Higher Performance Sensorless FOC with Enhanced Flight Range Implementation on Delivery Drone

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***Abstract*— An Engineer's goal to continuously innovate, automate, reduce costs and improve safety in given fields is greatly aided with the introduction of Drones. Drones are unmanned aerial vehicles that can be remotely controlled. They greatly vary in both size and weight. Reducing the weight of Drones is highly important to increase the amount of payload it can carry. In our project we try to implement the Sensorless FOC concept. This allows us to use a BLDC motor without the need of a dedicated encoder thus reducing the weight and also allowing us to operate at very high speeds without much wear and tear that would result from coupling the motor shaft to a dedicated encoder. FOC stands for field-oriented control. Drones allow us to deliver a variety of essential goods and medicines to otherwise inaccessible and remote areas and possess the capability to perform all these tasks at a moment's notice with the outbreak of the Covid19 virus, the medical infrastructure been overrun since the virus has immense propensity for spreading quickly. The driving force behind this project was a need to develop a method of distribution of vaccine vials while maintaining a sense of isolation. Contactless delivery and service fits the bill perfectly. Given our immense population finding a solution is imperative and drones provide us with the solution.**

***Keywords*—Sensorless, FOC, Drone, UAV, Motor, Control Delivery, BLDC, Higher Performance, Enhanced Flight Range**

I. INTRODUCTION

Since the outbreak of the Covid-19 pandemic our lives have been changed almost irreversibly. One term that's become almost synonymous with our daily lives is "Isolation". Whether it be work from home or online classes or food delivery apps, we are constantly shifting towards a more distanced and Contactless lifestyle. However, all these methods often require time and aren't as spontaneous as we may want them to be. Sometimes in states of emergency such delivery methods are simply too slow and don't cut it, especially when medical emergencies are involved. Moreover, since most home deliveries still require a valet to perform the task, there still remains an element of risk of spreading the virus. Drones essentially are UAVs or Unmanned Aerial Vehicles that possess unmatched manoeuvrability and efficiency that helps them find applications in many fields.

Another concept we wish to implement is Sensorless FOC. Field Oriented Control (FOC) makes the stator and rotor magnetic field orthogonal to each other to achieve the maximum electromagnetic torque. Sensorless FOC of motor increases the reliability of motor and reduce the cost of sensor, controller along with its circuitry. Sensorless-FOC also enables very high-speed motor operations with no wear and tear of sensor. Speed information is derived from the voltage and current phase sense of 3-phase stator winding terminals. This derived speed information is fed back into the input of motor control.

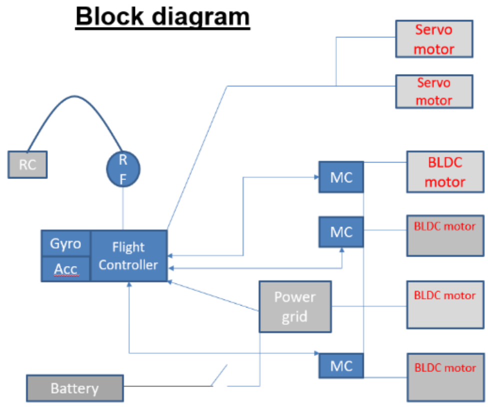
Replacing the sensors entirely in an FOC motor controller reduces the cost and increases the reliability of a motor, but also increases the complexity and cost of the controller. To replace the sensor, the information on the rotor speed is extracted from the voltages and currents in the stator windings via the motor terminals. This is then fed back into the current control of the motor.

II. IMPLEMENTATION OF SENSORLESS FOC

The application layer consists of two mains separate parts –

- The BLDC motors on the main quadcopter body along with 2 Servo motors on the arm of the quadcopter
- The Single BLDC motor attached to the DRV8305 and Piccolo microcontroller that emulate the functioning of the motor control board that is housed on the Quadcopter in a non-Form-Factor reproduction.
- The above setup shows us in a more detailed way how the Sensorless FOC concept in

