Development of a Meteorological Sensor Suite for Atmospheric Boundary Layer Measurement Using a Small Multirotor Unmanned Aerial System

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ABSTRACT

Small unmanned aerial systems (sUAS) are increasingly being used to conduct atmospheric research. Because of the dynamic nature and inhomogeneity of the atmospheric boundary layer (ABL), the ability of instrumented sUAS to make on-demand 3-dimensional high-resolution spatial measurements of atmospheric parameters makes them particularly suited to ABL investigations. Both fixed-wing and multirotor unmanned aircraft (UA) have been used for ABL investigations. Most investigations to date have included in-situ measurement of thermodynamic quantities such as temperature, pressure and humidity. When wind has been measured, a variety of strategies have been used. Two of the most popular techniques have been deducing wind from inertial measurement unit (IMU) and global navigation satellite system (GNSS) calculations or measuring wind making use of multi-hole pressure probes. Derived calculations suffer from low refresh rates and multi-hole probes have a finite cone of acceptance for flow angles and are limited in accuracy below a minimum requisite velocity. Hence, a hovering multirotor UA, conducive to making measurements at a specific point or within an obstacle-laden environment, may not be able to accurately measure modest atmospheric winds. This work details the development of an instrumentation suite for the measurement of thermodynamic atmospheric parameters and 3-dimensional atmospheric winds using two orthogonally mounted acoustic anemometers, along with the ability to telemeter data, while hovering.

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3-D WIND MEASUREMENT

- ACOUSTIC RESONANCE TECHNOLOGY
  - Unbounded horizontal plane allows air to flow freely
  - Vertical plane bounded by an upper and lower reflector and negligible air flow
  - A standing wave is resonated in the measurement cavity
    - high signal-to-noise (S/N) ratio, immune to vibrations and external acoustic noise
  - Wind speed and direction is discerned from the phase change of the acoustic signals
    - calculated independently of air pressure, temperature and humidity
  - 2 sensors mounted orthogonally inform the measurement of a 3-D wind field

Figure 1. Pole mounted acoustic resonance anemometer by FT Technologies that is used to measure horizontal (u,v) wind components.

THERMODYNAMIC MEASUREMENTS

- RESISTOR TEMPERATURE DETECTOR
  - Range: -50 – 100 °C
  - Accuracy: +/-0.1 K
- CAPACITIVE HUMIDITY SENSOR
  - Range: 0 – 100% RH
  - Accuracy: +/-0.5% RH
- PRESSURE SENSOR
  - Range: 10 to 1200 mb, -40 – 85 °C
  - Resolution: 10 cm

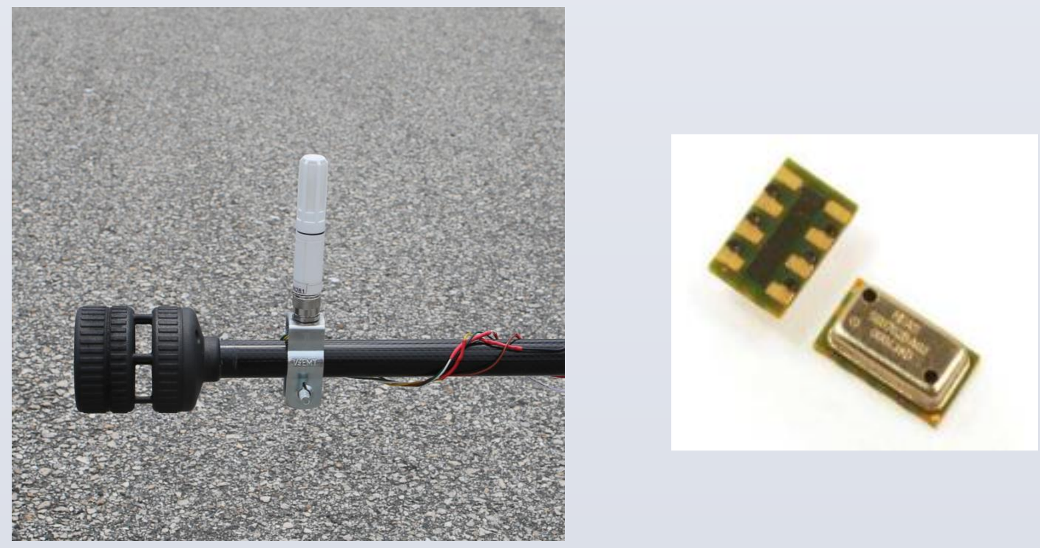


Figure 2. (a) Boom mounted acoustic resonance wind sensor that measures the vertical (*w*) wind component, along with the adjacent mounting of the HygroClip HC2A-S for thermodynamic measurements and vertical flux calculations; (b) barometric pressure sensor.

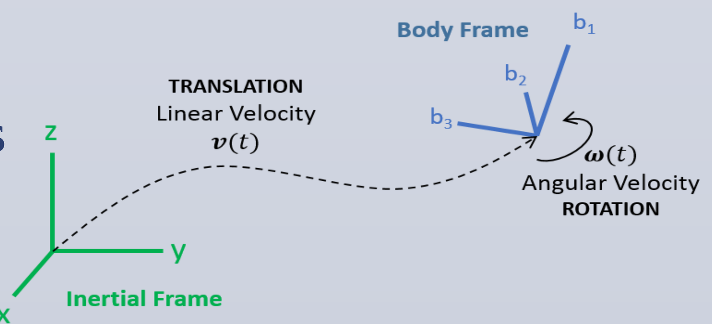
MICROCONTROLLER AND TELEMETRY

- ARDUINO MEGA MICROCONTROLLER
  - Establish and control communication between all sensors using UART
  - Supply required voltage
- 3DR RADIO TELEMETRY MODULE SET
  - Operating frequency: 915 MHz
  - Transmitted power: Up to 20 dBm (100 mW)
  - Air data transfer rate: 250 Kbps
  - 300 m range

Figure 3. Pixhawk flight controller, sensor suite microcontroller, and telemetry.

DATA REDUCTION

- Goal to make the sensor suite aircraft agnostic (no use of UA bus parameters)
  - Use ancillary IMU and GPS to produce Kalman filtered velocity; roll, pitch, yaw angles
- Wind velocity vector must be resolved from the wind sensor measurement signal
  - Transformation from the sensor to the body to the earth frame of reference



SYSTEM

- Hosted on a DJI S1000 octocopter
- Sensors mounted to two 1 m carbon fiber booms that extend sensors 150% beyond the observed rotor-induced flow field in order to sense the ambient atmosphere
- Ample payload capacity for future sensor expansion
  - LiDAR, thermal

Figure 4. Fully instrumented unmanned aircraft. microcontroller, power supply, data storage and telemetry are centrally located with all meteorological instruments mounted on booms: (a) on the ground; (b) in the air.

FUTURE WORK

- Atmospheric boundary layer
- Urban flow
- Marine boundary layer
- Wind turbine array boundary layer
- Microclimates