Deployment of an Autonomous Sensor Network for Remote Sensing Applications

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Abstract

Airborne and space borne remote sensing platforms often incorporate in-scene ground truth measurements as a means of calibration and increasing the robustness of the model used to extract information from the imaged scene. In large scale experiments it is often impractical to utilize human observers for ground truth measurements due to temporal and physical restrictions. A properly equipped in-situ sensor network has the ability to replace human observers and provide a rich stream of data autonomously which can later be utilized to enhance the product produced from the remote sensing platform.

The Laboratory for Imaging Algorithms and Systems (LIAS) along with the Digital Imaging and Remote Sensing Lab (DIRS) at the Rochester Institute of Technology (RIT) have designed and deployed a simple network of autonomously reporting sensors to support a cold weather power plant modeling effort currently underway funded by the US Department of Energy's (DOE) Savannah River National Lab. Commercial off the shelf equipment (COTS) was utilized to rapidly deploy a network that was survivable in harsh winter conditions and have the ability to report key measurements important to the development of the DOE's model.

Keywords: remote sensing, thermal imaging, ice thickness measurement, hydrodynamic modeling, COTS, rapid deployment

1 INTRODUCTION

Remote Earth observing systems are used daily by many people around the globe and are tasked to provide data for applications such as weather prediction, forest fire detection and general intelligence gathering for commercial and military applications. Many of these systems have complex sensing capabilities that extend beyond what is easily comprehended by a human observer looking at the raw data produced by the sensor. Computational models are often employed as a method of reducing raw data from multiple modalities to produce an end data product that a user can easily interpret to aide in a decision making process.

The development of models to be applied to raw remotely sensed data is an intensive task that often requires direct physical observation of various parameters contained in the scene during the time the area was imaged. Traditionally, human observers perform measurement tasks during an overpass; however this methodology often becomes impractical in certain situations such as a long running modeling effort in a remote location and/or one requiring a large and dense point cloud of ground measurements. A carefully designed network of simple ground sensors can be deployed in the scene being modeled to provide a constant observation of measured parameters independent of the possibility of a human observer's ability to be at the scene.

2 BACKGROUND

2.1 Motivation

The effectiveness of a power generation site's cooling pond has a significant impact on the overall efficiency of a power plant. The ability to monitor a cooling pond using thermal remote sensing, coupled with hydrodynamic models, is a valuable tool for determining the driving characteristics of a cooling system. However, the thermodynamic analysis of a cooling lake can become significantly more complex when a power generation site is located in a northern climate. Once the lake is partially or fully frozen, the predictive capabilities of the hydrodynamic model are weakened due to an insulating surface layer of ice and snow. In order to investigate the thermodynamic phenomena occurring within the cooling pond a two-branched data collection campaign, aerial data collection and ground data collection, was designed and launched. Due to the extreme environmental conditions present on a lake during winter, it was crucial to develop an autonomous ground data collection system. The designed system was required to be capable of continually collecting thermal data in the lake as well as weather data on shore when environmental conditions prevented personnel from physically accessing the lake. To satisfy these requirements five lake buoys and a stationary weather station were constructed and deployed [1].

2.2 Aerial Imaging System

The LIAS laboratory designs, constructs and flies its own aerial imaging systems. For the DOE program, its flagship sensor, the Wildfire Airborne Sensor Program (WASP), was chosen to provide aerial infrared imagery of the cooling lake to be used in the modeling effort. WASP, shown in Figure 1, is a high performance multi-spectral aerial mapping system with broad band imaging capability in 3 reflective and emissive bands of infrared along with high resolution coverage of near IR, red, green and blue regions of the spectrum. The system utilizes a high performance GPS/Inertial navigation system to tag the location of each exposure station allowing direct georeferencing of all the imagery to a typical absolute spatial accuracy of about 0.5 meters.

