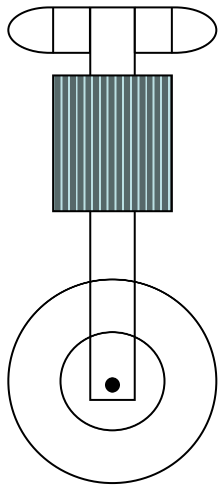
iSTAND – I can Stand

SPECIAL SENSOR REPORT



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For

EEL 5666 - Intelligent Machines Design Laboratory (Spring 2008)

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1.0 Introduction

iSTAND is a self balancing two wheeled robot based on the famous control system problem called as the Inverted Pendulum. It not only aims to balance itself and remain erect but also aims at going around wandering with obstacle avoidance like other naturally balanced mobile robots.

To do so it needs to keep track of certain parameters about itself and its environment and this is done by the sensors on it that act as its window to the outside. The parameters and the respective sensor being put on iSTAND are as follows.

1) Tilt Angle – ACCELEROMETER (special sensor)

2) Rate of change of Tilt Angle – GYRO (special sensor)

3) RPM of motor – ENCODER

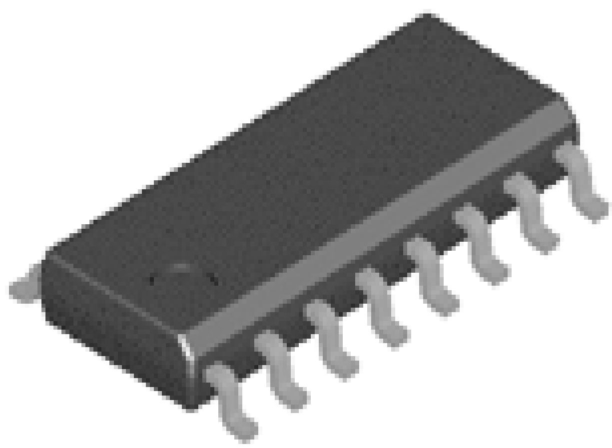
4) Torque delivered by the motor – CURRENT SENSOR in the MOTOR DRIVER

5) Obstacle Detection - SONAR

2.0 Tilt Angle – ACCELEROMETER

The accelerometer is a device that measures its static and dynamic acceleration along a particular axis fixed on it. Since, the acceleration due to gravity (g) is always acting downward and when ever there is a component of the acceleration due to gravity (g) acting along the accelerometer's sensing axis, it gets sensed by the accelerometer. Hence, when ever it is static the only acceleration subject onto it is a component of g. So measuring this component and comparing it with g, gives us the inclination or the tilt wrt vertical. Hence, It qualifies to be a tilt sensor.

I am using the FREE SCALE MMA1260EG which is a single axis (Z axis sensitivity) Low G (±1.5g) Micro machined Accelerometer. I got this IC as a free sample from www.freescale.com. It comes in a 16-lead SOIC SMD package.

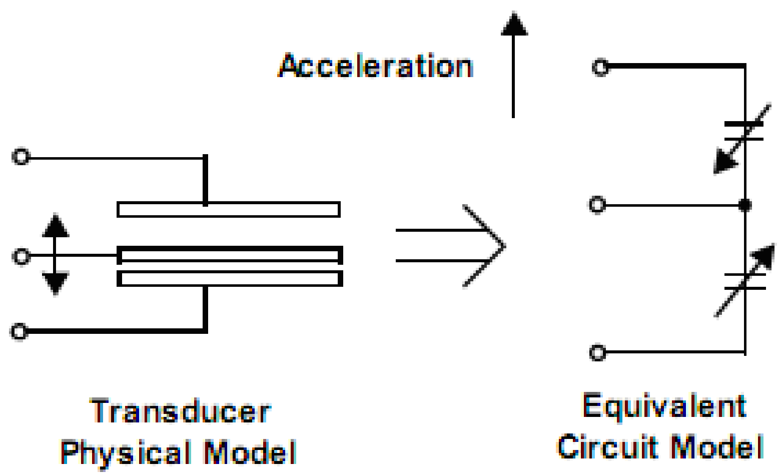


Some of its important features are:-

- Integral Signal Conditioning
- Linear Output
- 2nd Order Bessel Filter
- Calibrated Self-test
- EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shock Survivability

2.1 Principle of Operation

The device consists of a surface micro machined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The g-cell is a mechanical structure formed from semiconductor materials (poly silicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to acceleration. When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration. The g-cell plates form two back-to-back capacitors. As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

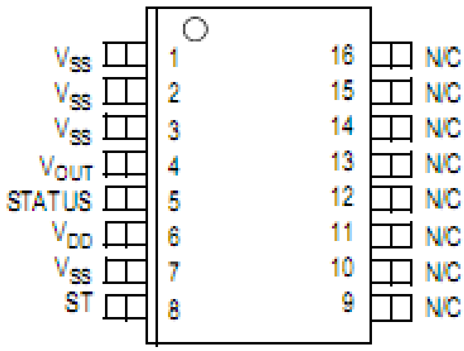


The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratio metric and proportional to acceleration.

Special Features in this IC are:

- **Filtering:** It has an onboard 2-pole switched capacitor filter. A Bessel implementation is used as it provides a flat delay response (linear phase) thus persevering the pulse shape.
- **Self-Test:** The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation.

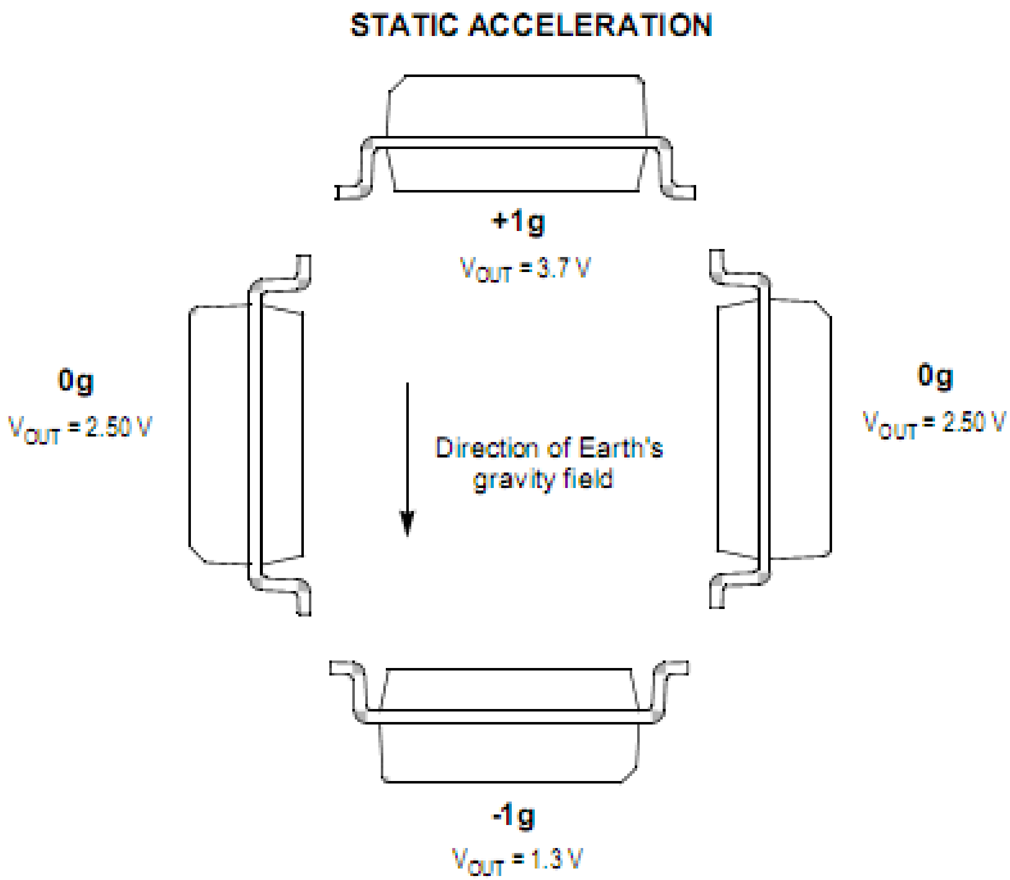
- **Status:** It includes fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high when the Parity of the EPROM becomes odd. The fault latch can be reset by a rising edge on the self-test input.

