Silicon Sensing® Rate Gyro Evaluation

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Background

Rate gyros are small devices that are able to measure the rate of turn. The aim of this work is to evaluate the performance and characteristics of three sensors mounted in three orthogonal axes. This would be used to determine the orientation of an underwater vehicle.

In a vehicle, these sensors would operate alongside accelerometers and an absolute heading sensor; the first step, however, is to assess the quality of these sensors in isolation when subject to various environmental factors. It is therefore important to understand zero offsets, their repeatability and differences due to temperature, and scale factors.

The sensors being investigated are manufactured by Silicon Sensing, a UK-based company. These sensors work by detecting how fast something is rotating using a small vibrating ring inside the device. When the sensor turns, the movement causes changes in the vibrations of the ring, which are picked up by sensitive electronic components. This information is then converted into either an electrical signal or a digital message. For this investigation, we have chosen to use the digital output.

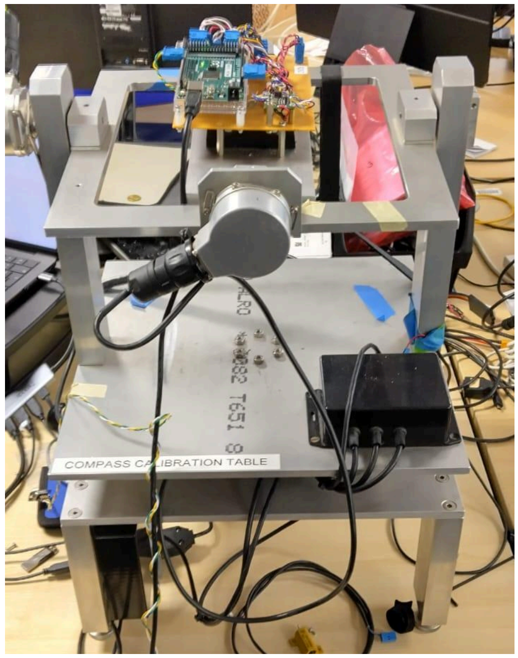
The digital output from the sensors is available over an SPI bus. SPI, or Serial Peripheral Interface, is a serial communication interface to connect a single master to many slave devices.

"Motorola's original specification (from the early 1980s) uses four logic signals, aka lines or wires, to support full duplex communication." [1]

The sensors can be read up to a maximum of 10,000 times per second. Speed is a very important factor, in order to capture both rapid & subtle movements, and to minimise coning errors when calculating attitude. Coning errors occur particularly in large sweeping motions and arise as a result of the gyroscope's output not being integrated quickly enough. This causes inaccuracies in attitude calculation.

The data was studied in various ways. To begin with, raw rate data was captured and plotted. Following this, attitude was also tracked by applying small rotations in sequence to an attitude matrix, using a quaternion-based algorithm, which is more stable than using 3×3 matrices. Quaternions allow for smooth and continuous representation of orientation without suffering from gimbal lock, a limitation often encountered when using Euler angles or 3×3 rotation matrices.[2]

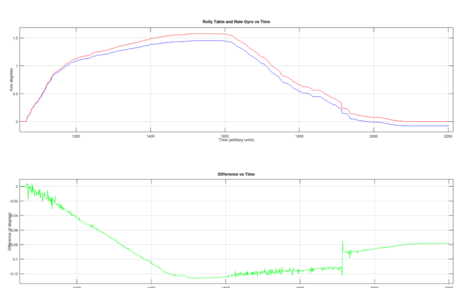
Comparison to Reference Data

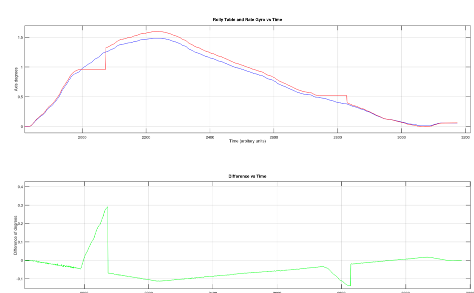


'Rolly Table' with the rate gyro sensor mounted

Reference data was obtained via a three-axis rotation table. The table is equipped with absolute angle encoders, giving 40 steps per degree. Once the rate sensors were calibrated, ideally the absolute angle data from 'Rolly Table' would match the integrated attitude values from the sensors.

