High Efficiency Motor Control Platform

Sponsor

This is a joint academic project based on research from Prof. Forrest Brewer, Dr. Joseph Poverelli, and Prof. Joao Hespanha. Prof. Brewer has 30+ years experience in real-time control and 2 years recent experience in motor power control. Dr. Poverelli recently competed his Ph.D. in the area of low-latency sigma-delta based controllers. Prof. Hespanha has decades experience in formal controls and control modeling. The project will additionally be mentored by Profs Ilan Ben-Yaacov and Yoga Isukapalli.

Background

Electrification of motors in applications where weight is a major issue (e.g., electric aircrafts) will require a large reduction in the weight of the propulsion systems, which include the motors and their drivers. Currently, the drivers outweigh the motors by about 5:1, so they contribute significantly to the overall weight of the system. Improving the efficiency of the drivers, even by just a few percent, can therefore allow for a significant reduction in system weight.

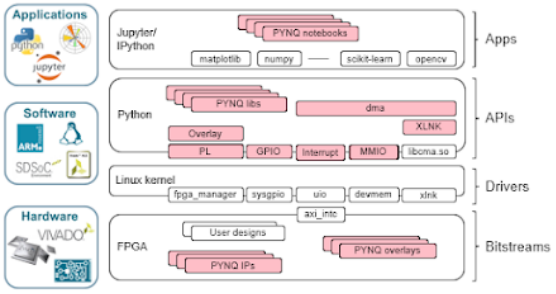
Conventional brushless motor control relies on generating 3-phase drive amplitudes (usually by table look-up) and then modulating the amplitude onto the motor windings via pulse-width modulation (PWM). This modulated signal is then fed into an H-bridge driver for each motor winding. H-bridge drivers have traditionally been implemented with silicon power MOSFETs or IGBTs switched at relatively low frequencies (typically 15-18 kHz). However, the recent advent of H-bridges utilizing GaN and SiC wide-bandgap transistors, which can be switched at much higher frequencies without degrading device performance, offer the potential to substantially reduce the power losses from the PWM drive through alternative switching schemes. Currently, several companies offer modules and chips aimed at taking advantage of the higher power density, higher operating voltages and lower losses that are possible with wide-bandgap transistors.

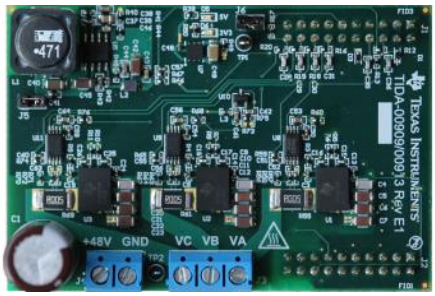
Motor controllers are almost universally based on small processors or DSP devices and operated in software. The benefits are substantive firmware, ease of computation (e.g. floating-point arithmetic) and the flexibility of the software environment. However, the limitation is control loop bandwidth – even DSP based controllers have difficulty hitting 20uS (50kHz) loop bandwidth and only at substantial cost. Recent advances in controller design allow for much simpler controller implementations as FPGA firmware. These provide very high performance at low cost, but can be substantially difficult to develop and debug.

Problem Statement

One of the large sources of power loss in motors and their drive circuits is that the drive currents may be asynchronous with the position of the motor. The goal of this project is to develop and program a drive circuit for a small motor that synchronizes the drive switching activity and the motor position so as to minimize the losses due to asynchronous drive modulation. This will be accomplished by measuring the

position of the rotor relative to the stator and providing real time feedback to the control circuit. Achieving this will require using newly developed digital control algorithms which require no multiply operations, so can be easily mapped into low-cost FPGA based controllers. The result is to lower the control loop time from tens of uS (i.e. 2-50kHz) to 20+Mhz. Effectively, the drive still pulses at relatively low frequency, but at exactly the correct time to optimize its conversion to motor torque.





Deliverables

The intent in this project is to instrument a small 3-phase drone motor with a propeller and create interfaces, control code, verilog controllers, and the electrical drive system for accurate experimentation and development of control and drive modulators. Specifically, what is desired is development of a test platform based on Pynq hybrid development cards and commercially supported GaN drive modules that can subsequently be used to develop optimal modulation and control schemes for the drive system described above. The platform consists of a dual-processor linux system supporting development of FPGA firmware as hardware *overlays*. The Pynq allows development of Web-based interfaces in Python via Jupyter Notebook so full system control is operable out of the box.

Student Qualifications

This project is multidisciplinary in that it will rely on expertise in a wide variety of topics within ECE, including power electronics, signal processing and control systems, printed circuit board design and development, embedded programming, and programming of GUIs and interfaces. Thus an ideal team will have approximately the following make-up:

- 1-3 students with interest in control algorithms and fixed-point controllers
- 1-3 students with python and gui development interests
- 1-3 students with interest in power electronics and circuit board development

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Resources

- **PYNQ** (http://www.pynq.io/) boards will be available
- **TI 48V/10A Driver Design** (http://www.ti.com/tool/TIDA-00909)
- **Prototype Verilog Controller** (TBA)