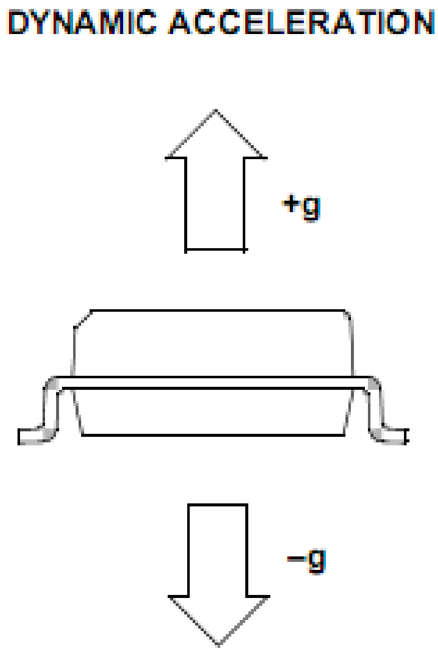


Pin Descriptions

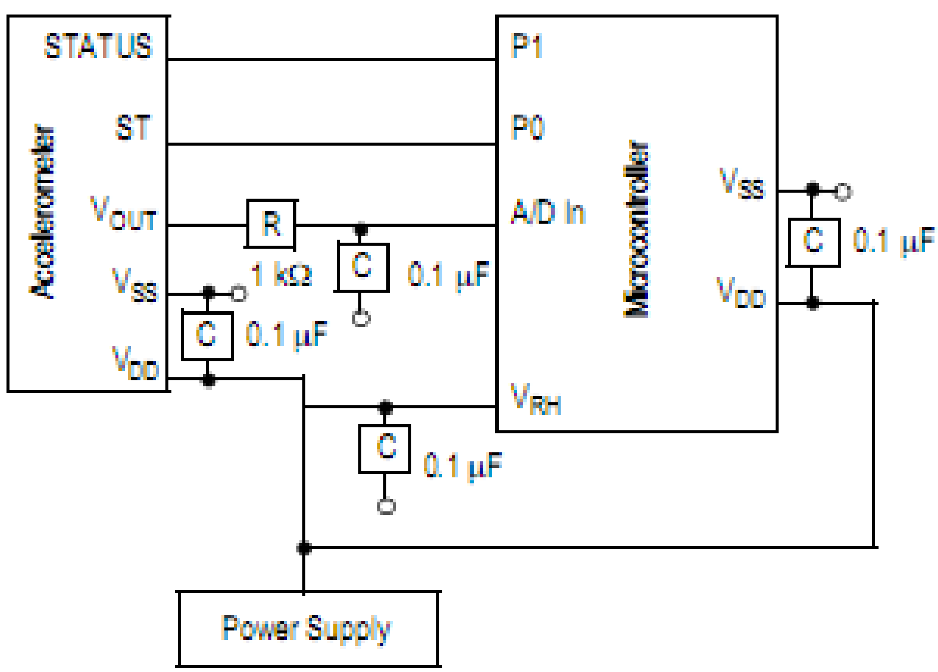
Pin No.	Pin Name	Description
1 thru 3	V_{SS}	Redundant connections to the internal V_{SS} and may be left unconnected.
4	V_{OUT}	Output voltage of the accelerometer.
5	STATUS	Logic output pin to indicate fault.
6	V_{DD}	The power supply input.
7	V_{SS}	The power supply ground.
8	ST	Logic input pin used to initiate self-test.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

