Fault Tolerant Controller Operation Manual

Team #9

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Introductory Material

The purpose of this project stems from a problem of failing motors on an airborne drone. The solution is an attempt to diagnose a problem with a faulty motor before it happens. The initial solution was to generate fault models of a particular motor and then develop a fault prediction algorithm. This algorithm would then take in measurements from the motors characteristics and determine the probability of a fault in real time. Due to time constraints and a stop work order issued by General Atomics, it has been decided to create a system that monitors characteristics in real time that outputs these characteristics to a webpage available for viewing. The system consists of various components that will be covered fully in the components list, however a brief overview will be given. The system will have several voltage, current, temperature, vibration and acceleration sensors all gathering their data from a drone motor. The data gathered by the sensors will be processed on a BeagleBone Black microprocessor board.. The resulting data will then be stored in a database where it is shown on a webpage in real-time.

Components

The basic components list is given as follows:

- Tiger Motor U3 KV700
- Tiger Electronic Speed Control Flame 25A
- Propeller
- Gravity 50A current sensor
- Phidgets precision voltage sensor
- Vibration sensor
- Analog temperature sensor
- BeagleBone Black Microprocessor
- Testing stand

The components will be discussed in detail.

Tiger Motor

The model of motor used is the U3 KV700, using a 12 inch prop the specifications are as follows:

Item No.	Volts (V)	Prop	Throttle	Amps (A)	Watts (W)	Thrust (G)	RPM	Efficiency (G/W)	Operating temperature(℃)
U3	11.1 (3S)	T-MOTOR 12*4CF	50%	2.5	27.75	350	4000	12.61	40
			65%	4.8	53.28	550	4900	10.32	
			75%	6.6	73.26	700	5500	9.56	
			85%	9.1	101.01	870	6300	8.61	
			100%	11.1	123.21	1000	6600	8.12	
		T-MOTOR 13*4.4CF	50%	2.9	32.19	400	3800	12.43	42
			65%	5.6	62.16	650	4900	10.46	
			75%	7.9	87.69	830	5300	9.47	
			85%	10.5	116.55	1000	6000	8.58	
			100%	12.6	139.86	1100	6400	7.87	
		T-MOTOR 14*4.8CF	50%	4.1	45.51	550	3500	12.09	43
			65%	7.7	85.47	890	4500	10.41	
			75%	10.7	118.77	1060	4900	8.92	
			85%	14.5	160.95	1300	5500	8.08	
			100%	17.3	192.03	1460	5800	7.60	

Figure 1: Tiger U3 KV700 Motor Specification Table

The motor is connected to the Electronic Speed control by three wires. The order in which the wires are connected does not matter, however if it is found that the motor is spinning in the wrong direction, simply change two of the connecting wires.

Tiger Electronic Speed Control

The Tiger ESC Flame 25A is the electronic speed control for the motor. This device takes in a DC voltage along with a pulse width modulation signal to control the speed of the motor. There are two methods to use the ESC to change the speed of the motor. By changing the duty cycle of the PWM input the speed of the motor changes. If the duty cycle remains constant, a potentiometer can be connected between the PWM input and ESC. By adjusting the resistance, the speed of the motor will change.The specifications of the input of this device is given in the chart below:

Parameters	FLAME25A			Unit
	MIN	Typical Value	MAX	
Input Voltage	6.4	14.8	17.4	V
PWM	3.0	-	5.0	V
Max Continuons Current	-	-	25	A
Peak Current(3S)	-	-	30	A
Oneshot125 Signal Frequency Compatible	30	-	600	Hz
Regular Signal Frenquency Compatible	30	-	500	Hz
Ambient Temp	-10	25	50	℃

Figure 2: Tiger ESC Flame 25A Specification Table

The ESC has some error states that are determined by the sound of the motor beeping. The following is a chart of the error state and description.

Error State	Description
BBBB…	Please check FC, receiver or RC equipment
B—B—B…	No throttle signal

Figure 3: ESC Error States

This device is connected to a power supply, as well as a PWM signal generated by the BeagleBone Black, it is then connected to the motor by three wires.

Propeller

The propellers used are carbon fiber 12 inch propellers. They are connected to the motor by a pair of screws and are used as the load to be tested. In order to change the load, the propeller can be defaced (drilled holes, cracked, etc.).