The sensors are capable of measuring 4 different ranges – ±75°, ±150°, ±300° or ±900°. The larger ranges are important for measuring fast movements, however they are less precise and accurate than lower ranges. Through the digital interface of the sensors, the desired range is specified before each measurement.





These graphs show a comparison between the reference data (red) and the integrated data from the rate gyro (blue). The difference between them is shown in green. The graphs suggest that there may be a scaling factor that the values require multiplication by in order to be more accurate.

Dynamic Range Switching

To minimise the requirement of multiple rate gyros for applications where the rate of turn changes frequently or very quickly, a dynamic range switching system is proposed. The sensor would be continuously measuring at the lowest but most accurate range until the rate of turn surpasses a specific threshold, triggering selection of the next range. This approach would allow the software to keep the maximum accuracy during rapid motion.

Zero Offsets

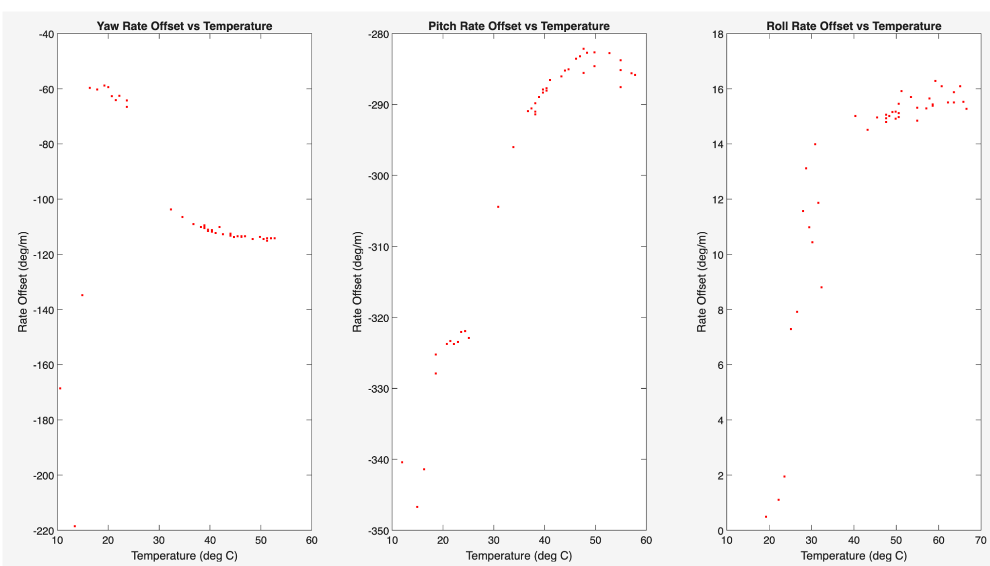
The zero offsets were measured continuously over a period of 15 seconds at the maximum speed of the Arduino (approximately 12,000 measurements are taken in this time). Measurements were also taken with completely different starting orientations, to see if it would alter the zero offsets. This was not the case and the offsets stayed consistent.

Variation across Ranges

The zero offsets varied across all 4 measurement ranges. They also tended to be more stable in the lower ranges. For the ±75° range, the offset is approximately 1°/s, while it can get as high as 6°/s for the ±900° range.

Effect of Temperature

The zero offsets are expected to be affected by temperature. The sensors were heated using a heat gun and cooled using freezer blocks. Temperature had minimal effect on lower ranges but a greater impact on higher ranges.



Zero offset vs temperature in the ±900° range

The data was repeatable allowing this behaviour to be corrected for in the driver software, maintaining accuracy across all operating temperatures.

At approximately a constant temperature, the uncertainty of the zero offsets were ±0.1°/m for yaw and pitch while the uncertainty for roll was ±1.2°/m across 50 samples. This highlights the consistency and reliability of these sensors and their zero offsets.