2.2 Acceleration Sensing Directions:

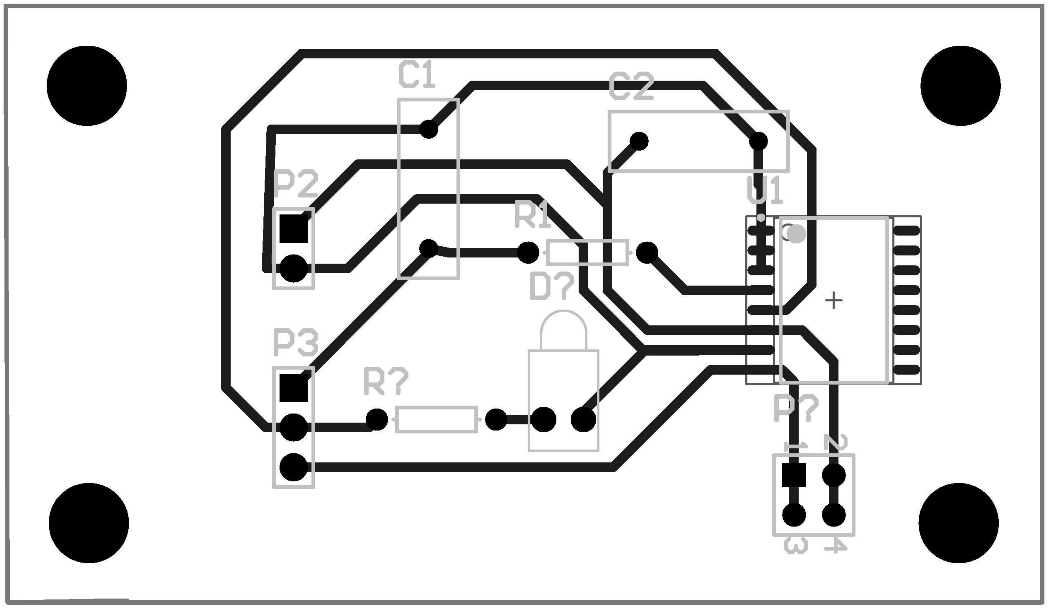


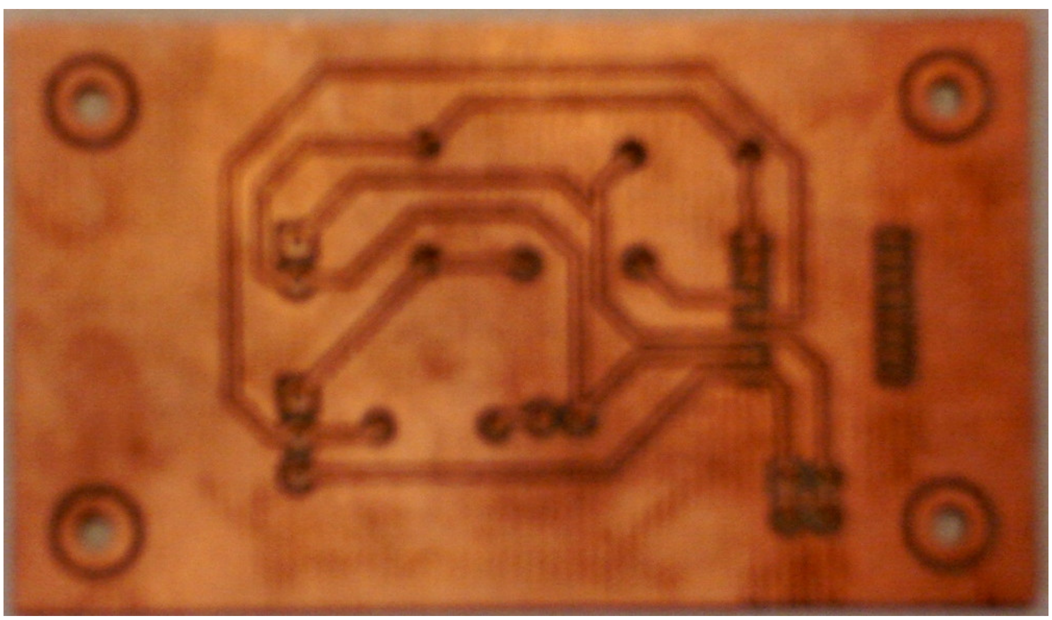


2.3 Interfacing to Microcontroller



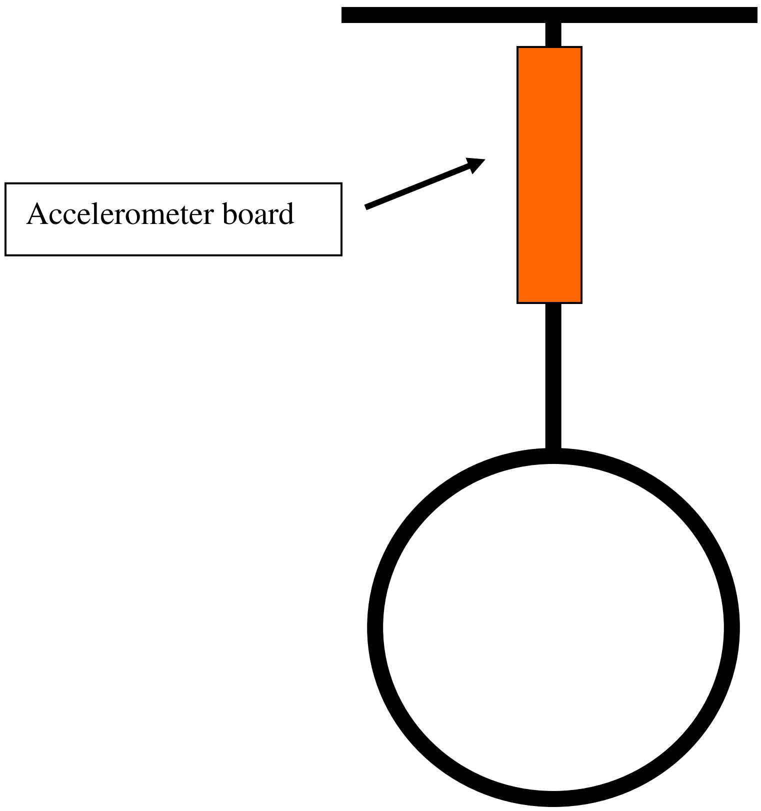
The 1K resistance and 0.1uF capacitor form a Low Pass filter was connected as shown to provide a delay and at the same time filter high frequency noise present in the analog voltage output before sending it to the A/D pin of the microcontroller. The PCB for this circuit was designed using ALTIUM Designer and then was cut out on copper board by help of the T-Tech Quick Circuit machine.





Unfortunately, there is an undesired result with the dynamic acceleration measurements. If the platform were to be to accelerate towards the ground (e.g. falling), the increase in acceleration appears at the accelerometer output. Hence, using the accelerometer alone as a tilt sensor is only effective if the platform is not accelerating. In addition, any vibrations that the motors create within the platform are also picked up by the accelerometer and cause noise in the output. To remedy this problem, another sensor is needed.

2.4 Position on the Robot body



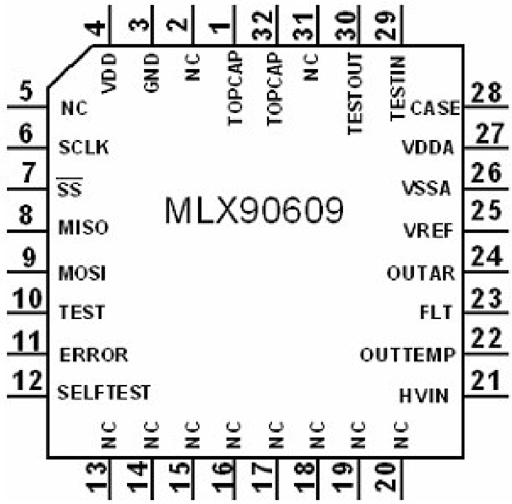
3.0 Rate of change of Tilt Angle – GYRO

A gyroscope is a device that measures angular rate/velocity. If the output of the gyro is integrated, the position of the platform can be determined. Ideally, the gyro can be used as a tilt sensor but there is an error introduced. Gyroscopes tend to drift over time and therefore report inaccurate information and the running integration of the output also introduces small errors. However, if the accelerometer and gyro were combined using a complementary filter, they would be able to help each other. The accelerometer would correct the drift of the gyro when the platform was not falling. The combination forms an **Inertial Reference sensor**.

I am using the MELEXIS MLX90609 which is a single axis (Z axis sensitivity) ANGULAR RATE SENSOR with a full scale range of +-75 deg/sec. I got this IC as a free sample from www.melexis.com. It comes in a CLCC32 SMD package.

