A Novel Method for Measuring Rotational Speed of BLDC Motors Using Voltage Feedback

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Abstract— **Applications of BLDC (Brushless Direct Current) motors are increasing each day. Air conditioners, electric pumps, fans, printers, robots, electric bikes, doors, windows, sun roofs, seats, mixers, food processors, blenders, vacuum cleaners, toothbrushes, razors, coffee grinders, etc. BLDC motors are most commonly used in easy to drive, high speed and long life applications. They have become widespread and are available in all shapes and sizes from large-scale industrial models to small motors for light applications (such as 12 V BLDC motors). In some cases it is needed to have a feedback of the motor's rotational speed in order to control it. Common speed meters use hall-effect sensors to measure the exact speed of the motor; and some kinds of BLDC motors include these sensors inside to give to the controller board. Nevertheless in some places it is hard or even impossible to locate these sensors around motor. Here we present a simple method for measuring the speed of a BLDC motor using simple electronic elements and a low cost microcontroller unit for measuring and transferring data. The main idea is to measure the frequency of the voltage between two phases of the motor; as we know the rotational speed of a BLDC motor is proportional to the phase signal frequency generated by the driver.**

Keywords: BLDC motor, Low pass filter, Driver, Low cost sensor

I. Introduction

SEVERAL RPM measuring technologies have been proposed in the last few decades. They can be briefly categorized into: back EMF analyzing [1], optical methods, mechanical and optical tachometers, shaft encoders, image-based, mechanical and magnetic systems [2]-[4]. Among them, magnetic sensors built with Hall-Effect sensors not only have small size and low cost advantages, but also offer relatively impressive performance in RPM determining applications [5]. Therefore, they appear to be the most promising one of all the available technologies in terms of tiny, self-contained, complete, accurate, fast, immune to occlusions, robust, tenacious, and cheap. However, the uses of Hall-Effect systems are still restricted because they are mostly embedded in the motors and if they are not, it is so difficult or even impossible to assemble them on the motor. Various methods including optical techniques (e.g. IR sensors) are so reliable and easy to drive. They can give the motor's angular velocity with the accuracy of 1RPM. Hence they could be used perfectly instead of magnetic sensors, but they all have the problem of their large size and difficulty to be assembled on the motor. Methods like image-based techniques and utilizing tachometers not only have the size problem and very low accuracy in high frequencies, but also they increase computational cost and therefore, end up with a complex system that requires more hardware and software resources.

Frequency measuring based on analog filters represents a promising stand-alone technology in which rotational speed of the motor can be measured solely relying upon the back EMF of the motor.

For many low accuracy (<±100RPM) applications, such as indoor robot controlling, general controlling of industrial motors, etc., the signal-to-noise ratio is low and thus any unmodeled error in the system would determine the effectiveness of the intended application.

The objective of this paper is to develop a physical model to effectively determine the rotational speed of BLDC motors in terms of the common parameters published in their manufactures' datasheets.

A prototype targeting at ±100RPM accuracy in speed (RPM) measurement for robot controlling is realized using commercially available motors and drivers. Finally testing of a sensor board including four RPM meters is performed to verify the design concept and its applicability as well.

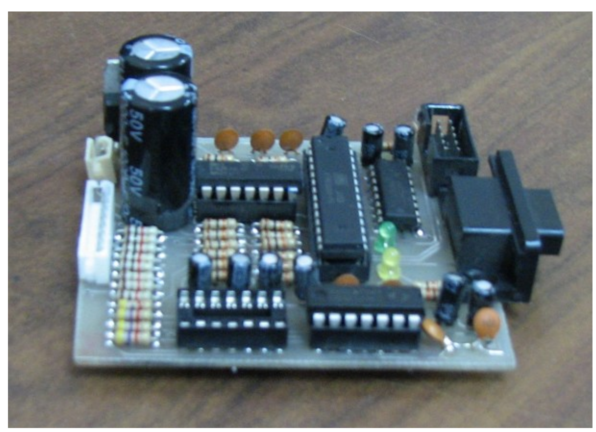

Fig. 1. The prototype including four sensors.

