DEVELOPMENT OF A THREE-DIMENSIONAL WIND MEASUREMENT SOLUTION HOSTED ON A SMALL UNMANNED AERIAL SYSTEM

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ABSTRACT

Small unmanned aerial systems (sUAS), unlike their manned counterpart, can operate safely at low altitudes and can be easily controlled in order to make atmospheric measurements with high spatial resolution. Consequently, they are playing an increasing role in atmospheric investigations of the lower atmosphere. While there have been several sUAS sensor suites developed for the measurement of scalar atmospheric parameters, such as temperature, humidity and pressure, only a small subset of these sensor suites are capable of measuring wind velocity. Most of these wind measurement solutions have been designed for fixed-wing unmanned aircraft (UA) and those designed for multirotor UA do not have a measurement frequency adequate for turbulence measurement. The aim of this research project is to enhance an existing meteorological sensor suite capable of measuring atmospheric temperature and humidity and enable it to accurately measure all three wind components. Two acoustic resonance anemometers, that each provide a 2-dimensional measurement solution, are orthogonally mounted to create a complete 3-dimensional measurement solution.

RESEARCH OBJECTIVES

- Integrate two acoustic resonance anemometers into an existing suite of scalar sensors hosted on a multirotor sUAS
- Orthogonally mount the two anemometers allowing for a complete 3-dimensional wind solution
- Enable a more thorough investigation of the atmospheric boundary layer, the lowest layer of the atmosphere, including surface flux calculations

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SENSOR INTEGRATION

- Data collection from the sonic anemometer:

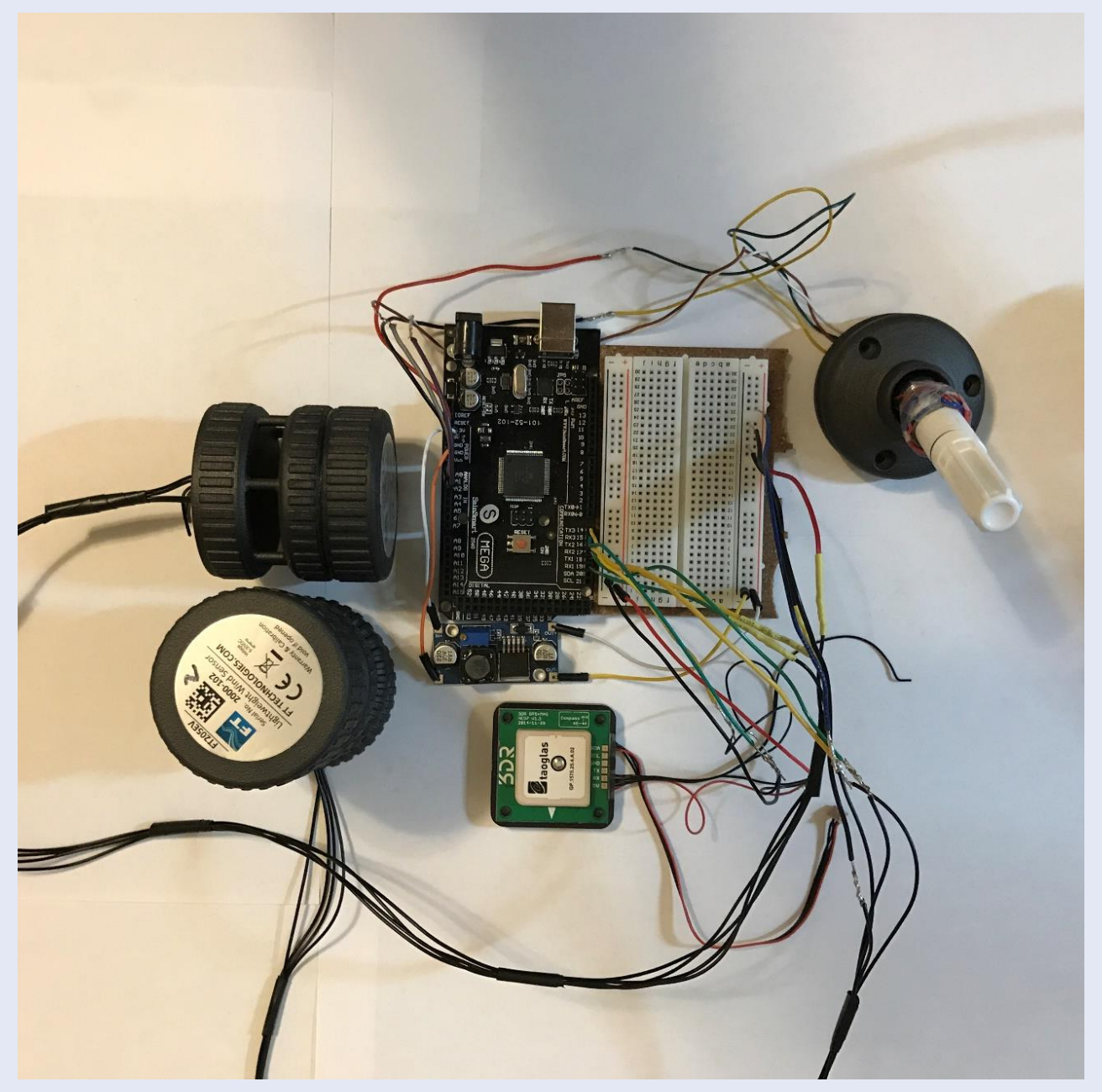
$$\$WI,WVP=020.0,045,0*73<cr><lf>$$

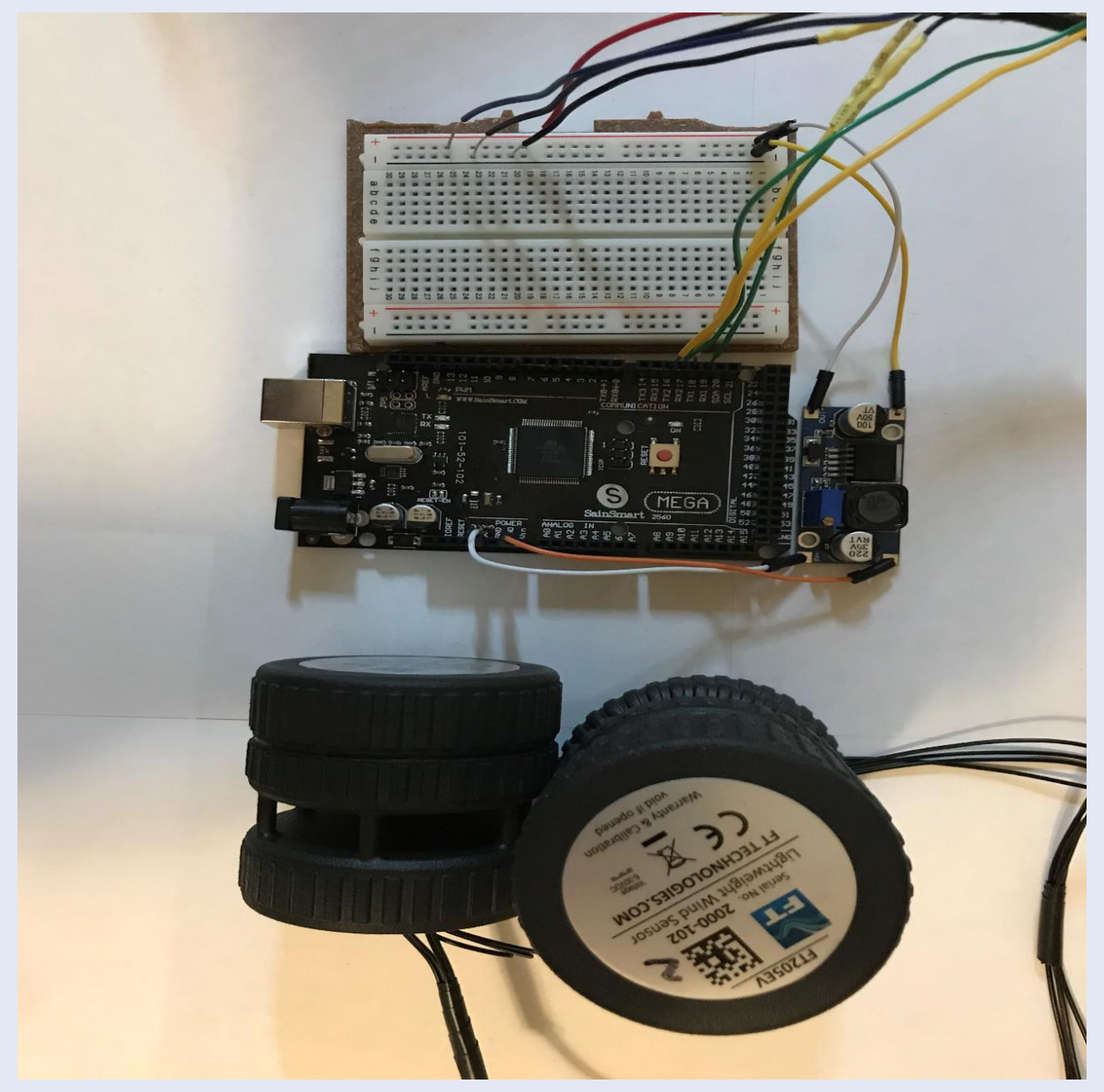
  - WVP indicates the use of a polar format
  - Reading and parsing the information as a string maintains a consistent format for combining with other sensors' data and for transfer
  - Algorithm design retains 10 Hz output frequency
  - Data collection from multiple sensors occurs without delay or massive loss of data