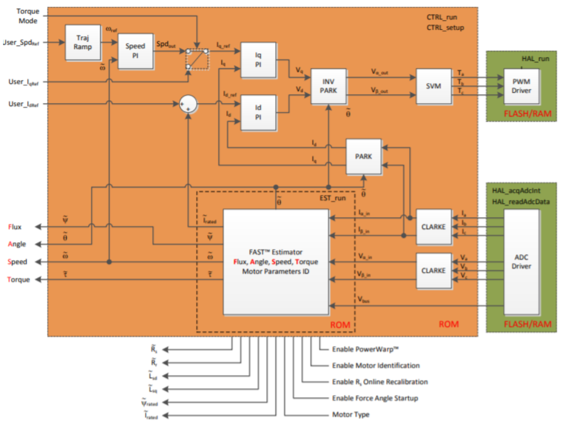
implemented with the help of BLDC motors and their controllers.



Certain Piccolo devices include a special software library in ROM, which can be described as follows:

FAST™ rotor observer/estimator-

- Provides rotor Flux, rotor flux Angle, rotor flux Speed and shaft Torque estimations
- Together – with Piccolo peripheral drivers - they enable a "Sensorless" InstaSPIN™-FOC solution which can identify needed motor parameters, provide a stable initial tuning and control of brushless DC (BLDC) motor without the use of any rotary sensors, like Hall sensor or optical encoder.
- The algorithm provides configuration of speed loop gain (Kp & Ki) automatically, which makes motor operation stable in most of the application.



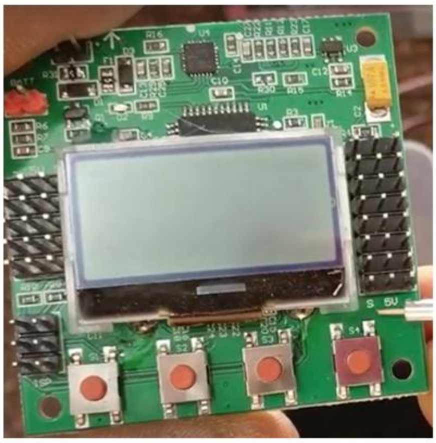
III. FLIGHT CONTROLLER SETUP

The flight controller of choice here is the KK2.1.5 Multi rotor LCD Flight control board which runs on an Atmel microcontroller Atmega644 PA [AVR microcontroller]

Its sensors include an MPU-6050 Six-Axis InvenSense (Gyro + Accelerometer) MEMS MotionTracking

The right-hand side of the flight controller houses 8 three pin connections. Since we only have four motors, we will use only 4 outputs to connect with the ESCs. The board is capable of handling up-to 8 motors however since we have a quadcopter, we shall use the first 4 by default.

The left side of the board houses 5 connection terminals that are used to connect to the RF Receiver. The RF receiver is a 6 Channel one and these channels can be connected to the flight controller in their respective pins.



The flight controller LCD by default displays several parameters such as-

1. Flight ready status
2. Self levelling control bit
3. Motor layout
4. Battery voltage
5. FET temperature
6. Roll and pitch angle

Four physical buttons allow us to navigate through the controller.

Under the menu we find several settings such as the Receiver test and receiver slider.

The Receiver test allows us to test our controls on board the RC controller using the respective joysticks:

Receiver sliders on the other hand are used to check if the Aileron, Elevator, Rudder and other parameters are set to zero. If not, we can we manually adjust them using the RC controller. It is advisable to set all the parameters except the elevator to zero to allow for a consistent vertical take-off as well as controlled level flight

Stick scaling can be used to either increase the precision and subtlety of each command or instead for providing increased feedback and power.

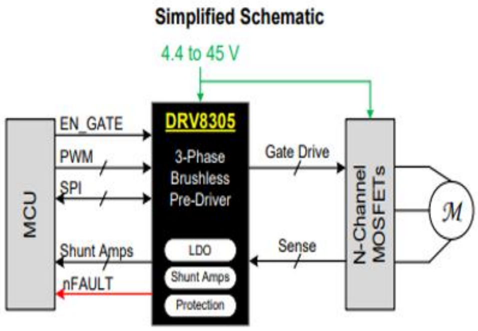
Now we proceed to setting up the motor layout. KK2.1.5 allows for multiple motor layouts from helicopters to tri copters to even octa- copters.

