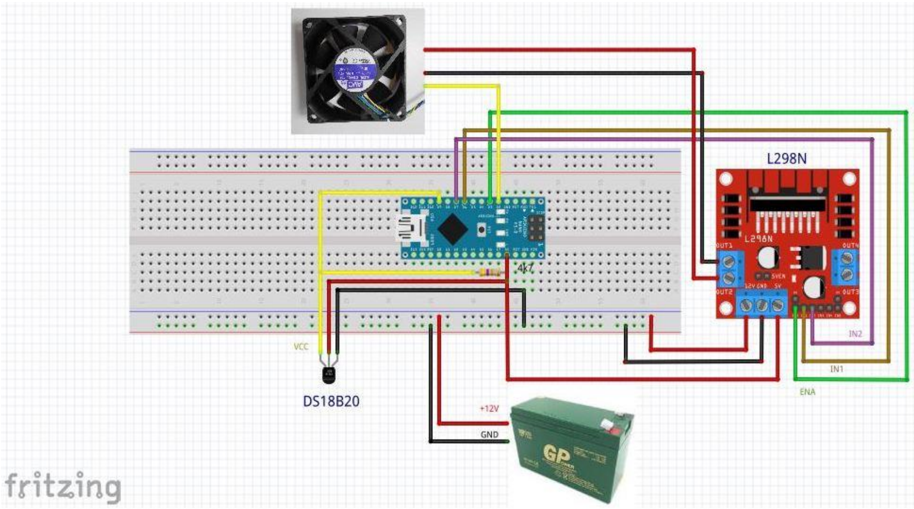

Fig. 2 - Electrical block diagram

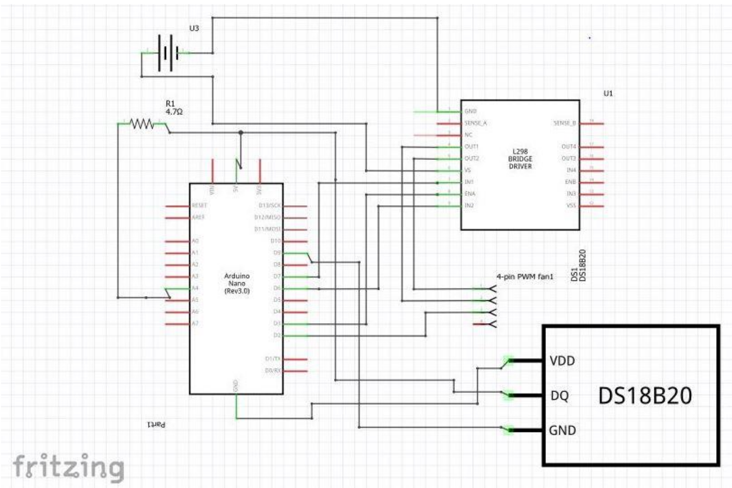

Fig. 3 - Electrical schematic diagram

2.1.2 Software Description

a) Arduino compiler - a tool to manipulate the real environment rather than the desktop. The Arduino programming language is implemented by Wiring, a similar physical platform focused on multimedia programming processing in the area.

b) Fritzing software - an ultimate tool to create electronic circuit and component diagrams for use with rapid-prototyping developments boards such as the open-source Arduino called Arduino Simulator online.

c) SOLIDWORKS - used in designing mechatronic systems.

2.2 Methods

First, the four phases of the duty cycle are configured as follows: Phase 1: PWM at 25%, Phase II: PWM at 50%, Phase III: PWM at 75%, and Phase IV: PWM at 100%. Then, thermal heat measurements were taken after 1 minute of axial fan rotation per minute (rpm) every 15 seconds at 25 percent, 50 percent, 75 percent, and 100 percent of the duty cycle. The selection of this axial fan was based on a high rpm of 4.8W Speed: 700 ~ 4800RPM, max flow 23.78cfm in the industrial market, so researchers use this axial fan because it is exceptionally light (65g). During the experimental phases I to IV, the heating process for the prototype commenced to meet the baseline temperature (40 degree Celsius). A metal sheet (30 × 30 cm) was placed on a burner by the researcher to enable a stable flame to produce heat at 40 degrees Celsius. The prototype flight controller was placed on the metal sheet. Eventually, the heat is transferred to the prototype flight controller offering equal heat dispersion. Direct heat will cause heat instability.

