Team 23

Development of a Wheel Force/Torque Sensor for Autonomous Ground Vehicles

Operations Manual

4/3/2015

John Gregulak	CpE	jg11m@my.fsu.edu
Oluwatosin Olaleye	EE	oluwatosin1.olaleye@famu.edu
Matthew Russo	ME	mdr02n@my.fsu.edu
Marc Saint-Fleur	ME	mas11k@my.fsu.edu
Randall Veliky	ME	rjv10@my.fsu.edu

Advisors

Dr. Oscar Chuy

Dr. Michael Frank

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Abstract/Executive Summary

Continuing on work performed by last year's senior design team, this team is tasked with developing a system that allows the autonomous ground vehicle, GOLIATH, to better live up to its all-terrain designation. This is going to be achieved by adding a wheel force/torque sensor onto one of the wheels, and having it wirelessly communicate with the vehicle's computer control system. To date, several design concepts were created and reviewed by the team. Evaluating these designs objectively, the team has decided to implement a design given by one of the project's advisors. Pairing this design with an electrical circuit optimized by the team specifically for this setup presents the best option to move forward in the project. In the near future, the team will need perform more comprehensive calculations on the selected design in order to verify that it is capable of withstanding every obstacle that the GOLIATH will tackle. Simultaneously, prototyping and parts testing will occur once ordered parts arrive in the coming weeks.

1.0 Functional Analysis

The ability to sense the force or torque applied to a wheel is essential to maintaining traction and stability of autonomous ground vehicles. The objective of this project is to devise a way to quantify the interaction between the wheel and ground of CISCOR's autonomous ATV, GOLIATH, shown in Figure 1. This is to be achieved via the use of a force/torque sensor mounted between the right front wheel and hub.

Figure 1 GOLIATH

To determine if wheel slip occurs the use of strain gauges to measure the torque on the axle will be needed. A strain gauge is designed to convert mechanical motion into electrical signal[4]. The most common strain gauges have a flexible backing with a metal wire pattern attached. A voltage is applied to the gauge that runs through the wire, as the gauge bends under strain the resistance through the wire changes as a function of the strain. Using this function and measuring the resistance change leads to an accurate calculation of the strain. To measure the resistance change the gauge is attached to a Wheatstone bridge. Many types of strain gauges have been made and are used on axles; however, most gauges only measure the weight experienced by the axle[5]. This gauge will measure forces in all directions, as well as accompanying moments.

The torque sensor for this project works based off these principals. The created assembly consists of a central section and mounting adapters and plates to attach it to the ATV. The central section is a cross with strain gauges mounted of each of the four faces on the arms. The wheel is connected to the center, and the ATV hub is connected to the outside ring. The forces from these two will cause elastic deformation in the arms, which the mounted strain gauges will detect and then transmit.

Each strain gauge is paired with another directly opposite on the arm in a Wheatstone bridge. The signal will then be amplified and converted from an analog to a digital one. Afterwards,

the on board microcontroller will take this data and apply the proper conversion to force. Finally, the microcontroller will transmit this data to the ATV's control system.

2.0 Product Specification

The main cross section is shown below, in Figure 2. This is the largest piece of the assembly. The overall diameter of the assembly is constrained by the inner diameter of the ATV's wheel. As such, the assembly is no more than 290mm (11.4 in) at the widest point. Each piece of the assembly is machined from a solid block of aluminum 7075. This was chosen for its strength and weight, as well as its corrosion and fatigue resistance.

