

**Abstract**—Wearable robots, such as powered prostheses and active exoskeletons, often rely on electric motors for actuation. Emulating biological joint angle and torque profiles requires special sensors, high peak power and advanced real-time controls. Safety is paramount and fail-safe circuits are required to detect and correct problematic situations. A smaller, lighter circuit can lead to a more efficient and affordable robot. Few commercial motor drivers accommodate all of these requirements. In this paper we present FlexSEA-Execute, the advanced motion controller part of FlexSEA, the FLEXible, Scalable Electronics Architecture designed for wearable robotic applications. At 36cm<sup>3</sup> and 34.8g, this PSoC-based design integrates a 8A/30A (continuous/pulse) brushed/brushless motor driver, a safety co-processor, multi-drop RS-485, a strain gauge amplifier, a 6-axis inertial motion unit (IMU), USB, and a programmable expansion connector.

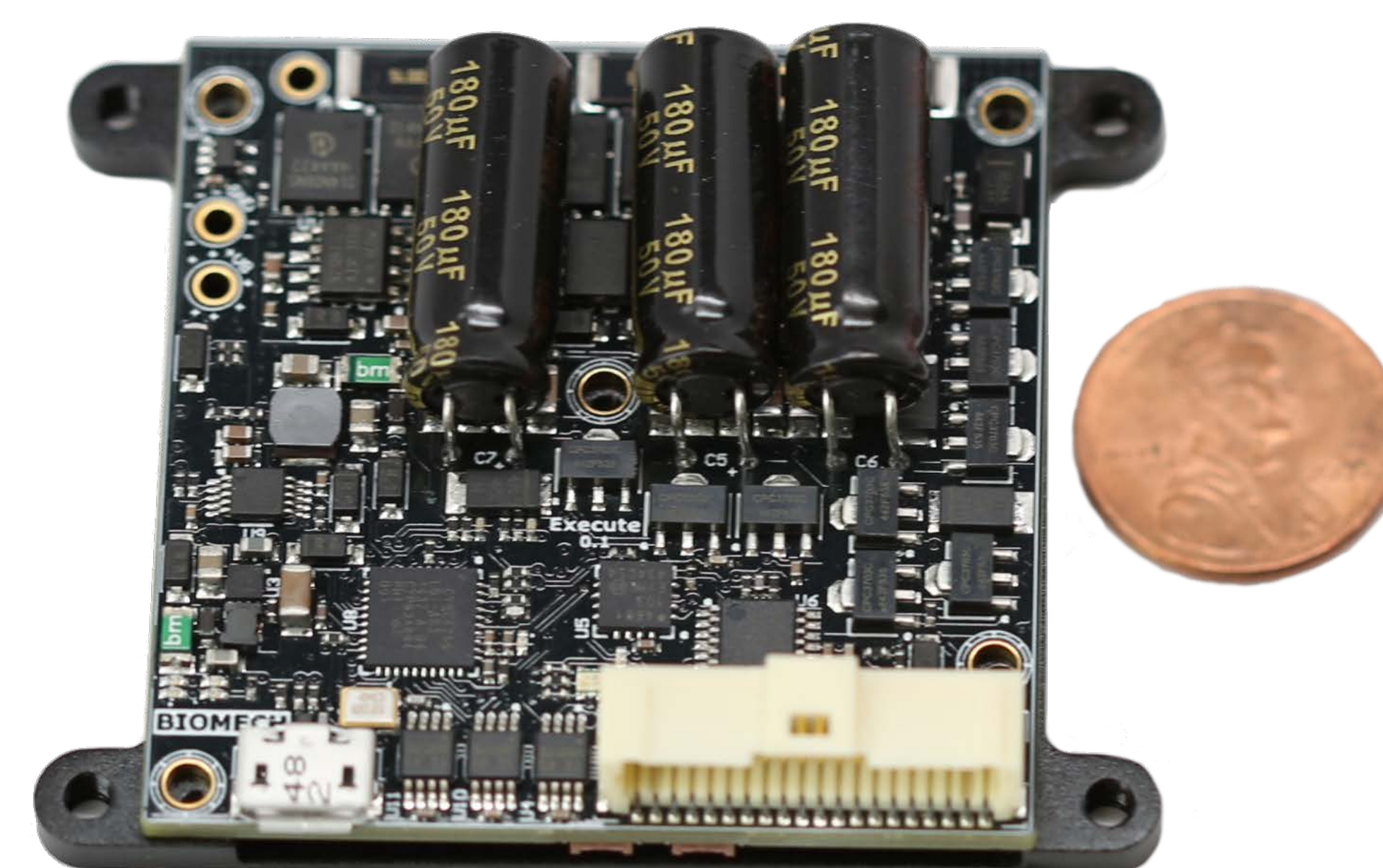
## Key Specifications

- Supports brushed and brushless DC motors, four quadrant (4Q) operation, 20-100kHz PWM
- 15-48VDC, 8A continuous 30A peak (100ms every second)
- Communication: multi-drop RS-485, USB, I<sup>2</sup>C, UART, SPI
- Controllers: current (20kHz sampling), position (with trapezoidal trajectory generator), impedance, custom.
- Built-in safety detection and correction circuitry (brownouts, disconnected battery, software fault, over/under-voltage, over-temperature, etc.)
- Extra: strain gauge/load cell amplifier, 6-axis IMU, expansion port (analog, digital, serial), 64Mb FLASH memory, power output
- 49 x 49 x 15mm 34.8g including minimalist heatsink/mounting plate

