2009 ENME480 – Rocket Systems Engineering

Inertial Measurement Unit (IMU) Proposal

Introduction

An Inertial Measurement Unit (IMU) is to be designed for the control of the model rocket. Key features are that it is fully featured (can measure angular rates and accelerations in each X, Y, and Z axis), produces reliable and accurate measurements, and is relatively cheap compared to comparable commercial units.

Research

Off the shelf IMUs can be purchased, but are typically expensive and would be too costly considering the relatively low project budget.

One source of IMU systems aimed at hobbyists are those sold by Sparkfun. These range between $125USD to $450USD, with the lower end having three gyros and three accelerometers while the upper end having these and also Bluetooth and magnetic sensors. However, none of these IMU modules are suited to the project, as the Z axis sensors are not adequately rated. They also use cheaper sensors, which have a low bandwidth. The issue of sensor bandwidth is mentioned later on.

The successful rocket 'Pike' produced by the 'Chimaera Hybrid Rocketry' group from the Utah State University used the Microstrain 3DM-GX2 attitude heading reference system (AHRS). This is a high performance solution, which can be purchased online for around $1700USD. Clearly purchasing this unit is well out of the question.

Even though the 3DM-GX2 unit is not a viable option, it is a prime example of a suitable IMU system. The 3DM-GX2 appears to be customizable when bought straight from Microstrain, and contains three gyros, three accelerometers, and a three axis magnetometer. Each gyro/accelerometer sensor is sampled by a separate 16-bit ADC so that each sensor can be read simultaneously. It contains a variety of interfaces such as RS-232, USB and wireless. The company does not appear to release specific details about the exact sensors that are used in their AHRS unit.

In AHRS systems such as 3DM-GX2 the lateral heading measurement is important. In addition to measurements taken from rate gyros and accelerometers, other sensors are used including GPS and a magnetometer to improve the accuracy of the measurements.

Design

Since the lateral heading of the rocket was not overly important, the magnetometer was deemed redundant. Furthermore, magnetometers typically have very low update rates (similar to GPS units). Clearly this sensor will not be of much use during the first two seconds of the rocket's flight – where the IMU data is most valuable to the control of the rocket.

The sensors used in the proposed IMU design are as follows:

- ADXL320 – ±5g X-Y axis Analog Accelerometer
- ADXL321 – ±18g Z axis Analog Accelerometer
- ADXRS610 – ±300°/s X axis Analog Accelerometer
- ADXRS610 – ±300°/s Y axis Analog Gyro
- ADXRS610 – ±300°/s Z axis Analog Gyro

Note that the Z axis gyro has surrounding circuitry that will allow the increase of the dynamic range, at the expense of decreased sensitivity and increased gyro drift. Refer to the attached schematic.

The reasoning for selecting these sensors is as follows:

- The acceleration in the Z axis would be significantly higher (10g) than that in the X-Y plane, so a higher range accelerometer was chosen.
- The roll rate in the Z axis for rockets can be quite high (12Hz, i.e. 4320°/s). A sensor setup for this axis was selected such that the user was able to change the dynamic range of the gyro.
- Less expensive gyros were considered (such as the IDG500 and IXZ650 from InvenSense) however these analog gyros had an internal LPF which limited the bandwidth to 100Hz.
- The bandwidth of each of these proposed sensors is up to 2500Hz, which is more than adequate.
- Sensors are available that have a digital interface (such as SPI and/or I2C) however these typically incorporate a less precise ADC unit and have a bandwidth too low for the task.

Other key features of the proposed IMU system include:

- Highly precise and fast measurement of all the analog sensor signals provided by an ADS8345EB 16-bit 100kSPS 8 Channel ADC.
- Provision for temperature control of the sensors, by thermally coupling all the sensors via a single heat-sink heated by a resistive element. This is to remove the effect of sensor output temperature dependence.
- On-board microcontroller provides a means of checking the current temperature, changing the temperature regulation point, and also instigating sensor self-checking functions.
- Use of tightly line regulated low drop-out linear voltage regulators. This is important as all the accelerometer and gyro sensors are ratiometric, i.e. their analog output depends on the input/reference voltage.