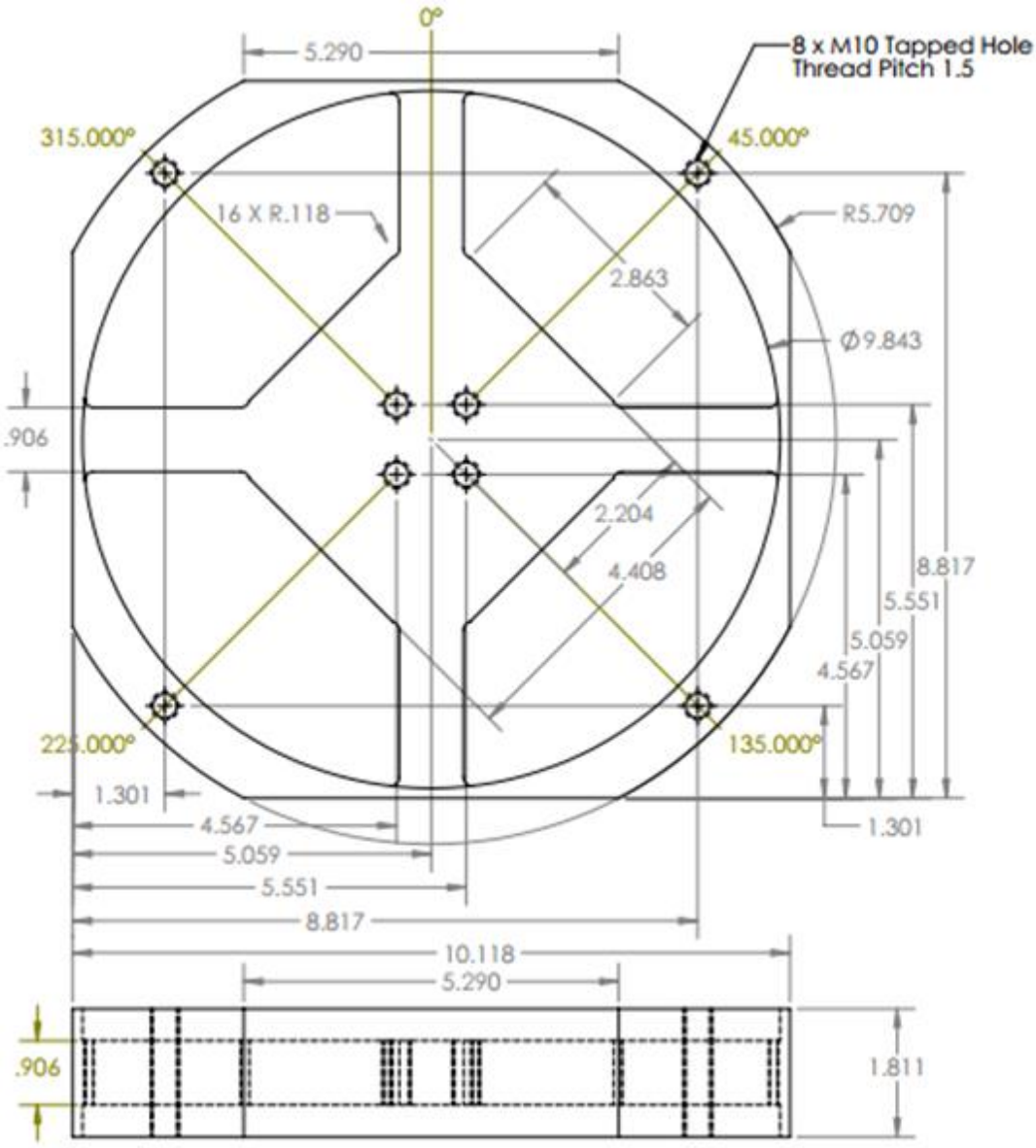

Figure 2 Dimensions of main section

3.0 Circuit and Microcontroller

3.1 Circuit and Circuit Electronics

The electrical unit of the wheel torque sensor comprises of sixteen strain gauges connected in a half bridge configuration. Two of these strain gauges are independently connected to form eight half bridges. Each of these Wheatstone Bridge is made up of two 350 ohms resistors connected to two KFH-series 350 ohm nominal value strain gauges. The AD620AN a high precision amplifier is used to amplify the associated output voltage resulting from the strain on the bridge. A 500 ohms resistor provides the amplifier with a gain of a thousand and the typical tantalum 1 µF capacitor in the circuit acts as the bypass capacitor for the amplifier's 5 volts input voltage. The bridge is connected in a single rail power input to eliminate negative output from the bridge. The Wheatstone bridge was calibrated to center its output at 2.5 volts by using a voltage reference of 2.5 volts.