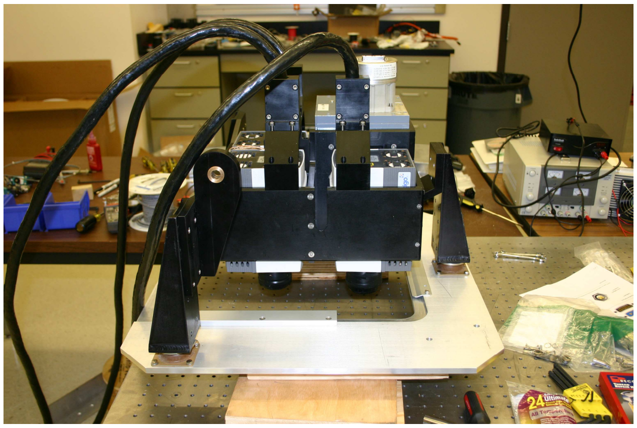

Figure 1 - WASP Sensor Head

To support the DOE program, WASP was upgraded by LIAS to carry two thermoelectric plate black body reference sources shown in Figure 2 that are imaged at various times during the mission. The calibration sources provide a means of performing non-uniformity corrections and calculation of the sensor reaching radiance observed by the midwave and longwave imagers in the system. An accurate temperature measurement of an object in the scene with a known emissivity can be applied to the collected thermal imagery to create a fixed emissivity temperature map which can be then used by the model. Water makes an acceptable calibration target given the large thermal mass and relative uniformity over localized areas; for this project data from both the in situ autonomous sensors and manual measurements of the water's surface temperature will be used to help remove atmospheric effects and calibrate the thermal imagery gathered by WASP.

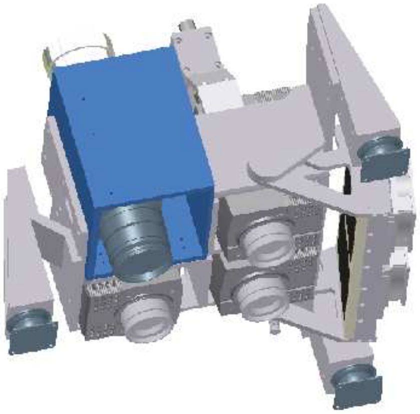

Figure 2 - WASP sensor rendering with swing-in black body calibration sources

2.3 Ground Based Measurements

Two key inputs to validate the model for a cold weather power plant are a vertical water column temperature measurement and the thickness of any ice layer that has formed at various locations across the cooling lake. These measurements are desired to be observed at a fairly high temporal rate which lends itself to some sort of autonomous system performing the collection. It was decided that a network of floating observation buoys would be designed to make these observations at discrete locations in the cooling lake.

Local weather is another variable that contributes to the effectiveness of the model. A high precision in-situ weather monitoring station was constructed to provide metrological data for the experiment. The station was placed on the same network infrastructure as the buoy network; this allowed the data from all of the ground-based sources to be easily aggregated into a single location.

3 DESIGN REQUIREMENTS

Schedule and survivability were two key considerations that drove many of the design decisions for the autonomous ground stations. Due to program scheduling, there was only a 6 month window to design and implement a full collection system/network before the first collection campaign was scheduled to occur. The LIAS laboratory has previous experience in the design, implementation and deployment of custom ground based sensing and logging systems for specialized applications, however, very little background in networking these systems. A new electronics package would have to be developed to support the enhanced functionality.

The very nature of the environment in which the experiment was to be conducted drove many of the mechanical design decisions. Any site chosen to be observed for the winter would subject any sensor network to extremely cold, windy and snowy weather along with the hazards of ice formation as the cooling pond undergoes cycles of freezing and thawing. The autonomous sensor network would have to measure two parameters at various locations on the cooling lake, the thickness of any ice that has formed and a vertical water column temperature profile from the surface to near the bottom.

Gathering meteorological measurements at the site is a much simpler problem to solve compared to the efforts required in the development of the buoy sensors. Commercial weather components are readily available and proven to be reliable in various weather conditions. In addition to the typical temperature, wind, pressure, humidity and precipitation measurements, sensors will also be required to observe the downwelling radiation in both the shortwave and longwave infrared portions of the spectrum. It is also desirable that the weather station utilizes the same network infrastructure as the buoys for reporting its observed data to simplify the infrastructure.

4 IMPLEMENTATION

Given all of the requirements for the autonomous sensors, a design was developed that utilized many commercial off the shelf components to save development time. The buoy was designed around using a 2’x3’ dock float as a platform from which to make measurements due to their high buoyancy and durability. The dock float is anchored at the observation location and a series of potted K-type thermocouples are placed at 1 foot increments along the mooring chain to generate a temperature profile of the water column. Automating the measurement of ice thickness required a novel approach; a pole with 42 thermocouples spaced at 1 inch intervals was mounted to the side of the buoy with the goal of observing the air-ice-water boundaries over time and measuring thickness based upon the temperature differential of the water phases along the pole. Structurally, the float is framed out with an aluminum structure with an antenna mast for communications and a NEMA 6P enclosure housing the logging electronics and battery as seen in Figure 3. A large weight was used to help keep the buoy moored in one location while still allowing some mobility given the potential for large ice sheets to push the unit around the lake during periods of freezing and thawing. Given the importance of the data to be gathered and abbreviated testing schedule, individual TidBit temperature loggers from Onset were placed along the mooring chain as a backup measurement method.