The activities associated with this project could be mentioned briefly as: describing components of the electrical board in section two, experimental results and output diagrams in section three and presenting a test platform by making a quadrotor helicopter in final section.

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II. HARDWARE DESIGN AND ELECTRICAL CONFIGURATION

The sensor function is based on measuring the frequency of the voltage between two electrical phases of the BLDC motor. The BLDC motors have a driver which generates three-phase voltage for rotation of the motor using a DC source for powering and a PWM (Pulse Width Modulation) source for triggering and a DAC (Digital to Analog Converter) for making sinusoid voltages [6]. When the motor is rotating, it also acts as a voltage generator which affects the input voltage. The frequency of the generated back EMF (Electromagnetic Force) is directly proportional to the rotational speed of the motor. So, by measuring the frequency of this voltage, we can find out the RPM of the motor.

The BLDC drivers generate a sinusoid voltage using DAC modules which a sample generated pulse is shown in Fig.2.

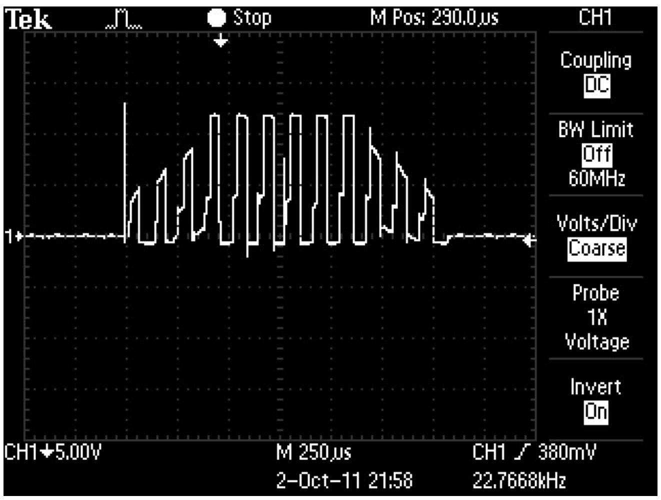

Fig. 2. Sinusoid wave generated by the driver.

So first we need to design a frequency meter. In this project we designed an analog circuit to convert this type of sinusoid voltage to a periodic square wave signal with a variable period and constant duty-cycle. Then a microcontroller measures this frequency and sends it via a serial interface.

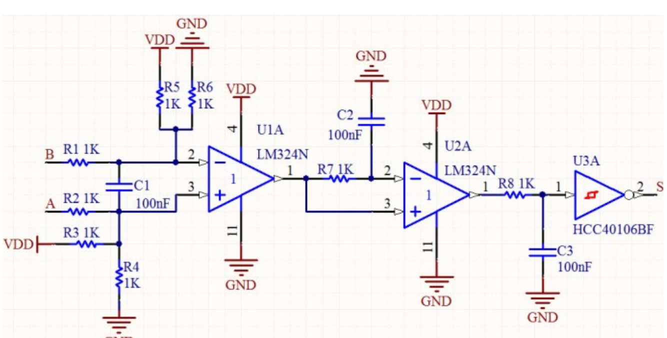

Fig. 3. The converter circuit schematic.

The analog circuit includes some low pass filters by utilizing op-amps and RCs to convert the sinusoid voltage to rectangular voltage pulse using an appropriate threshold (Fig.3).

By connecting two cords of the motor to the A and B connectors, the output of the DAC module, which is a stepping wave making an approximate sinusoid wave signal, will be passed through these low pass filters and get smoothed; then using a buffer, it will be clearly converted to a square wave signal (Fig.4).