3.1.1 Operation Instructions for Circuit

- The overall electrical circuitry as shown above is made up of 8 Wheatstone bridge circuit fabricated from 16 strain gauges and 16 resistors.
- Each bridge circuit comprises of two 350 ohms resistors connected in series.
- This is in turn connected to two KFH-series 350 ohm strain gauges to form a Wheatstone bridge.
- The resulting half bridge configuration is supplied with a 5 volts regulated voltage from a switching regulator.
- The strain two strain gauges from each bridge is mounted on selected points on the elastic plate measure the torque/force acting on the wheel.
- The output of the bridge is connected to the instrumentation amplifier (AD620AN).
- Pins 1 and 8 of the amplifier are used to connect the gain resistor, pin 7 is connected to a 1 µF capacitor to eliminate electromagnetic impulses from the DC supply.
- Pins 4 and 5 are connected to the ground and reference voltage respectively.
- The amplified output centered at 2.5V from pin 8 of the amplifier is fed into the ADC for signal processing.

3.2 Microcontroller and Analog to Digital Converter

The Microcontroller being used in a Beaglebone Black paired with an 8 channel, 12 bit MCP3208 Analog to Digital converter. Seen in Appendix 10.1 is the proper wiring diagram between the Beaglebone Black and the Analog to Digital converter and also the pin assignments and pin names to aid with proper connectivity. Ensuring that all the wires are connected to the proper locations is the only way to ensure that the unit will function properly.

3.2.1 Operating Instructions

Begin, by properly connecting all of the wires to the appropriate connections as shown above. Once power is applied to the board, the code will automatically execute, No further input or operation is necessary.