A duty cycle may be defined as the amount of time in a particular period during which the pulse is active or high. The tested temperature makes the spinning speed varies in low, medium fat, very fast, zero relating to different duty cycles. Fig. 4 shows flow chart of the temperature controller with varying duty cycles. The approach is by introducing compensation of temperature caused variability in duty cycle. The flow sensor will feedback every 500 ms on the number of pulses, and the new system is measured to produce instant flow. The input of the Arduino Nano AT Mega 328 microcontroller is the deviation between the simultaneous stream rate and the cooling system's destination flow. When the Arduino control algorithm is running, the duty value is the output, and a PWM square wave is generated with the duty ratio of the spinning.

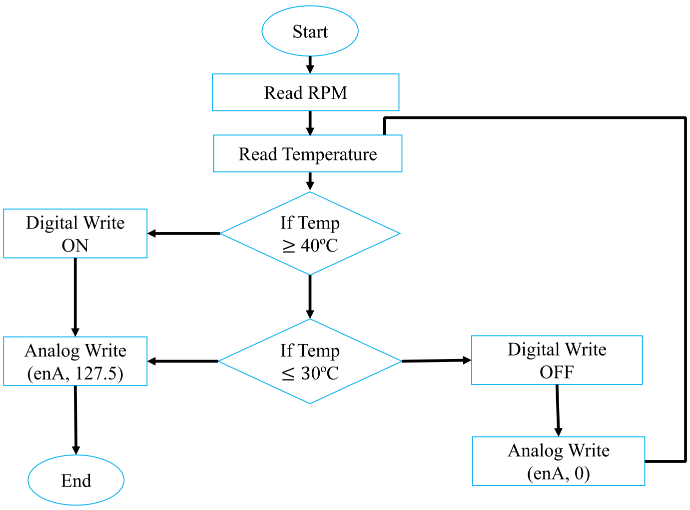

Fig. 4 - Flow chart on a control program

Using the formula T = 1/f, calculate the period, or "T," of the frequency, or "f." For example, if the frequency is 20 Hz, T = 1/20, yielding 0.05 seconds. Determine the duty cycle, denoted by the letter "D," using the formula D = PW/T.
The duty cycle represents D is measure as the following:
Duty Cycle = Pulse Width (sec) * Repetition Frequency (Hz) * 100.
For example, if PW is 0.03 seconds and T is 0.06 seconds, then D = 0.03 / 0.06 = 0.5 or 50%.

3. Results and Discussion

The influence of axial-fan on the spinning speed (rpm) taken via tachometer, temperature coverage via digital thermometer, pulse width modulation of 25%, 50%, 75%, and 100% deposition was analyzed and simulated regarding a different operating parameter of temperature. The temperature was set at a baseline of 40 degrees Celsius, and the recording of temperature was taken every 15 seconds for 1 minute following the fan speed at duty cycles of PWM.

3.1 Results for Objective 1: To Develop a Cooling System for the Flight Controller to Prevent Overheating

The prototype designs an isometric view (Fig. 5), prototype design of front view (Fig. 6), the actual design of isometric view (Fig. 7), and the overview of isometric actual design (Fig 8). The coding system is shown in Fig. 9.

