

Cooling Fan Uses the BLDC Motor

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ABSTRACT

The article presents simulation results, experimental results, and calculations of temperature control via an NTC temperature sensor and then demonstrates Oled SH1106 using the I2C port for communication. The author uses a 12V/100W BLDC motor with a maximum speed of 5380rpm to replace a 12V/100W DC motor with a maximum speed of 2200rpm. The author uses Arduino to control the speed of the cooling fan and shows it through the OLED screen. The input of the control is an NTC-type temperature sensor. However, this control method is independent of the control on the vehicle's control box. This may be a limitation, but this research mainly demonstrates the applicability of BLDC motors. Using the overview method of DC motors compared to BLDC motors, calculate the temperature to control BLDC motors to reduce the heat of internal combustion engines and electric motors on cars. Replacing DC motors with another motor is a step forward in the electric motor industry. BLDC motor is an option to replace the DC motor.

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1. Introduction

The design of the electric systems in the automobile is undergoing a revolution, aiming to improve fuel efficiency, safety, comfort, and convenience [1]. We know that in the case of Internal Combustion engines, the combustion of air and fuel takes place inside the engine cylinder, and hot gases are generated. The temperature of gases will be around 2300-2500°C. This is a very high temperature and may result in the burning of oil film between the moving parts and may result in seizing or welding. So, this temperature must be reduced to about 150-200°C at which the engine will work most efficiently. Too much cooling is also not desirable since it reduces the thermal efficiency. An internal combustion engine produces power by burning fuel within the cylinders; therefore, it is often called a "heat engine." However, only about 25% of the heat is converted to useful power. What happens to the remaining 75 percent? Thirty to thirty-five percent of the heat produced in the combustion chambers by the burning fuel is dissipated by the cooling system along with the lubrication and fuel systems. Forty to forty-five percent of the heat produced passes out with the exhaust gases [2].

Cooling systems in the automotive industry are important systems for cooling the engine when it's working. System components include a radiator to dissipate heat, a fan or fans to ensure adequate airflow for radiator cooling, a thermostat valve that opens when the desired operating temperature is reached and a water pump (or coolant pump) to circulate coolant through the engine, hoses, and other components. The engine cooling fan is one of the key parts of the electric system in the automobile, in which high efficiency, high reliability, and low vibration are required to meet the above standards [3]. Engine Coolant Temperature (ECT) sensor measures the engine temperature and indicates how much heat the engine is giving off. The sensor works with the Engine Control Module (ECM). The ECT sensor monitors the engine coolant temperature continuously and makes sure the engine is running at the optimum temperature. The resistance of the temperature sensor (NTC Thermistor) varies with temperature when ECM sends voltage to the ECT sensor [4].

BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor rotate at the same frequency. BLDC motors do not

experience the “slip” that is normally seen in induction motors. BLDC motors come in single-phase, 2-phase and 3-phase configurations [5]. Brushless direct current (BLDC) drives are used nowadays for a wide range of applications and can be realized by using a multitude of different motor concepts [6]. Brushless direct current (BLDC) motors are mostly preferred for dynamic applications such as automotive industries, pumping industries, and rolling industries. It is predicted that by 2030, BLDC motors will become mainstream of power transmission in industries replacing traditional induction motors [7].

BLDC has been used in different applications such as industrial automation, automotive, aerospace, instrumentation and appliances since the 1970’s. BLDC motor is a novel type of DC motor in which commutation is done electronically instead of using brushes. Therefore it needs less maintenance. Also, its noise susceptibility is less, looking forward to having an integral motor. Electronic commutation technique and permanent magnet rotor cause. BLDC has immediate advantages over brushed DC motors and induction motors in electric vehicle applications [8]. Due to the absence of carbon brushes, brushless DC motors need less frequent brush replacement, which lowers maintenance expenses. The lifetime of brushed DC motors is around six times lower than that of brushless DC motors. Due to their tiny, compact diameters and excellent torque-to-weight ratio, brushless DC motors are well suited for a variety of robotics and medical applications including robotic arms and legs. When compared to other motors with the same ratings, brushless DC motors operate quite quietly, a brushless DC motor with a very high [9]. Instead of commutating the armature current using brushes, electronic commutation is used for this reason it is an electronic motor. This eliminates the problems associated with the brush and the commutator arrangement, for example, sparking and wearing out of the commutator brush arrangement, thereby, making a BLDC more rugged as compared to a DC motor [10].

2. Materials and Methods

Methods used: Overview method: an overview from content compiled from reputable scientific sources (ScienceDirect, springer, IEEE...) related to the BLDC engine under study or unresolved limitations.