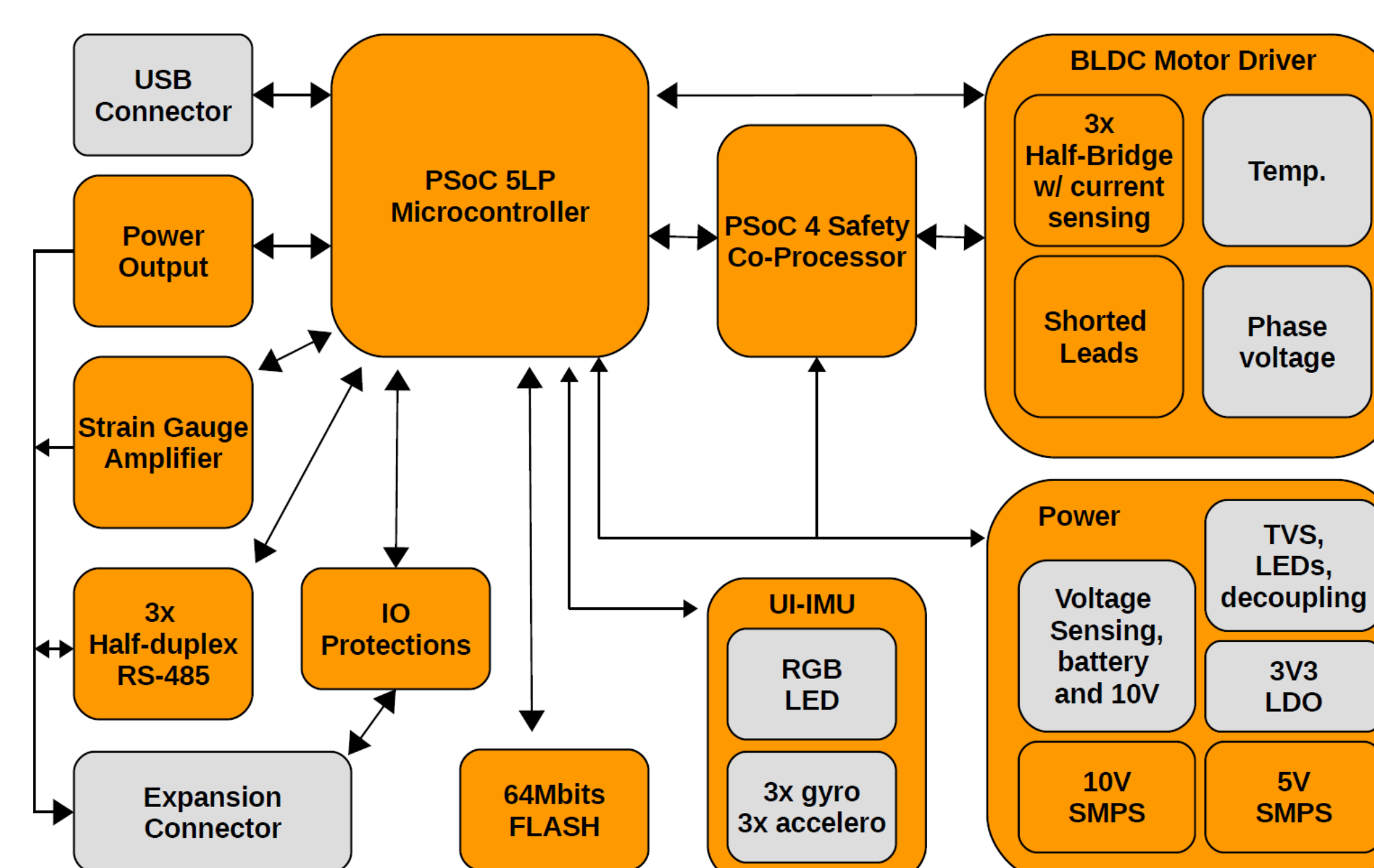
## Full Specifications

Category	Sub-category	Specifications / Details
Electrical	Supply voltage (V)	15-48V
	Motor current (A)	8A Continuous, 30A pulsed (100ms every s)
	Int. supply	10V 500mA SMPS
	Logic supply	5V 500mA SMPS
Motor	Type	3-phase brushless (BLDC)
	Sensor(s)	Hall effect, optical encoder
	Commutation	Block (Sinusoidal & FOC HW supp.*)
	PWM	12 bits 20kHz, 9.65 bits 100kHz
	Inductance	Unspecified, min. value tested 63μH
Microcontroller	Reference	PSoC 5LP - CY8C5888AXI-LP096
	Special features	Programmable analog and digital blocks
	CPU/RAM/IOs	80MHz ARM Cortex-M3, 256KB RAM, 62 IOs TQFP
	Software / IDE	PSoC Creator 3.1, C (GCC 4.7.3) and graphical prog.
	Co-processor(s)	PSoC 4 - CY8C4245LQI-483
Serial interface	Type	3x Half-Duplex RS-485
	Bandwidth	Up to 4Mbps with 1TP, 2Mbps tested
USB		Full-Speed (FS) 12 Mbps
Current control	Hardware	3mΩ resistor
	Software / control	20kHz PI controller, 18.5mA/bit
Safety features	Overvoltage	TVS clamps at 53V
	Overcurrent	Software protection
	Locked rotor	Hardware - lead shorting circuit
	Board temp.	CPU + bridge temperature reading
Power output		8-bits PWM, 1A
Strain gauge amp.		5 < G < 1000, high CMRR, programmable gain & offset
External peripherals	Connector	Molex PicoClasp 40 positions, SMD 1mm pitch
	IOs available	12
	Digital IOs	Up to 12
	Analog inputs	Up to 8 (12-bit SAR, 8-20-bits Sigma Delta)
	Serial	I <sup>2</sup> C, SPI, UART
	Other	Optical encoder (A/B/I), Hall effect encoder (3 pins)
Physical	X (mm)	49
	Y (mm)	49
	Z (mm)	From 12 to 15mm depending on capacitors
	Weight	20.1g barebone, 34.8g with heatsink
	Layers	6
PCB technology	Copper	1 Oz
	Trace/space/via	5/5 mils trace/space, 8/20 mils blind vias
	Assembly	Double-sided
	Other	