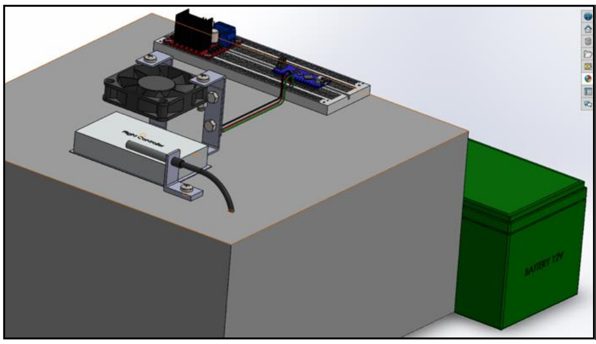

Fig. 5 - Prototype design (isometric view)

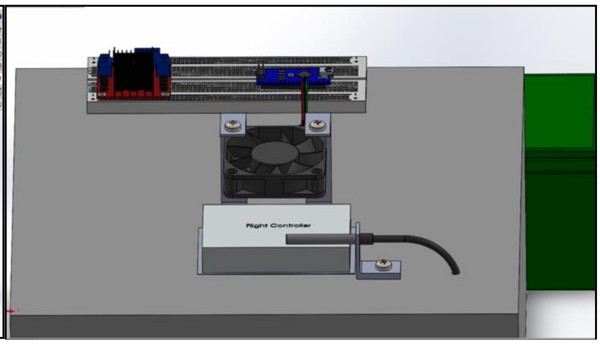

Fig. 6 - Prototype design (front view)

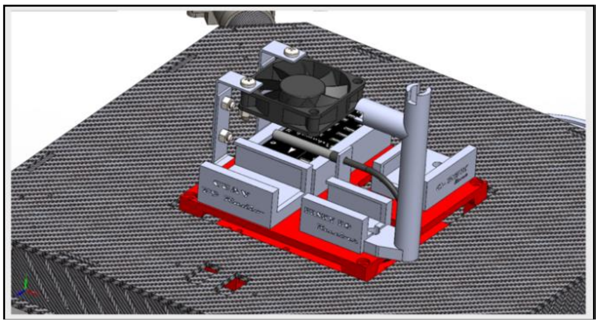

Fig. 7 - Actual design (isometric view)

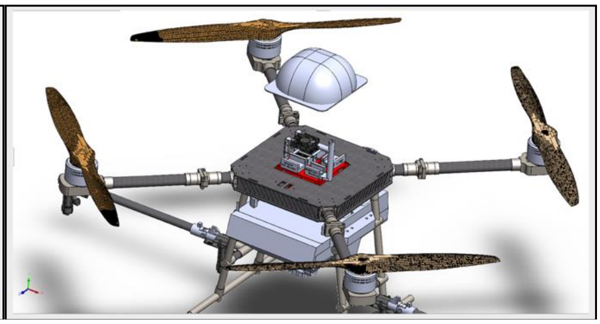

Fig. 8 - Overview of isometric actual design

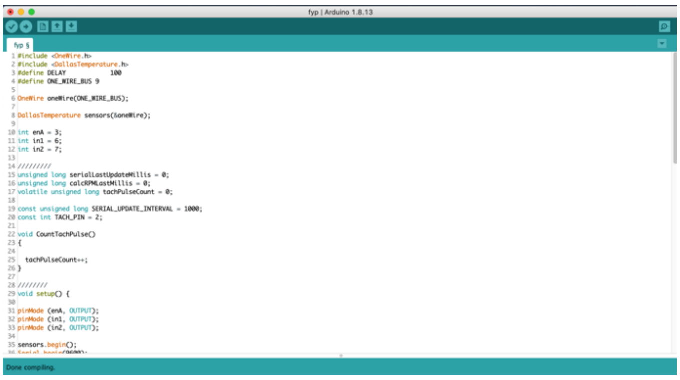

Fig. 9 - Coding system

3.2 Result for Objective 2: To Evaluate the Temperature Set Up for the Flight Controller Cooling System to Function at Maximum Duty Cycles of 25, 50, 75, and 100 Percent Using Temperature Levels in a Particular Time lapse

Fig. 10 shows the temperature level 1 [0 - 30 ºC] at 60 seconds, temperature level 2 [31.1 - 33 ºC] during duty cycle of 50%, 75%, and 100% compare with the duty cycle of 25% [the lowest is temperature level 2 at 31.1 - 33 ºC. Therefore, during the operational duty cycles of PWM 50 to 100, the temperature drops dramatically. So the researcher measured the temperature in line with the duty cycles. The room temperature is around 32-33 degree Celsius, and the environmental temperature does not intervene in the experiment. The cooling system has begun to operate as a resulting success in temperature decline following the PWM with a temperature level of 0 - 30 ºC. This outcome is similar to a study by Landman et al. (2005) where the temperature was taken in a closed area with minimal noise and air.