4.0 Project Assembly

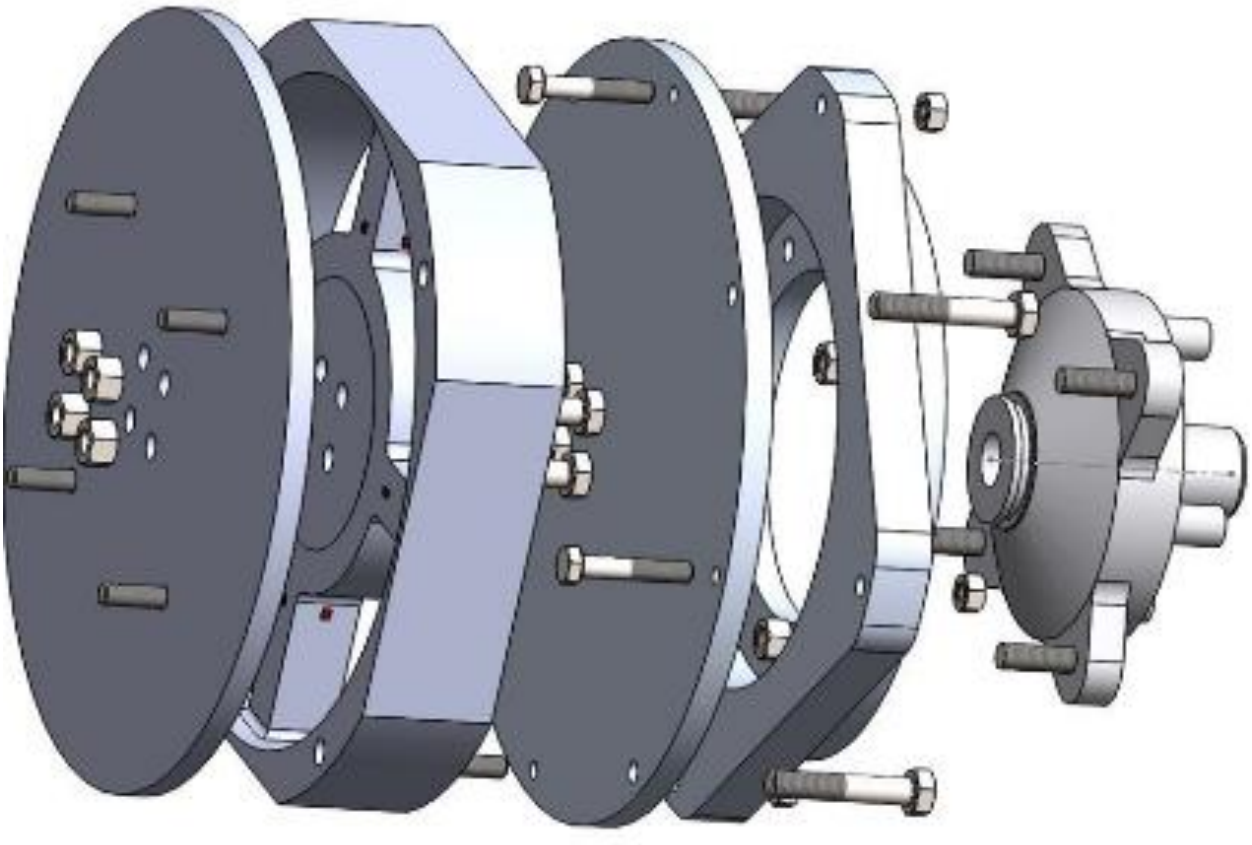

Figure 3 Torque Sensor Assembly

From **Error! Reference source not found.**, above, it can be seen how the unit attaches to he ATV; between the hub and the wheel.

5.0 Operation Instructions

5.1 Mounting

The following is the procedure for mounting the assembly to the ATV:

1. Using a 17 mm socket with appropriate ratchet, loosen the four lug nuts on the ATV. **DO NOT REMOVE THE NUTS AT THIS TIME.**
2. Using a suitable lift point, preferably on the frame, place a jack underneath the ATV and lift it so that the wheel is off the ground. Support the ATV with a suitable jack stand. **DO NOT WORK ON OR UNDER ANY VEHICLE THAT IS SUPPORTED ONLY BY A JACK.**
3. Remove the lug nuts and the wheel.

4. (Figure 4) Place hub adapter on hub, and attach with provided short lug nuts. Torque lug nuts to 45 lbf ft with a 17 mm socket.

Figure 4 Hub Adapter

5. (Figure 5) Place inner plate on hub adapter and attach with M8x1.25 bolts. Tighten bolts to 25 lbf ft with a 13 mm socket.

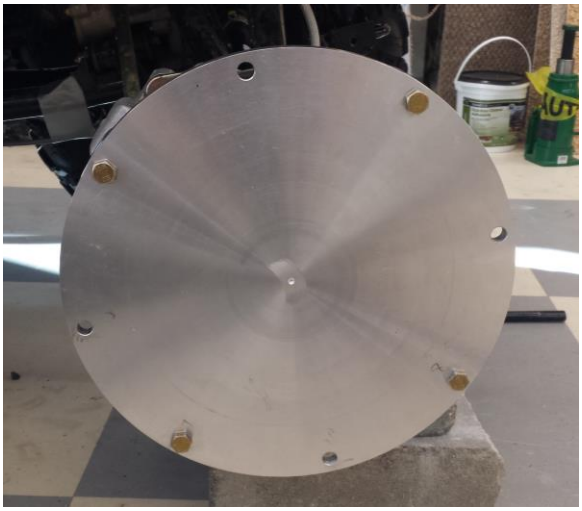

Figure 5 Inner plate

6. (Figure 6) Attach hub adapter to inner plate with M10x1.25 x 60mm bolts through the back of the inner plate. Tighten bolts to 35 lbf ft with a 13 mm socket. Be careful to not strike or crush electrical components when placing and securing section. Microcontroller, circuit boards and battery should fit within blank areas of section with ample room on all sides.

