Alan Kilian Summer 2011

Design and construct an absolute heading sensor for a mobile robot.

Introduction:

This project is intended as a demonstration of my skills in three specific areas:

1. Evaluating sensor design principals.
2. Implementing sensors.
3. Testing sensors.

For this report, I will use a robot I created in earlier projects called Trippy as a base to test various heading sensor designs. I will explain the design choices I made and the results of those decisions.

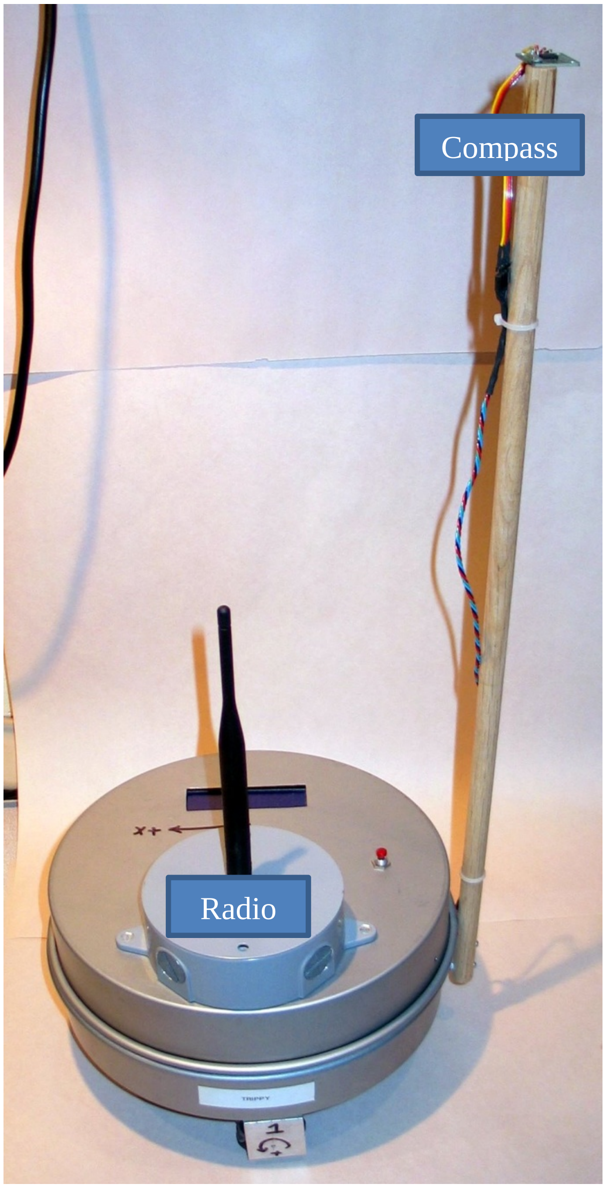


Figure 1 Trippy overview diagram

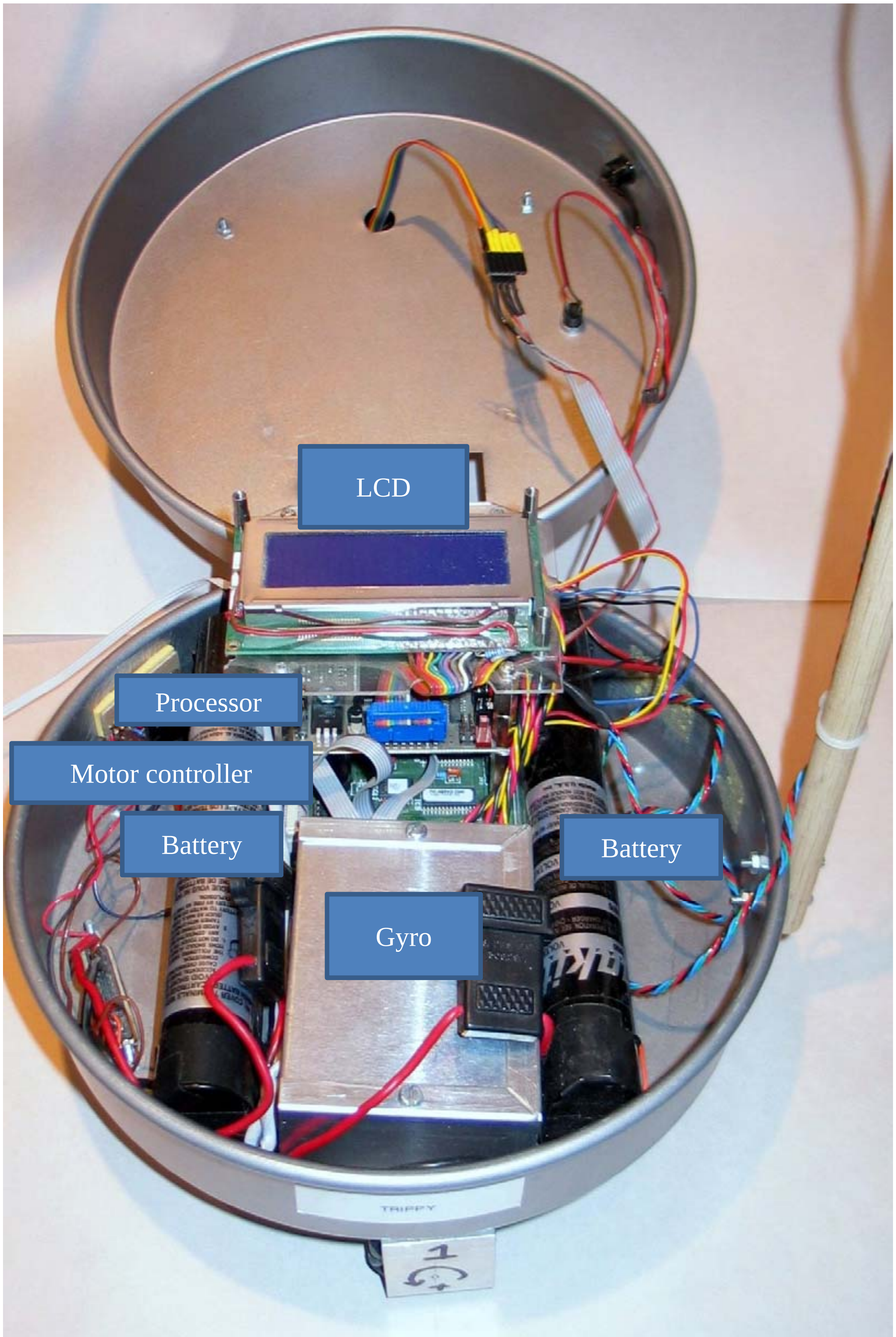


Figure 2 Trippy detailed diagram

Demonstrate understanding of the design principles and mechanics of an absolute heading sensor for a mobile robot.

In order to determine the heading of the robot I decided to use a geomagnetic compass unit which was available for $25. This sensor consisted of a magnet free to