However, we shall be selecting the quadcopter mode with a "+" layout. From here we can proceed to selecting the motor directions, each one running in the opposite direction to the adjacent and the same direction as the opposite.

The next step is performing the Accelerometer + Gyroscope calibration by placing it on a level surface.

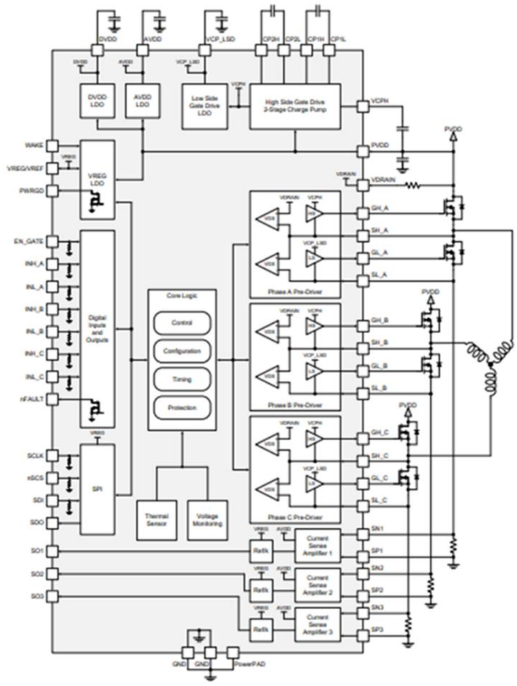
IV. MOTOR DRIVER

- Booster pack of DRV8305 provides 3-phase gate drive control of BLDC motors-based applications. DRV8305 enables 3-half bridge drivers of high accuracy, driving both high-side and low-side of N-channel MOSFET.
- The features of DRV8305 gate driver includes 3-bidirectional current-shunt operational amplifiers, which enables low-side current measurements with high accuracy due to variable gain settings, along with an adjustable reference offset.
- DRV8305 makes use of handshaking technique in automatic manner, to prevent any access current from passing through the motor driver; thus, enabling safety mechanism.
- DRV8305 allows for low-voltage operation and it can tolerate up to 45-V of load dump voltages.
- Integrated voltage regulator of DRV8305 enables both 3.3V or 5V to support different types of MCU, having different power requirement in a system.



To ensure device is in active state and not gone in an unknown state, watchdog function of external MCU controller that is giving instructions, is incorporated in the DRV8305.

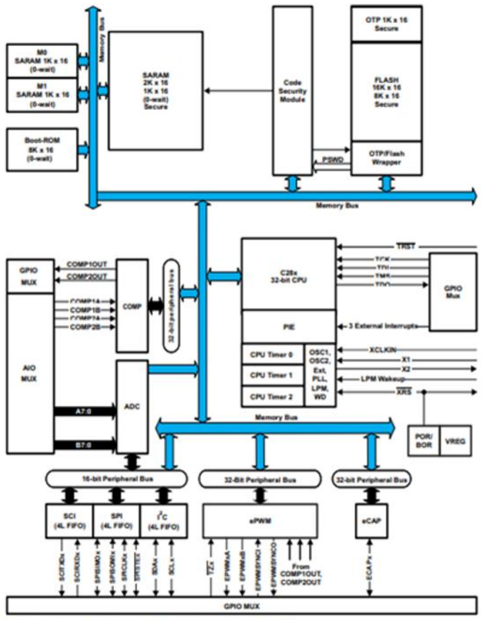
- Detection to a watchdog fault in DRV8305 is done in following manner:
- Gate driver of DRV8305 are transitioned to safe state, the instance of fault is latched. Thereafter recovery sequence needs to be appropriately initiated.
- SPI of DRV8305 functions in slave mode and is used to configure the device, setting the operating parameter and reading diagnostic information of the device.



In summary, 3-phase BLDC motor along with the external power MOSFETs is driven by the DRV8305, integrated with 3-half bridge gate driver, current shunt operation amplifier for each of 3-phases, low dropout regulator for 3.3V or 5V, slew rate control that is adjustable and high level of protection measures making a DRV8305 a very robust gate driver.