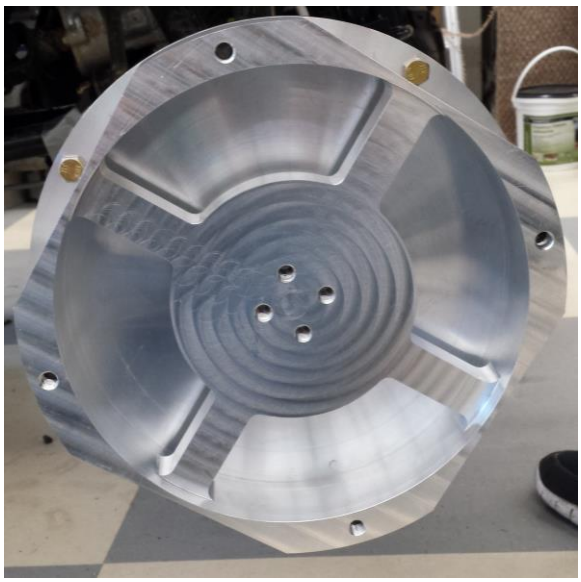

Figure 6 Cross section

7. Connect strain gauges to circuits. Pay attention to what connections are made; connect plugs 1 and 1, 2 and 2, etc.
8. Turn on system.
9. (Figure 7)Place outer plate and attach with M10x1.25 x 70mm bolts. Torque bolts to 35 lbf ft with 17 mm socket.

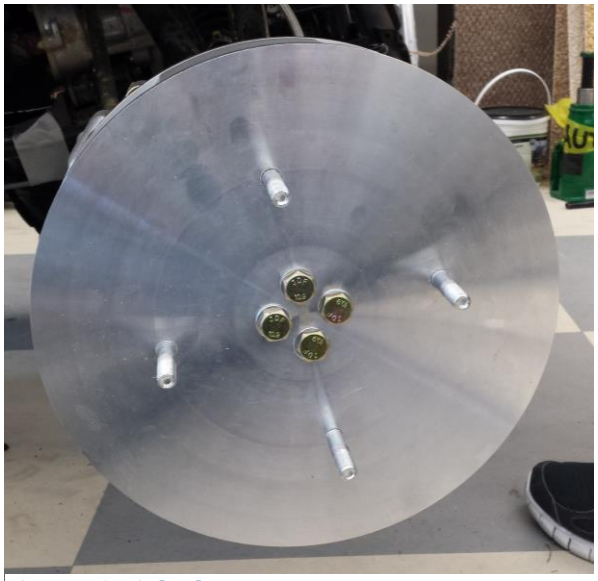

Figure 7 Outisde plate

10. (Figure 8) Place spacer on studs.
11. Place wheel on studs and install supplied long lug nuts.
12. Lower ATV
13. Tighten lug nuts to 45 lbf ft with 17 mm socket.