rotate on a vertical shaft similar to a compass used for camping. The sensor incorporated two hall-effect sensors to determine the position of the magnet relative to the outer package.

It was quite straightforward to read these two hall-effect sensors and to calculate the heading of the robot however; the sensor had a characteristic which made it unsuitable for this application.

In order to prevent the rotating magnet from moving around under conditions of vibration, the manufacturer immersed it in a cell containing a viscous oil to dampen any movement caused by high frequency vibrations.

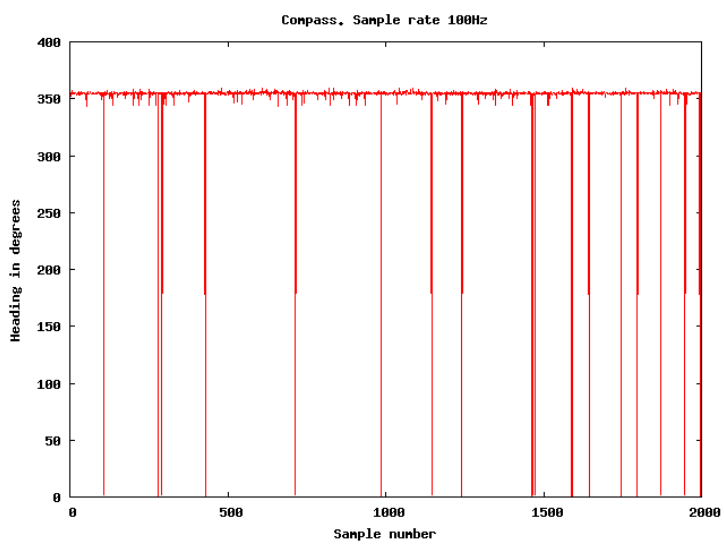
This caused the measured heading to lag behind the actual heading by as much as 15 seconds for a 90-degree change in heading.

This lag in measurement meant that the maximum rate of turn of the robot would be on the order of 1 rotation per minute with an error of 6 degrees.