Figure 4: Tiger 12 in. Carbon Fiber Propeller

Gravity 50A Current Sensor

The Gravity current sensor is designed to sense up to 50A of AC or DC current. This device is intended to measure the current through each phase of the motor to determine if it is being fed the correct amount of current. This will be connected between the ESC and the Motor. The output of this sensor measures 40 mV per 1 A it senses. This sensor takes 5V to power and is powered by the BeagleBone Black board. There are three current sensors used to measure the current of each phase of the motor. Using figure 9 as reference, pins P9_5, P9_6, and P9_7 supplies the 5 V, pins P9_1, P9_2, and P9_43 act as a ground, and pins P9_33, P9_35, and P9_36 are the analog inputs. A simple diagram of the setup is shown below:

Figure 5: Gravity Current Sensor Connection Diagram

Phidgets Precision Voltage Sensor

The Phidgets voltage sensor is designed to sense between -30 to 30 V differential. This device only detects DC voltage therefore it will be connected between the power supply and ESC to measure the input voltage. The output of this sensor shows between 0.5V and 4.5V. At 2.5 V output, the sensor is reading 0 V differential. A formula must be applied to the output voltage read to determine the actual differential voltage which is given below. This sensor takes 5V to power and is powered by the BeagleBone Black board. Using figure 9 as reference, the sensor is powered by pin P9_8, grounded by P9_44, and the analog input to the board is P9_37. A simple diagram is shown below:

$$V_{diff} = \frac{\frac{SensorValue}{200} - 2.5}{0.0681}$$

Equation 1: Formula to convert sensor data into usable real values

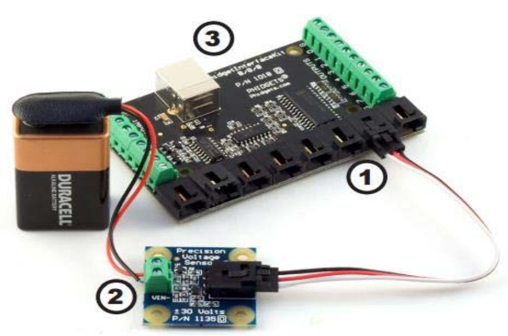

Figure 6: Phidgets Voltage Sensor Connection Diagram

Looking at figure 6, the sensor is being powered by, sending the output voltage, and is grounded by three wires connected to the board on the right. The sensor is measuring the voltage of the battery on the left.

Vibration Sensors

There are three versions of the vibration sensors. They are labeled as Slow, Medium, and Fast. The labels determine the amount of force it takes to trigger them. The vibration sensors works as a simple switch which when vibrated enough will close the switch and allow the current/voltage through them to be read by the BeagleBone Black. These do not have a required power amount, however they will be powered by the 1.8V port on the BeagleBone Black, pin P_32.

Figure 7: Vibration Sensor

Analog Temperature Sensors

The temperature sensor is designed to read from a range of -50ºC to 125ºC. The sensor is powered by a source between 2.7 and 5.5V and it outputs a voltage between 0V and 1.75V. The formula given to determine the correct temperature based on the voltage reading is given below

$$Temp\ {}^{o}C = 100 * (reading\ in\ V) - 50$$

Equation 2: Formula to convert temperature data into usable values

Using figure 9 as reference, the temperature sensor is connected to pin P9_3 for power, P9_45 for ground, and P9_38 for the analog input.

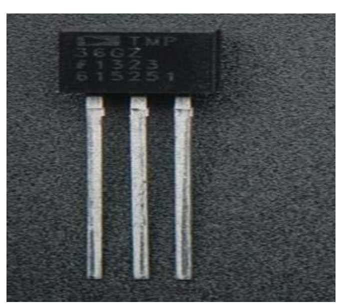

Figure 7: Temperature Sensor

BeagleBone Black

The BeagleBone Black is the processor that will be reading in the measurement parameters while also supplying power to most of the sensors that have been described above. The processor has several power pins to provide power to the other devices as well as many analog input pins to take in the measurements that the devices are reading. The BeagleBone Black itself can be powered through a computer using a USB cable, or through a 5V power supply.