14. There are probably some more steps with the electronics, connecting with the ATV computer, etc…

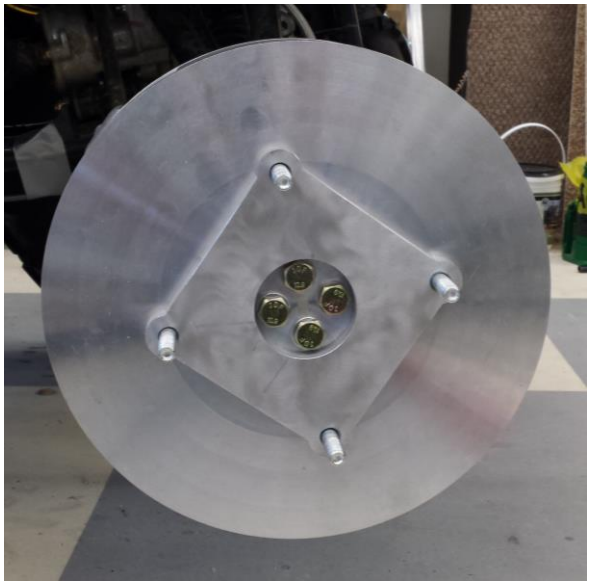

Figure 8 Spacer

5.2 Operation of unit

Unit requires no further user input when operating ATV. However, the operator should always drive operate ATV responsibly, never driving recklessly or in hazardous conditions. Furthermore, before any driving, the ATV should be checked for proper operation (oil and gas level, tire pressure, etc.). The unit does not impede driving or operation of the ATV, but it does affect the driving characteristics. Care should be taken when first driving the ATV until user is familiar with handling characteristics.

6.0 Trouble Shooting

1. Electronics not powering on
    1. Check to verify that the battery is fully charged. Fully charged battery should output 7.2V. If the battery is fully charged proceed to step 1.3.
    2. If the battery is dead or not fully charged, charge the battery and allow it to charge for at least an hour if dead or until fully charged with the provided charger.
    3. Check that the terminals connecting from the battery to the electrical components are properly connected.
    4. If the above steps pass, proceed to check that all electrical components receiving power directly from the battery are properly connected. There should be no loose or disconnected wires. Also, do an inspection of the microcontroller and all other electronics for any noticeable issues.
    5. After the above steps are completed, attempt to power on the electronics to see if the issue has been resolved. If the issue is still not resolved, proceed to the next step.

6. Try replacing the battery with another battery that outputs at least 6V. If this resolves the issue, a new battery will need to be inserted into the unit. If the issue is still not resolved, proceed to the next step.
7. Verify the Beaglebone Black is still functional. Inspect the board more thoroughly checking to see if the power supply port is loose or damaged in any way. Check that the PCB is not cracked or damaged. If the board is receiving power, the blue LED labeled "PWR" nearest to the input labeled 5V should be illuminated solid.

2. Wires have come loose or disconnected
    1. Don't attempt to reinsert disconnect wires without first consulting one of the attached wiring guides. Placing a wire in the incorrect location could cause damage to the electronics resulting in permanent failure.
    2. Loose wires can be reinserted to the proper location gently.
3. No readings are coming from the unit
    1. If there are no readings coming from the unit the first thing to check is that the unit is indeed powered on. Verify that the unit is powered on by repeating all of Step 1 above before continuing. After verify the above steps proceed to the next step.
    2. Check for any loose or disconnected wires throughout the unit. If one wire is disconnected it will cause the whole unit to not produce an output.
    3. If a wire is determined to be disconnected, connect the wire to its proper location by using one of the attached wiring diagrams.
    4. Follow steps in Appendix 10.2 to verify SPI is functional.
4. Wireless is not working
    1. Check that the router on the ATV is powered on and is properly working.
    2. Check that the USB dongle attached to the Beaglebone Black is properly inserted into the USB port.
    3. Verify the wireless settings in the appropriate folder
    4. Power off the unit and power it back on by using the reboot command from a terminal application while SSH to the board.
5. Unit is hard to assemble
    1. Before attempting to assemble the unit check the aluminum for any deformations, scratches, markings or any other defect. If a defect is found, do not continue assembling the unit as it may cause serious injury or even death.
    2. Remove the piece in question and inspect it further
    3. If the defect is bad enough, a replacement part will be necessary in order to ensure the safety of the rider and vehicle.
6. A piece has broken
    1. First, attempt to identify the piece that has been broken. NEVER RETURN A BROKEN PART TO THE UNIT.

    2. Once the part is correctly verified order a replacement part and replace the part.

7.0 Regular Maintenance

- Battery should be recharged before each use
- Connections should be inspected before each use. Should any appear loose or broken, repair or replacement will be necessary.
- Bolt/screws responsible for securing components should be checked before each use. If any are loose, they will need to be tightened. If any have damage (broken threads, damaged heads, etc.) they will need to be replaced.
- All regular maintenance of ATV should also be performed when necessary. Refer to service manual or Polaris for full ATV maintenance.