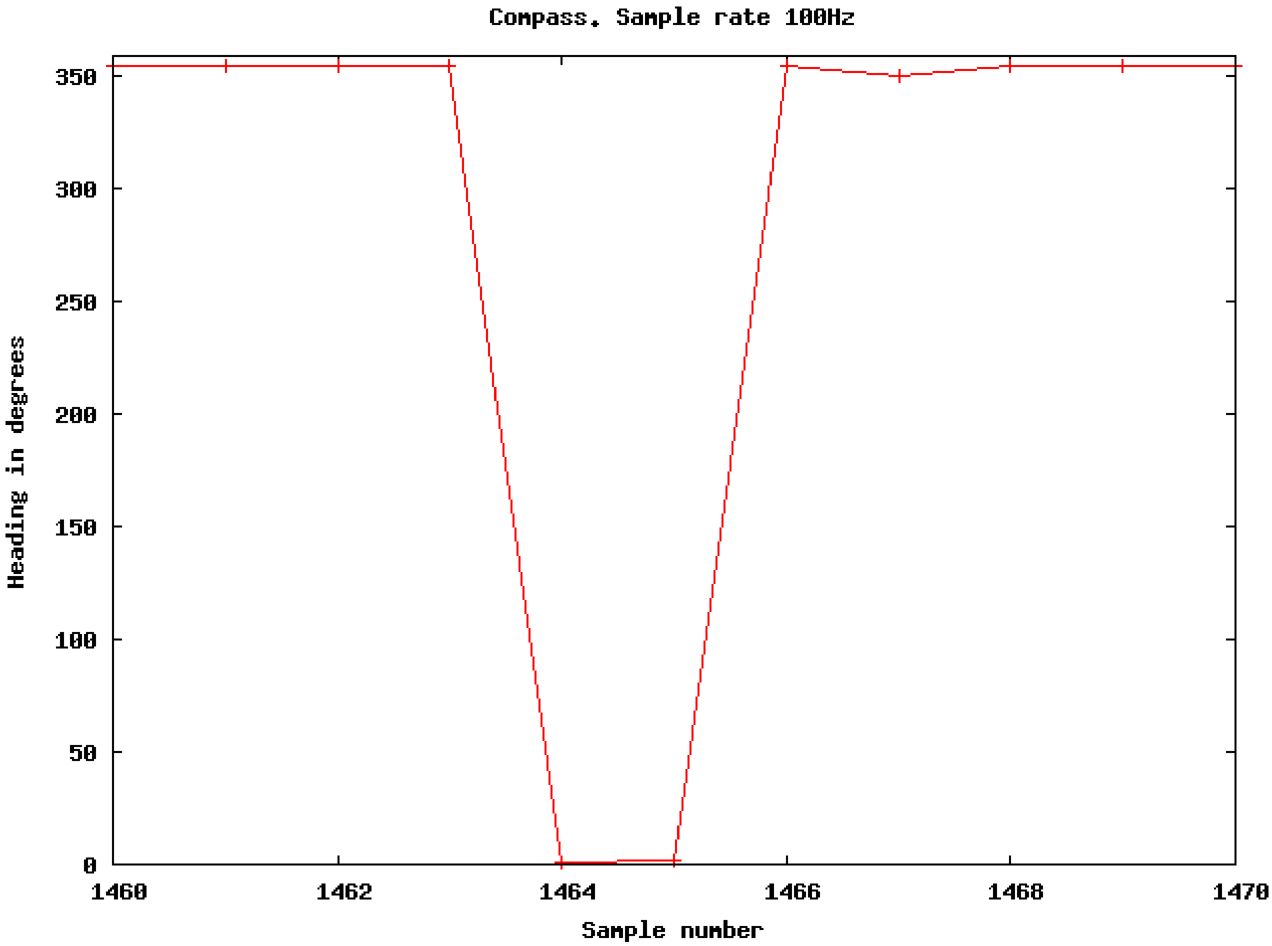
I decided that this was unacceptable and waited for better sensors to become affordable.

In 2009 a new sensor became available from the Honeywell Corporation which uses a solid-state sensing method not susceptible to vibrations. I purchased this sensor and began to experiment with it.

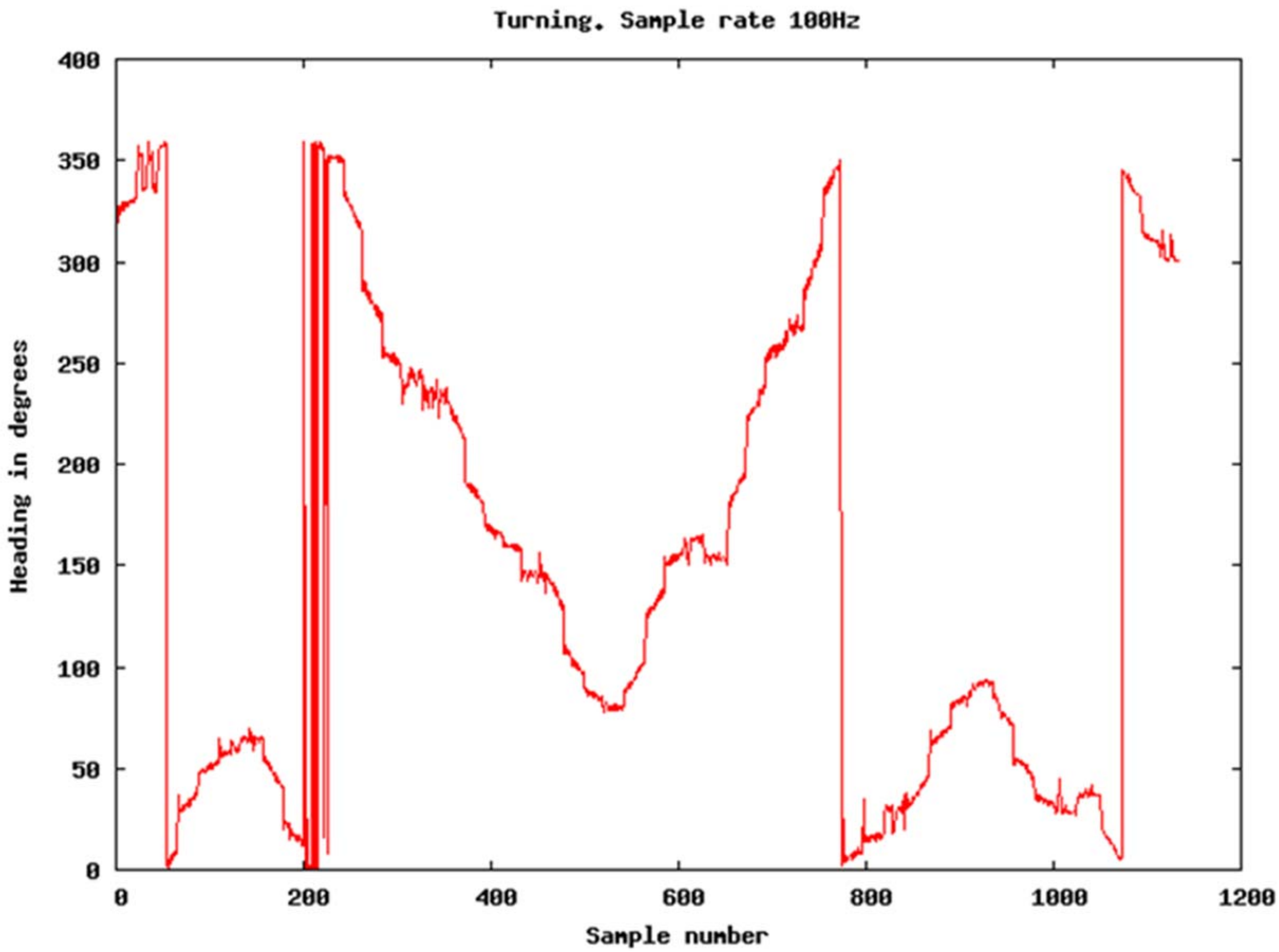
Initial measurements showed unexpected results where the measurement changed abruptly for short periods of time.



