Embedded Challenge Fall 2023

The Embedded Gyrometer
"The Need for Speed"

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https://youtu.be/Q_W8RipLa7M

Introduction:

Embedded system design focuses on gathering useful data, processing that data, and providing a useful representation of information. In the past decade, we have seen an explosion of wearable health devices ranging from heart rate sensors to step counters to distance trackers. These devices are designed to help us meet our fitness goals and help us keep in good physical shape.

This semester's embedded challenge aims to build a wearable speedometer that can calculate velocity by measuring angular velocities available from our built-in gyroscope L3GD20 - without a GPS. The gyroscope can measure 3-axis angular velocity and by placing the sensor on the legs or feet can capture the angular velocities. With a bit of processing, those angular velocities can be converted to linear forward velocity and distance traveled can be calculated.

Approach:

We are using a Gyroscope L3GD20 that generates analog signals representing angular velocity. We use Serial Peripheral Interface for communication between the gyroscope and STM32F429 Discovery board. Through the SPI interface, the microcontroller can send configuration commands to the gyroscope, receive data from the gyroscope, and control its operation.

Mathematics Involved:

The mathematics involved integrates several key concepts to process and interpret the data from a gyroscope for velocity measurement. The procedure begins with the application of a scaling factor, essential for adjusting the raw data from the gyroscope to meaningful values. This step is crucial to ensure the data is in a usable format for further processing.

After scaling, the data undergoes smoothing through a digital low-pass filter, which plays a significant role in reducing noise and fluctuations. The low-pass filter is described by the difference equation:

$$y[n] = \alpha\, x[n] + (1 - \alpha)\, y[n-1]$$

In this equation:
- $y[n]$ represents the output at time n
- $x[n]$ is the input at time n
- α is the smoothing factor, determined by the cutoff frequency and sampling rate

This filtering not only smoothens the data but also introduces a slight delay, which is a common characteristic of such filters. The delay is a trade-off for achieving a smoother signal.

Following the filtering process, the report applies the formula for linear velocity in the context of circular motion:

$$v = r * \omega$$

In this equation:
- v = linear velocity
- ω = angular velocity
- r = length of the leg (from knee to ground)

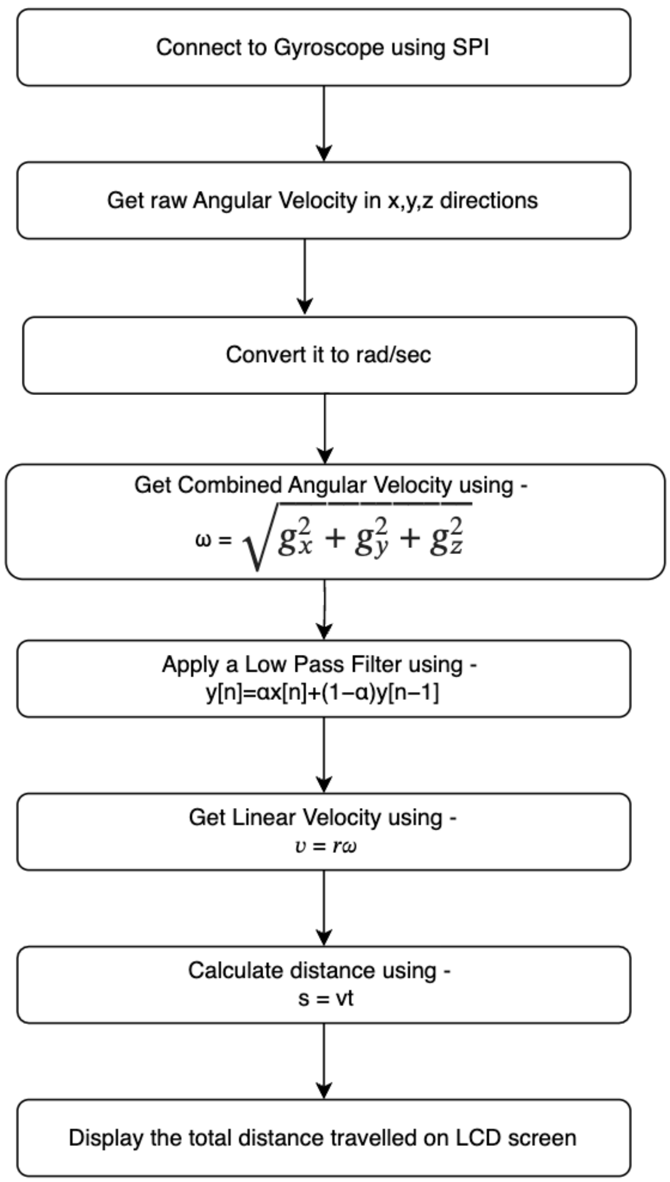
This formula is fundamental in converting angular velocities measured by the gyroscope into linear velocity. The radius involved in this formula is specific to the application or the physical setup from which the gyroscope data is being measured. By multiplying the radius by the angular velocity (post-filtering), the linear velocity can be accurately calculated.

