US Anemometer: The Better Way to Measure Wind

Group 10: Nicolas Castellanos, Anthony Chalmers, Marshall van den Hoogen
Department of Electrical & Computer Engineering, Dalhousie University

Visimetrics Inc.

DALHOUSIE UNIVERSITY

Introduction

Background & Significance:

Ultrasonic anemometers are devices used to measure wind direction and speed using ultrasonic sound waves. The lack of moving parts makes them appropriate for long-term use in harsh marine environments.

Problem Statement

Most of the ultrasonic anemometers on the market today are extremely expensive. As a result, this makes them inaccessible to fishermen, researchers, hobbyist sailors, and dingy racers. The US Anemometer project is addressing these concerns through the development of the theory and a prototype for a robust and low-cost anemometer, suitable for use on various sized boats.

Design Requirements:

- **Wind Speed:** The wind speed relative to the boat must be known to an accuracy of $\pm 5\%$ (correctness plus precision) over an operating range from 0 m/s to 30 m/s.
- **Wind Direction:** The wind direction relative to the boat must be measured to an accuracy of $\pm 3°$ (correctness plus precision) over an operating range from 0 m/s to 30 m/s.
- **Output Rate:** The device must provide wind measurements at a minimum output frequency of 2 Hz.

Project Deliverable:

A prototype that will measure wind speed along a single axis. It will encompass a combination of concepts used to achieve the required functionality of the proposed system with the necessary level of performance needed to meet the project specifications.

Hardware Design

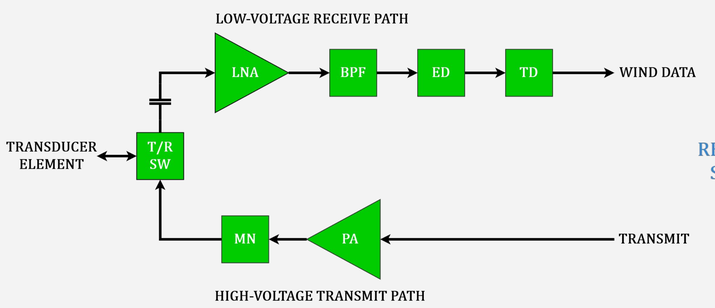
High-Voltage Transmit Path:

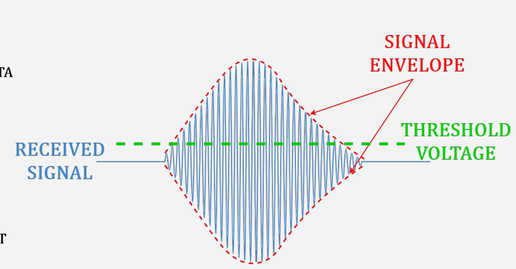
To produce a measurement of the speed of the wind, a microcontroller generates low-voltage pulses to drive the transceiver's high-voltage Power Amplifier (PA) and excite the transducer element. A Matching Network (MN) is used to maximize power transfer to the transducer element.

Low-Voltage Receive Path:

The receiver consists of a Transmit/Receive (T/R) Switch, a Low-Noise Amplifier (LNA), a Bandpass Filter (BPF), an Envelope Detector (ED), and a Threshold Detector (TD):

- Each transducer element is connected to an LNA through a T/R switch, which protects the LNA input from the high-voltage transmit signal.
- The LNA provides a fixed gain to optimize the receiver's noise performance.
- The bandpass filter removes noise contained in frequencies outside the band of interest (40 kHz).
- The envelope detector extracts the envelope of the received signal.
- The threshold detector converts the output of the envelope detector into a digital signal that can be read by the microcontroller.





Future Work

Hardware Tasks

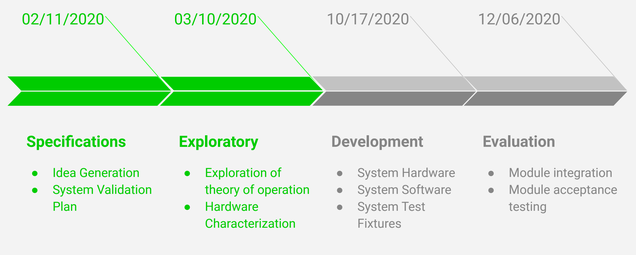
- Test transmit/receive hardware modules
- 3D print test rig and build test enclosure

Software Tasks

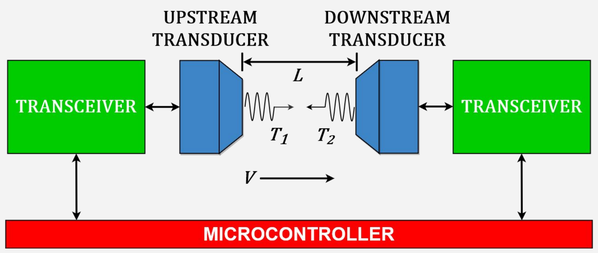
- Implement software system

Integration Tasks

- Construct & validate final prototype
- Deliver final prototype & test enclosure



Theory of Operation



UPSTREAM TIME OF FLIGHT:

$$T_1 = \frac{L}{C+V}$$

DOWNSTREAM TIME OF FLIGHT:

$$T_2 = \frac{L}{C-V}$$

WIND SPEED: $V = \frac{L}{2}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$

Software Design

Software Architecture:

The software of the device will be structured in a hierarchical architecture with 3 distinct layers: Control, Task, and I/O:

- Control Layer: Manages the state of the device and the tasks that are being performed
- Task Layer: Contains modules that will control the ultrasonic transducers for the device
- I/O Layer: Low-level drivers that manage the hardware for the various sensors and amplifiers in use

References

Ghahramani, A., Zhu, M., Przybyla, R., Andersen, M., Galicia, P., Peffer, T., . . . Arens, E. (2019). *Measuring Air Speed With a Low-Power MEMS Ultrasonic Anemometer via Adaptive Phase Tracking*. IEEE Sensors Journal, 19(18), 8136-8145.

Hans, V., & Swarek, V. (2000). *The Ultrasonic Cross-Correlation Flow Meter – New Insights into the Physical Background.* In Flomeko 2000 - IMEKO TC9 Conference. Retrieved from https://www.imeko.org/publications/tc9-2000/IMEKO-TC9-2000-016.pdf

Horowitz, P., & Hill, W. F. (1989). *The Art of Electronics* (7th ed.). New York, NY: Cambridge University Press.

Lu, Z., Yang, C., Qin, D., Luo, Y., & Momayez, M. (2016). *Estimating ultrasonic time-of-flight through echo signal envelope and modified Gauss Newton method.* Measurement, 94, 355-363.

On Theta Instruments Co. *Advantages of ultrasonic wind speed wind direction instrument in wind power industry_THETA INSTRUMENTS.* Retrieved from: http://www.theta-instruments.com/applications.asp?ID=7

Pro-Wave Electronic Corporation. *Selection and use of Ultrasonic Ceramic Transducers.* Retrieved from Pro-Wave website: http://www.prowave.com.tw/english/item/qa.htm

Pro-Wave Electronic Corporation. *Equivalent Circuit of Ultrasonic Transducers.* Retrieved from Pro-Wave website: http://www.prowave.com.tw/english/item/qa.htm