UAV-deployable Sensor Packages for the Measurement of Hydraulic Parameters

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Outline

• Introduction
• Development of UAV Delivery Systems
• Stage Sensor
• Rain Gauge Sensor
• Power Consumption Challenges
• Conclusion
Purpose

Develop drone-deployable sensor packages for monitoring hydraulic and environmental parameters during wet-weather emergencies.
Introduction: Stage Sensor

• Stage sensor: device used to measure vertical water height
  • Ultrasonic, radar, pressure

• Main types:
  • stilling well (A) – gage established at water table to measure stage
  • bubble gage (B) – gage uses submerged pressure sensor to determine stage
  • rapid deployable gage (C) – emergency gage measures stage using radar

• Existing stage sensors are large, permanent, expensive

Introduction: Rain Gauge

• Rain gauge: device used to measure precipitation
• Main types:
  • weighing bucket collector (A) – spring measures weight of water
  • tipping bucket collector (B) – two buckets pivot to complete a circuit, which causes the pen to write on the moving drum
  • float system (C) – a float rises with the water level
• Bulky, lots of moving parts

Development of UAV Delivery Systems
Experimental Setup: Deployment and Retrieval Flight Test
Flight Test Video
Development: UAS Platform

<table>
<thead>
<tr>
<th>Electropermanent Magnet #1</th>
<th>Electropermanent Magnet #2</th>
<th>Sensor Package</th>
<th>UAS</th>
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<tbody>
<tr>
<td>Unmagnetized</td>
<td>Magnetized</td>
<td>Attached to UAS</td>
<td>At delivery</td>
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<tr>
<td>Magnetized</td>
<td>Unmagnetized</td>
<td>Attached to structure</td>
<td>Package deployed</td>
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- Electropermanent magnet #1
- Electropermanent magnet #2
- Docking platform
- Electropermanent magnet #1
- Sensor package frame
- Ferromagnetic material
Ceiling Effect

- Lift increases as a UAV flies near the ground or ceiling
- Air pressure between the rotors and ceiling decreases
- The UAV will get “sucked” upwards

Control Scheme

Mission ID
Filtered Drone Position

if ID=1
if ID=2
if ID=3
if ID=4

Mission 1
Mission 2
Mission 3
Mission 4

Does drone position equal desired position
Does drone position equal desired position
Set desired position to safety exit point
Set desired position to land

yes no
yes no

Update desired point
Update desired point

Desired Position

Modeling of Ceiling Effect

- Ansys CFD model
- Simulates a propellor in a closed boundary surface
Results

- Velocity profiles were found at set distances from the ceiling.
- Velocity at the ceiling increases as distance from ceiling decreases.
- Thrust force increases as distance from ceiling decreases.
Experimental Setup
Stage Sensor
Hardware Design Goals

1. Low cost per unit ($200) ✔
2. Portable size suitable for UAV deployment (0.5 kg) ✗
3. Low power operation (1 week of operation) ✗
4. Wide range of operating conditions (winds up to 20 km/h) ?
5. Wireless data transfer (100 meters) ✔
6. Comparable accuracy to existing USGS sensors (3 mm) ✗
7. Battery power monitoring (± 5%) ✗
Hardware Design: Stage Sensor

- Microcontroller based
- EPM allows drone deployment
- Ultrasonic sensor measures stage
- Solar cell helps power package
- 0.83 kg
- Measures up to 4 meters
Package Features

• Teensy 4.0 microcontroller
• EPM V3 R5C electropermanent magnet
• HCSR04 Ultrasonic distance sensor
• Micro SD Card data logger
• DS3231 real time clock
• ADS1115 battery voltage monitoring
• nRF24L01+ wireless RF communication
• GUI integration
• Packages are relatively uniform, just swap sensors
Software

- Arduino language is used for the microcontroller
- Basic data logging processing
- Data is sent wirelessly to a GUI for user access
Sensor Verification

![Sensor Verification Diagram]

- True Distance
- Sensor Measurement

![Sensor Verification Image]

- 16" clamp
- Collar
- Ultrasonic Sensor
- Position markers
- 10" clamp
- Ultrasonic Sensor
Field Results

- Sensor package data verified against existing USGS bubble gage data
Rain Gauge
Hardware Design: Rain Gauge

- Counts the number of individual rain drops per area
- Funnels drops to electrodes and does a binary count
- Same PCB can be used
Design Parameters

• World’s maximum rainfall in one hour: 30.5 cm
• The system must process 1 mL of water every 7.75 seconds
Field Testing

• Tested during a rainfall event in Columbia SC, March 26, 2021
• Higher resolution
• Similar results despite a 1/2-mile separation
• Next step: integrate mobile PCB electronics and test next to USGS rain gauge to correlate
Power Consumption Challenges
Power Down Mode

• Idea: use transistors to switch off the sensors on the PCB, excluding the Teensy 4.0 and the nRF24L01+ wireless communication module

• Physical switches were used to simulate transistors
Power Draw

- 0-30, 60-90 seconds: modules are on
- 30-60 seconds: modules are off
- Total power conserved: 0.055 Watts
Current Consumption

- Teensy is most power consuming device

Total draw: 120.9 mA
Ideal lifespan: 12.4 hours

Total draw: 39.92 mA
Ideal lifespan: 37.6 hours
Conclusions

• UAVs can deliver packages despite ceiling effect
• Stage sensor and rain gauge provide accurate readings of hydrologic parameters
• Need to reduce power consumption
• Use solar panels to prolong battery life