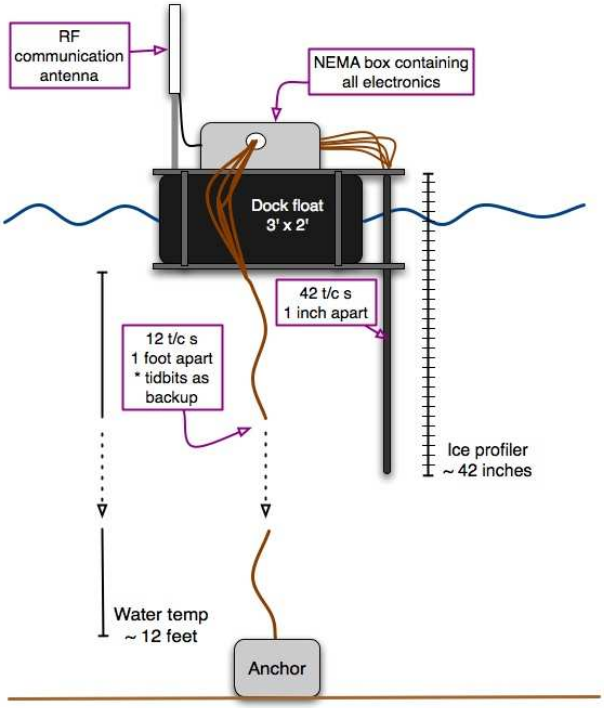

Figure 3 - Layout of autonomous sensor buoy

Given the large number of inputs to be logged and compressed development schedule, a Campbell Scientific Incorporated (CSI) CR1000 with two 25 channel digital multiplexers was chosen as the base controller for the buoy. The CSI logger is COTS solution that is ruggedized, has low power consumption and provides for a rapid programming environment. Each electronics package was also fitted with a Sierra Wireless EVDO modem which interfaced to the CR1000 over a serial PPP connection. The logger natively supports the FTP protocol which was utilized to upload the logged data to a central database at RIT at 12-hour intervals.

Each buoy was powered by a single 12V 18Ah sealed lead acid battery that was sized to last the entire collection season based on the nominal current consumption of all components in the system and the de-rating of the battery’s capacity based on the nominal cold temperature deployment environment. The initial design did not incorporate any solar charging capability based upon the concern for ice buildup and the high number of native birds on the lake obscuring the view of the charging system.

The weather station was built around a CSI CR3000 data logger and commercial precision metrological sensors. Like the buoys, an EVDO modem was included in the sensor package to provide a method of remotely reporting observed data. Eppley Laboratory PSP and PIR sensors were added to the standard weather sensor package to provide measurement of downwelling radiance. The system, seen in Figure 4, receives supplementary power from two solar panels for the logger, sensors and defrosting fans for the downwelling sensors.

Figure 4 - Weather station deployed at site

Based upon the capabilities and features of the CSI loggers, the sensor network was designed using a star topology as seen in Figure 5. Each buoy along with the weather station individually opens an FTP session with a server located at RIT over Verizon's EVDO network and uploads its data twice a day. The server ingests all the uploaded data into a MySQL database, reduces the data, and serves up a dynamic web site for researchers to easily access, search, visualize and download the data.

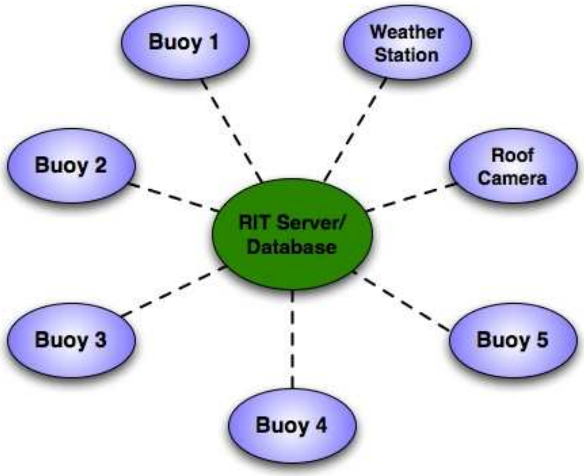

Figure 5 - Network topology of the deployed sensor network

5 DEPLOYMENT

In November of 2009 the sensor network was deployed to the Midland Cogeneration Venture (MCV) power plant in Midland, Michigan. MCV is a gas-fired steam recovery power plant with a closed-circuit cooling lake; it's location in mid Michigan made it an optimal site to use for the model validation experiment. The buoys were placed at discrete locations in the lake and the weather station on the north shore as seen in Figure 6. It was crucial to deploy the buoys before ice began forming on the lake making placement more difficult.