Fig. 11 demonstrates the entire phase of duty cycle 25%, 50%, 75%, and 100%, demonstrating the fluctuating temperature according to duty cycle and fan speed activating the cooling system during the duty cycle of 50, 75, and 100 percent respectively. The temperature typically oriented downward trend starting from 45 seconds in every phase of duty cycle gradually convergence and steady condition amid its increment of fan speed. The findings conclude that the operational duty cycles of PWM 50% to 100%, with is cooler thermal heat during the time of 45 seconds onwards to 60 seconds with an appropriate fan speed of 3000-4000 rpm in 60 seconds. The cooling system functions without interrupting the fan speed.

Fig. 10 - Mean fan speed against mean temperature measurement (baseline of 40ºC)

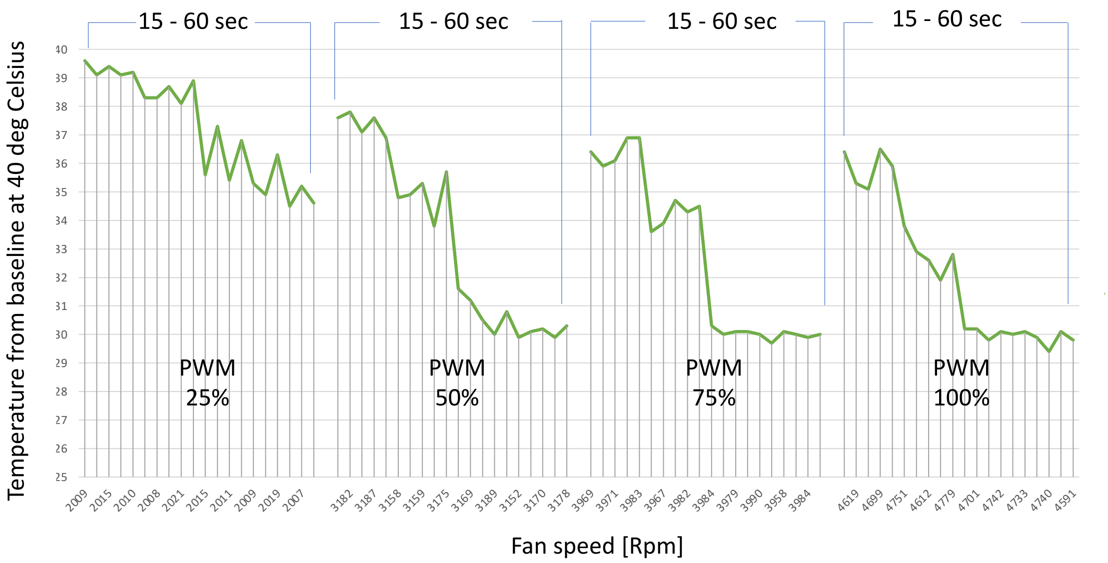

Fig. 11 - Fan speed vs temperature from baseline at 40 º C in duty cycles

3.3 Result for Objective 3: To Evaluate the Relationship Within [Temperature vs Rpm], by Choose Precise Duty Cycle of a Cooling System in 60 Seconds with Precision of Axial Fan Efficiency

The temperature and fan speed were measured throughout the following duty cycles: 25%, 50%, 75%, and 100%, the temperature is significantly correlated with the fan speed [r= -575, Sig. = .000, p<.001, n=80] (Table 1). However, the researcher has only reference related to experimental design and unable to compare with the conventional design due to movement control order. The temperature begins to decline as the fan's revolutions increase. The cooling system has been turned on. The statistical evidence shows the temperature scale strongly correlates with the revolution of axial fan when the experiment was carried out in 60 seconds.

