Power, Controls and Backplane for RoboSub

Proof of Concept

Test Plan

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Ocean’s Seven

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Power Systems

A. Merge Circuit: Validation

Functionality Demonstrated: Safely merge current from two 14.8V, 100A Lithium Ion Polymer batteries while maintaining a maximum current flow of 200A without current back feeding into either battery.

Relation to Overall System: The merge circuit is the external power source’s point of entry to all systems in CU RoboSub. It is responsible for allowing two Lithium Ion Polymer batteries to safely operate in parallel. If this circuit does not work the system will not be able to draw the required current for normal operations of all systems. If the circuit is flawed or thermal damage causes a short between the two batteries, there is a significant potential for the LIPos to fail catastrophically resulting in the batteries being rendered inoperable or causing them to catch fire.

***Safety Considerations:*** Lithium Ion Polymer batteries are extremely hazardous if handled improperly. If they are overcharged to an output voltage greater than or equal to 16.8V, or depleted to an output voltage of less than or equal to 12V, it becomes very probable that the batteries will become unstable and catch fire. The resulting chemical fire **CANNOT** be extinguished by normal means. The batteries must be quickly placed in a bucket of water and sealed. More information can be found in the attached Material Safety Data Sheet.

To address the safety issues concerning Lithium Ion Polymer batteries, a 5 gallon bucket, mostly filled with water, will be present during all tests involving the use of the batteries. Should a battery start to smolder or catch fire, it will immediately be placed into the bucket and a lid will be affixed.

Description:

1. Preconditions:

A. Two voltage sources set to 14.8V and 1A max current

B. Multimeter set to measure DC voltage <= 20V

C. Two 14.8V, 100A Lithium Ion Polymer batteries, >=95% full charge

D. One 1.5 ohm, 5% power resistor rated for 200 Watts

E. Power systems test board

2. Testing:

A. Attach one voltage source to each of the inputs on the merge circuit

B. Turn on voltage sources

C. Using a multimeter, measure the output voltage of the merge circuit

D. Turn off, then remove both voltage sources

E. Attach test load to the merge circuit output and ground

F. Connect one Lithium Ion Polymer battery to input 1 and one battery to input 2.

G. Using the multimeter, measure the voltage drop across the resistor

H. Disconnect both batteries and remove the power resistor

3. Success

A. Voltage output is 14.8V, |err|<3V

B. Voltage measured across the load resistor is 14.8V

B. Voltage Conversion Confirmation: Verification Testing

Functionality Demonstrated: Buck conversion from 14.8V to: 5V at 1A, 12V at 1A; Boost conversion from 14.8V to: 48V at 1A, 48V at 0.5A voltage conversion and maximum current limits meet specifications. These will be tested to ensure stable output voltages for subsystems.

Relation To Overall System: The voltage conversion board is responsible for stepping up/down the 14.8V input voltage to source the required voltage levels of the CU RoboSub subsystems and provide enough current capacity to power all of the anticipated subsystems.

Description:

1. Precondition:

A. One voltage source set to 14.8V with a max current draw of 3A

B. One multimeter set to measure up to 50V

C. 100 Ohm, 100W rheostat to simulate loads of CU RoboSub subsystems

D. Power systems test board

2. Testing:

A. Attach the voltage source high and low voltage lines to the input and ground pins, respectively, of the power systems test board. Turn on voltage source.

B. Using the multimeter, measure output voltages between following test points and ground:

1. 5V Test

2. 12V Test

3. 48V Test-1

4. 48V Test-2

C. Turn off voltage source

D. Using the multimeter set to measuring resistance, adjust the rheostat to 5 Ohms +/- 1%, attach between 5V Test and ground

E. Using the multimeter, measure the voltage drop across the rheostat

F. Turn off voltage source, remove the rheostat.

G. Using the multimeter set to measuring resistance, adjust the rheostat to 12 Ohms +/- 1%, attach between 12V Test and ground

H. Turn on voltage source.

I. Using the multimeter, measure the voltage drop across the rheostat

J. Turn off voltage source, remove the rheostat

K. Using the multimeter set to measuring resistance, adjust the rheostat to 48 Ohms +/- 1%, attach between 48V Test-1 and ground

L. Turn on voltage source

M. Using the multimeter, measure the voltage drop across the rheostat

N. Turn off voltage source, remove the rheostat

O. Using the multimeter set to measuring resistance, adjust the rheostat to 96 Ohms +/- 1%, attach between 48V Test-2 and ground