- Consolidation of data from four different sensors into a single string for easy transfer:

$$\$13605,3,29.08,-81.23,020.00,143,054.23,201,25.09,55.23,*12$$

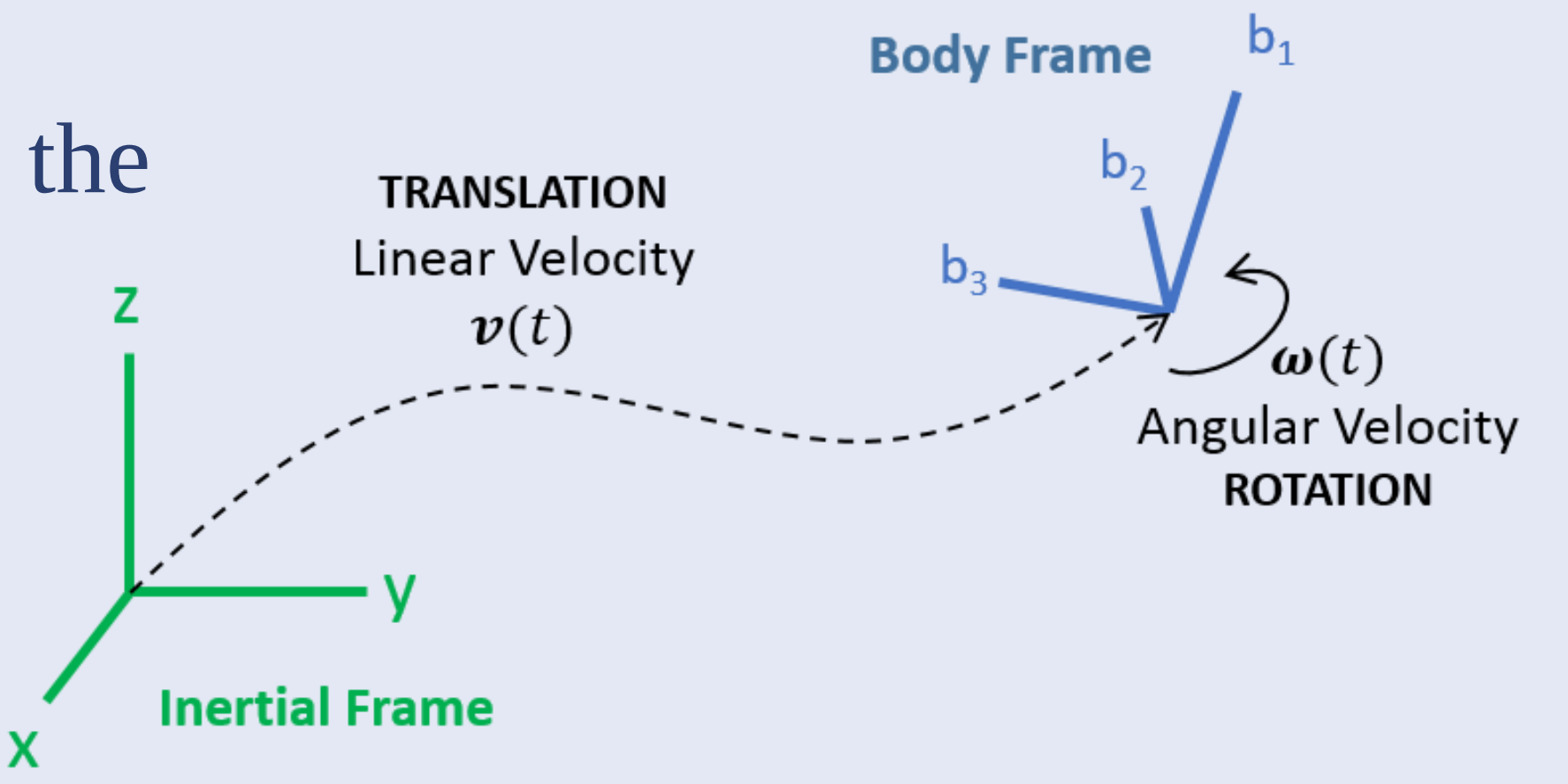
1) GPS time that data collection occurred
2) GPS fix
3) Latitude
4) Longitude
5) Wind Speed from first sensor
6) Wind Direction from first sensor
7) Wind Speed from second sensor
8) Wind Direction from second sensor
9) Temperature
10) Relative Humidity
11) Checksum





DATA REDUCTION

- Wind velocity vector must be resolved from the air velocity sensor measurement signal
  - Sensor mounted on an air vehicle with 6 DoF
  - Transformation must be made from the aircraft body-fixed frame to the earth-fixed frame

