UNIVERSITY OF QUEENSLAND

Adaptive Sensor Network to Monitor Lake Conditions and Detect Weather Events Proposal

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Abstract

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This project aims to create a robust mesh sensor network around the three University of Queensland Lakes. The network will have a user friendly, real-time sensor monitoring software. Long-term data will be collected in an online database and used to assess two adaptive sensing techniques for weather event monitoring. The methods are 1. using local sensor data analysis to identify and select an appropriate sampling frequency and 2. using an external cloud source to preemptively prepare and adapt to abnormal weather events. The aim of the project is to create an energy and space efficient system that adapts the sampling frequency to capture the most relevant data depending on the current weather situation.

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1. Topic Definition

The following section, outlines the intended coverage and contribution of the Lakenet Project as well as the intended approach and outcomes.

1.1 Statement of Purpose

The purpose of the Lakenet Project is to create a real-time adaptive sensor network to assist in weather monitoring and educational purposes. The network will collect weather and lake water metrics suitable for immediate monitoring and long term statistical analysis. With regards to education, the network will primarily be used for the School of Geography for ecological analysis and the School of Information Technology and Electrical engineering for wireless sensor network's course material.

1.2 Goals

The goals of the Lakenet project are to:

- Create a robust 6 node sensor network around the three University of Queensland Lakes.
- Store the collected data in a raw format in an online database.
- Create an online interface to access the real-time data readings.
- Investigate adaptive sensing techniques for weather event monitoring using sensor data and/or external cloud sources.

1.3 Adaptive Sensing

The main point of investigation in this project will be the adaptive nature of the network. In this sensor network, adaptivity relates to the frequency of sampling. There are two main benefits to making this network adaptive.

1. Sampling frequency is directly related to power consumption so a network which samples with low frequency for the majority of the time and high frequency based on event detection will be more power efficient than one with a static sampling frequency.

2. Data collection for long term analysis can easily result in large amounts of uninteresting data. A static sampling rate means that rapid, interesting events are under sampled and slow changes are over sampled.

An adaptive network is well suited to weather related monitoring as there will most likely be slow, cyclical changes in the metrics for the majority of the time until a weather event brings on rapid changes in conditions.

This project will investigate adaptivity based on sensor data, as well as online sources. Using sensor data to decide dynamic behaviour requires an artificial intelligence component to the system. This relies on local data and allows the network to be self contained, however, the event must be detected after it has started which will result in a delay in data collection during each event. Using an online source can counteract this effect as there is notification to the event before its occurrence. This project will investigate both of these approaches and a combination of the two, to optimise weather event detection and ensure an adequate sampling rate during events.

The rate at which to increase sampling can be determined using algorithms to create a continuous set of possible sample rates or past statistical analysis to create a discrete set. This project will examine the benefits of each approach and employ the most effective technique.

1.4 Lakenet Overview

1.4.1 Placement of Sensors

The proposed placement of sensors were selected based on the most interesting features of the lakes. Each lake has a central node to monitor their separate environments. The other two nodes are located on the largest lake. One was selected to be in line of site of the base station, which is also the southern side of the lake. The base station is located in the School of Information Technology and Electrical Engineering. The other two nodes will be located on an inlet to and an outlet from the lake. Each node has been named and numbered for easy of reference. See map in Figure 1.1

FIGURE 1.1: The proposed 6 sensors in the sensor network

For the longitudinal and latitudinal co-ordinates of each node, see Figure 1.2. There is also the length of the lake measured to give scale.