P. Turn on voltage source

Q. Using the multimeter, measure the voltage drop across the rheostat

R. Turn off and remove the voltage source. Remove the rheostat

3. Success Criteria

A. Voltage outputs on the power systems test board:

1. 5V Test measures 5V +/- 1%

2. 12V Test measures 12V +/- 1%

3. 48V Test 1 measures 48V +/- 1%

4. 48V Test 2 measures 48V +/- 1%

B. Voltage drop across rheostat on the power systems test points

1. 5V Test measures 5V +/- 1%

2. 12V Test measures 12V +/- 1%

3. 48V Test-1 measures 48V +/- 1%

4. 48V Test-2 measures 48V +/- 1%

C. 19 Volt Stability Stress Test: Validation Testing

Critical Functionality Demonstrated: The 19V conversion circuit reliably outputs 19V during high power flux when the kill switch is tripped.

Relation to Overall System: The main CPU used by the CU RoboSub relies on an extremely stable 19V, 3A input. If the voltage supplied to the CPU varies too much, it can cause the CPU to reset which would delay or prevent completion of the competition course. Tripping the kill switch can cause fluctuations in voltage and current provided to the conversion circuit. It must be robust enough to compensate for these fluctuations.

Description:

1. Preconditions:

A. One voltage source set to 14.8V with a max current draw of 3A

B. One multimeter set to measure up to 50V

C. 100 Ohm, 100W rheostat to simulate the CPU load

2. Testing:

A. Attach the voltage source high and low voltage lines to the input and ground pins, respectively, of the power systems board. Turn on the voltage source

B. Using the multimeter, measure the voltage difference between the 19V Test point and ground

C. Turn off the voltage source

D. Turn on function generator, vary amplitudes and waveforms

E. Repeat B and D as necessary

F. Turn off function generator and attach test load

G. Measure current draw

3. Success:

A. Maintains 19V +/- 0.5V without noise

B. Maintains 19V +/- 0.5V with noise f>x Hz,Vpp>x V

C. Max current draw greater than or equal to 3A

Backplane

A. Board-to-Board Connectivity: Feasibility Testing

Critical Functionality Demonstrated: Subsystem boards will be able to connect to the backplane, via a board to board connector and be able to draw current from the power systems through the backplane.

Relation to Overall System: The impetus for developing the backplane is to reduce the use of wire harnesses and standardize integration and connectivity of submodules to the CU RoboSub. Success in this test means that subsystems will be able to be attached to and powered through the backplane.

Description:

1. Preconditions:

A. Voltage source set to 14.8V with 3A max current draw

B. Functioning power systems test board

C. Backplane test board

D. Multimeter set to measure voltages up to 50V

2. Testing:

A. Slot the power systems test board into the power systems slot on the backplane test board

B. Attach the Voltage source’s high and low voltage lines to the input and ground pins, respectively, of the backplane test board. Turn on voltage source.

C. Using the multimeter, measure the voltage difference between ground and the following test points on the power systems board:

1. 5V Test

2. 12V Test

3. 19V Test

4. 48V Test-1

5. 48V Test-2

D. Using the multimeter, measure the voltage difference between ground and the following test points on the backplane test board,:

1. 5V Test

2. 12V Test

3. 19V Test

4. 48V Test-1

5. 48V Test-2

E. Turn off voltage source

F. Using the multimeter set to measuring resistance, adjust the rheostat to 5 Ohms +/- 1%, attach between 5V Test and ground on the backplane test board

G. Using the multimeter, measure the voltage drop across the rheostat

H. Turn off voltage source, remove the rheostat.

I. Using the multimeter set to measuring resistance, adjust the rheostat to 12 Ohms +/- 1%, attach between 12V Test and ground on the backplane test board

J. Turn on voltage source.

K. Using the multimeter, measure the voltage drop across the rheostat

L. Turn off voltage source, remove the rheostat

M. Using the multimeter set to measuring resistance, adjust the rheostat to 6 Ohms +/- 1%, attach between 19V Test and ground on the backplane test board

N. Turn on voltage source

O. Using the multimeter, measure the voltage drop across the rheostat

P. Turn off voltage source, remove the rheostat

Q. Using the multimeter set to measuring resistance, adjust the rheostat to 48 Ohms +/- 1%, attach between 48V Test-1 and ground on the backplane test board