Scale Factors

Scale factors were measured and remained consistent within 3% across all measurements ranges and temperature range. This level of consistency indicates that a single scale factor per range can be used in the driver software. These results are consistent with those of similar tests in the data sheet.[3]

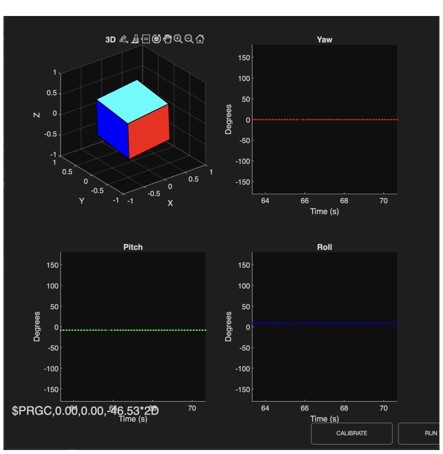
Stability

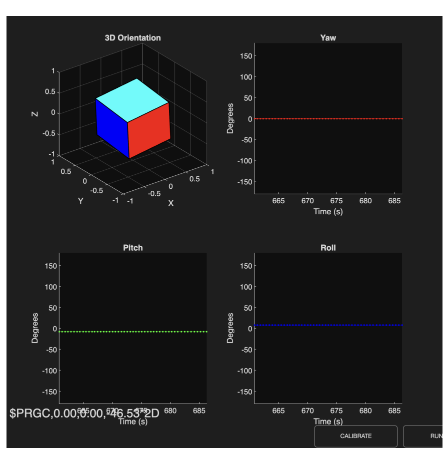
Stability tests were performed by integrating the measured rates over a period of 10 minutes at a time. The aim was to assess how much drift accumulates when the sensor is stationary and thus should report zero rotation. These integrated values were then compared to the reference provided by 'Rolly Table' under the same conditions.

In an ideal world, a perfectly stable sensor would show no change in orientation over time while stationary. However, due to noise and other errors, the integrated attitude can slowly drift even when the sensor is not moving.

The comparison with the 'Rolly Table' allowed the drift to be quantified. For the lower measurement ranges (e.g. ±75°), the drift was minimal, ending with a difference of ~0.2° between the rate gyros and 'Rolly Table'. At higher ranges such as ±900°, the accumulated drift increased more noticeably over time (difference of ~40°), indicating a larger influence of noise and offset instability. This behaviour is expected and confirms the trade-off between measurement range and accuracy.

Here are the before and after screenshots of the rate gyro over the 10 minute period:





75 degrees

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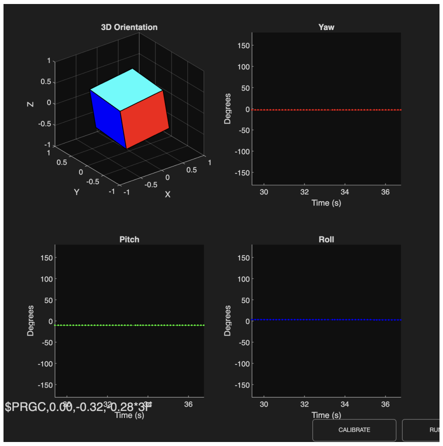
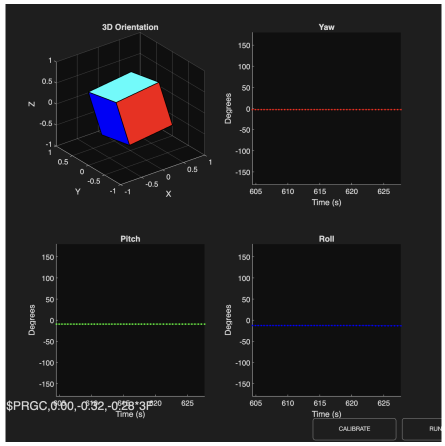
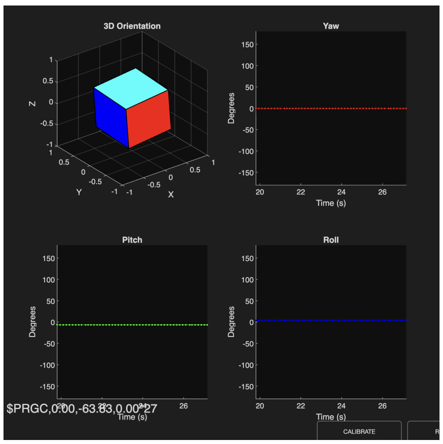
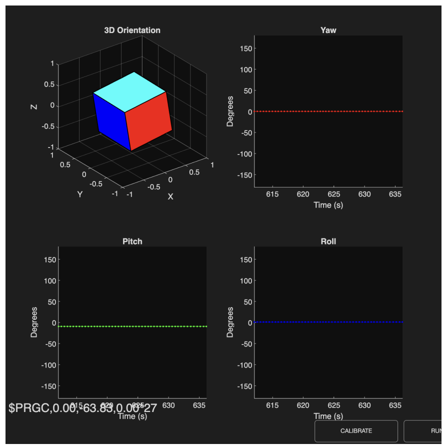