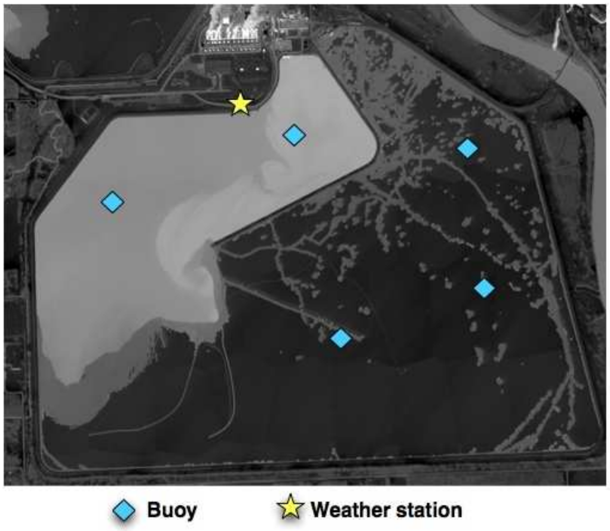

Figure 6 – Sensor Locations overlaid on a WASP thermal image mosaic of the partially frozen MCV cooling lake

A cold December in Michigan prompted early formation of ice on the lake. The artificially elevated lake temperatures due to the power plant's dumping of waste heat aided in raising the relative humidity in areas of open water prompting the development of a thick layer of ice on top of the buoys floating in open water as seen in Figure 7a. Unfortunately a lack of adequate testing time yielded the need to perform service work on the buoys periodically over the winter. Access and maintenance was treacherous by either traversing the ice on foot as in Figure 7b or by a specially equipped airboat capable of traversing both ice and water.

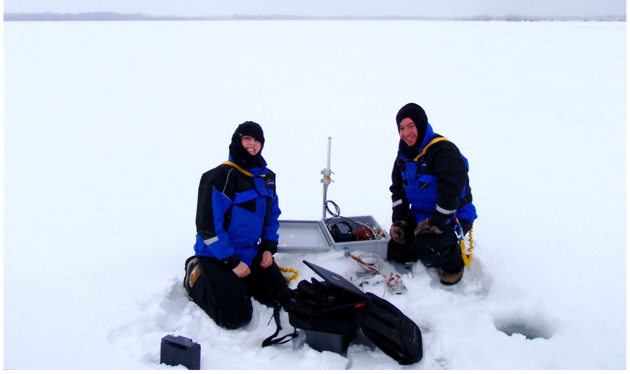

Figure 7a – Deployed buoy floating in open water
Figure 7b – Servicing a buoy froze into 13 inches of ice

6 RESULTS

Many lessons were learned on what it takes to properly deploy a sensor network in a harsh winter environment. Despite a few stumbling blocks and a compressed schedule, meaningful data was collected to start the model validation process. Figure 8 shows an example plot of the ice-thickness profiling sensor as generated by the website. Note the two easily visible inflection points along the curve showing what appears to be the air, water and ice boundary location. Work is currently underway to further reduce and calibrate the acquired data. Many visualization tools were implemented for the dynamic web site as the live data was fed into the database to aid in interpreting the raw data. The reliability of Verizon's network was found to be acceptable, although the project experienced several occasions where connectivity was interrupted or lost. In all, the sensor network successfully performed its intended job and significantly reduced the work load of the team making ground measurements at the site.

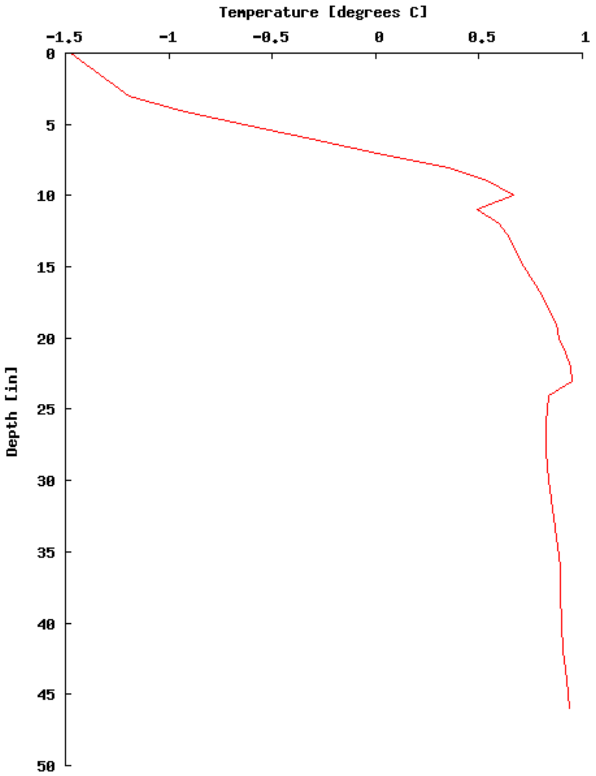

Figure 8 – Depth vs. temperature plot of ice thickness measurement sensor generated by the web site