8.0 Spare Parts

Spare parts for operation of unit are as follows:

- Bolts, both M10 and M8. There are enough spare bolts to replace each one being currently used on the assembly.
- Microcontroller. One spare Beaglebone Black is available.
- Strain gauges. Five spare strain gauges with lead area available.
- Electrical components. There are enough components (analog to digital converter, resistors, voltage regulators, etc.) to recreate two more full circuits.

9.0 References

1. *Darpa Robotics Challenge*. DARPA, n.d. Web. 26 Sept. 2014.
2. Parks, Bob. "Taking It to the the Street." *Popular Science* 270.5 (2007): 58-66. Print.
3. Akbar, Marc, Merrick Salisbury, Michael Brazeau, Lester Kendrick, Omesh Dalchand, Jeremy Hammond, and Nahush Kulkarni. "Gas Operated Land Intelligent All Terrain Hub." FAMU FSU COE, 17 Apr. 2014. Web. 26 Sept. 2014.
4. Brier, Hyman. Strain Gauge Load Indicator. Ohio Commw Eng Co, assignee. Patent US 2813709 A. 19 Nov. 1957. Print.
5. "The Strain Gage." *The Strain Gage*. N.p., n.d. Web. 10 Oct. 2014.
6. *Vehicle Test Sensors.* Sensor Developments, n.d. Web 01 Dec 2014