The proposed IMU can be interfaced to as follows:

- Sensor readings will be accessible via a Serial Peripheral Interface (SPI) bus. This can be run at a very high speed, so a high system bandwidth may be obtained. Note that the sampling rate of the ADC is dictated by the speed of the SPI bus.
- An Inner-Integrated-Circuit (I2C) bus is used to connect to the on-board microcontroller to check sensor temperature, set desired regulation temperature, and also to instigate sensor self-checking functions.

Current Issues – Sensor Bandwidth

Note that the schematic attached does not specify the bandwidth of the sensors (provided by an external resistor-capacitor low pass filter (LPF)). This is the case as a decision has not been reached as what the bandwidth of the system should be.

Having a higher sensor bandwidth will mean the system will be able to be meaningfully sampled faster, so as a system it may respond faster. However a higher sensor bandwidth also introduces more sensor noise into the readings.

As the required sensing bandwidth has yet to be determined, and probably would not be adequately determined until more thorough modelling is carried out. Meanwhile a cunning way around this problem is as follows:

1. The sensors have a user selectable (via a LPF) bandwidth up to 2500Hz. It is unlikely that the actuation surfaces will be able to react anywhere near this frequency, so select capacitors to limit sensor bandwidth to, say, 1000Hz.
2. It is likely that 1000Hz is still well above the response frequency of the actuation surfaces, but dead reckoning using IMU data to estimate altitude will benefit from a high update rate.
3. 1000Hz is still a relatively high bandwidth, and thus it is likely these readings will contain high levels of sensor noise. Before this data is used, it could be passed through a digital LPF implementation running on the embedded computer. The advantage of a digital filter is that its knee frequency can be actively changed, and also this frequency is not affected by temperature variations.
4. Higher order digital filters can also be trialled without the time consuming process of changing the hardware.

Conclusion

The proposed IMU adequately satisfies the key features that are required of it. These include having a fully featured unit (6 D.O.F), capable of producing reliable and quick measurements, and also is relatively cheap compared to a similarly featured commercial unit.

It is envisaged that the proposed IMU can be built for around $260USD using breakout boards and components from Sparkfun and Farnell. It can also be made even cheaper – by buying the discrete sensor chips from Digikey and producing breakout boards for them the setup can be built for around $176USD.

Building the IMU from discrete sensor chips is possible, and in addition to the lower cost it will also allow more customization, i.e. the breakout boards can be designed large enough to have mounting holes (the ones from Sparkfun do not have adequate space for drilling mounting holes).

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X Gyro 300 degree/s Breakout
Current Bandwidth: XX Hz
Y Gyro 300 degree/s Breakout
Current Bandwidth: XX Hz
Z Accelerometer 18G Breakout
Current Bandwidth: XX Hz
ADC 16 bit 100kSPS
Z Gyro 300 degree/s
Bandwidth: F = 1 / (2 * Pi * 200K * C)
Current Bandwidth: XX Hz
XY Accelerometer 5G
Bandwidth: F = 1 / (2 * Pi * 32K * C)
Current Bandwidth: XX Hz
ATMega8 @ 8MHz Internal Osc
3V Analog Regulator 100mA
Line Regulation: < 0.1%
3V Analog Regulator 100mA
Line Regulation: < 0.1%
5V Regulator 100mA
Line Regulation: < 0.1%
Notes:
1. VCC must be greater than 6V, but less than 10V
2. All sensors will be thermally connected via a heat sink
3. The temperature of the heatsink will be heated by a resistive heating element
4. The accelerometers may be operated at 5V, but are specified for 3V
5. Interface connectors will be 0.1" pitch and have a snap lock
Z Gyro Rate Modifications:
1. Installing RZ1 will increase gyro range to 1200 deg/s
2. Installing RZ2 and removing C14, C15, C16 increases gyro to 11000 deg/s
3. Combining 1. and 2. will further increase rate to ~ 50000 deg/s
4. Performing 1. increases gyro drift as much as 2 deg/s over temperature range
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File: F:\Robert Tang\..\imu.SchDoc
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Drawn By: Robert CS Tang