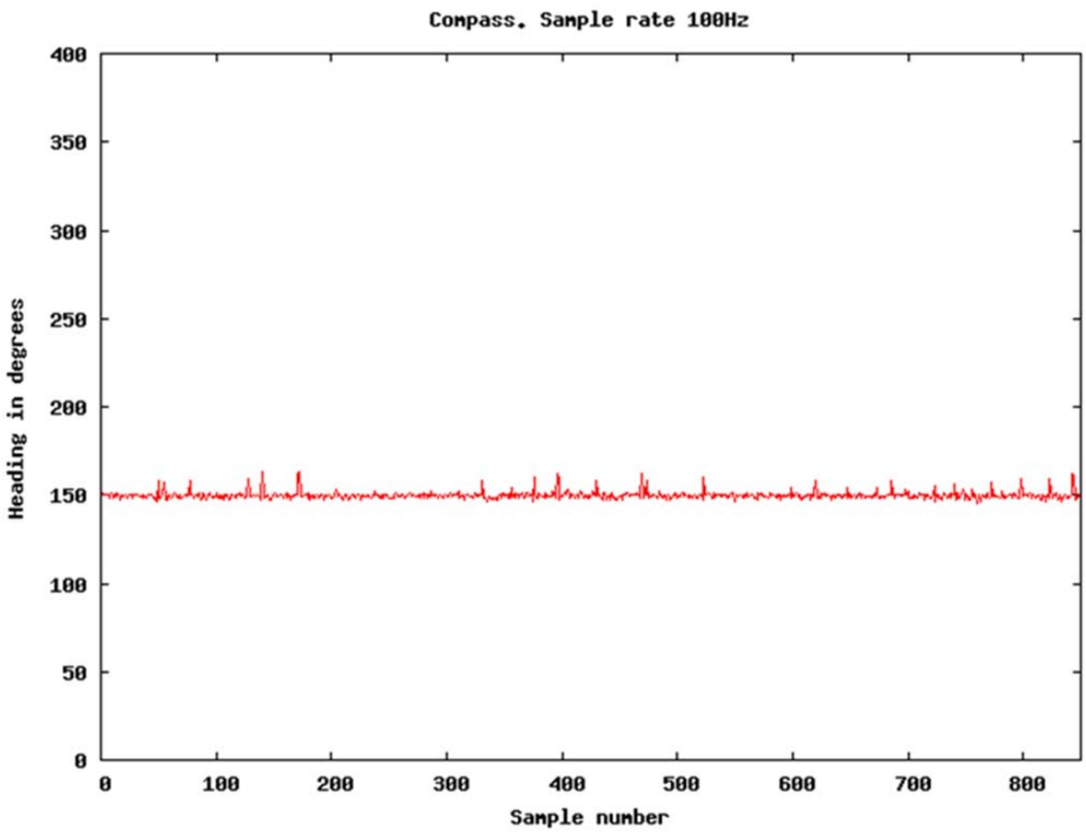
Looking closer at the data I saw that this was not caused by any failure of the sensor, but was caused by the sensor shifting back and forth across the 359.9 degree to 0.0 degree discontinuity.



Gathering more data by commanding the robot to rotate 90-degrees at a time and recording the resulting sensor values showed that this sensor does indeed have a discontinuity at 0 degrees of heading.