R. Turn on voltage source

S. Using the multimeter, measure the voltage drop across the rheostat

T. Turn off voltage source, remove the rheostat

U. Using the multimeter set to measuring resistance, adjust the rheostat to 96 Ohms +/- 1%, attach between 48V Test-2 and ground on the backplane test board

V. Turn on voltage source

W. Using the multimeter, measure the voltage drop across the rheostat

X. Turn off and remove the voltage source. Remove the rheostat

3. Success

A. Voltage outputs on the power systems test board:

1. 5V Test measures 5V +/- 1%

2. 12V Test measures 12V +/- 1%

3. 19V Test measures 19V +/- 1%

4. 48V Test 1 measures 48V +/- 1%

5. 48V Test 2 measures 48V +/- 1%

B. Voltage outputs on the backplane test board:

1. 5V Test measures 5V +/- 1%

2. 12V Test measures 12V +/- 1%

3. 19V Test measures 19V +/- 1%

4. 48V Test 1 measures 48V +/- 1%

5. 48V Test 2 measures 48V +/- 1%

C. Voltage drop across rheostat on the backplane test points

1. 5V Test measures 5V +/- 1%

2. 12V Test measures 12V +/- 1%

3. 19V Test measures 19V +/- 1%

4. 48V Test-1 measures 48V +/- 1%

5. 48V Test-2 measures 48V +/- 1%

B. Communication Stress Testing: Feasibility Testing

Critical Functionality Demonstrated: UART and I2C communication and PWM signals will function in an environment with the high levels of EM noise that will be generated by the eight motors drawing upwards of 200A.

Relation to Overall System: Communications testing will ensure that the various submodules of the CU RoboSub are able to reliably communicate with each other. If digital communications are untenable in the noisy environment that is expected then alternate designs will have to be pursued for communications and or power systems.

Description:

1. Preconditions:

A. Voltage source set to 14.8V with a max current draw of 3A

B. Two microcontroller dev boards (the STM32 Nucleo-144 and an Arduino Uno, in place of the sensors that use I2C comms) with firmware loaded to support sending and receiving data via I2C and UART communication protocols at 9600 Baud

C. A desktop computer with a serial terminal to communicate with the microcontroller

D. Electromagnet

E. Backplane test board

F. Power system test board

G. BlueRobotics ESC 30A (electronic speed controller)

H. Blue Robotics T100 Thruster

Note: The *control set* of strings is defined as {‘UART’, ‘I2C’, ‘motor-on’, ‘motor-off’}. These are used throughout the test.

2. Testing:

A. Slot the power systems test board into the power systems slot on the backplane test board

B. connect the 5V and ground lines on one end of the backplane test board to the power and ground pins of the Nucleo board

C. Connect the TX pin of the Nucleo to the RX pin on the backplane test board

D. Connect the I2C SCL pin of the Nucleo to the I2C SCL pin on the backplane test board

E. Connect the 5V and ground lines on the opposite end of the backplane test board to the power and ground pins of the Arduino.

F. Connect the TX pin of the Arduino to the RX pin on the backplane test board

G. Connect the I2C SCL pin of the Arduino to the I2C SCL pin on the backplane test board

H. Connect the voltage source’s high and low voltage lines to the backplane test board input and ground pins.

I. Connect the Nucleo to the desktop computer via USB

J. Turn the voltage supply on

K. Send the string ‘I2C’ through the serial terminal on the desktop computer. This sets the microcontroller to use the I2C communication protocol

L. Send strings (not in the control set) to the Nucleo using the terminal

M. Record the information returned to the terminal

N. Send the string ‘UART’ through the terminal on the desktop computer. This sets the microcontroller to use the UART communication protocol

O. Send strings (not in the control set) to the Nucleo using the terminal

P. Record the information returned to the UART terminal

Q. Connect the ESC PWM header to the male ESC header on the backplane

R. Using jumper wires, connect pin PX.XX of the Nucleo to the PWM pin of the female ESC header on the backplane, and connect the other 2 pins on the ESC header to 5V and Ground (they are labeled)

S. Connect the power and ground cables of the ESC to the connectors labeled as ESC power and ESC ground

Plug the 3-phase cables into the motor

T. Send the string ‘motor-on’ to turn on motor, then place it near the backplane test board (note: ‘motor-off’ will turn off the motor)

U. Repeat steps K through P recording the data separately

V. Turn off the voltage source, disconnect the microcontrollers, remove the power systems test board from the backplane test board

W. Compare the sample data with the recorded data

3. Success:

A. Fidelity of data sent via I2C is 99% or higher

B. Fidelity of data sent via UART is 99% or higher

C. Fidelity of data sent via I2C with the motor running is >95%

D. Fidelity of data sent via UART with the motor running is >95%

Controls

A. Communication and Firmware: Feasibility Testing

Functionality Demonstrated: STM32 Nucleo-144 (in place of the final controls board) will communicate via PWM and the UART serial communication standard to an ESC (electronic speed controller) and a PC, respectively.

