Where Am I? Development of a Gyroscope-Free Inertial Measurement System

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Introduction and Background

- Imagine that you had an airplane, submarine, or guided missile. You need to know exactly where your vehicle is and which way it is pointing. GPS is much too slow and not accurate enough.

  You need something better.

- Engineers have turned to inertial measurements to fix this problem. By measuring the linear and angular accelerations of the vehicle, we can use integration to compute the change in position and orientation of the vehicle.

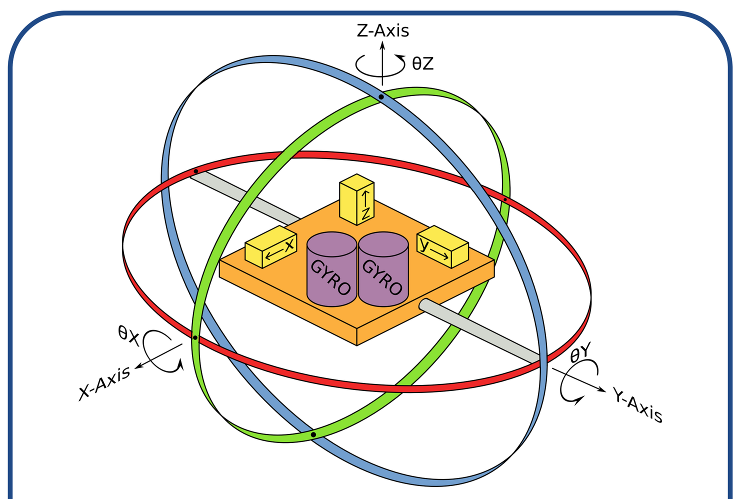

Figure 1: Gimbal Platform

- Measuring linear acceleration is straightforward, but measuring the angular acceleration is more difficult. In the past, a gyroscope-stabilized gimbal platform was used (see Figure 1), but this is a heavy mechanical device and has problems with maintainence and wear, as well as weight and expense. Micro-electromechanical systems (MEMS) gyrometers are very expensive, especially when compared to MEMS accelerometers.

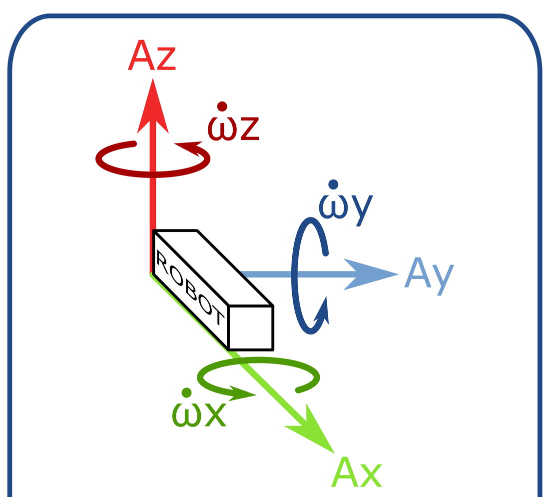

Figure 2: 6 Degrees of Freedom

- If we could devise a way to use only inexpensive linear accelerometers, this would produce a replacement for the gyroscope that would weigh considerably less and would not be mechanical.

  Are Linear Accelerometers the Answer?

- Our goal is to create a device to measure all six degrees-of-freedom belonging to a three-dimensional object. There are three linear acclerations and three angular accelerations, for a total of six accelerations (see Figure 2, left).

How can we measure all linear and angular accelerations using only linear accelerometers?

Proposed Solution

Use extra accelerometers to measure the angular accelerations.

- We can demonstrate these ideas using overhead views of a two-wheeled robot.
- If we simply used one accelerometer to try and measure all six degrees of freedom, we would not notice any vehicle rotations that were rotating around the accelerometer, as shown in Figure 3, at right.