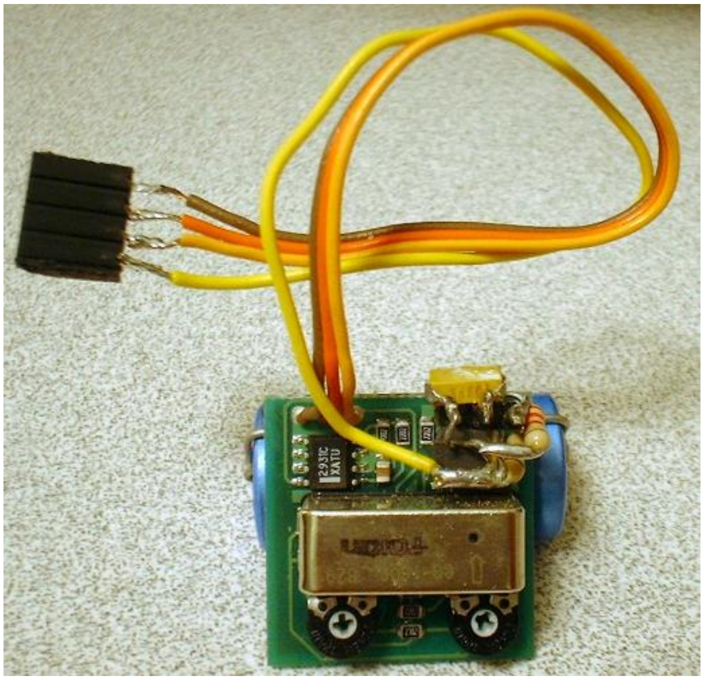
Changing the robot's heading manually and letting it sit stationary showed the compass has adequate noise and very low drift.



This sensor appears to be a good choice for a heading sensor.

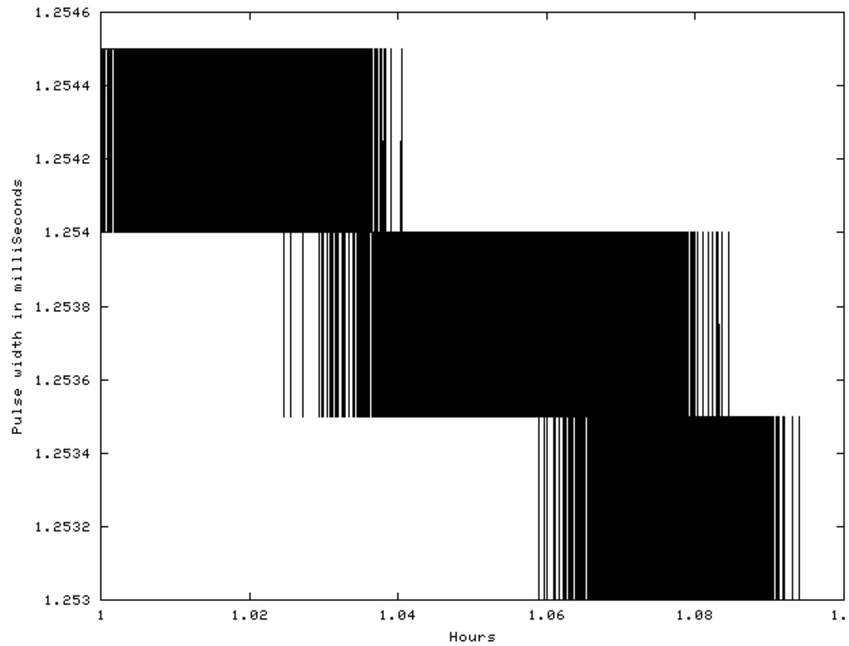
Gyroscope design:

When I started this project in 2002 the only gyroscope available to me for less than $500 was used for hobby helicopter yaw stabilization. These gyroscopes consist of a vibrating tuning fork and a set of electronics which transformed the rate of rotation into a pulse with a duration of between 0.5 milliSeconds and 1.5 milliseconds depending on the direction and rate of rotation of the sensor.



I built an electrical circuit and a small microcontroller board so that I could measure the performance of this sensor.

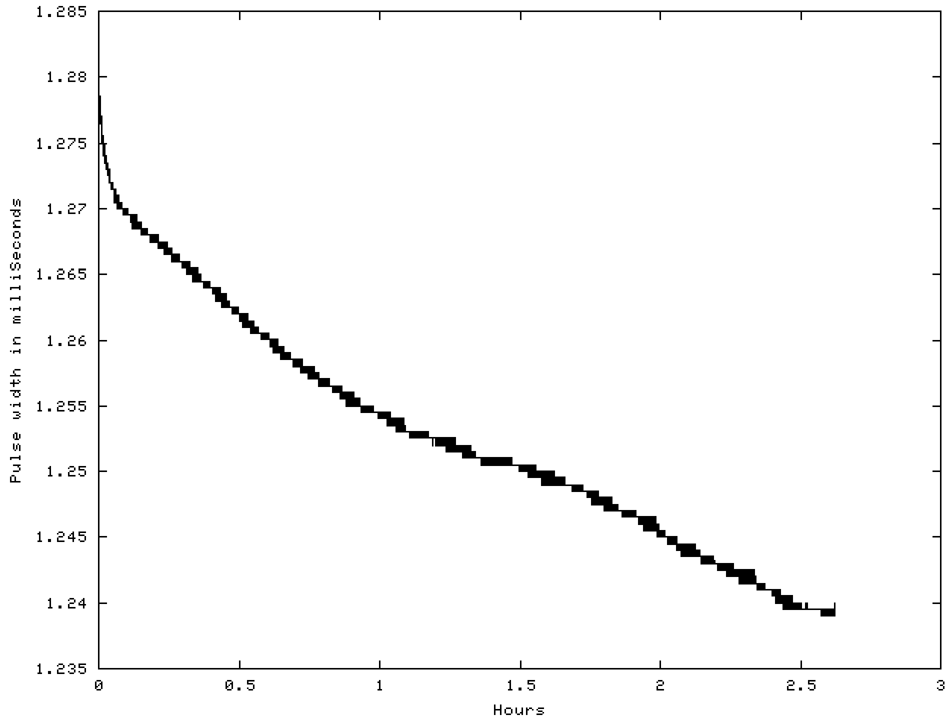
These sensors have a characteristic called ‘drift’ where the output value changes over time even when the sensor’s rate of motion is not changing. I started by measuring tis drift by holding the sensor motionless and measuring its output value.