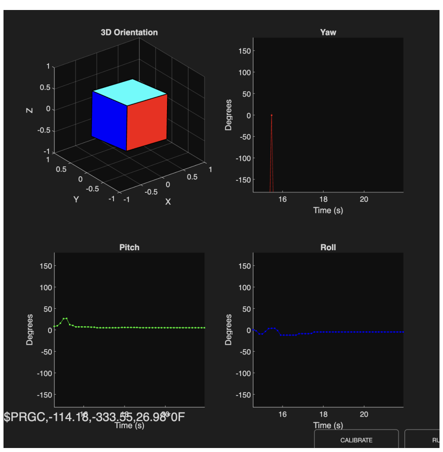


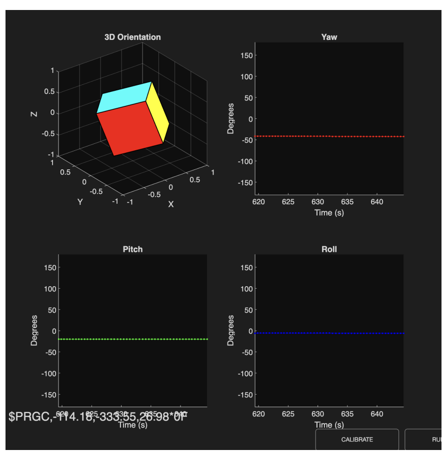
150 degrees





300 degrees





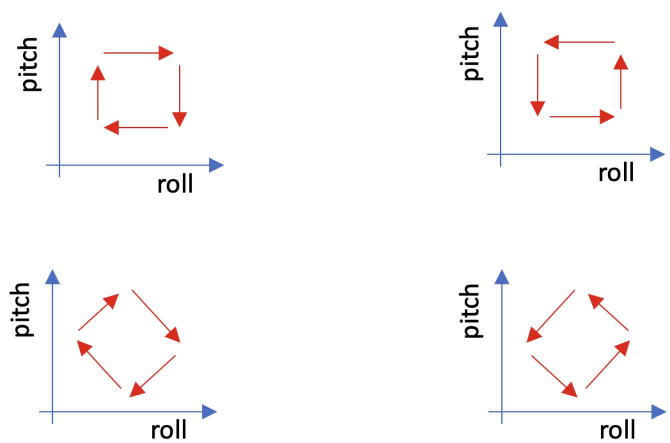
900 degrees

Coning Errors

Coning errors mostly arise from rapid movements of roll, pitch and yaw. These operations are not commutative which results in an accumulation of errors as the rotations are sequentially applied. The errors are minimised by breaking down rotations into smaller substeps, therefore sampling the sensors at maximum speed.

These errors were tested through a repetitive sequence of movements: roll up, pitch up, roll down, pitch down. Repeating this a number of times is expected to generate a systematic drift in integrated position. When reversing the sequence, the drift is expected in the opposite direction.

A test was conducted with systematic offsets in the calculation order to see whether the systematic drift could be reduced. Using pure roll and pure pitch movements, the compensation is not expected to have much effect, but compound rotations may be affected.



Tests to stimulate coning effects

These errors are more pronounced when the order in which the calculations for each axis are made is identical each time (e.g. *Pitch, Roll, Yaw* every time). To combat this, the order can be changed each time, either by switching the first and last axis (e.g. *Pitch, Roll, Yaw* then *Yaw, Roll, Pitch*) or by shifting the axis each time (e.g. *Pitch, Roll, Yaw* then *Yaw, Pitch, Roll*). Both these methods have a very similar effect on the data, increasing overall accuracy.

Conclusion

This study has successfully evaluated the Silicon Sensing® rate gyros and found that they can be used to reliably track orientation in 3D over a period of several minutes.

Zero offsets are consistent to within 2°/m for the ±75° range, while the offsets are consistent to within 40°/m for the ±900° range.

Scaling factors are consistent to within 3% for all ranges.

Integrated attitude calculations are stable to within 1° over 10 minutes, under quiet conditions (no movements faster than 5°/s); or within 15° under more vigorous conditions (continual movements, amplitude of the order of 60°/s).