Theoretical calculation method: calculation about the engine temperature to control the cooling fan by Arduino UNO R3 then shows on OLed SH1106. Design a BLDC motor shelf using Solidworks and then print it with a 3D printer.

Experimental method: testing the applicability of BLDC on specific cars on actual vehicles. Toyota Vios 2010 was used as an experiment. This article uses a BLDC motor to replace a DC motor according to Figure 1a, 1b. However, these two motors have different sizes, so a shelf is needed for the BLDC motor to attach to the fan frame.



(a)



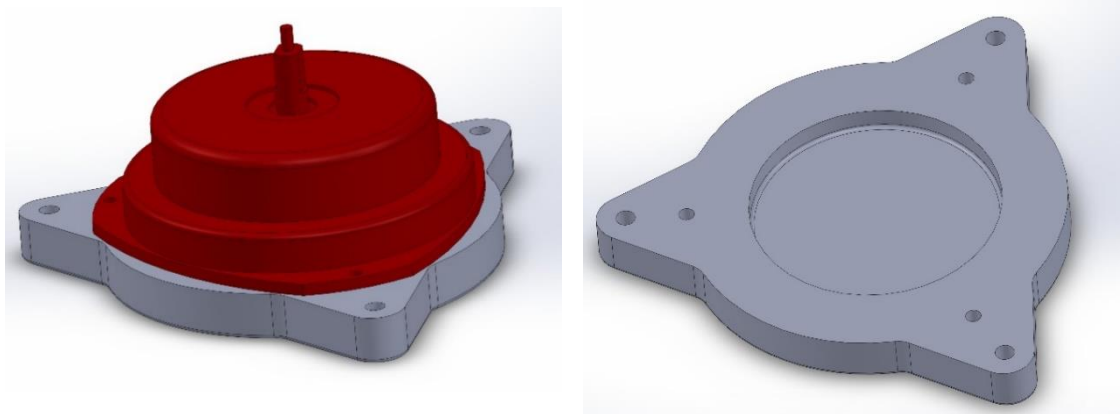
(b)

Figure 1. Cooling fan: (a) DC-12V/100W; (b) BLDC-12V/100W

Table 1. Specifications of DC Motor and BLDC motor

Rank	Specification	DC	BLDC
1	Brand	Denso	No brand
2	Wattage	100W	100W
3	Voltage	12V	12V
4	Speed without load	2200rpm	5380rpm
5	Shaft	8mm	8mm
6	frequency	No frequency	Operating frequency from 75Hz to 600Hz
7	Circuit diagram	2 output wires	4 output wires
8	Made in	Indonesia	China

From the size difference between a DC motor and a BLDC motor shown in Table 1, the authors combined 3D drawings to redesign the frame for the BLDC engine to fit into the engine cooling fan on Toyota Vios. Then print it with a 3D printer to install the BLDC motor.



(a)

(b)

Figure 2. Frame design for the BLDC: (a) BLDC and frame; (b) The frame

3. Equations and Formulations

Calculations for engine coolant temperature characteristics. We should determine the curve of engine coolant temperature. According to Ishfaque Ahmed [11], the following formula to calculate:

$$R_T = R_0 * \exp \left[1 - B \left(\frac{1}{T} - \frac{1}{T_0} \right) \right] \quad (1)$$

With the experimental planing method, we could determine the curve $R=f(T)$ by the experimental formula:

$$R = 0.01800038 * \exp \left(3466.70 * \frac{1}{T} \right) \quad (2)$$

Where: T is the temperature in Kelvin, $1^\circ\text{C} = 274 \text{ (K)}$

From the expression (2), we can survey the results table, the graph shows the correlation between the temperature and the resistance of the ECT sensor. The resulting temperature scale $[-20^\circ\text{C}, 100^\circ\text{C}]$.

To easily calculate in Arduino, the temperature zone from 80°C to 100°C (where the fan begins to work) we use the function $R = aT + b$ to find the coefficients a, and b embedded in the controller.

$$\text{Choose: } \begin{cases} T = 80^\circ\text{C} \\ R = 331\Omega \end{cases} \text{ và } \begin{cases} T = 100^\circ\text{C} \\ R = 196\Omega \end{cases}$$

$$R = -6.75T + 871 \quad (3)$$

Then:

$$V_{out} = \frac{R_1}{R_1 + R} * V_{cc} \quad (4)$$

ADC is an analog-digital converter:

$$\text{ADC} = \left(\frac{V_{out}}{V_{cc}} * 1024 \right) - 1 \quad (5)$$

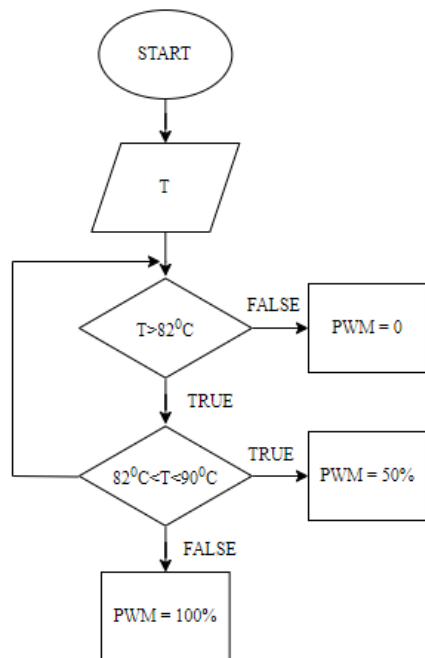
From (1.4), (1.5) we have:

$$R = \frac{1024 * R_1}{\text{ADC} + 1} - R_1 \quad (6)$$

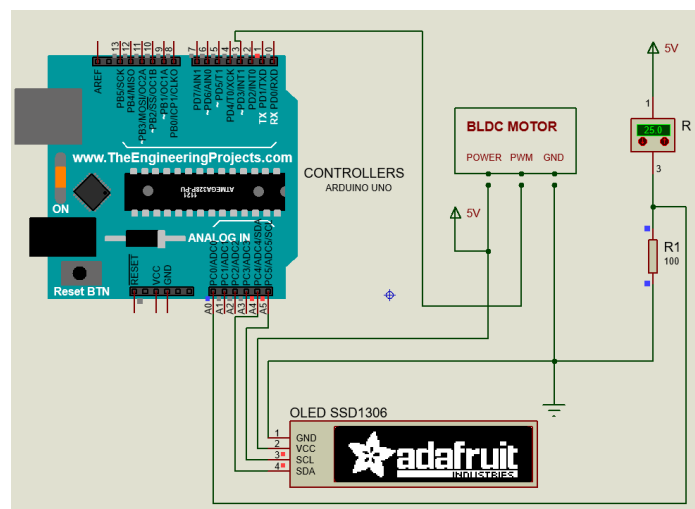
Choose $R_1=100 \Omega$

$$T = -\frac{102400}{(\text{ADC} + 1) * 6.75} + \frac{971}{6.75} \quad (7)$$

The equation (7) has been used to program in arduino:



(a)



(b)

Figure 3. Control method: (a) The control algorithm for BLDC motors; (b) The electrical diagram of the BLDC motor control

4. Result and Discussion

After calculating and programming the control, the author conducted a test to replace the DC fan motor and obtained the results. The object is the cooling fan motor on the TOYOTA Vios 2010. Then use the G Scan 2 diagnostic machine to get water temperature data.

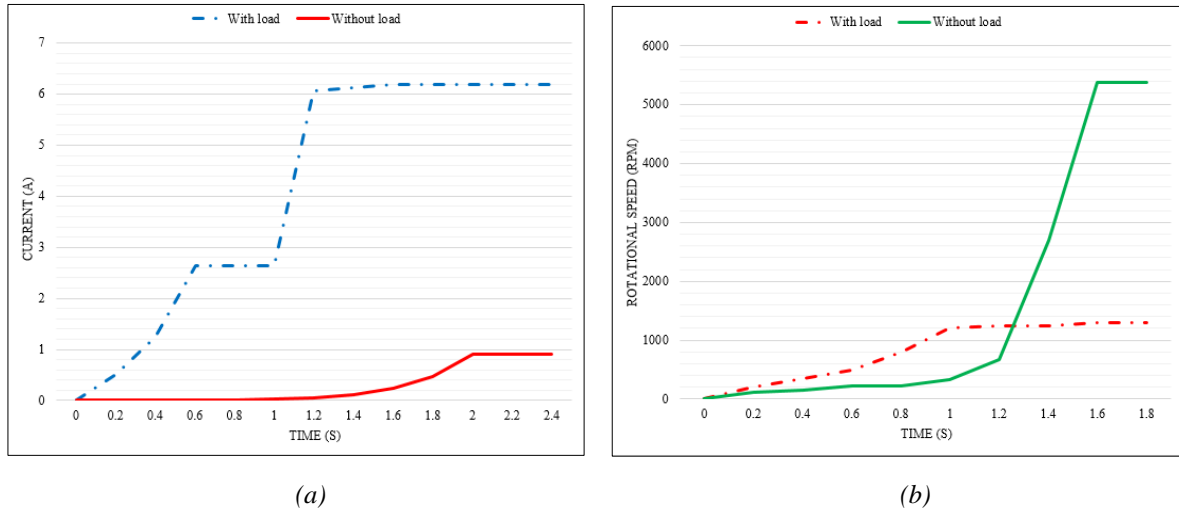


Figure 4. Experimental result with/without load: (a) current characteristics ; (b) speed characteristics

In figure 4a, the blue line represents experimental result with load of the BLDC motor the red line represents experimental result without load of the BLDC motor. Through the results of figure 4a, we see that when the starting current gradually increases after a time of 1.8(s), the BLDC motor reaches maximum speed and consumes 6.2(A) of current. This current is low compared to a traditional DC motor with a load of 8(A). Through this result, we can see that BLDC motors will consume less current than traditional DC motors.