The precise duty cycle of a cooling system in 60 seconds with temperature levels is shown in Fig.12. The findings, we can conclude that the operational duty cycles of PWM 50% to 100%, with is cooler thermal heat during the time of 45 seconds onwards to 60 seconds with an appropriate fan speed of 3000-4000 rpm in 60 seconds. The cooling system functions without interrupting the fan speed. The duty cycle 50%, 75%, and 100% demonstrates extensive temperature reduction from the baseline compared with the duty cycle of 25%. However, the duty cycle of 50% has presented the cooling condition of a flight controller as the fan speed is a manageable range of 3000rpm and the temperature is low at 30 º C.

Table 1 - Pearson correlation between temperature and Rpm

Temperature	Pearson Correlation	1	-.575**
	Sig. (2-tailed)		.000
	N	80	80
FanSpeed (Rpm)	Pearson Correlation	-.575**	1
	Sig. (2-tailed)	.000	
	N	80	80

**Correlation is significant at the 0.01 level (2-tailed).

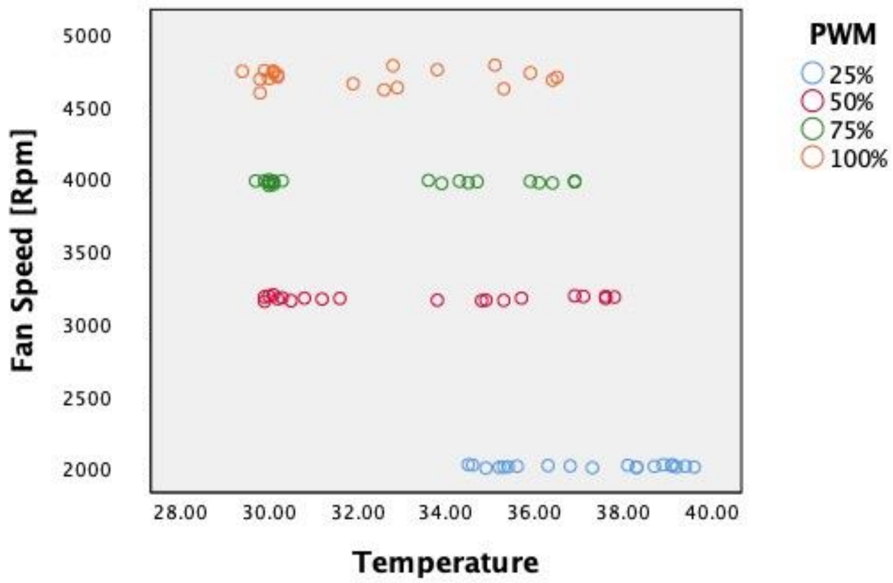

Fig. 12 - Temperature vs fan speed during duty cycles

The axial fan seems to have contributed in the cooling system for a prototype design, (0 to 30ºC, n=24; 30.1 to 33ºC, n=13, 33.1 to 36ºC, n = 16, and 36.1 to 39ºC, n=6). Overall, 46.3%, n=37, temperature measurement is below 33ºC. Thus, the temperature reduction demonstrates the precision of thermal application to avoid delays in the response of the spinning rate approximately above 3000 rpm.

3.4 Discussion

The finding in this study indicates that the duty cycle of PWM at 25%, the average thermal heat is at 36 degrees Celsius. At the duty cycle of PWM 50%, the temperature begun to drop, and the cooling system has been activated for the flight controller. The sustainability of lower temperature is recorded during the duty cycle of PWM 75% and 100%. The Scatter plot graph shows there is linearity between the pulse width modulation and fan speed, R^2=0.98. As the duty cycle of PWM increases, the fan speed accelerates. The trendline of the form $y = 1.25E3 + 8.886E2 * x$ were fitted to published data as they best represented the trends in data whilst accounting for the variation of duty cycle and fan speed. The presented form is quantitively indicates the range of thermal performance provided by the axial fan to judge whether the data produced in this experiment is valid. This experiment yielded data on the PWM series' temperature change as well as the fan speed.