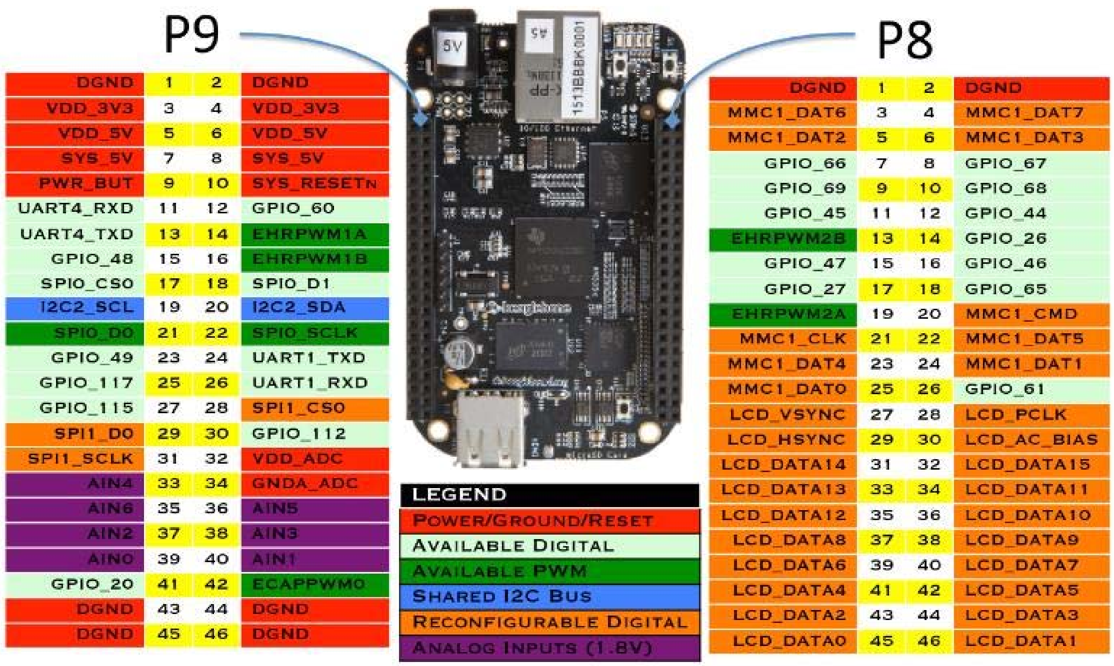

Figure 9: BeagleBone Black Pin Layout

Testing Stand

A testing stand has been designed by the team and built by the College of Engineering machine shop to safely mount and test our motor and other devices. This stand is made of wood and aluminum and is to be clamped to a table when in use. A picture is found below:

Figure 10: Testing Stand for the Motor and Components

Setup

General

To safely set up the system, be sure to read and understand the specific manuals for each part. It is the goal to be able to connect everything from this operation manual, however if some things are missed, refer to each devices manual. Be sure when connecting devices to avoid short circuits between the devices or incorrect connections between any of the pieces of equipment. To avoid unnecessary complications, ensure all of the sensors are mounted to the wooden board in an organized manner.

Hardware

The hardware setup begins with the mounting of all of the equipment onto the testing stand. The holes in the vertical aluminum piece are for the motor to be mounted there. All other pieces of equipment should be mounted onto the wooden base of the stand. There is to be 3 current sensors connected in between the ESC and the Motor to measure the current of each phase. There is one voltage sensor connected between the ESC and the power supply. There are 2 temperature sensors that will be connected in/on the motor. One will be placed inside the motor touching the coils to get an internal measurement of the temperature, while the other is to be placed on the outer shell of the motor. The sensor placed inside the motor should be held there by an insulative epoxy that will not affect the motor. The vibration sensor will be placed on the outside of the motor. The motor/ESC will be powered by a desktop voltage supply, while the sensors will be powered through the BeagleBone Black. The sensors output will also be fed to the BeagleBone Black.

Wiring

A wiring diagram has been drafted to help understand the setup. Each yellow wire of this diagram is made to represent 3 total wires. Two of the wires are to be the power and ground of each device needing to be powered which is supplied by the BeagleBone. The third wire is to be the output of the sensor which will be measured by the BeagleBone. On the schematic, several voltage dividers, simply consisting of resistors, are shown. These are due to the BeagleBone's analog reading limitation of 1.8V. These voltage dividers were created to make sure the voltage going into the BeagleBone's pins is below 1.8 V so no damage to the BeagleBone occurs.