In figure 4b, the green line represents experimental result without load of the BLDC motor the red line represents experimental result with load of the BLDC motor. Through the results of figure 4b, we see that when starting the motor speed gradually increases after 3(s), the BLDC motor reaches a maximum speed of 1300rpm. This no-load speed is not expected to be higher than that of a traditional DC motor. While the traditional DC motor's maximum speed reaches 1780rpm. Through this result, it can be seen that the BLDC motor is still affected a lot by the rotor load, it is necessary to calculate to redesign the rotor to increase the speed of the BLDC motor higher.

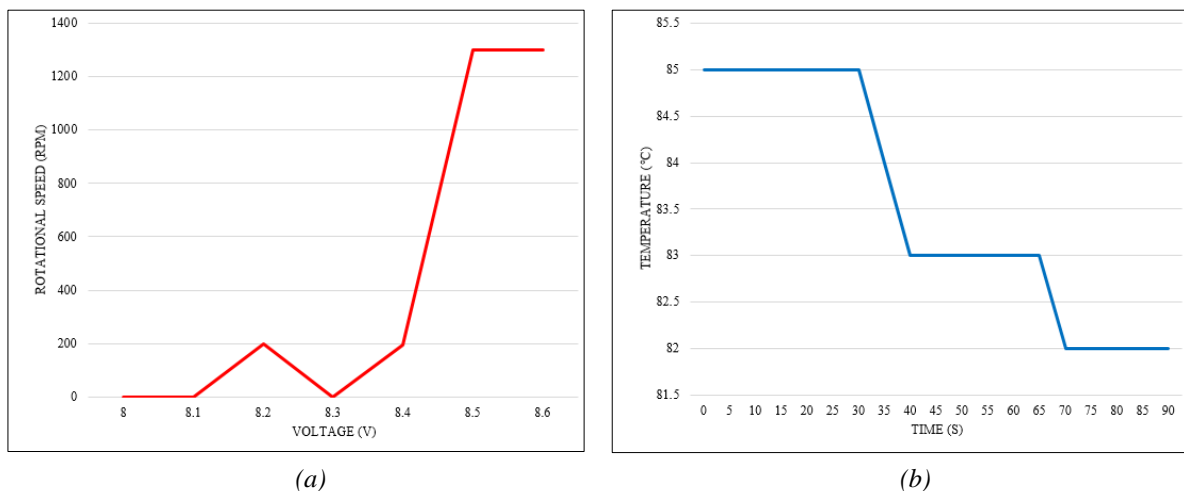


Figure 5. Experimental result with load: (a) voltage characteristics; (b) Cooling capability of BLDC

Through the results of figure 5a, we see that the BLDC motor only operates effectively at the voltage range [8.5V; 15V]. Then the BLDC motor will reach a maximum speed of 1300rpm when attached to the load. If the voltage supplied to the motor is lower than 8.5V, the BLDC motor isn't stable.

Through the results of figure 5b, we see that the cooling ability of the BLDC motor is effective in responding after 35 seconds, from 85°C the temperature drops to 84°C and after the next 35s the temperature drops to 82°C. With such cooling efficiency, it can be confirmed that the response ability of the BLDC motor is good even though the maximum speed when loaded is only 1300rpm.



Figure 6. Cooling fan: (a) Test cooling fan; (b) Test cooling fan in Toyota Vios 2010

Evaluate experimental results: Through the test results of figure 6a, 6b with the characteristics of the BLDC motor we can see that the BLDC motor could be applied in cars.

5. Conclusions

In this paper, a BLDC motor is used as the cooling fan motor to replace the 100W DC motor with a no-load speed of 2200rpm. With a compact design, and a simple control method using Pulse Width Modulation. Control the motor speed by detecting the motor temperature with a temperature sensor and then controlling it with an Arduino control circuit. Compared to a DC motor with the same capacity, this BLDC motor has a quieter performance and better control speed range. BLDC motors are still limited and cannot fully utilize the advantages of BLDC motors. This is the premise for developing more and more popular applications in cars.

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Conflict of Interest

The authors declare no conflict of interest.

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