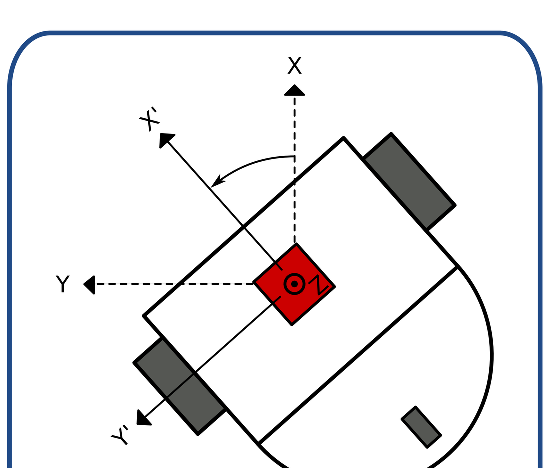

Figure 3: Unobservable Rotation

- To measure these rotations about the accelerometer, we can add another sensor, located at another location on the vehicle. This way, even if the vehicle rotates around one of the accelerometers, the other will still be moving, and the rotation will be noticed by the inertial measurement system. See Figure 4, below.

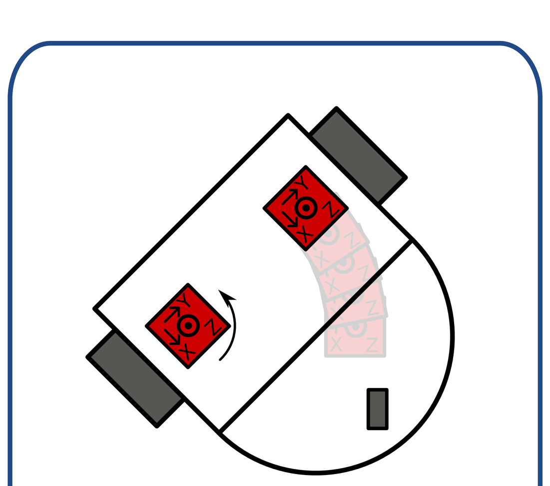

Figure 4: Rotation with 2 Accel.

- We can further extend this idea to all three dimensions by adding a third accelerometer unit. If we ensure that all three sensors are not co-linear, then we will always be able to detect any vehicle rotations.

We will constuct a data-logging system using three accelerometer units.

Implementation

- We have constructed a data-logging system using three, triple-axis accelerometers, an SD flash memory card, and a PIC18F4520 micro-controller from Microchip.

  How often do we need to sample the data?

- We have chosen to use a 50 Hz sampling rate for each sample set. Since each sample set consists of nine analog-to-digital conversions, we need to perform a single conversion at a rate of 450 Hz, or once every 2.22ms.
- A 768-byte circular buffer is used to store the sampled accelerations before writing them to the SD card. Writes to the card must be in blocks of 512 bytes, so we must wait for at least that many bytes to accumulate before writing data to SD.