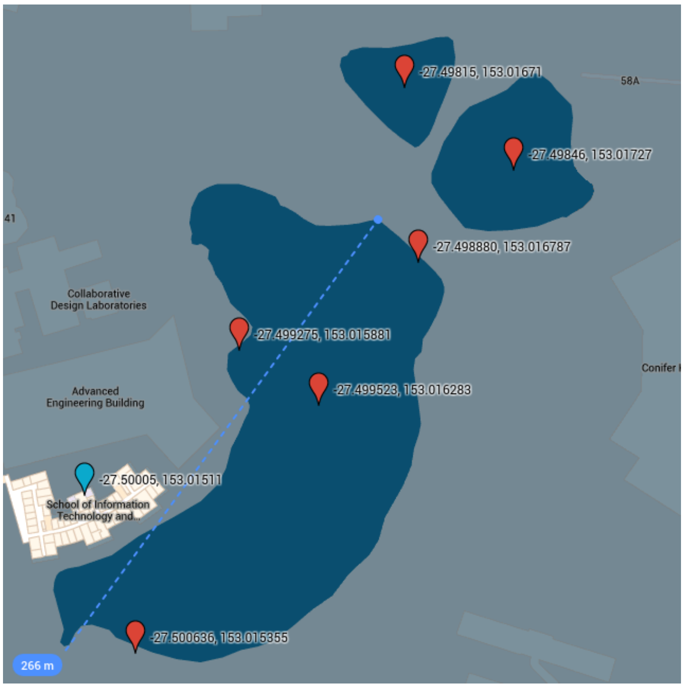

FIGURE 1.2: The proposed locations of 6 sensors in the sensor network

1.4.2 Types of Sensors

The network will primarily consist of elements from the Metronome System. [1]. This includes:

NeoMotes: which are ultra low power motes with wireless communication protocols on board and serial output.

A Network Manager: which is a Linux based, IPv6 equipped manager with automatic networking protocols compatible with the NeoMotes. The manager handles the network configuration, schedules inter-device communication, manages message routes, and monitors network health.

Relay Boards: which are wireless boards that supply 4, 10-bit ADCs to the network.

Solar Chargers: which provide the power source for the outside nodes.

The central node of the largest lake (6. Weather Station) will be a Vaisala Weather station[2]. This node is not part of the Metronome System but is compatible with regards to serial output and networking.

The following table, Table 1.1, outlines the types of nodes in the network.

Table 1.1: Types of sensors and intended metrics

Sensor	**Type of Sensor**	**Purpose/Metrics**
0. Base Station	Network Manager	Linux based data sink
1. Line of Sight	NeoMote	Temperature, humidity, salinity, pH, depth logger
2. Lake Inlet	NeoMote	Water flow, temperature, humidity, salinity, pH
3. Lake Outlet	NeoMote	Water flow, temperature, humidity, salinity, pH
4. Amy Pond	NeoMote	Depth logger, water flow, temperature, humidity, salinity, pH
5. Rory Pond	NeoMote	Depth logger, water flow, temperature, humidity, salinity, pH
6. Weather Station	NeoMote with Vaisala Weather Station	Barometric pressure, humidity, precipitation, temperature, and wind speed and direction

1.4.3 Networking Protocol

The Lakenet Wireless Sensor Network will use the self-organising and self-healing wireless HART protocol. The protocol is ideal as it uses IEEE 802.15.4 compatible radios and operates in the 2.4GHz Industrial, Scientific, and Medical radio band [3] and the network will be used for educational and research purposes.

Each device in the mesh network can serve as a router for messages from other devices. This project will be small so a lot of the benefits from this are not immediately apparent, however, factors such as extended range, redundancy for robustness and ease of adding new nodes are taken into consideration for good scalability.

2. Literature Review

2.1 Wireless Sensor Networks for Outdoor Monitoring

One of the primary uses of wireless sensor networks (WSN) at the moment is outdoor monitoring. This area has many projects researching different aspects of the WSN.

One of the largest WSN is the Trio Testbed, "a new outdoor sensor network deployment that consists of 557 solar-powered motes, seven gateway nodes, and a root server. The testbed covers an area of approximately 50,000 square meters and was in continuous operation during the last four months of 2005" [4]. The test bed is one of the largest solar-powered outdoor sensor ever constructed and was created to test system and application software on such a large scale, namely, robust multi-target tracking algorithms at scale. The Lakenet system, will be constructed to research weather event detection and adaptive sensing, however, it will be on a much smaller scale than the Tio Testbed and more long term. The Trio network found that solar powered nodes were feasible regualarly operating between 20 - 40% duty cycle [4].

There has also been research into the ideal network configuration for specific environmental applications. Monitoring water quality and weather detection is an unusual hybrid, and so combines a few of the requirements explored in Huang-Chen Lee's generalisation of WSN requirements [5]. The most analogous situation is a combination of the requirements for pollution monitoring and landslide monitoring. Pollution monitoring, as it is a long term, slow changing system focused on air quality, vibration, sound, noise and temperature which is parallel to lake metrics of water depth, water flow, temperature, humidity, etc. Landslide monitoring is analogous to abnormal weather event detection as it is long-term and requires a quick identification and response of the network to an event. Both metrics suggest a mesh network with accurate time synchronisation, a small deployment area, long-term deployment with failure tolerance routing. [5] The combination will require not only periodical reporting but also an event report. The frequency of the reporting will have to experimentally optimised but the sampling period expected to be between 1-10 minutes. [5]