A. Piccolo Microcontroller F2802xx

- The F2802xx Piccolo microcontrollers are highly integrated low pin count device having powerful C28x™ core with control peripherals for motor control.
- Single-rail operation is achieved using an internal voltage regulator. To control the PWM output, analog comparator is integrated in the device. Fixed full-scale range of 0-3.3V can be converted using the analog to digital convertor (ADC), which is optimized for lower latency and overhead.
- TMS320C2000™ microcontroller (MCU) is a platform device for F2802xx (C28x) device family and have same 32-bit fixed point architecture as C28xx platform MCU devices.
- For the development and implementation of mathematics algorithms and integrating high-level language system control software, a very highly optimized C/C++ compiler is provided to enable the users.
- For in-circuit debugging, a standard IEEE 1149.1 JTAG interface is implemented in the device. Real time operation support of modifying memory contents, peripherals and its register location is provided in the device; while processor is executing code, servicing interrupts and control data is getting transferred.
- Above features makes device highly efficient 32-Bit CPU (TMS320C28x™) microcontroller operating with a single 3.3V Supply.



A. Not all peripheral pins are available at the same time due to multiplexing.

B. Memory Bus Architecture

- To move data between CPU, peripherals and memories, multiple buses are incorporated, similar to other MCU devices. Data read and write bus for program and data is part memory bus architecture.
- Single cycle 32-bit operation is enabled by 32-bit wide data busses, whereas 32 data lines and 22 address lines are used in program read bus.
- Harvard bug is common name used for the multiple bus architecture, that allows the C28x to fetch an instruction, read a value and write a value all in a single cycle. All the peripherals attached to the memory bus prioritize memory accesses.
- Erasing, programing and validating a Flash sector, can be individually done by the user, while leaving other sectors untouched. However, it is not possible to use one sector of the flash or the OTP to execute flash algorithms that erase or alter other sectors.
- To enable the flash module achieving better performance, special memory pipelining is provided. The flash/OTP is mapped to both program and data space; therefore, it can be used to execute code or store data information.

C. InstaSPIN

InstaSPIN-MOTION is a comprehensive torque-, speed-, position- and motion-control software solution that delivers robust system performance at the highest efficiency for motor applications that operate in various motion state transitions.

Robust speed and position control

- Controller provides more accurate compensation, both in steady state and in situations varying speed, position and load
- Motion Engine easily calculates the reference signal (with feedforward) based on current reference, target, acceleration, deceleration, and jerk

Compensation for real mechanics of the system

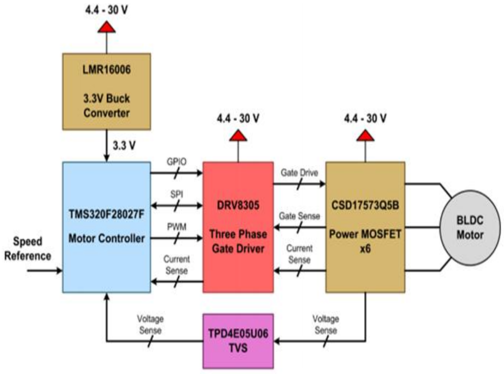
- Estimates and cancels system disturbance, in real-time.
- Eliminates recalibration - Works over the ENTIRE operating range

Simple tuning

- 1-variable “gain” allows for instant tuning
- Single tuning parameter for combined position and speed

Easy design and execution of complex motion sequences

- Motion Profile Generator creates time-optimal curves within specified acceleration, deceleration, and jerk limits.
- Supports trapezoidal (ramp), s-Curve and LineStream’s proprietary st-curve. The st-curve provides additional smoothing of the trajectory.



Three phase machines and their characteristics are governed by their voltage and current equations. The coefficients of the differential equations that describe their behavior are generally time varying an exception being while the rotor is stationary.

Since the electric circuit is constantly in motion, it creates flux and induced voltages in the circuits and hence the analysis of such a system is very tedious. Thus, we use transforms to decouple variables and find solutions to these time varying variables by considering them in a common reference frame.

Some of the well-known transforms are –

- Clarke transformation
- Park transformation

which will be the two main transformation methods we will be focusing on here.