Relation to Overall System: The best way for us to communicate with the main computer of the Robosub is UART via USB, so we must prove that we can do that given our framework of microcontroller and backplane. Additionally, one of the most important functions of our system is to actually move the sub, so testing our PWM control of the ESCs is important.

Description:

1. Preconditions:

A. An STM32 Nucleo-144 dev board with firmware to support two PWM channels

B. Two 30A AfroESC electronic speed controllers

C. One voltage supply set to 5V with 2A max current draw

D. One voltage supply set to 14.8V with 6A max current draw

E. One VideoRay motor

F. One Blue Robotics motor

G. Oscilloscope set to a 1V step and a 100us step

H. Desktop Computer with serial terminal

I. Backplane test board

2. Testing:

A. Connect the 5V voltage source high and low voltage lines to the power and ground pins, respectively, on the microcontroller.

B. Connect the microcontroller to the desktop computer

C. Turn on 5V voltage source

D. Open UART terminal on the desktop computer

E. Send 0 over the UART terminal.

F. Using the oscilloscope, measure the frequency and duty cycle of the outputs of PWM channel 1 and channel 2.

G. Repeat E,F using UART inputs of -100, -75, -50, -25, 25, 50, 75, 100

H. connect the Blue Robotics T100 motor to an AfroESC.

I. connect the AfroESC to one PWM channel on the microcontroller using jumper wires (pin PX.XX and the 5V and GND pins)

J. Connect the VideoRay motor to the second AfroESC

K. Connect the AfroESC to the second PWM channel using jumper wires (pin PX.XX and the 5V and GND pins)

L. Connect the 14.8V voltage source high and low voltage lines to the power and ground pins of both AfroESCs

M. Repeat steps E-G and verify the motors stop with a 0 command and spin clockwise with positive values and counterclockwise with negative values

3. Success: Consistent communication is achieved between the STM board and the ESC/PC in a way that will be easily ported to the final version of the controls board, meaning it makes minimal use of any features of the Nucleo board and relies on the STM32 Hardware Abstraction Layer drivers (specific to the microcontroller, not the development board) to achieve communication and motor control.

The speed and direction of both motors should change to be consistent with the values sent as percentages of max speed. This means all the PWM and serial communication code is working correctly and ready to be ported to the controls board.

“Zero Order Hold” PID Controls: Feasibility testing

Unknown Functionality Demonstrated: Given a desired heading and velocity, the control system can maneuver the CU RoboSub in a level plane to achieve the desired values with minimum settle time.

Relation to Overall System: This simple PID approach to maneuvering the Autonomous Underwater Vehicle (AUV) is essential to being able to operate in the water. It will require the AUV to come to a complete stop, rotate as necessary, then continue in the desired direction

Description:

1. Preconditions: Design a model to represent overall drag coefficients, and inertia. This simplified model will be represented by a cylinder with boxes at the locations of motors. This model of system will be created in Simulink

2. Testing:

A. Set the desired velocity to (0, 0, 0) for it’s x, y, and z vectors.

Given this response show that the vehicle remains at its current location.

B. Provide inputs corresponding to changed velocity without changing

Heading. Monitor stability of system response using either a root locus plot or a bode plot.

C. Provide inputs corresponding to zero velocity change and acute

heading changes. Monitor stability of system response in the same

manner as B

D. Provide inputs corresponding to velocity changes and acute heading

changes. Monitor stability of system response

E. Repeat C and D with 90 degree turns and 180 degree turns. Monitor

stability of system response

3. Success:

A. For each test condition above, the system model will not enter a

region of instability on a bode or root locus plot

B. For each test condition above, system settle time is < n seconds/degree

C. For each test condition above, overshoot and undershoot are <= 5%

D. For each test condition above, the steady state error will be <=1%