Module 21

Introduction: Sensor Integration

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Educational Objectives:

REVIEW interrupts, NVIC, the Nyquist Theorem and the Central Limit Theory
UNDERSTAND how to use the I2C to interface integrated sensors to the robot. Using the sensors implement real-time data acquisition systems, observing noise, choosing a sampling rate and thinking about aliasing (undesired frequency components)
EXPLORE the world of digital processing by implementing some simple digital filters, in order to improve signal to noise ratio, and run fast Fourier transform (FFT) on sampled data
LEARN the I2C protocol to interface a variety of sensors to pull and push data to and from the bus
DESIGN, BUILD & TEST A SYSTEM that measures either distance from a time of flight sensor or acceleration from an Inertial Measurement Unit (IMU) or input from environmental sensors, then integrate sensors to solve a task

Prerequisites (Modules 10, and 13)

- SysTick periodic interrupts and arrays (Module 10)
- Timer_A periodic interrupts (Module 13)

Recommended reading materials for students:

- Chapters 11,15,17, and 21, **Embedded Systems: Introduction to Robotics,**
  Jonathan W. Valvano, ISBN: 9781074544300, copyright © 2020

A **physical signal** is continuous in both amplitude and time. Neglecting quantum physics, most signals in the world exist as continuous functions of time (e.g., position, angle, speed, force, pressure, temperature, and humidity etc.) In other words, the signal has amplitude that can vary over time, but the value does not instantaneously change. A **transducer** converts the physical signal into an electrical signal. We define the electrical signal as analog, because it is analogous to the physical signal. In this module, the analog signal may be a voltage or a time-dependent value like phase. A **digital signal** is one that is discrete in both amplitude and time. To represent a signal in the digital domain we must approximate it in two ways: **amplitude quantizing** and **time quantizing**. From an amplitude perspective, we will first place limits on the signal restricting it to exist between a minimum and maximum value (e.g., 0 to +3.3V), and second, we will divide this amplitude range into a finite set of discrete values. The **range** of the system is the maximum minus the minimum value. The range has units, such as volts or cm. The **precision** of the system defines the number of values from which the amplitude of the digital signal is selected. Usually precision is given in binary bits. For example, an 8-bit system can uniquely identify 256 different values. The **resolution** is the smallest change in value that can be reliably distinguished. The resolution is given in the same units as the range.

range = resolution*2^n, where n is the precision in bits

The second approximation occurs in the time domain. Time quantizing is caused by the finite sampling interval. In practice we will use a periodic timer to trigger an **analog to digital converter** (ADC) to digitize information, converting from the analog to the digital domain. In this module we will use devices that combine the transducer, electrical circuits, ADC, and digital interface into one integrated circuit (IC). The **Nyquist Theorem** states that if the signal is sampled with a frequency of f_s, then the digital samples only contain frequency components from 0 to ½ f_s. Conversely, if the analog signal does contain frequency components greater than or equal to ½ f_s, then there will be an **aliasing** error during the sampling process. Aliasing is when the digital signal appears to have a different frequency than the original analog signal.

In this lab, we will either measure distance from a time of flight sensor, acceleration from an Inertial Measurement Unit (IMU), or environmental parameters such as temperature, humidity or light. We will write low level software that communicates with the integrated sensor using I2C. We will develop digital filters to improve signal to noise ratio. We will evaluate the sensor(s) in configurations similar to manner in which the sensors will be used on the robot. We will perform measurements to determine parameters such as accuracy, noise, and response time.

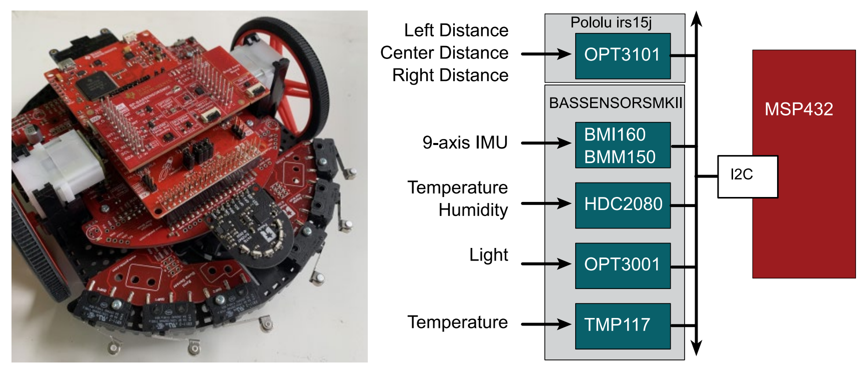

Figure 1. RSLK with the Pololu OPT3101 Time of Flight module used to measure distance, and the TI BP-BASSENSORSMKII Boosterpack used to measure acceleration, rotation, magnetic field, temperature, humidity, and light intensity.

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