Conversion of 3-phase time domain components of motors is converted into 2-orthogonal stationary frame (αβ) by Clarke Transformation, whereas these 2 components are converted to rotating frame (dq) by Park transformation. Thereby these two consecutive Clarke and Park transformation helps in converting alternative voltage and current phase signals into direct current signals, makes computation simple.

Clarke transformation-

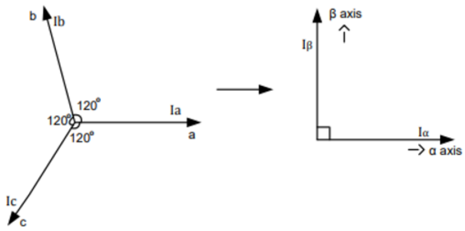
$I\alpha = 2/3\ (Ia) - 1/3\ (Ib - Ic)$ Eq1

$I\beta = 2/\sqrt{3}\ (Ib - Ic)$ Eq2

$I\alpha = Ia$ Eq3

$I\beta = 1/\sqrt{3}\ (Ia + 2Ib)$ Eq4

Note: Ia, Ib, Ic are three phase quantities, Iα and Iβ are stationary orthogonal reference frame quantities.



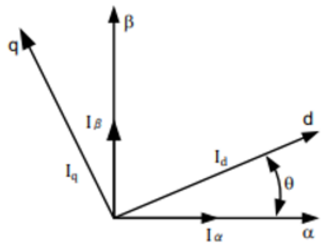
Park transformation-

$Id = I\alpha * \cos(\theta) + I\beta * \sin(\theta)$ EQ1

$Iq = I\beta * \cos(\theta) - I\alpha * \sin(\theta)$ EQ2

where, Id, Iq are rotating reference frame quantities

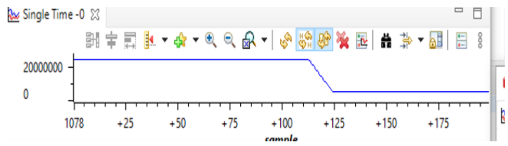
Iα, Iβ are orthogonal stationary reference frame quantities



V. STANDALONE SENSORLESS FOC CHARACTERISTICS

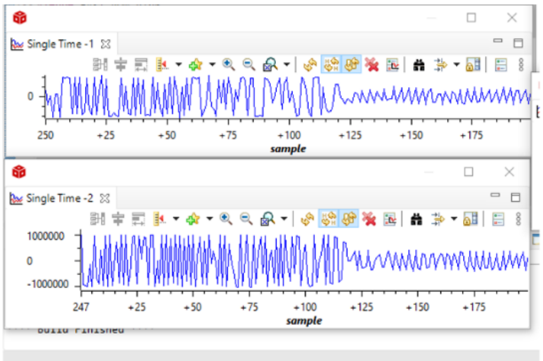
The graph denotes the estimated velocity that is calculated after applying the Clarke and Park transforms.

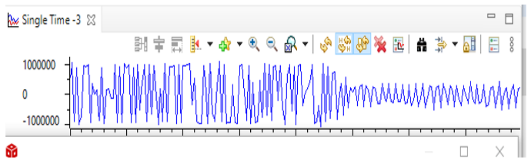
The estimated velocity is compared with the velocity set by the user and the error percentage is calculated. In order to reduce the error, the Piccolo microcontroller with the help of the DRV8305 EVM sends corrective PWM signals to adjust the motor speed and reduce the error between the estimated and the set velocity. Thus, we are constantly trying to reduce the error between the two parameters.



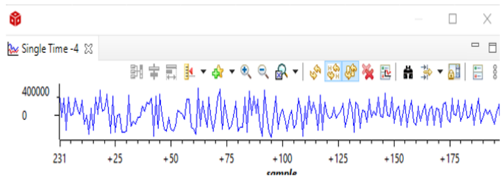
A. PWM signals, ADC currents and voltages

The next three graphs denote the PWM signals being supplied to the motors. As mentioned before these are constantly varying to try and minimize the error between the velocity set by the user and the estimated velocity. It has 3 phases since the motor is a 3 phase BLDC motor. The max voltage value of the PWM signal is 3.3V



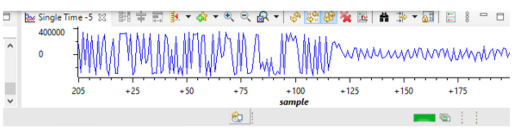


The next graph shows us the ADC current values which are the sensed current values that are being fed back to the DRV8305 and the Piccolo microcontroller.