In previous studies, the researchers tested fan scaling laws and demonstrated to accurately predict fan performance based upon rising fan speed and power input in high-pressure conditions [9,10]. However, the finding in this study shows the accuracy of PWM with range fan speed at 98% linearity at 60 seconds with ambient pressure. Similarly, [11] offers an extensive range of thermal performance in the mass flow rate range.

The graph in Fig. 13 depicts temperature against fan speed based on pulse width modulation. During the 25% PWM, the fan speed is set at 2000 rpm, and the thermal heat is reduced from 40 º C to 34 º C in 1 minute. Whereas the thermal heat reduces by 6 º C from the baseline, the fan speed remains constant at 3000-3500 rpm. Similarly, when the revolution is 4000 - 5000 rpm, the temperature drops to 30 º C. Temperature evaluation is at the lowest during the duty cycle of PWM 50-100%, and the duty cycle of PWM is linear, with the fan speed at 98 percent. The cooling system operates when the duty cycle of PWM is set to 50% or even above.

The cooling mechanism proposed in this study will be resulted in a printed circuit board (PCB) for the PWM duty cycle to empower the flight cooling system which can be used for the respective duty cycle and choose the optimum cooling temperature that gives the desired performance. Thus, the performance allows the user to test and characterize a system consisting of an axial fan, digital oscilloscope, flight controller: this group of components is mounted on the sensors head of the bench board. Thus, maintenance is instead an optimal part of UAV's performance for fly time longevity.

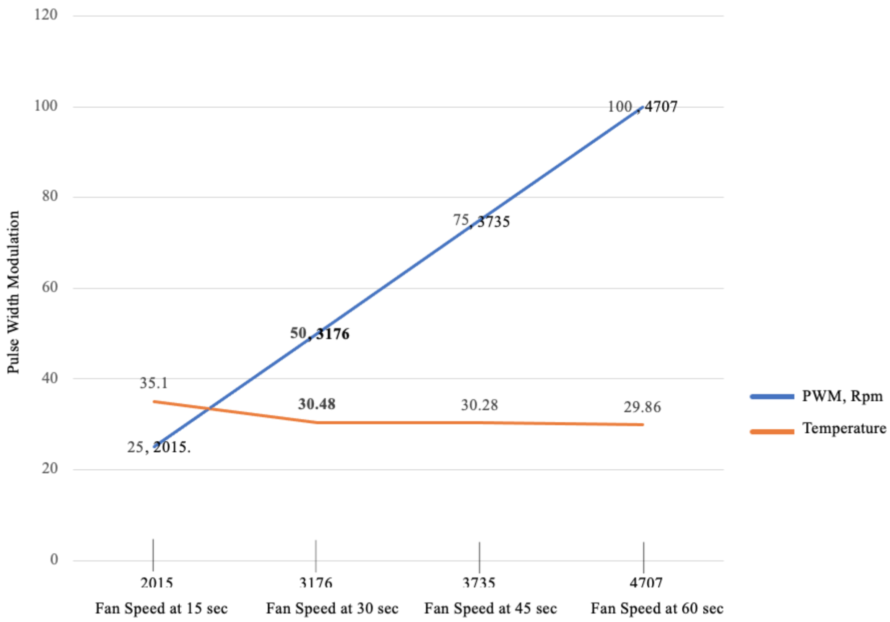

Fig. 13 - Fan speed vs temperature measurement of baseline 40º C in 1 minute

4. Conclusion

In conclusion, when the duty cycle of PWM is set to 50%, the temperature is considerably below 30ºC. The researcher believes that optimal utilization can be maintained when the PWM is set at 50% to enhance longevity. However, when the duty cycle of PWM is at 75% and 100%, the maximum speed of the low temperature sustains during the 45 and 60 seconds may cause a power wastage. The extensive usage during the duty cycle of 75 and 100 percent may cause wastage of 15 seconds spinning. The basic concept behind this project is to turn on the DC motor fan when the temperature measured by the temperature sensor exceeds a threshold value of [40 degrees Celsius]. The researcher utilized an Arduino Nano ATMega 328 microcontroller on a beard board to program the microcontroller via USB in this study.

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