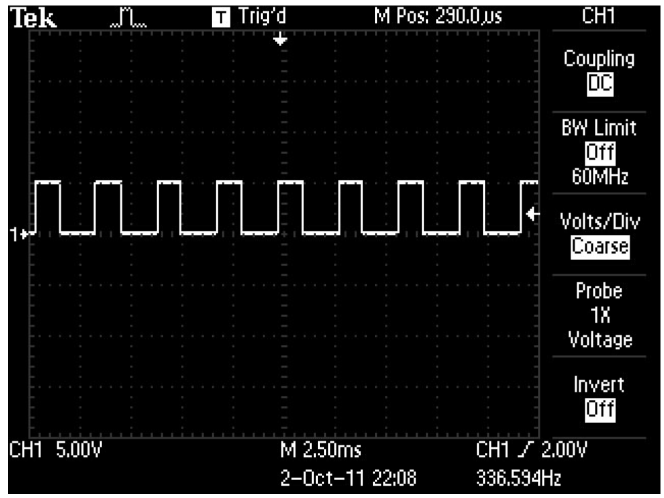

Fig. 4. Square wave, the output of the analog filter.

It is also possible to rotate the motor's shaft manually and observe the output signal. The second op-amp could be removed if the output of the first level is smooth enough and the measured value by the sensor is acceptable.

Finally a microcontroller measures the frequency of the square wave signal using I/O modules and internal timers. The measured values will be sent through a RS232 serial interface for an external controller.

III. EXPERIMENTAL RESULTS AND ERROR ANALYSIS

In this section we propose some diagrams indicating the measured values from the sensor versus the real values. Diagrams of the sensor board are prepared using 3 different test platforms which are discussed here.

The first diagram shows the measured values versus real values for a XM2830CA-14 DualSky motor derived by a XC1812BA DualSky driver (Fig.5).

The second diagram shows the measured values ratio to the real values for a Gold Line AXI2814-16 AXI motor derived by a XC4018BA DualSky driver (Fig.6).

The final diagram shows the sensor values versus the real RPMs for an X2212-13 SunnySky motor derived by a Pentium-30A HobbyWing driver (Fig.7).

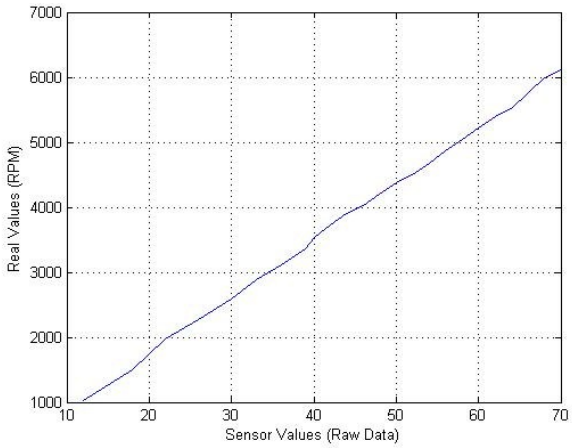

Fig. 5. XM2830CA-14 DualSky motor - XC1812BA DualSky driver.

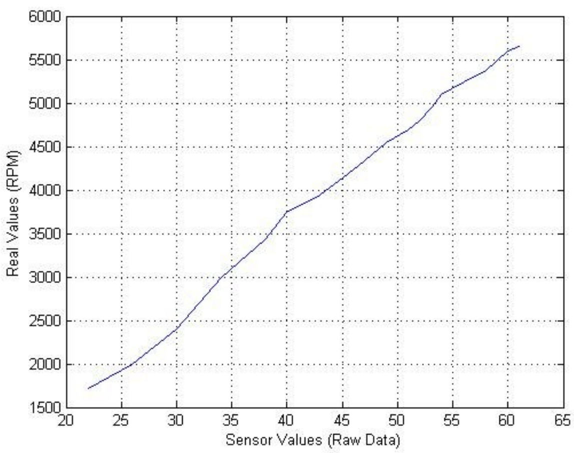

Fig. 6. Gold Line AXI2814-16 AXI motor - XC4018BA DualSky driver.