Finally, the last graph denotes the ADC voltage values which again are sensed values or also known as back EMF which is sent through a transient voltage suppressor (TVS) to the Piccolo microcontroller which then uses the Clarke and Park transforms to calculated the estimated speed of the rotor and then sends this feedback.

There are totally 6 current and voltage values however for sake of convenience we have plotted only 2 values.



B. Quadcopter Vs Standalone Sensorless-FOC setup

Sl no	Motor Rpm	Quadcopter ΔVrms	Standalone ΔVrms
1	900	0.51	0.3
2	1100	0.58	0.39
3	1500	0.71	0.55
4	1800	0.79	0.7
5	2100	0.88	0.8

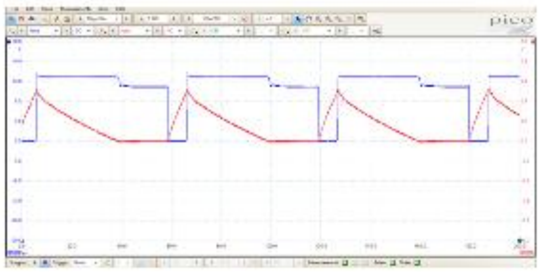
The following table provides us with a comparison between the ΔVrms values at various motor rotation speeds on board the Quadcopter and the Standalone Sensorless-FOC setup.

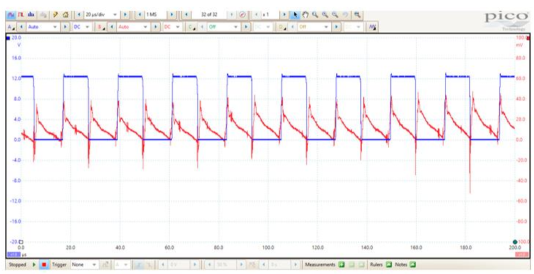
The ΔVrms values on the Quadcopter are clearly higher than the ones seen on the Standalone Sensorless FOC setup at all the various motor rotational speeds.

Thus, at the same motor rotation speed the Sensorless-FOC setup consumes much less power than the equivalent setup on board the Quadcopter. Thus, the Sensorless-FOC setup grants us much better operational time when compared to the Quadcopter setup thus helping us circumvent one of the issues we had earlier of low operational time if we are to implement this setup on board our Delivery Drone.

In addition, it is observed that at the same speed input the Quadcopter setup experiences a constant oscillation between the required speed however with Standalone Sensorless-FOC setup we do not experience such issues and is far more accurate at achieving the users set Reference speed.

C. V, I characteristics of the Quadcopter setup Vs Standalone Sensorless-FOC setup





- The following graphs represent the V and I characteristics of the Quadcopter and Standalone Sensorless-FOC setup respectively. The Blue graphs represent Voltage and Red represents Current.

- As seen from the above graphs the time period of each cycle is much greater on the Quadcopter as compared to the Sensorless-FOC thus the frequency of any operation is much higher on the Standalone Sensorless-FOC setup as compared to the Quadcopter.
- Higher operational frequency translates to finer control and better accuracy.
- Power (V x I) is lower on the Standalone Sensorless-FOC setup as compared to the Quadcopter, thus giving higher operational time

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REFERENCES

[1] X. Zhang, "Adaptive Control of Quadrotor UAV Based on Arduino,"
[2] DRV8305 Three Phase Gate Driver with Current Shunt Amplifiers and Voltage Regulator
[3] KK2.1 & KK2.1.5 Instruction Manual
[4] FlySky FS-CT6 (A/B) User Manual
[5] TMS320F2802xx Piccolo Microcontrollers Datasheet
[6] C. J. O’Rourke, M. M. Qasim, M. R. Overlin and J. L. Kirtley, "A Geometric Interpretation of Reference Frames and Transformations: dq0, Clarke, and Park,"