Some of its important features are:-

- High resolution and dynamic range
- **Both digital (SPI) and analog outputs**
- Low acceleration and angular rate cross sensitivity
- Low zero rate output drift
- Cost effective and compact solution
- High-performance MEMS sensor in mono crystalline Si yielding a superior long term behavior reliability and dynamic range
- Programmable bandwidth
- Factory set full scale range
- On chip EEPROM calibration
- Operating temperature range: -40°C to 85°C



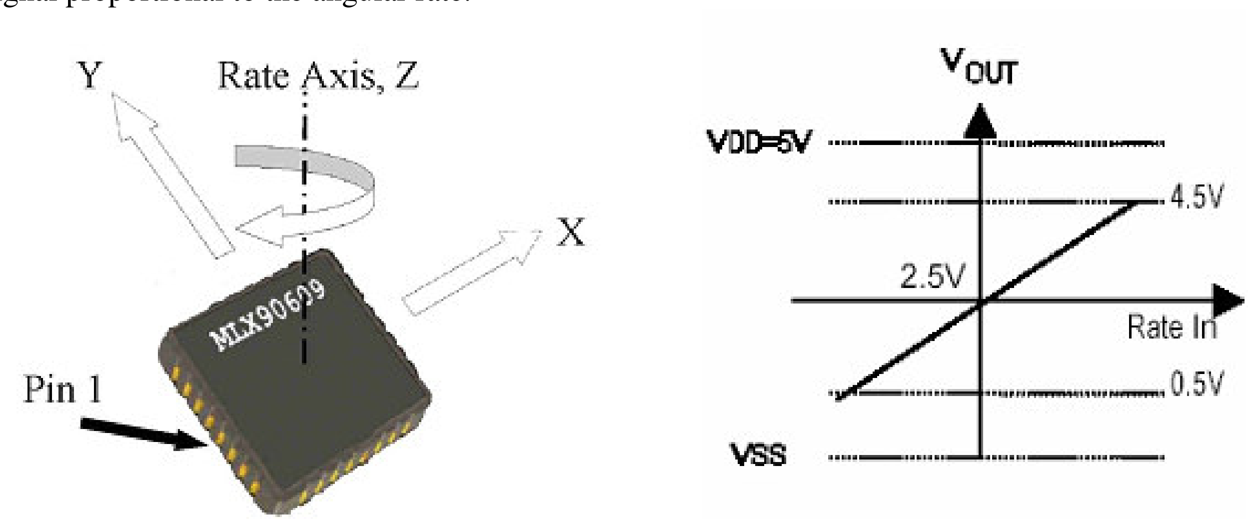
MLX90609 pin-out

Group	Pin Name	Function
Power Supply Pins	VSS	Digital ground 0V
	VDD	Digital 5V
	VDDA	Analog Supply 5V
	VSSA	Analog ground, 0V, externally tied to digital ground
Serial Communication Pins	SCLK	Clock for serial data transfer, In, digital
	MISO	Master In, Slave Out
	MOSI	Master Out, Slave In
	$\overline{SS}$	Slave/Chip select (active low)
Factory Test Pins	TEST	Test-mode control pin (internal pull-down, In application tight to ground for EMC reasons)
	TESTIN	In application tight to ground for EMC reasons
	TESTOUT	Do not connect
User Diagnostic Pins	SELFTEST	User on request self test input (for automotive applications)
	ERROR	Continuous self test output (for automotive applications)
Output Pins	OUTAR	Analog angular rate output
	OUTTEMP	Analog output of the temperature sensing module
General purpose pins	VREF	2.5V Output reference voltage
	HVIN	High voltage filter capacitor
	FLT	External capacitor for bandwidth setting
	TOPCAP	Tie to VSSA
	CASE	Tie to VSSA
	NC	Tie to VSSA
	FLT	External capacitor for bandwidth setting

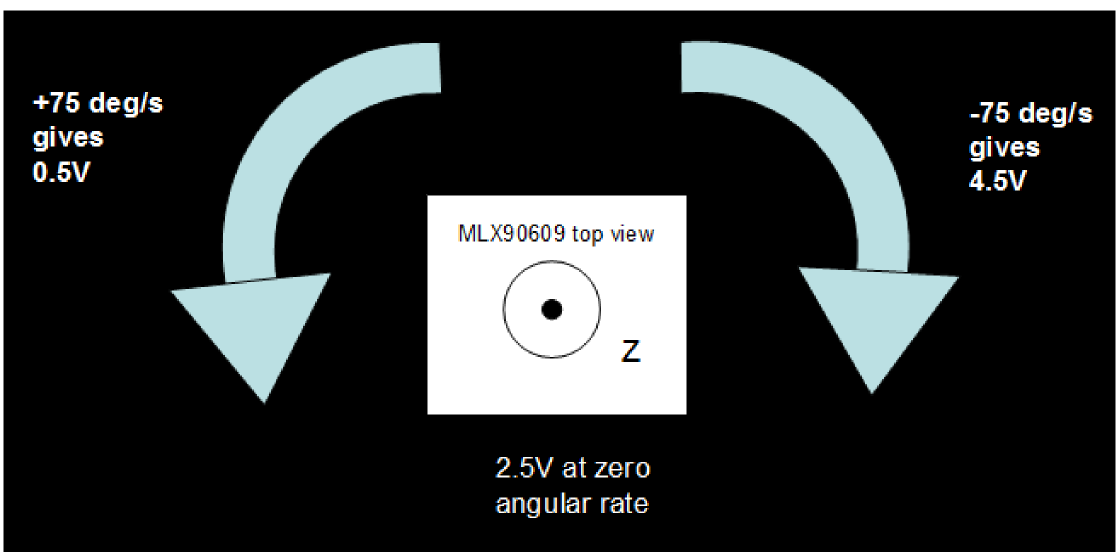
MLX90609 Pin description

3.1 Principle of Operation

The MLX90609 is a Z-axis rate-sensing device, also called yaw-rate sensing. It produces an analog positive going output voltage for clockwise (CW) rotation around the axis normal to the package top, i.e., clockwise when looking down at the package lid as well as a digital SPI signal proportional to the angular rate.