Then, from linear velocity, we calculate the distance traveled by using the below formula:

$$\triangle distance = linear\ velocity * time$$

This combination of scaling, filtering, and application of the linear velocity formula provides a comprehensive approach to interpreting gyroscope data for velocity measurements, illustrating the interplay between physical principles and mathematical processing in embedded systems and sensor data analysis.

Flowchart:



Error Calculation:

Run	True Value	Calculated value	Pace	Difference of Calculated value and True Value	Average Error from 10 samples	Average Error calculaed for all type of paces	Error
1	5	5.3	Slow	0.3			
2	5	5.61	Slow	0.61			
3	5	4.71	Slow	-0.29			
4	5	6.15	Slow	1.15			
5	5	4.66	Slow	-0.34	0.128		
6	5	4.27	Slow	-0.73			
7	5	4.85	Slow	-0.15			
8	5	5.59	Slow	0.59			
9	5	6.14	Slow	1.14			
10	5	4	Slow	-1			
1	5	6.4	Fast	1.4			
2	5	6.51	Fast	1.51			
3	5	5.86	Fast	0.86			
4	5	8.43	Fast	3.43			
5	5	7.33	Fast	2.33	1.421	0.82	± 9%
6	5	6.11	Fast	1.11			
7	5	6.04	Fast	1.04			
8	5	6.78	Fast	1.78			
9	5	5.37	Fast	0.37			
10	5	5.38	Fast	0.38			
1	5	5.11	Normal	0.11			
2	5	4.94	Normal	-0.06			
3	5	5.97	Normal	0.97			
4	5	6.26	Normal	1.26			
5	5	5.07	Normal	0.07	0.911		
6	5	6.54	Normal	1.54			
7	5	5.77	Normal	0.77			
8	5	6.89	Normal	1.89			
9	5	6.27	Normal	1.27			
10	5	6.29	Normal	1.29			

Overall error margin calculated at 9% reflects the variability observed in measurements across different conditions. This figure was derived by taking the mean of three sets of readings, each representing a distinct pace: slow, normal, and fast.

The 9% error margin, considering both upwards and downwards deviations, indicates a consistent level of discrepancy across different speeds. It suggests that while the system is relatively stable in its performance, the accuracy fluctuates with the change in pace.

Summary:

In this project, we gained valuable insights into sensor-based velocity measurement and data processing. By interfacing a gyroscope with an STM32F429 Discovery Board and implementing a methodology that included data scaling, smoothing through a digital low-pass filter, and applying the $v = r * \omega$ formula for velocity calculation, we deepened our understanding of handling and interpreting sensor data. The process of calculating the accuracy, which involved averaging readings across different movement speeds and resulted in a 9% error margin, further enhanced our comprehension of the challenges and nuances in sensor data analysis. This project not only provided practical experience in embedded system development but also enriched our knowledge in applying theoretical concepts to real-world applications.