2.2 Wireless Sensor Network Protocols

The metronome system utilises the WirelessHART (WHART) protocol [3]. In 2007 the standard was finalized , and in 2010 it was ratified as an IEC standard. WHART utlises IEEE 802.15.4 standard compliant radios and operates in the 2.4 GHz band offering a bit rate of 250 kbit/s [6]. "On top of the physical layer, WHART employs a TDMA-based MAC protocol and additionally performs slow frequency hopping (hopping on a per-packet basis). The frequency hopping pattern is determined from a well-known pseudo-random sequence. The TDMA slot allocation is centrally controlled and slots are assigned at network configuration time" [7]. This makes WHART appropriate for the Lakenet system as the protocol satisfies the requirements outlined by Huang-Chen Lee [5] such as being suitable for a mesh network.

The Lakenet system will be using solar power, and while established as feasible by the Trio Testbed, there were concerns about low duty cycle and abnormal weather events [4]. The WHART protocol generally has low power requirements however, there are measures that can be taken to ensure efficient power usage [8]. "Energy efficiency of a WirelessHART network relies on, to a great extend, the design of the network manager. In a mesh topology, routing and link scheduling will directly affect how quickly the power of a device is drained when it is often used for forwarding data. It is important to avoid situations where some devices become isolated and cut-off from the rest of the network" [8]. In the metronome system, the network manager has pre-installed software to optimise power consumption [1] and thus will not be a focus in this project. Also, because the network is static, i.e. without any moving nodes, there is no risk of node isolation, bar faulty nodal links. These factors should ensure that power consumption should not pose major issues to the project.

2.3 Adaptive Sensing

There has been increasing instances of adaptive WSN over the past decade. This adaptive behaviour takes form in two main ways. 1. identifying redundant nodes and putting them into a passive mode [9][10] and 2. minimising the amount of data transmitted by dynamic compressive sensing and focusing on power consumption and extending the life of the network [11][12]. Neither of these approaches are suitable to the Lakenet project. The first method is suitable for large scale networks which are monitoring abnormal events. The second method focuses on energy efficiency, which while important is not the focus of the network as addressed in Section 2.2, solar power and efficient system management minimises these concerns. Also, with an online database and a longer base sampling period, the benefits from this approach are minimal. As the Lakenet system is a small scale, long term system, with the dual goals of long term metric collection and event detection, the adaptive behaviour will be related to sampling frequency.

There will be two main methods investigated for the host application to base the sampling frequency upon. A cloud base notification, such as from the Bureau of Meteorology website [13]. This allows the system to preempt the arrival of the weather event. The other method to be investigated will be detecting weather events using the local metrics. This is a slower detection method, however, local detection has its merits in being a self-contained system, being able to detect smaller events and portability to other locations and countries without external notification systems.

There is research basing the adaptive nature of the system on overall remaining energy[14]. To find the most efficient sampling frequency, a zero-order hold model has been shown to be effective when using a single varying parameter[15]. However, selecting the frequency at which to sample to ensure both high quality data during normal weather conditions and abnormal weather events is a relatively unexplored topic and will be explored further using results from the testing stages of the project.

3. Project Plan

The following outlines the proposed project milestones, including resources and duration. See Appendix A.

3.1 Key Milestones

3.1.1 Initial Testing of Network

Date/s: 3rd of September - 12th of October 2015

Description: The aims of this stage is to establish and test the mesh network on a smaller scale in a more controlled environment. Communication will be established in an inside environment with a smaller range (max link length within 10 ms).

Resources: The hardware required will be the network manager and a subset of the neomotes (e.g. 4). Software required will be the drivers for the motes and a interface to output raw data.

Deliverables:

- Compiling and programming firmware in a linux environment.
- Two-way communication established with network manager and neomotes.
- Test readings from neomotes outputted in readable format.

3.1.2 Thesis Seminar

Date/s: 12th - 16th of October 2015

Description: An oral presentation describing the scope and relevance of the project, the reviewed literature, and progress made. The presentation will also include justification of the progress made so far.

Resources: The presentation will be oral so the only required resources is a presentation. An optional demonstration would require the hardware and software in section 3.1.1.

Deliverables: A recorded presentation during an allotted time period.

3.1.3 Outdoor Test of Lakenet

Date/s: 12th - 30th of October 2015

Description: This stage involves a short-term test of the network. Over the course of a few hours, the network should be tested for two-way functionality, upload of data to a database and accuracy.