Angular rate (positive for clockwise rotation) to voltage output



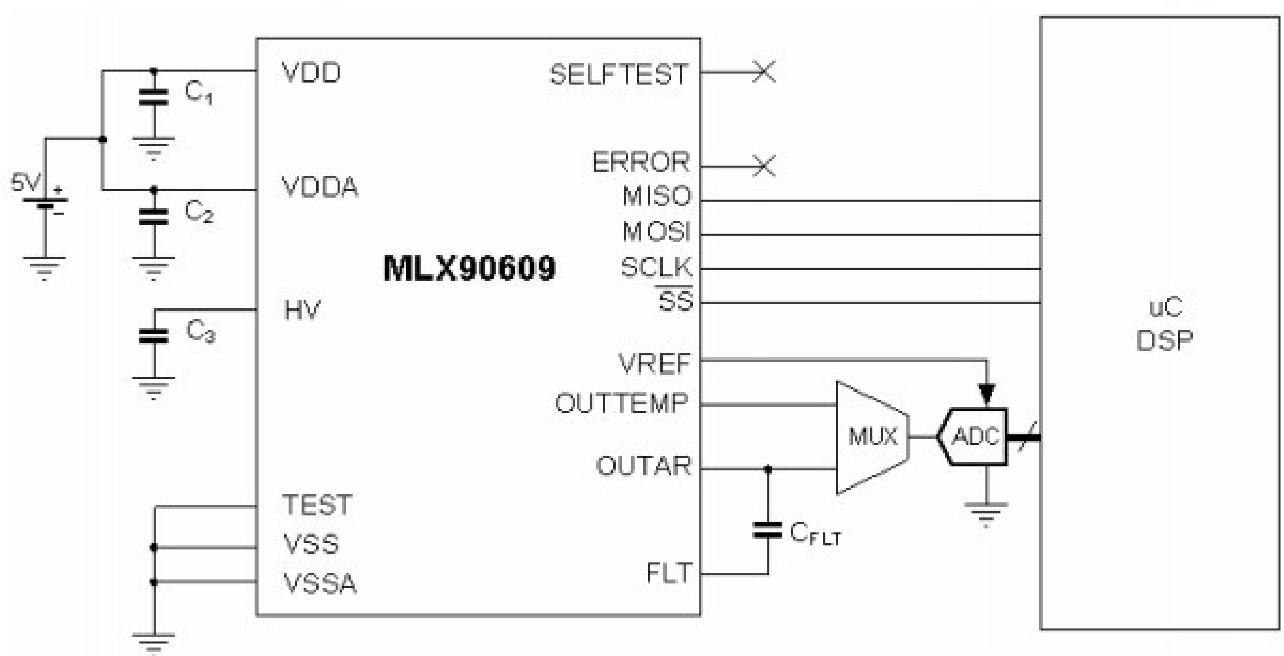
The sensor is a MEMS gyroscope sensitive to Coriolis forces. To create a Coriolis force a movement must be induced. The gyro has an actuated oscillating mechanical structure (primary mode). The Coriolis force creates a second oscillating movement when the gyroscope rotates (secondary mode). As Coriolis force is usually extremely weak the primary mode is driven into resonance to keep the mechanical noise level low for the signal bandwidth used and to have a good sensitivity. A capacitance change in the secondary mode is detected and transformed into an output voltage by the electronic interface circuitry. The electronic interface must convert a change in the sensor capacitance ΔC into a change in transducer output voltage VOUT according to the following transfer equation:

$$V_{OUT} = Bias + Gain * AngularRate$$

The bias and gain are adjustable over temperature in order to compensate for the TC of sensor and readout. After adjusting the bias and gain values and after setting operating mode switches during the calibration process the transducer output voltage versus angular rate must stay as shown in Figure above over the specified temperature range.

3.2 Interfacing to Microcontroller

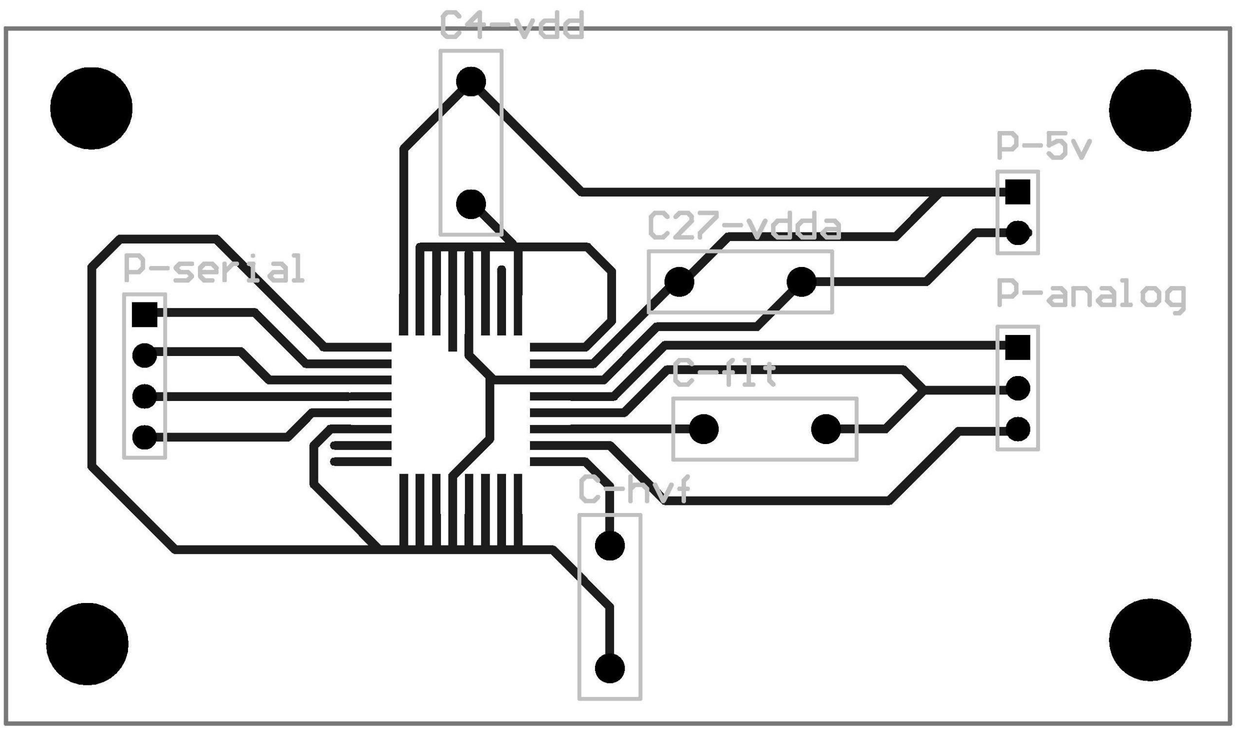
It gives output in two formats - an analog voltage output proportional to the angular rate and SPI digital output.