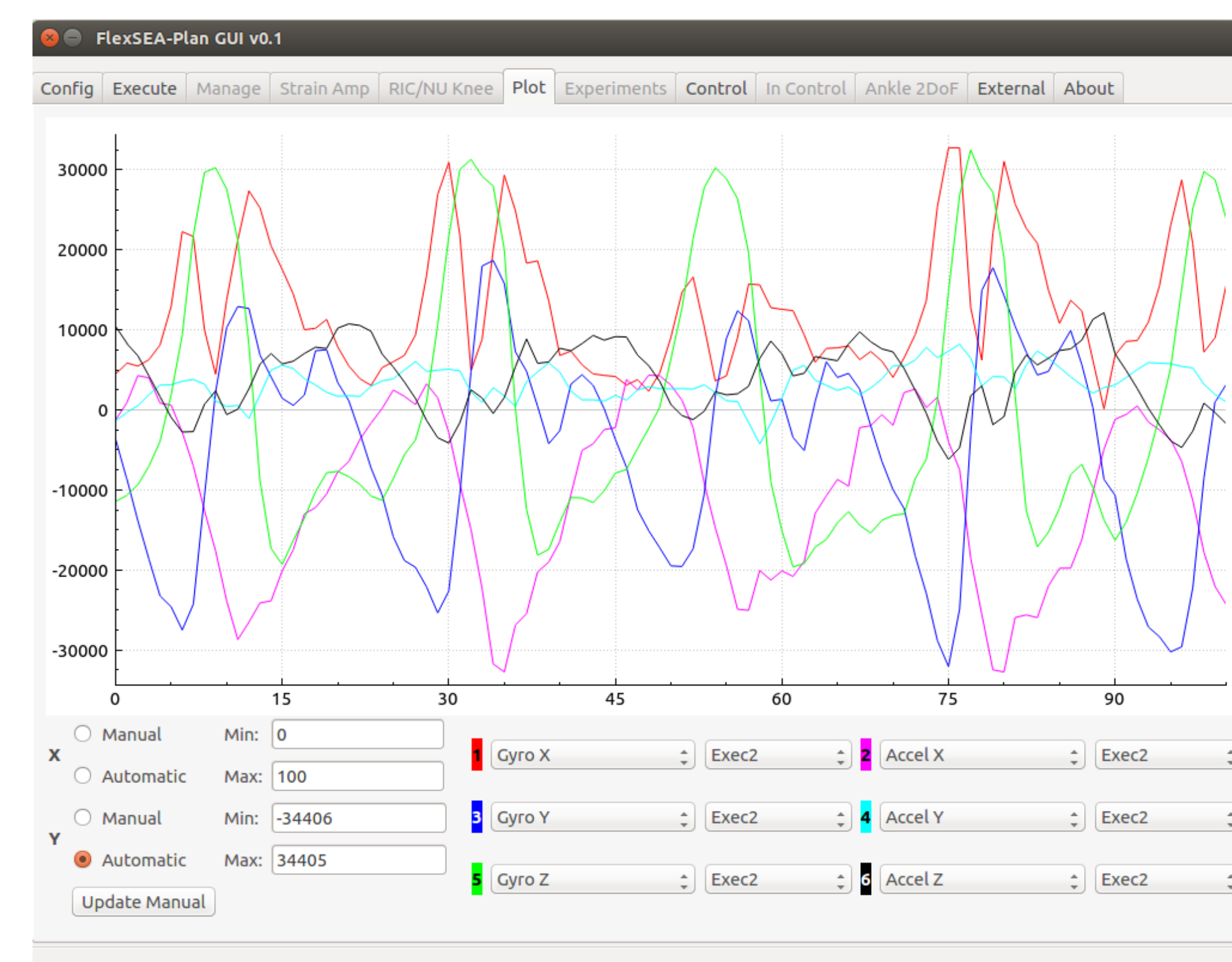
## FlexSEA-Execute is a motor driver optimized for wearable robotics



## System diagram



## Graphical User Interface



## Using and Contributing

The FlexSEA toolkit is licensed as open-source hardware and software to promote collaboration and to quicken the prototyping and design of revolutionary artificial limbs and human augmentation machines. Talk to us if you would like to be a user, or if you would like to contribute to the project.

**For schematics, design files, source code, tutorials and guides:**

<http://flexsea.media.mit.edu> | [jfduval@media.mit.edu](mailto:jfduval@media.mit.edu)