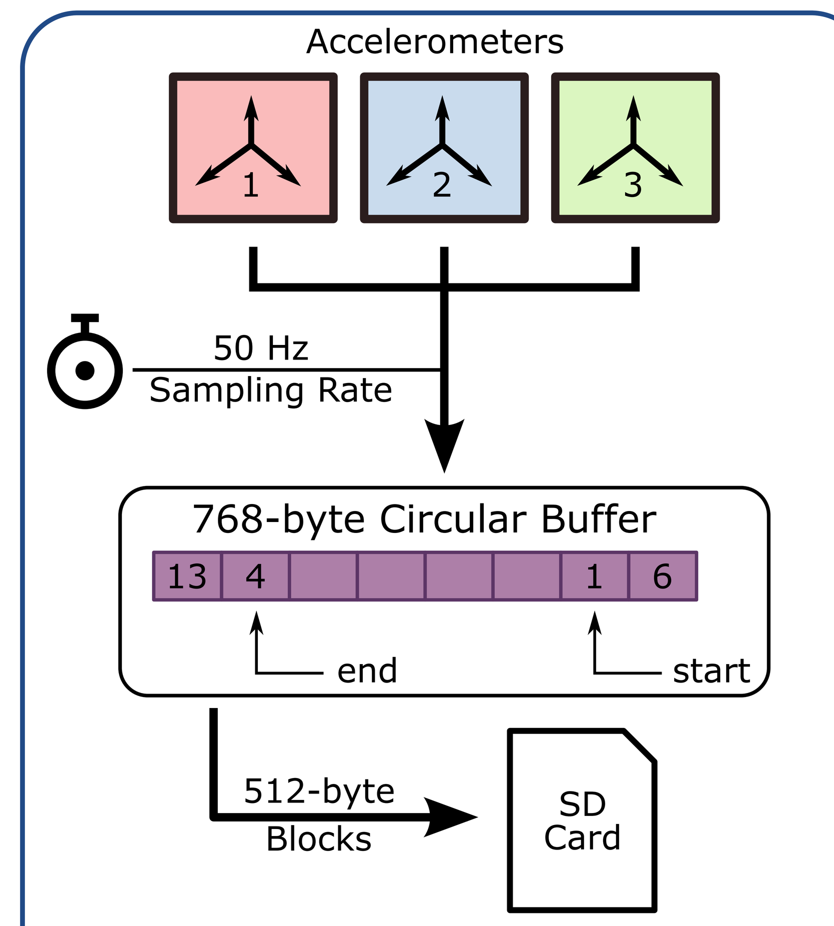

Figure 5: Program Block Diagram

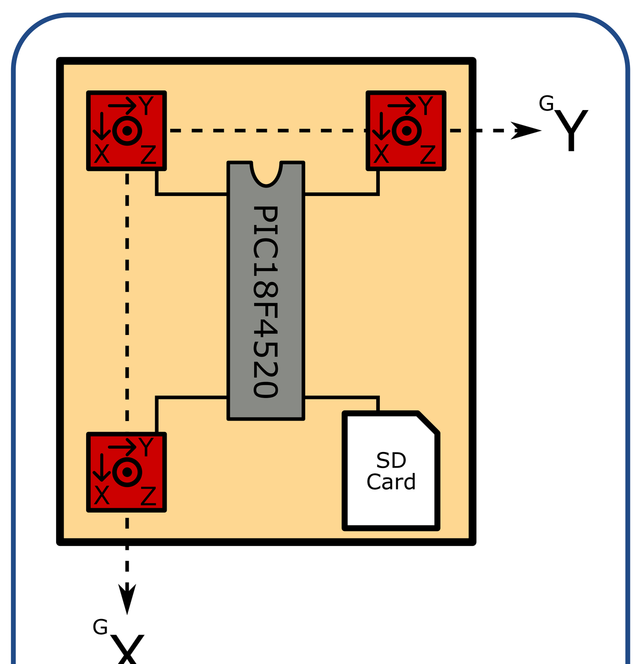

Figure 6: Board Layout

- To simplify the relationship between the individual accelerometer's coordinate-frame and the vehicle's coordinate-frame, we have decided to mount the sensors according to the scheme presented in Figure 6 at left.

  How much storage space is required to record data?

- The sampled accelerations are 10-bit values, meaning that each sample set is 18 bytes. If we sample 50 sets per second, we are creating 950 bytes per second. For an hour's worth of recording, we require 3.24 MB. The 1 giB SD card used in testing can record data for over 13 days! For more information regarding the amount of data generated for a variety of time scales, please see the data table.

How accurate are the sensors?

- During initial work with accelerometers accuracy, we carefully aligned the sensor packages with the earth's gravity. We took readings over a lengthy time and found each of the nine sensor's output for 1 gravity worth of acceleration. These measurements are presented in the results section below.

Data Storage Requirements

Time	Bytes
Second	950
Hour	3.24 miB
Day	78.27 miB
Year	27.90 giB

Results

- After recording the sampled accelerations, the remaining task is to create computer software to parse, analyze, and display the data. We will be using the Extended Kalman Filter to estimate the state of the dynamic system, despite the noisy measurements received from each of the accelerometers.
- Preliminary measurements of the accelerometer's output values when subjected to standard Earth gravity are included in the table. To increase the accuracy of these measurements, we are constructing a turntable-like device capable of producing a controlled acceleration on the sensors, which will then be compared to the measured acceleration.

Accelerometer Sensitivites (mv/g)

Sensor	Value
A1-X	305.73
A1-Y	386.52
A1-Z	180.59
A2-X	326.24
A2-Y	419.69
A2-Z	213.59
A3-X	348.49
A3-Y	344.20
A3-Z	220.08

What is planned for future development?

- First and foremost is a complete characterization of the accelerometer accuracy. Following that will be the completion of the PC software to analyze the sensor data.