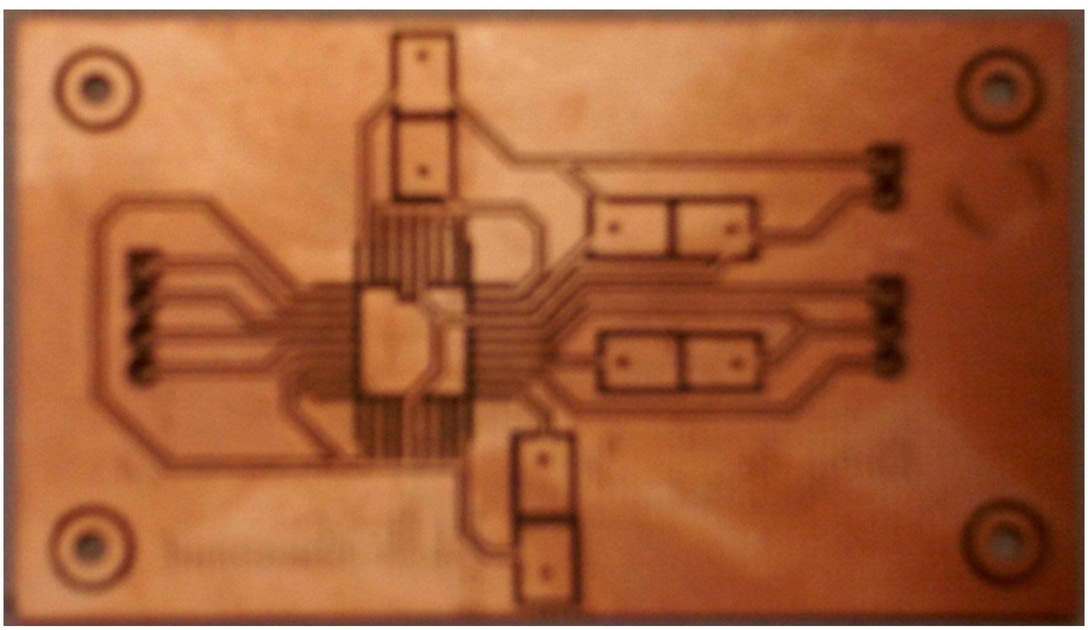


MLX90609 with simultaneous analog and digital output

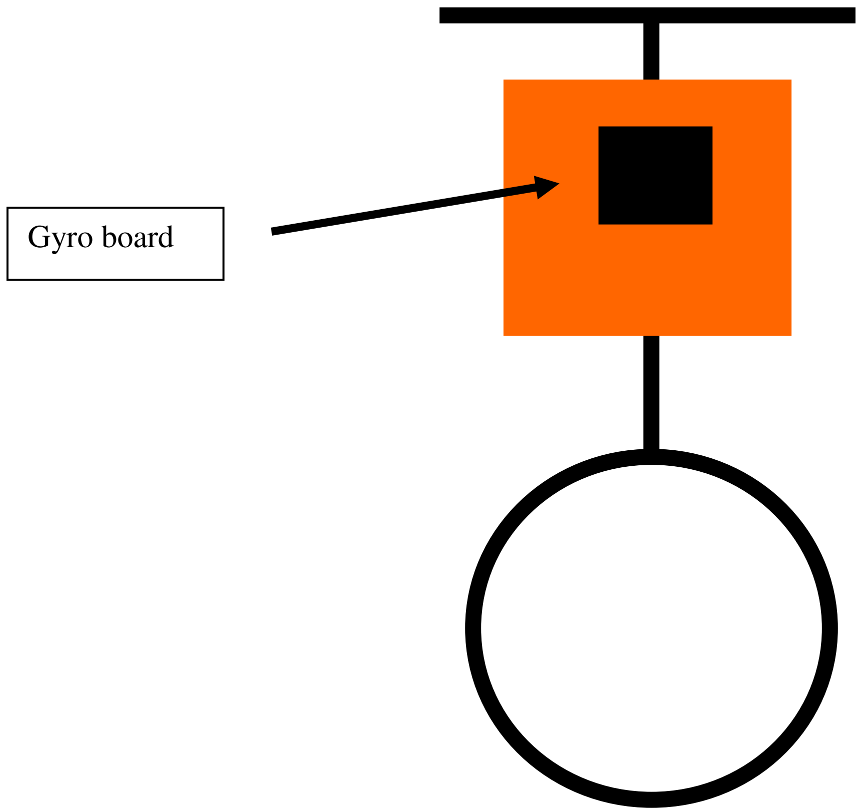
The MLX90609 can simultaneously output analog and digital signals. The analog output signal can be fed to a microcontroller (µC) that contains an analog-to-digital converter. A multiplexer can be used to select between the temperature and the angular rate signals. The MLX90609 generates an internal reference voltage used for supplying the ADC, thereby maintaining accuracy regardless of the supply voltage of the µC. As in diagram above, The Cflt implements a first order low pass filter cascaded with an internal 4-th order SC filter.

The PCB for this circuit was designed using ALTIUM Designer and then was cut out on copper board by help of the T-Tech Quick Circuit machine.


C4-vdd
P-5v
C27-vdda
P-serial
P-analog
C-flt
C-hvf



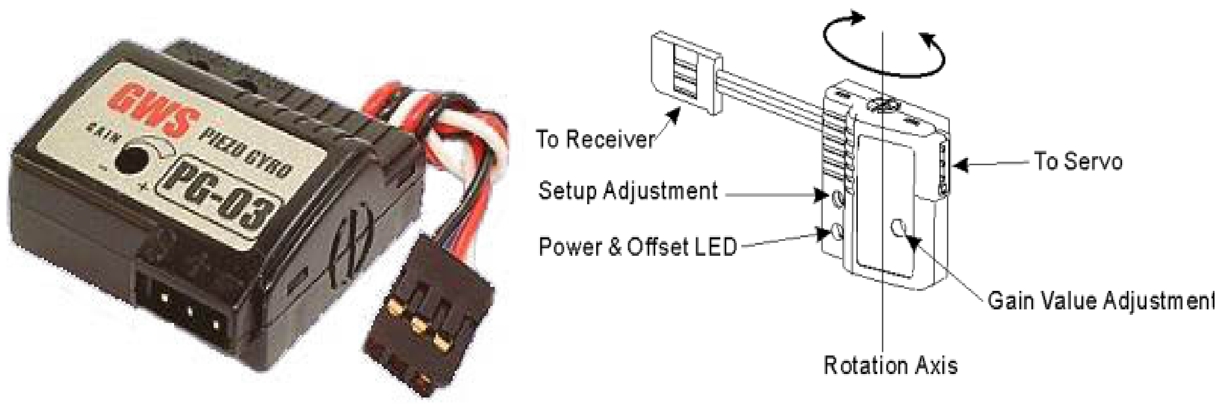
3.3 Position on the Robot body



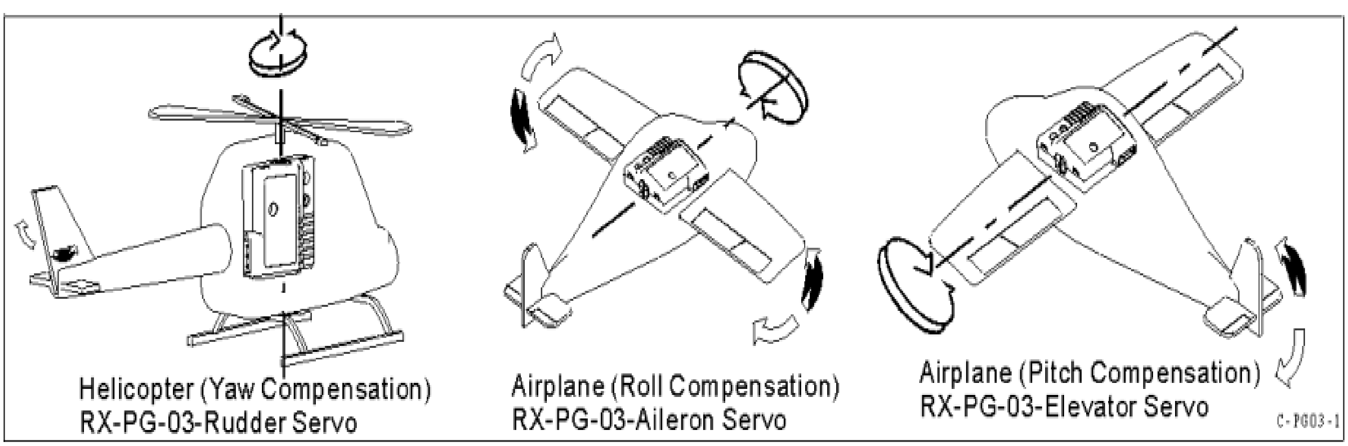
4.0 Rate of change of Tilt Angle – PIEZO GYRO (alternative)