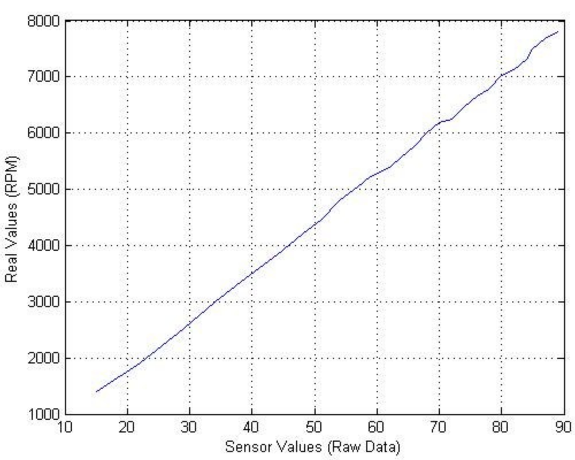

Fig. 7. X2212-13 SunnySky motor - Pentium-30A HobbyWing driver.

As it is shown the Fig.5-7, it is obvious that the real value of angular velocity of the motor is proportional to the measured value from the sensor. The coefficient is averagely about 89.6154.

IV. UTILIZING THE SENSOR IN A TEST PLATFORM

This part describes utilizing this type of sensor in building a quadrotor aircraft and controlling it using flywheels and another aircraft using IMU in combination with this RPM meter.

Quadrotor is a four rotor air craft with the ability to flight vertically. Stabilizing the Quadrotor can be achieved by controlling propeller's relative rotation speed and usually complicated controllers based on MEMS (Micro Electro Mechanics systems) sensors. It can be controlled by the means of an IMU (Inertial Measurement Unit) and a control algorithm e.g. PID.

Due to the high torque, high speed of rotation, easiness of driving using PWM pulses, fast responding and light weight, mostly BLDC motors are used as actuators in hovering quadrotors.

Quadrotor is an under-actuated system because it has six degrees of freedom (DOF) but only four actuators. Therefore controlling of a quadrotor is not easy at all. The idea is to make this machine stable enough to be controlled directly by a pilot or an autonomous piloting system. So we proposed a novel and especially simple method to control a quadrotor dynamically using flywheels. Usually the inertia effect caused by the rotation of the motors is neglected, but we increase it by assembling two flywheels on two motors thus its moment of inertia will be increased and it will be more desired to maintain its dynamic attitude so we can control it dynamically.

Fig. 8. The designed quadrotor in IUST using this type of sensor.

For controlling the quadrotor the general model has four input forces which are basically the propellers' thrusts. Forward and backward, left and right, and rotation forces are generated by adjusting each of four rotors' speed to change the thrust and torque produced by each. Forward/backward motion is achieved by increasing/decreasing the front/rear rotor's speed and decreasing/increasing the rear/front rotor's speed simultaneously to change the pitch angle. Left and right movements are done with the change in roll angle in the same way.

It should be noticed that all motors should have equal torques, so the Quadrotor doesn't turn around itself. As we know the torque of a motor has a direct relation to its consumption power, and consuming power has a direct relation to the load of the rotor. So if we put the same loads on the same motors, the torque will be dependent just on angular velocity. Hence we should maintain the speeds of the same motors (with and without flywheel) equal. This could be accomplished by using either an RPM sensor or a well-designed lookup table to relate the motor's speed to the PWM inputs of its driver. In this project we used the aforementioned RPM meter [7]. The sensor board measures the angular velocity of the motors and gives them to the main controller via a serial interface. Because the quadrotor is a very unstable system, the sensors and actuators must be fast and reliable enough to achieve a robust control.

Normal quadrotors also need a RPM meter sensor or at least a lookup table to relate the motor's speed to the voltage the motors. Another platform was built using an IMU in combination with the developed sensor board. The system was integrated in the Chakavak robot, developed to participate in a robotics contest, the Robocup Iran Open 2011, where situations as those referred to above are frequent.

V. Conclusion

This paper discusses the design, implementation and error elimination methods for an electrical BLDC RPM meter using a combination of low pass filters and a microcontroller for reporting data. The sensor has several advantages in terms of its compact size, low cost, and acceptable accuracy in rotational speed measurement. Having acknowledged the behavior and characteristics of individual components via a series of tests, we propose sensor calibration and error cancelling methods for the prototype. Preliminary tests prove that it achieves ±100RPM accuracy in RPM measurement. However, supplemental tests still need to be performed for other applications under high dynamic conditions. Future work will also include employing the BLDC RPM meter in various applications, such as industries, robotic, etc.

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