Small Stream Hydrologic Monitoring Using Outdoor IoT Technologies: A Pilot Project at Clemson University

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Motivation and Focus
- Accurate, low-cost, resilient, near real-time water quantity and quality monitoring systems

Sensor Network Components
- Anatomy of sensor network

Remote Sensing
- Non-contact water level sensing

Clemson University Hunnicutt Creek Test Bed
- Comparison of three level sensing technologies
- Level data throughout a rain event

Outline
Motivation

South Carolina is enduring some of its worst flooding from Florence, more than a week after it departed.

Under calm, blue skies, eight days after Florence's final drops rained down, parts of northeast South Carolina and southeast North Carolina are experiencing devastating flooding from the long-departed hurricane. Entire communities are underwater as some rivers continue to rise.

Carolina's Precipitation Patterns & Probabilities: An Atlas of Hydroclimate Extremes

1998-2002 Drought

Beginning in 1998, many areas in the Carolinas experienced several years of below-normal precipitation; precipitation deficits over the next four years were among the largest ever recorded. The meteorological drought quickly became an agricultural one: farmers and foresters were particularly affected. The prolonged duration of the drought had severe hydrological effects, with the cumulative shortfall of precipitation resulting in record lows for streamflows, groundwater levels, and reservoir storage.
Anatomy of a Sensor Network

**SENSE**
- Non-contact sensing when possible.
- High accuracy, low cost, low power.

**EMBEDDED PLATFORMS**
- Low power, networked embedded computing platforms

**DEPLOYMENT SYSTEMS**
- Enclosure/Battery/Power systems are key to long-term, low cost deployments

**NETWORKS**
- LPWAN
- LoRaWAN/Sigfox
- CAT-NB1/CAT-M1

**DATA STORAGE AND ANALYTICS**
- Location-aware sensor data storage linked to detailed metadata about sensor and deployment systems

**PEOPLE**
Remote sensing of water level has distinct advantages over direct, contact sensing. Sensors placed above water bodies should be able to last for years without human intervention. New sensor advances in distance sensing are lowering the cost of accurate water level measurement.
A commercial LoRaWAN gateway has been deployed to serve the campus sensing community. Redundant gateways are planned.

Approximate LoRaWAN network coverage live at Clemson.

LoRaWAN Gateway
Headwaters Ultrasonic Ranging Sensor

MaxBotix Ultrasonic Level Sensor
Headwaters Ultrasonic Ranging Sensor

MaxBotix Ultrasonic Level Sensor

**Ultrasonic Level Sensor Example**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td><strong>Range</strong></td>
<td>~5 – 10m</td>
</tr>
<tr>
<td><strong>Reported Accuracy</strong></td>
<td>± 2-5mm</td>
</tr>
<tr>
<td><strong>Observed Accuracy</strong></td>
<td>± 5mm</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>$140</td>
</tr>
<tr>
<td><strong>Potential Issues</strong></td>
<td>Temp Stability</td>
</tr>
</tbody>
</table>

![Graph of Ultrasonic Sensor Data](image)
**LiDAR Level Deployments**

LiDAR Level Sensor
LiDAR Level Deployments

### LiDAR Level Sensor Example

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>~4m</td>
</tr>
<tr>
<td>Reported Accuracy</td>
<td>± 2.5mm</td>
</tr>
<tr>
<td>Observed Accuracy</td>
<td>± 2.5mm - ± 10mm</td>
</tr>
<tr>
<td>Cost (with case)</td>
<td>$20</td>
</tr>
<tr>
<td>Potential Issues</td>
<td>Light Interference</td>
</tr>
</tbody>
</table>

![LIDAR Sensor at New Newman Road](image)

**LiDAR Level Sensor**
Radar Deployment

77 Ghz Radar Level Sensor
Radar Deployment

**Radar Level Sensor Example**

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<thead>
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<tbody>
<tr>
<td><strong>Range</strong></td>
<td>~10m</td>
</tr>
<tr>
<td><strong>Reported Accuracy</strong></td>
<td>± 3mm</td>
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<tr>
<td><strong>Observed Accuracy</strong></td>
<td>~ ± 5mm</td>
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<tr>
<td><strong>Cost</strong></td>
<td>~$300</td>
</tr>
</tbody>
</table>

**77 Ghz Radar Level Sensor**

![RADAR Sensor at Old Stadium Road](image_url)
Radar Data with Rainfall

RADAR Sensor at Old Stadium Road

NEXRAD RAIN DATA
What about the data?

Location-aware data storage and analytics with extensive Metadata that describes all aspects of the sensors and deployment Systems.
Current Efforts

- Developing rating curves and modeling water flows with PCSWMM
- Testing radar-flow based methods to automate rating curves
- Deploying 25 additional water level sensor nodes and water quality sensors in the testbed
- Determining packet loss and optimal sampling frequency
- Validating accuracy with pressure transducer loggers
- Using LiDAR UAV based terrain models to visualize surface hydrology
Questions ?