Due to the soldering difficulties inherent with the MELEXIS MLX90609, I also explored on an alternative to it. It is the **GWS PG-03 SINGLE AXIS PIEZO GYRO** designed specifically for and popularly used in RC toys, planes, helicopters, boats, etc to provide stability. Although I won't be any more implementing this on the robot but I included some information about it in brief because I studied this and pursued it as an alternate option. This is also a single axis sensitive gyro as shown in the figure below.

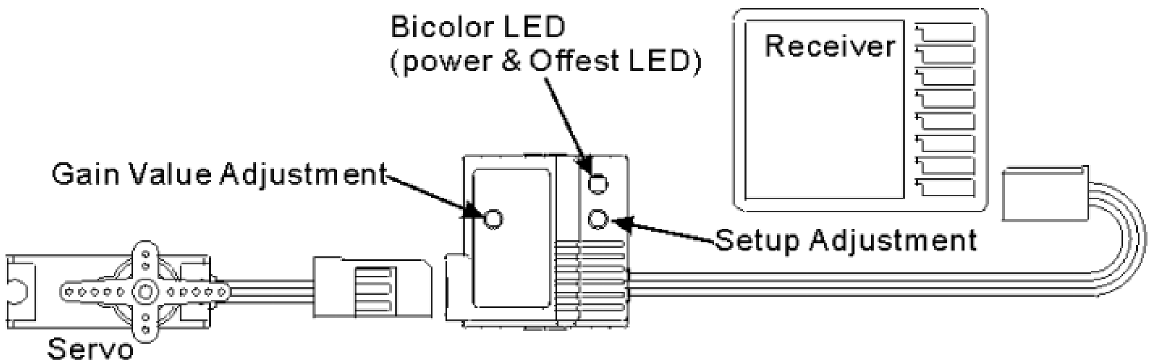
I bought it from www.junun.org for $35 (shipping $ 4.60).



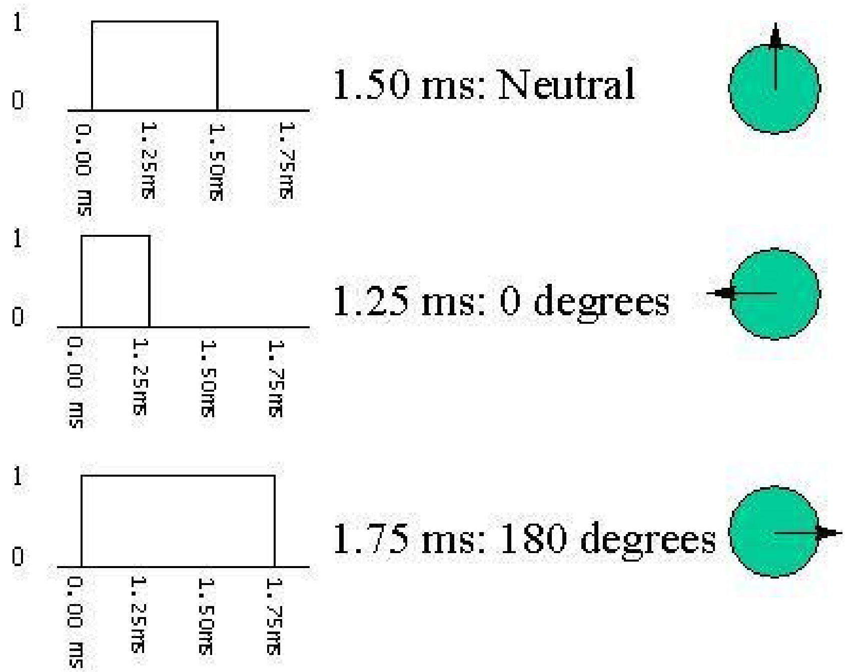
4.1 Typical Operation and my Experiments to measure angular rate



As shown in the diagram below typically it receives PWM signal (exactly same as the one given to drive a servo motor) from the RC receiver and in turn provides PWM signal output to a servo motor. The signal gets stabilized when sent to the servo thru this gyro rather than sent directly from the RC receiver.



I simulated the same using a signal generator to provide PWM signal that ensures neutral position in an un-hacked servo motor. The output was seen on a CRO, it gave exactly the same PWM signal as output after doing the setup adjustment. But under such a condition if the Gyro is given a angular rate about its rotation axis in one direction, the pulse widths in the output started decreasing like the PWM signal that causes the servo to move to 0 degree position and when given an angular rate about its rotation axis in the other direction the pulse width in the output started decreasing like the PWM signal that causes the servo to move to 180 degree position.



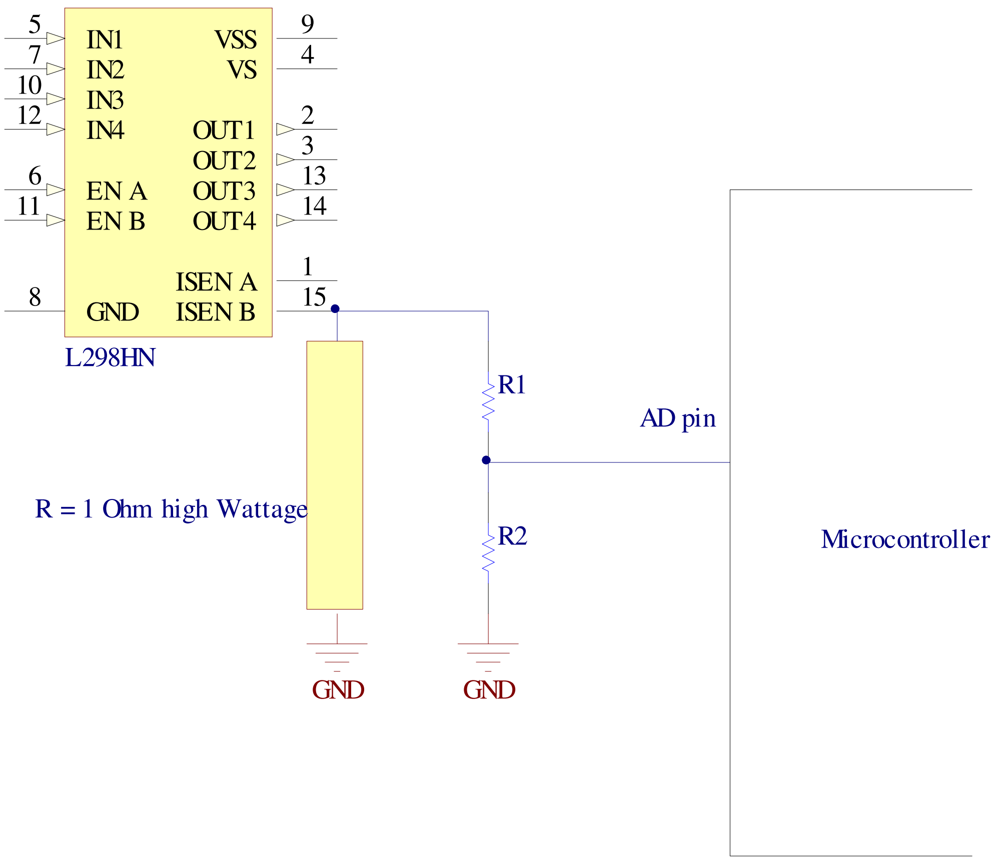
Hence, I concluded that if a standard PWM signal (neutral) is given as an input to this gyro using a 555 timer or the microcontroller, then the output contains pulses whose width indicates the angular rate of the gyro and hence, of the body on which it is mounted. This pulse width can be easily read by the microcontroller to determine the angular rate.