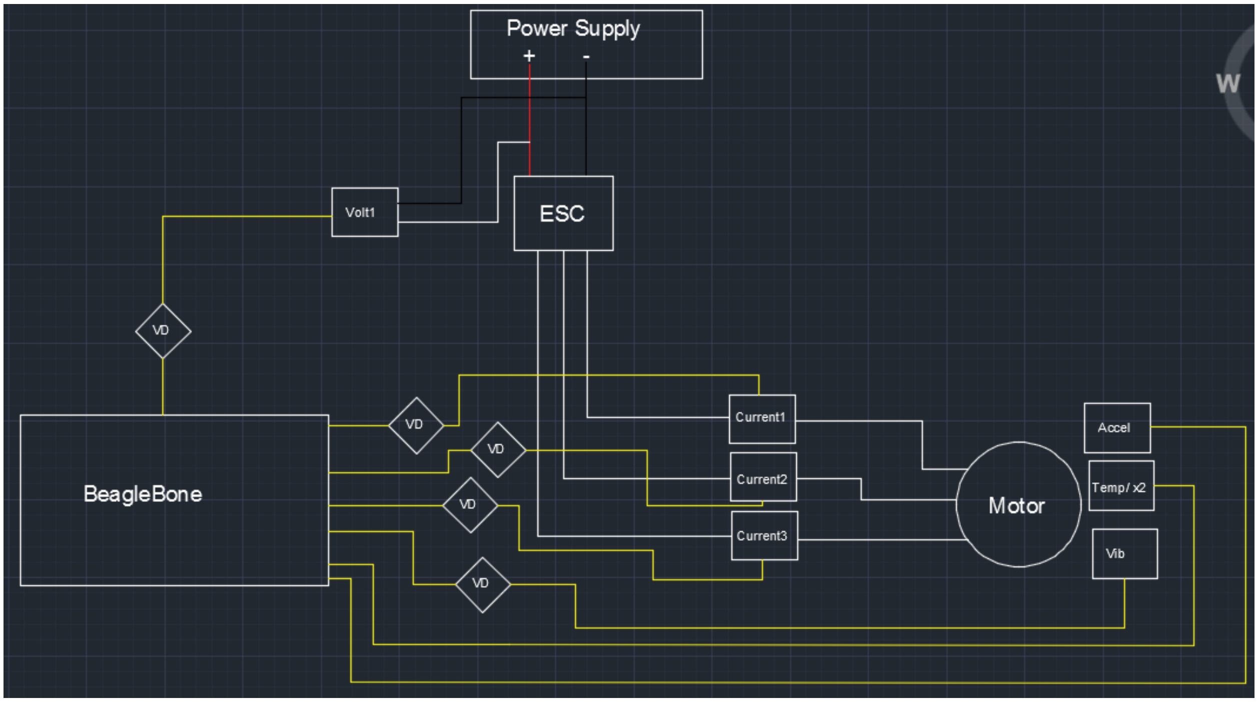

Figure 11: Wiring schematic of testing setup

Software

There have been several programs created by the team in order to test our product. These programs are located in the root directory and they are written in the python programming language. If there is any trouble working with the BeagleBone, it is suggested to go to Beagleboard.org/getting-started. The output of these programs can be seen on the BeagleBone itself, or through the website that the data is being transmitted to.

Operation

After successful setup is complete, the system can be operated. First make sure the ESC as well as all the sensors are being powered by the correct sources. Next, the system can be operated by simply running a program from the BeagleBone. This program will allow for change in the speed of the motor, by adjusting the PWM signal duty cycle, as well as show all of the characteristics of the sensors measurements. Be sure to test the motor in a safe environment. Make sure there is proper safety equipment in place when the motor is running in case something were to break. Do not touch the propeller when the motor is operating and be sure to enclose the propeller to prevent injury. Do not touch any of the electronics while operating in case of electrical shock.

Troubleshooting

A common problem found with the motor is not supplying a correct PWM voltage, make sure the ESC has a PWM signal between 3-5 V to allow the motor to work. Make sure no lines are shorted when the experiment is in progress. Be sure to have all the equipment properly mounted. The motor is small but powerful and could get out of control.