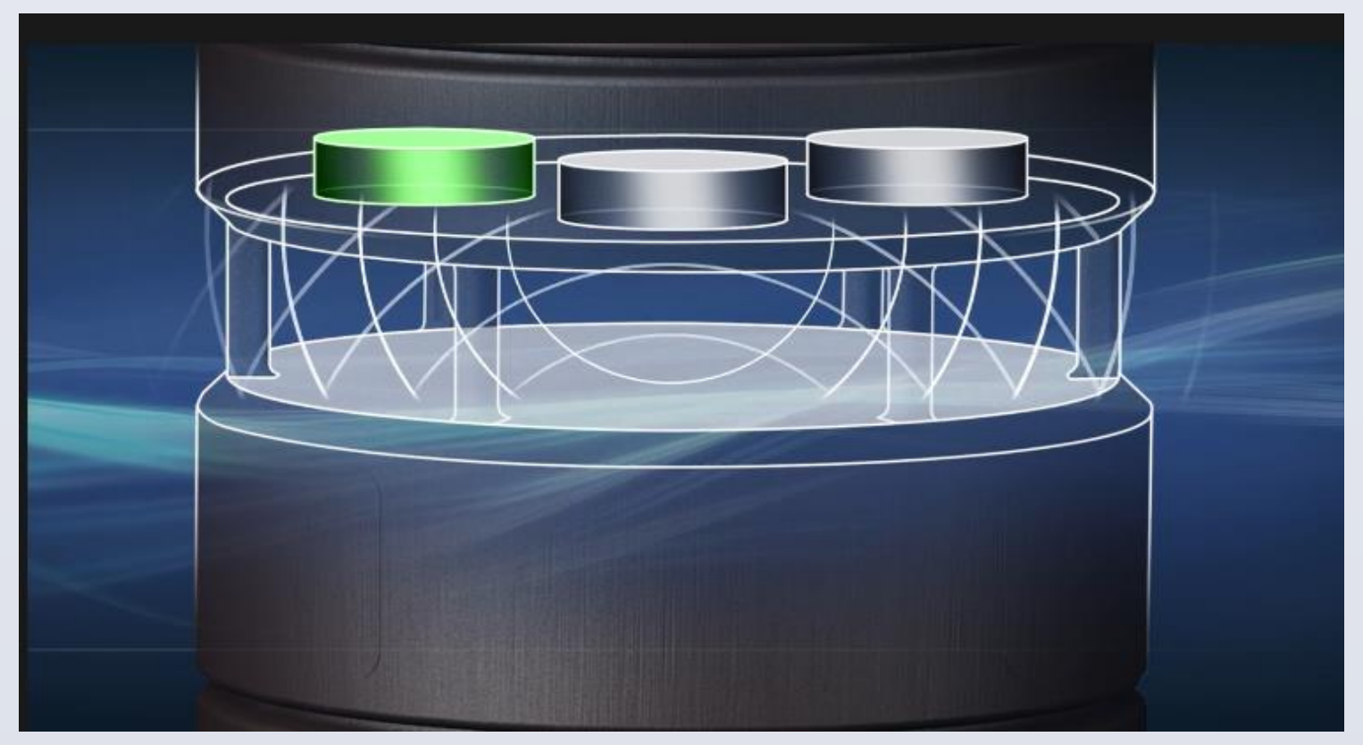


- Goal to make the sensor suite aircraft platform agnostic
  - Use external IMU and GPS receiver
    - GPS update rate lower than IMU ∴ IMU uses aircraft velocity to interpolate between GPS positions making use of a Kalman filter

$$\begin{bmatrix} V_{x,g} \\ V_{y,g} \\ V_{z,g} \end{bmatrix} = \begin{bmatrix} \cos(\theta)\cos(\psi) & -\cos(\varphi)\sin(\psi)+\sin(\varphi)\sin(\theta)\cos(\psi) & \sin(\varphi)\sin(\psi)+cos(\varphi)\sin(\theta)\cos(\psi) \\ \cos(\theta)\sin(\psi) & \cos(\varphi)\cos(\psi)+\sin(\varphi)\sin(\theta)\cos(\psi) & -\sin(\varphi)\cos(\psi)+cos(\varphi)\sin(\theta)\cos(\psi) \\ -\sin(\theta) & \sin(\varphi)\cos(\theta) & \cos(\varphi)\cos(\theta) \end{bmatrix} \begin{bmatrix} V_{x,a} \\ V_{y,a} \\ V_{z,a} \end{bmatrix}$$

ULTRASONIC WIND SENSOR

- ACOUSTIC RESONANCE MEASUREMENT
  - Unbounded horizontal plane allows air to flow freely
  - Vertical plane bounded by an upper and lower reflector and negligible air flow
  - Acoustic (ultrasonic) waves generated and received by three vibrating diaphragms
  - Reflected waves combine to create a quasi-standing wave which, in the horizontal, behaves as a 2-dimensional radial traveling wave
  - A net phase difference results from airflow between each pair of diaphragms
  - Vector combination of airflow components yields wind speed and direction



- ACOUSTIC RESONANCE ANEMOMETER
  - No moving parts
  - 100 grams
  - 0 – 75 m/s
  - 10 Hz data update

EXISTING SCALAR SENSORS

- RESISTOR TEMPERATURE DETECTOR
  - Range: -50 – 100 °C
  - Accuracy: +/-0.1 K
- CAPACITIVE HUMIDITY SENSOR
  - Range: 0 – 100% RH
  - Accuracy: +/-0.8% RH