5.0 RPM of motor – ENCODERS

The motor that I am using for my robot has inbuilt dual channel optical encoders that can be used as incremental encoder to measure the RPM of motor. They keep sending output in form of pulses and the number of pulses per sec determines the speed of rotation of the motor shaft.

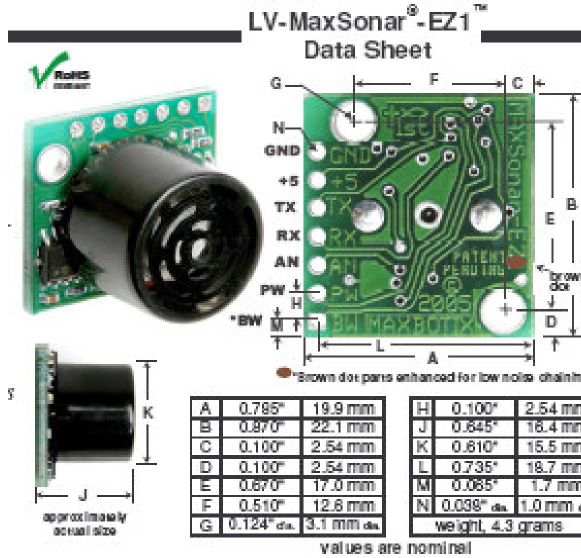
6.0 Torque delivered by the motor – CURRENT SENSOR on the MOTOR DRIVER IC

I am using the STmicroelectronics L298HN which is a dual full bridge driver to drive the DC motors on the Robot. The current passing through the motor driver is same as the current flowing through the motor. Normally, the current sense pin on the L298 and ground are shorted. But by connecting a high wattage low resistance between the current sense pin on the L298 and ground, we can cause a small voltage drop which is proportional to the current. This voltage can then be scaled down using a voltage divider circuit and fed to the ADC on the microcontroller. As we know that the torque delivered by a motor is proportional to the current flowing through its windings, the torque can thus be sensed.



7.0 Obstacle Detection – SONAR

SONAR or the Ultrasonic Range Finder called the LV-MaxSonar- EZ1 manufactured by www.maxbotix.com is being used for this. This has some merits over other competitive SONAR Sensors like the Devantech SRF05 and the Parallax PING. It uses only one transducer to Transmit as well as receive the Echo. Hence, the board size is smaller and power consumption is lesser.



A	0.785"	19.9 mm
B	0.870"	22.1 mm
C	0.100"	2.54 mm
D	0.100"	2.54 mm
E	0.670"	17.0 mm
F	0.510"	12.6 mm
G	0.124" dia.	3.1 mm dia.

H	0.100"	2.54 mm
J	0.645"	16.4 mm
K	0.610"	15.5 mm
L	0.735"	18.7 mm
M	0.065"	1.7 mm
N	0.039" dia.	1.0 mm dia.
weight, 4.3 grams		

values are nominal

Features

- Continuously variable gain for beam control and side lobe suppression
- Object detection includes zero range objects
- 2.5V to 5.5V supply with 2mA typical current draw
- Readings can occur up to every 50mS, (20-Hz rate)
- Free run operation can continually measure and output range information
- Triggered operation provides the range reading as desired
- All interfaces are active simultaneously
  - Serial, 0 to Vcc
    - 9600Baud, 81N
  - Analog, (Vcc/512) / inch
  - Pulse width, (147uS/inch)
- Learns ringdown pattern when commanded to start ranging
- Designed for protected indoor environments
- Sensor operates at 42KHz
- High output square wave sensor drive (double Vcc)

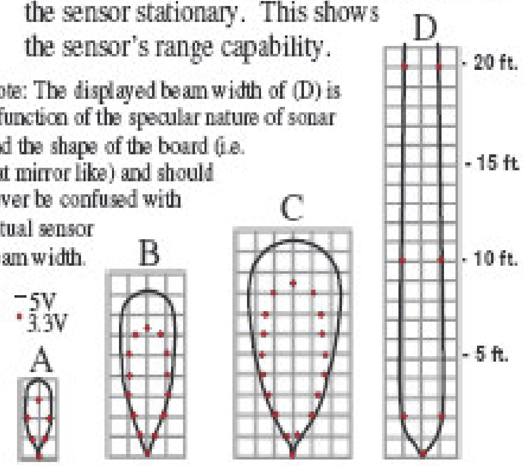
Benefits

- Very low cost sonar ranger
- Reliable and stable range data
- Sensor dead zone virtually gone
- Lowest power ranger
- Quality beam characteristics
- Mounting holes provided on the circuit board
- Very low power ranger, excellent for multiple sensor or battery based systems
- Can be triggered externally or internally
- Sensor reports the range reading directly, frees up user processor
- Fast measurement cycle
- User can choose any of the three sensor outputs

Beam Characteristics

People detection requires high sensitivity, yet a narrow beam angle requires low sensitivity. The LV-MaxSonar®-EZ1™ balances the detection of people with a narrow beam width.
Sample results for measured beam patterns are shown below on a 12-inch grid. The detection pattern is shown for;
(A) 0.25-inch diameter dowel, note the narrow beam for close small objects,
(B) 1-inch diameter dowel, note the long narrow detection pattern,
(C) 3.25-inch diameter rod, note the long controlled detection pattern,
(D) 11-inch wide board moved left to right with the board parallel to the front sensor face and the sensor stationary. This shows the sensor's range capability.

Note: The displayed beam width of (D) is a function of the specular nature of sonar and the shape of the board (i.e. flat mirror like) and should never be confused with actual sensor beam width.



beam characteristics are approximate