Over very short time periods, the output in stable as shown in the following graph:
This graph shows the output varying by only 1 microsecond out of 1.25 milliSeconds which is 0.08%. This is a very small amount of drift, however the time period measured is only 5 minutes.

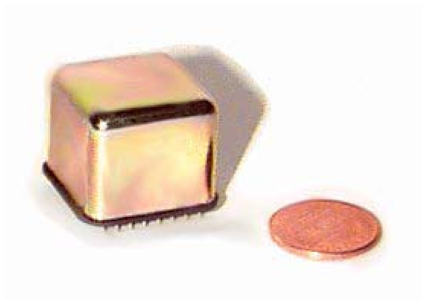
When the drift is measured over a longer time it gets larger:

This graph shows a drift of 2.7% over a period of 2.5 hours.



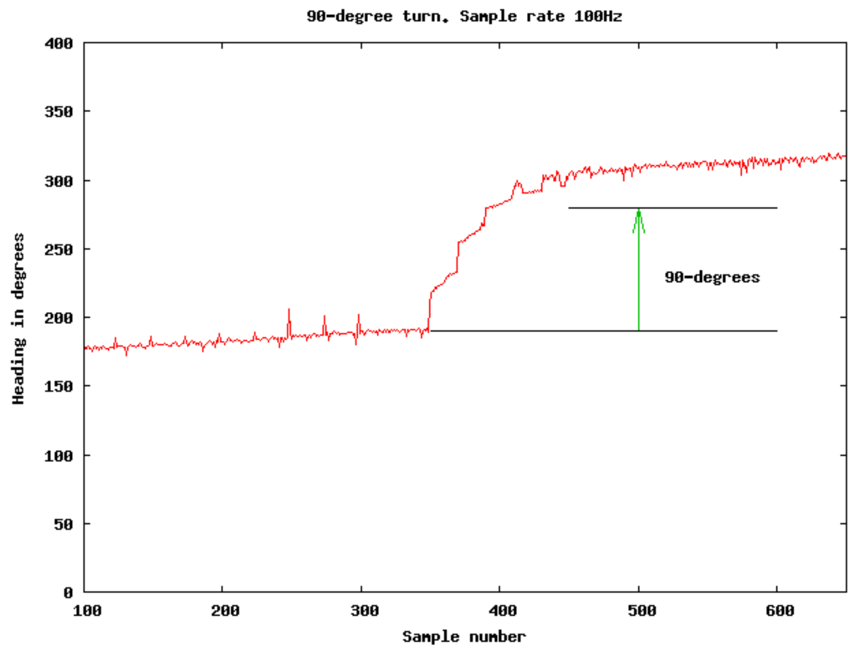
When making an instantaneous measurement of angular rate as is used in the hobby helicopter application, this drift is inconsequential, however if this sensor is intended to be used as part of a heading sensor, the drift will result in a constant error which will be integrated and will result in a sensor that produces a result that does not represent the true heading of the robot. I determined that this sensor was unsuitable for use in an absolute heading sensor and stopped working on the project.

In 2004 a new type of Micro Electro Mechanical System (MEMS) rate gyro became available for $100 from the Gyration company called the MicroGyro 100.



This device is a 2-axis rate gyro and an accompanying Application Specific Integrated Circuit (ASIC) which allows simple interfacing to small computer systems. The Gyration MG100 provides a two-axis rate-of-rotation output. Only one rate output is necessary for determining the heading of the robot.

I performed some test moves by having the robot rotate 90-degrees and recording the results.