10.0 Appendix

10.1 Wiring Diagram for BBB and A2D

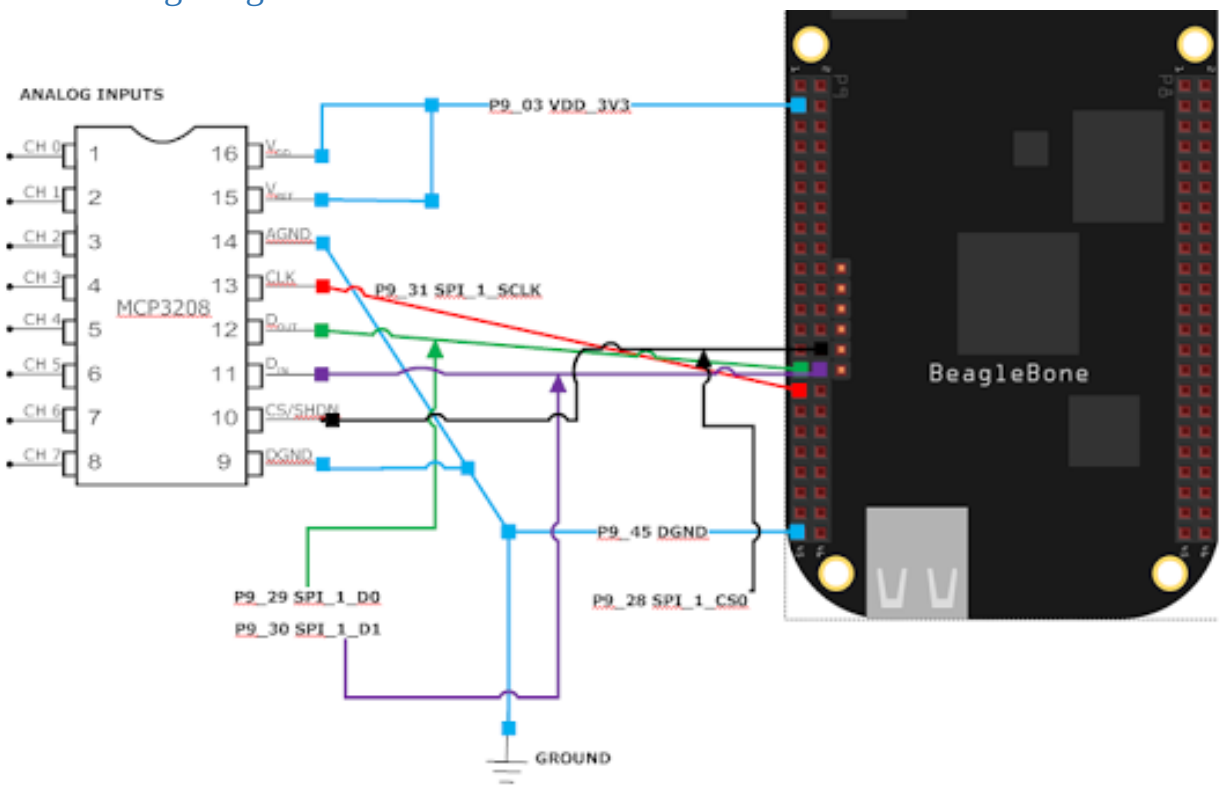

Figure 9 Wiring Diagram for BBB

Beaglebone Black Pin	Beaglebone Pin Name	ADC MCP3208 Pin
P9_03	VDD_3V3	VDD, VREF
P9_31	SPI_1_SCLK	CLK
P9_29	SPI_1_D0	DOUT
P9_30	SPI_1_D1	DIN
P9_28	SPI_1_CS0	CD/SHDN
P9_45	DGND	DGND, AGND

Table 1 Pin Assignment table

10.2 Disable HDMI Interface

In order for the SPI pins to be properly enabled, the overlying HDMI interface has to be disabled. To disable the HDMI interface, follow the instructions below.

SPI1 D1 Output and Do Input

Start nano

```
nano BB-SPI1-01-00A0.dts
```

Copy-paste this into the file

```
/dts-v1/;
/plugin/;

/* SPI1 */
/* D1 Output and D0 Input */

/ {
   compatible = "ti,beaglebone", "ti,beaglebone-black";

   /* identification */
   part-number = "spi1mux";

   fragment@0 {
      target = <&am33xx_pinmux>;
      __overlay__ {
         spi1_pins_s0: spi1_pins_s0 {
                  pinctrl-single,pins = <
                        0x190 0x33     /* mcasp0_aclkx.spi1_sclk, INPUT_PULLUP |
MODE3 */
                        0x194 0x33     /* mcasp0_fsx.spi1_d0, INPUT_PULLUP | MODE3
*/
                        0x198 0x13     /* mcasp0_axr0.spi1_d1, OUTPUT_PULLUP |
MODE3 */
                        0x19c 0x13     /* mcasp0_ahclkr.spi1_cs0, OUTPUT_PULLUP |
MODE3 */
```

```
            >;
        };
    };
};

fragment@1 {
    target = <&spi1>;
    __overlay__ {

        #address-cells = <1>;
        #size-cells = <0>;
        status = "okay";
        pinctrl-names = "default";
        pinctrl-0 = <&spi1_pins_s0>;

        spidev@1 {
            spi-max-frequency = <24000000>;
            reg = <0>;
            compatible = "linux,spidev";
        };
    };
};
};
```

Close the file (Ctrl-o, Ctrl-x) and compile using dtc:

```
dtc -O dtb -o BB-SPI1-01-00A0.dtbo -b 0 -@ BB-SPI1-01-00A0.dts
```

Then, copy the file into /lib/firmware/:

```
cp BB-SPI1-01-00A0.dtbo /lib/firmware/
```

Then enable the device tree overlay:

```
echo BB-SPI1-01 > /sys/devices/bone_capemgr.*/slots
```

Plug in your BBB to a host computer using the mini usb data cable.

Go to My Computer>BeagleBone Getting Started> and open uEnv.txt Copy and paste this command into the .txt file. Make sure to save your changes. (Ctrl+s)

```
optargs=quiet drm.debug=7 capemgr.disable_partno=BB-BONELT-HDMI,BB-BONELT-HDMIN
capemgr.enable_partno=BB-SPI1-01
```

after you save the changes, reboot your beaglebone black
Make sure it is enabled You should now have two spidev-files in the folder /dev/

```
ls -al /dev/spidev1.*
```

The SPIDEV 1.0 folder should display.

10.3 Constructed Circuit