One buoy's electronics were lost to water damage at some point during its deployment. The initial design of the platform was vulnerable to freezing at an angle; this in combination with the constant freezing and unfreezing of the lake exposed the need for a new method of ensuring the electronics enclosure was subjected to minimal possible submersion.

The buoy sensors were re-deployed in the summer of 2009 with several upgrades and enhancements to support the ongoing collection campaign. As shown in Figure 9, an infrared radiometer, bulk water upwelling pump and GPS unit was added to the sensor platform. The addition of these sensors increased the demand on the buoy's power bus so a larger battery was located in a separate enclosure from the logging electronics and a 12 Watt solar panel was added to maintain uninterrupted operation.

The logger acquisition firmware was upgraded to accommodate the new package of sensors along with increased robustness in dealing with the Verizon network connections sometime spotty availability. Long term flash storage was added to the controller to provide data redundancy and accommodate the data from an increased sampling frequency required for the summer project given the limited internal memory of the CSI CR1000 logger.

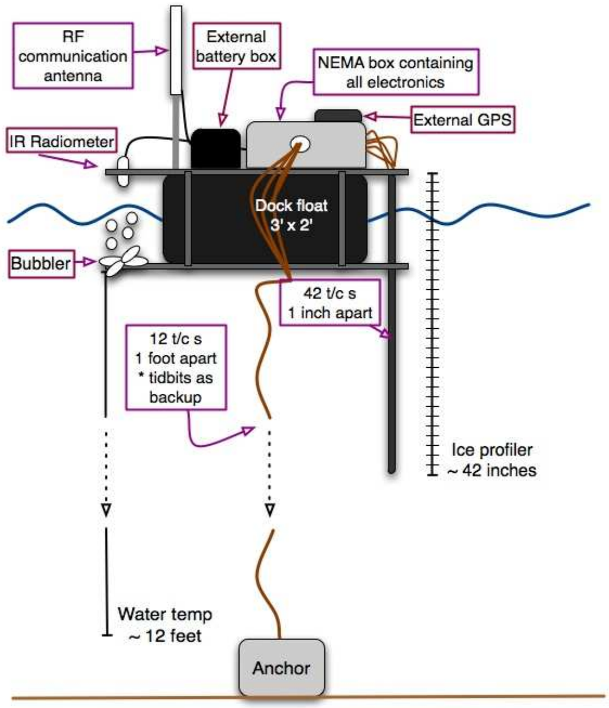

Figure 9 – Upgraded buoy layout for summer deployment

7 FUTURE WORK

The buoys are scheduled to be redeployed during the winter 2009 season in Midland and will undergo another re-design before being tasked. A larger float is being utilized to help stabilize the platform along with a new mooring strategy to help mitigate issues with buoy leveling during freezing and thawing cycles. A 3-axis inclinometer is being added to the suite of sensors to help refine the ice thickness measurement should the profiling sensor end up being frozen in at an angle. The buoy’s firmware will go through another software revision to add in features for redundancy of data transmission over the Verizon network along with several other feature enhancements aimed at making deployment and debugging in the field easier.

A new sensor node will be added to the network for the next winter deployment; a camera with a wide area field-of-view lens and acquisition computer will be set atop a nearby building to observe and estimate the percentage coverage of ice across the lake. This camera will provide a more complete temporal coverage of ice formation on the lake to compliment the aerial imagery from WASP which has a revisit time of approximately 1 week. Human observers stationed at Midland in 2008 observed rapid daily changes in ice coverage on the lake exposing the need for such a sensor to be added to the project.

The roof-mounted camera will utilize the same network structure and data aggregator as the buoys and weather station. An embedded Linux computer will control a 9-megapixel color camera contained in a weather tight enclosure and upload the image data via the Verizon network to the server at RIT for analysis.

8 CONCLUSIONS

A simple sensor network was successfully deployed to take the place of human observers for gathering ground truth data in a remote sensing exercise. The utilization of COTS technology significantly sped up the development process and enabled the deployment of a robust and rugged network. Future work will emphasize enhancements in platform design, survivability and robustness of the network link.

9 ACKNOWLEDGEMENTS

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10 REFERENCES

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