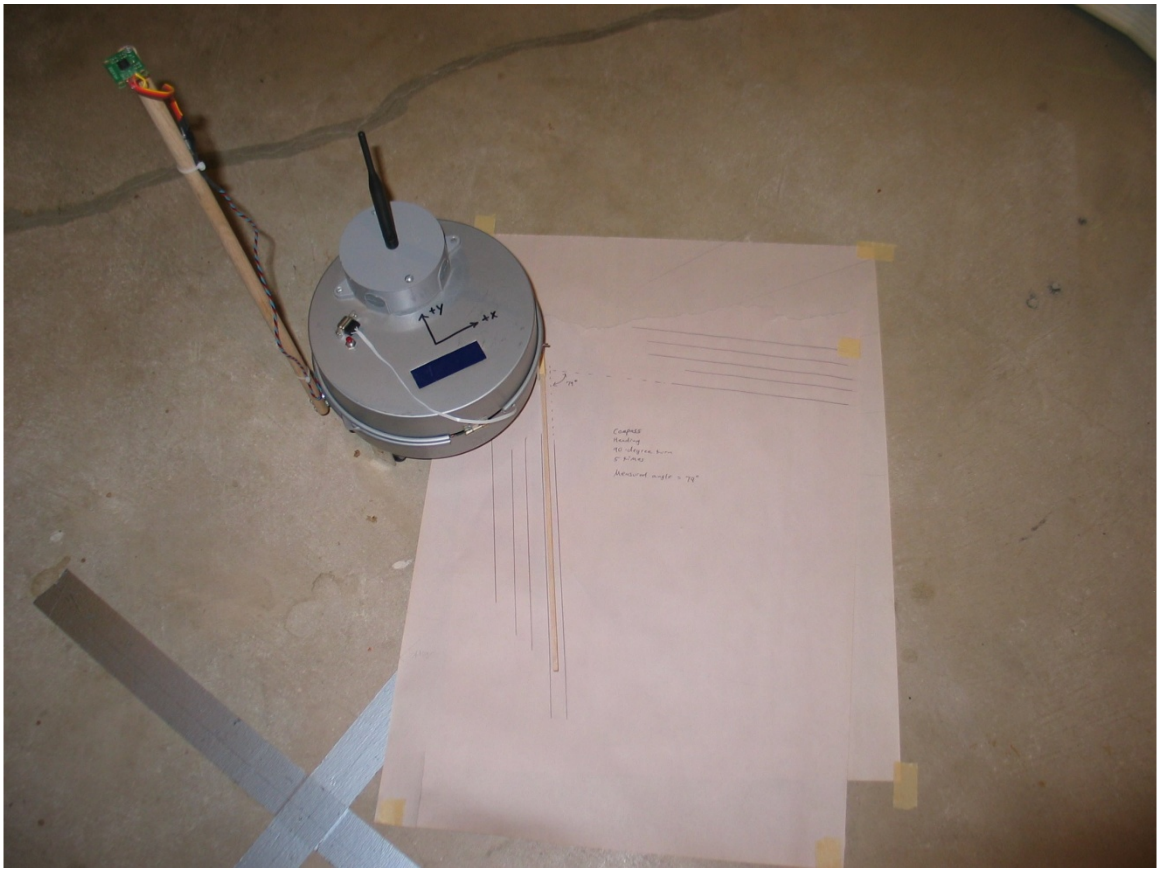
An issue is demonstrated by this test: I'm using a "dead-zone" programmed in to the gyro integrator so that if the turn-rate is less than 1.6 degrees-per-second, I ignore it and don't integrate it into the heading. This allows me to not have to worry about the gyro's baseline drift, but it makes the gyro insensitive to slow turns.

Therefore, when the robot is turning slowly, the gyro doesn't notice, but the compass does.
That's what you see in the left-hand part of the graph when the angle is increasing even though the heading-hold part of the program doesn't notice.

Because of this dead-band, when the robot starts and stops the move, that motion does not
get integrated into the total-move, so the robot overshoots the desired angle.

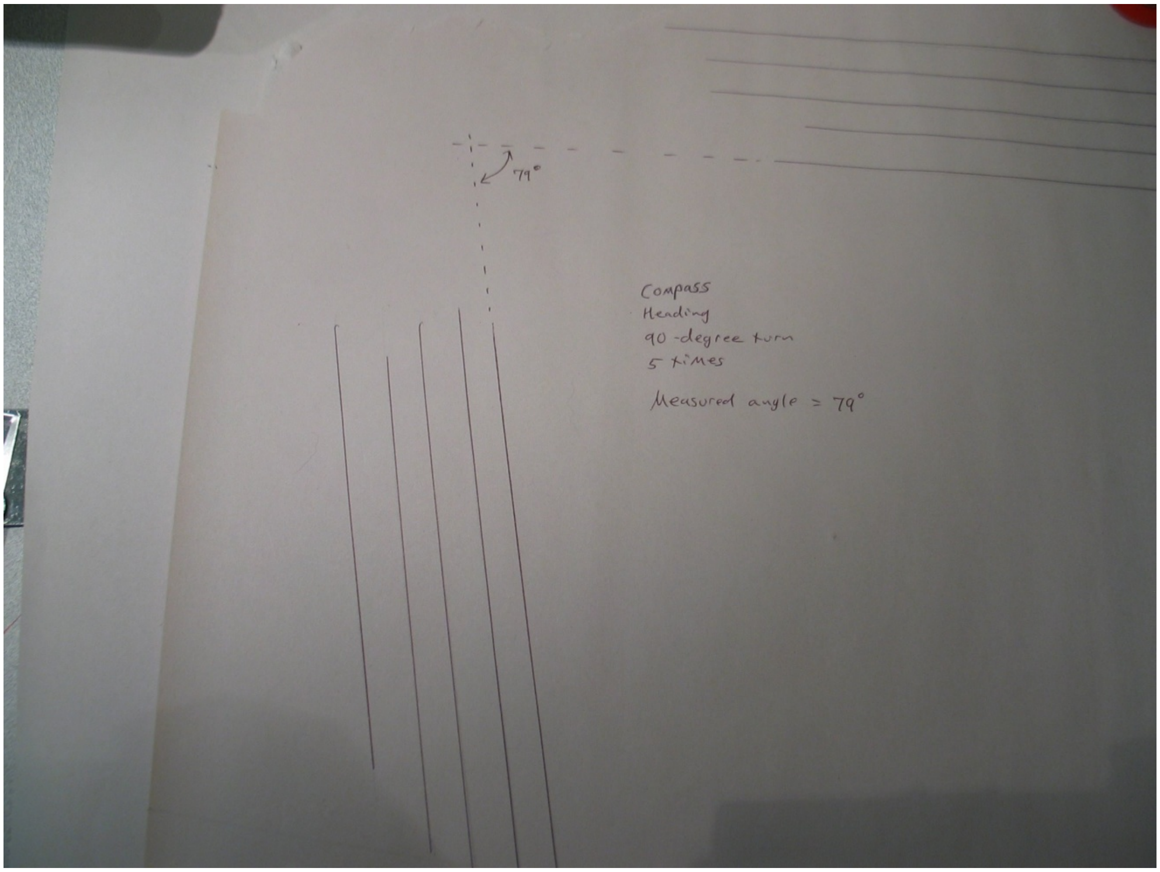
Testing:

I taped a rigid stick to one wheel mount on the robot so that I could record the heading of the robot onto a sheet of paper taped to the floor of my lab.



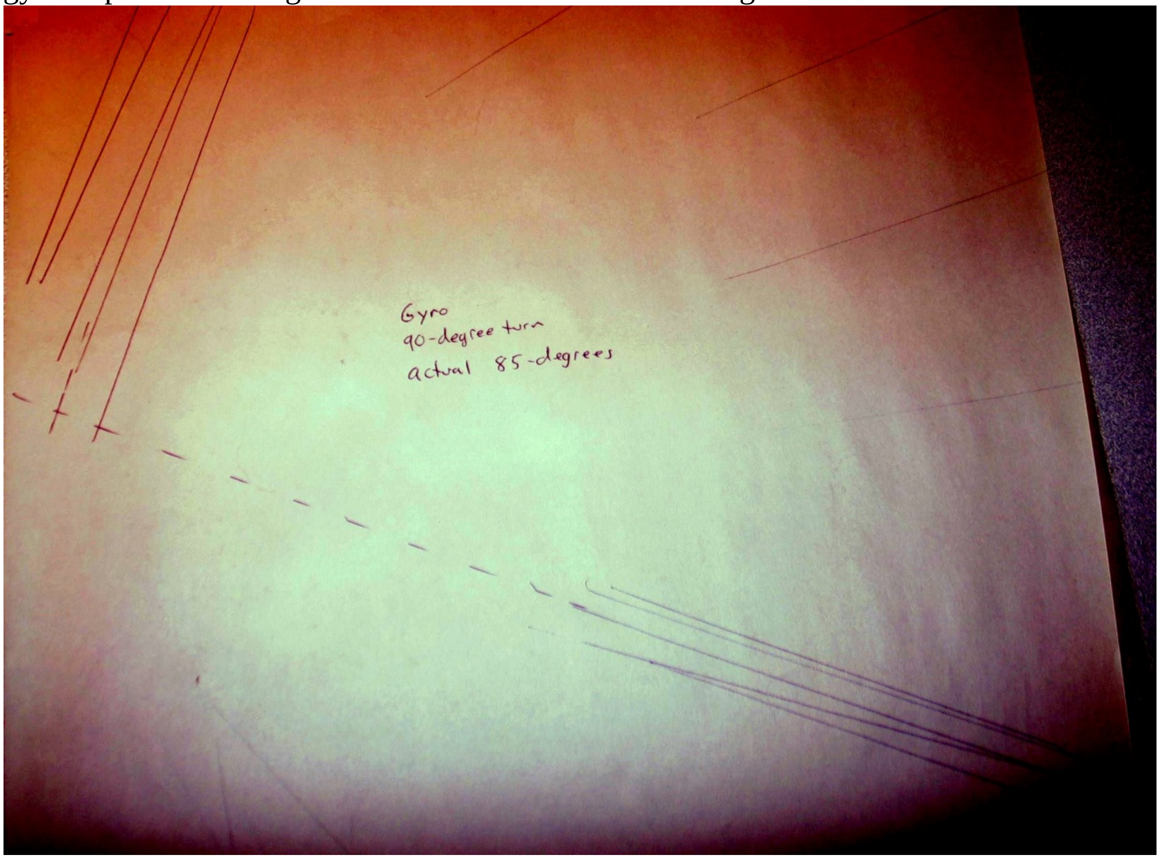
Then I commanded a 90-degree rotation using the compass as an absolute heading sensor and marked the new orientation.

This resulted in a map of orientation vs. commanded position as shown.



This shows that the robot does not make a precise 90-degree turn. I believe that this is due to disruption in the magnetic field near hard-iron objects in the basement.

Using the same method as above, I commanded 90-degree orientation changes using the gyroscope as a heading sensor and measured the following results:



The actual heading change is more accurate, but the variation increases.

In future work, I would like to attempt to merge these two sensors using some technique like a Kalman filter. I have read about this technique for sensor fusion and its description makes me thing it would be an excellent technique for creating a robust absolute heading sensor. I do not have the background to understand its implementatin at this time however.