Resources: This stage depends on the completion of deliverables in stage 3.1.1. Also the network will be expanded to the full 6 nodes.

Deliverables:

- Fixing any issues from the initial test in Section 3.1.1.
- Short term data recorded in the online database.

3.1.4 Outdoor Test Deployment

Date/s: 30th of October - 15th of November 2015

Description: This stage involves a long-term test of the network. This stage should be used to assess the behaviour and efficiency of the system over weeks.

Resources: All the hardware and software in the network. The data will be analysed from the database rather than the real-time viewing software.

Deliverables:

- Fixing any issues from the outdoor test in Section 3.1.3.
- Long term data recorded in the online database.
- Weather proof casing and hardware stations completed.

3.1.5 Full Deployment

Date/s: 15th of November 2015 - 15th of February 2016

Description: At the completion of this stage the network should be functioning completely and properly. There should be the identification of abnormal weather events but not necessarily respond appropriately to the event.

Resources: All the hardware and software in the network. Host application should be created but not necessarily complete.

Deliverables:

- Fixing any issues from the outdoor deployment in Section 3.1.4.
- Recognition of abnormal weather events using sensor values.
- Recognition of cloud based event notification of weather events.

3.1.6 Host Application Completion

Date/s: 15th of February - 20th of May 2016

Description: At this stage, the adaptive nature of the network should be tested and refined. There should be an evaluation of online weather notifications against local event detection.

Resources: All resources in Section 3.1.5

Deliverables:

- A real-time user friendly view of the sensor values.
- Long term recorded data including energy consumption, abnormal weather events and typical metrics.
- Response in sampling frequency to abnormal weather events using sensor values.
- Response in sampling frequency to cloud based event notification of weather events.

3.1.7 Thesis Demonstration

Date/s: 27th of May 2016

Description: An interactive presentation describing the outcomes of the project. The presentation will include a demonstration of the project and data collected so far.

Resources: The presentation will be interactive and thus require all hardware and software to be functioning. As a major element of the project is event detection, recorded data demonstrating the behaviour of the system during a weather event is required.

Deliverables:

- A poster outlining the research performed using the provided template.
- Interactive, verbal presentation of project outcomes.

3.1.8 Thesis Report

Date/s: 13th of June 2016

Description: The report is the major means of reporting the contribution of the project. The thesis includes material on the problems and goals of the project, applicable methods, the approach taken, major decisions and the reasons for the selection of goals and methods, results, the extent to which the goals have been achieved, the relevance, importance and context of achievements and the reasons for any shortcomings [16].

Resources: All completed deliverables.

Deliverables: A 70-80 page report written for an audience of peers.

- Create a robust 6 node sensor network around the three University of Queensland Lakes.
- Store the collected data in a raw format in an online database.
- Create an online interface to access the real-time data readings.
- Investigate adaptive sensing techniques for weather event monitoring using sensor data and/or external cloud sources.

A. Risk Assessment

A.1 Laboratory Risk Management

The assigned Thesis Lab (47-401) is a low risk laboratory. The Interactive Design Research Lab (78-105) is low risk. Low risk labs are covered by general OHS laboratory rules. The full management plan is available on the *UQ Risk Management Database*.

A.2 Onsite Lake Risk Management

The project is situated the UQ Lakes which presents its own risks. The following Table A.1.

TABLE A.1: Risk assessment for lake side project

Category	**Hazard**	**Description**	**Risk Level**	**Control Measures**
Electricity	Electric Shock	Electrical devices near water can lead to shock, burns, cardiac events and electrocution.	Medium	Use water proof casing for electronics when on site. Take care when opening water proof casing. Wear rubber sole shoes.
Environmental	Sun exposure	This project takes place during summer. Risks are heat stroke, sun burn and dehydration.	Low	Wear sun screen, wide brim hat, long sleeve shirts and bring water bottle.
Environmental	Water	Risks include drowning and exposure to disease/ bacteria.	Low	Notify another project member when on site. Only members who have adequate swimming ability should leave the path.
Environmental	Storms/ Weather	Risks include wind burn, falls and hypothermia.	Low	Project members should seek shelter during weather events.
Environmental	Animals	Typical animals at the site: fish, eels, ducks, turtles, and bush turkeys. Exposure can lead to disease and/or attack.	Low	Avoid encounters with animal life. Report any hazardous interactions and seek medical advice.
Environmental	Unstable Surface	Surfaces near lakes can be unstable and lead to falls, sprains, abrasions and bruising.	Medium	Wear flat, closed in shoes and stay on stable path wherever possible.

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