[This is a live/working document and the project is open for critique/collaboration. Contact the author jaw224@pitt.edu]

Wildfire Detection Using a Wireless Sensor Network

Submitted to:

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Project Description

Project Start Date:

Fieldwork Start Date:

Fieldwork End Date:

Project End Date:

Primary Fieldwork Location: Deschutes county, Mono Lake

Fieldwork Longitude:

Fieldwork Latitude:

Primary Focus: Research

Secondary Focus: Technology

Lens: National Geographic Wildlife

Field of Study: Engineering: Multidisciplinary

Project Summary

Modern wildfire detection methods are slow, uninformative, and inefficient. First responders stand to benefit from modern data collection and visualization methods. Deploying wireless sensor networks to monitor wildfire prone areas has been studied by academics, however the bridge from academia to the field has yet to be made. This project aims to deploy a system of wireless sensor nodes in an area prone to forest fires. This network of sensors will provide real time data to a computer for analysis. Data processing will dramatically increase fire detection time from hours to minutes. Fed with live, rapidly sampled field data, geographical information system (GIS) software will generate models of the environment based on the data analysis to inform first responders of current fire behavior.

Project success is defined by deploying sensors, analyzing data, and interfacing with first responders. The sensors should be able to function on a network for six months with minimal maintenance. This network should effectively deliver environmental data to a central computer for processing. In order to interface with the first responders, the computer will generate GIS maps for easy data interpreting.

The key to this project is applying wireless sensor technology in the field, culminating in comprehensive information for first responders. Project success results in a process for delivering information from the sensor, into the hands of the fire chief. Connections with wildfire firefighters has been secured in order to consult on the effectiveness of GIS imaging in a live fire application.

Qualifications:

The project leader earned a Mechanical Engineering degree from the University of Pittsburgh. He was an undergraduate research fellow through the Mascaro Center for Sustainability where he collected and analyzed experimental data on 3D printed structures. His research background gives him an understanding of the research process and mindset. During his coursework he built wireless networks using ZigBee communication devices, which is the same hardware that has been implemented for this project. The project leader has years of building with sensors in makerspaces, hackathons, and undergraduate coursework, and understands how to build integrated research processes from the ground up.

Career Goals

I'm passionate about designing and innovating for change. I consider myself a leader and my attention is drawn to the big picture. I am passionate about Engineering and projects. In my career I'd love to be a project leader where I believe I could put my big picture skillset to use. This grant will make this project possible so that I can spend my time passionately innovating for a better tomorrow. This project will allow me to showcase my technical ability, as well as my ability to manage a timeline, process, budget, and people. This addition to my portfolio will open doors for me to work in positions where I can affect positive change.

Total Project Budget: $9,350

Project Details

Background and Relevance

Every year over four million households in the United States are exposed to high or extreme risk of being damaged by wildfires [1]. In 2017, 10 million acres were burned as the result of wildfires. On top of huge monetary costs (over 12 billion in October-December of 2017 alone) these fires are taxing on already limited public resources.

While wildfires do play an important role in the life cycle of many plant species, fires have increasingly been the result of human activity. Fires put protected lands, vulnerable wildlife habitats, citizens, and first responders in the path of catastrophic dangers.

Despite rapid technological advances in academia, modern technology is slow to breach the field of public safety. Historically, wildfire detection occurred through the development and staffing of fire towers. The widespread civilian adoption of cell phones reduced the need for fire tower operation [2.] Civilian reporting is still one of the most functional tools for wildfire detection. Other strategies have been developed including spotter planes, I.R. drones, and satellite monitoring [3.] These methods all have significant limitations with respect to discrete data collection, and sampling frequency. The National Infrared Operations system, for example, flies only once a day and only generates a perimeter geographic information system (GIS) map of existing fires. With so much land at risk of fire, existing systems fail to provide first responders with modern, comprehensive data about the dangers of the area.

In recent decades, wireless sensor technology has been developed and researched extensively in an academic setting. Systems have been designed which describe a mesh of sensor nodes deployed in a wilderness environment [4.] This network of sensors is capable of collecting and relaying discrete, real-time data for a broad region of land. This method of data collection has the potential to revolutionize what field data is available for researchers and first responders. Whereas modern field data collection requires researchers to go into the field, a network of wireless sensors has the capacity to transmit temperature, pressure, relative humidity, wind speed and direction, and other chemical data to a central computer without relying on human resources in the field. With live, time stamped data, the types of GIS models that could be generated would stand to be much more comprehensive and informative. In addition to monitoring the field for environmental factors, the sampling rate of these sensors could detect the ignition of a fire much more rapidly than existing practices. They also offer precise geographic location information on ignition points not available with modern detection.

The types of models generated by a network of sensors would greatly improve the information available to first responders. The live data could be used to feed fire prediction algorithms, allowing new strategies to be developed for fire fighting [5.]

This project aims to bridge the gap between the academic research, and implementation in the field. The goal of this project is to develop the complete process from data collection to delivering models to first responders.
A pilot network is proposed, consisting of three central nodes each equipped with three sensor nodes. This network would be implemented in collaboration with the U.S. Forest Service in order to complete the process from data collection to providing first responders with GIS models.

Goals and Objectives

In order for this project to be successful, an efficient process from data collection to informing first responders must be developed. In the pursuit of this goal, four development sprints have been identified. Hardware development, network deployment, GIS model generation, and data reporting (see methodology.)

Completion of these sprints will manifest in deliverables advancing the overall goal of developing a process for reporting processed data. First, a data set acquired as a result of network deployment will be made available to Forest Service partners. This discrete data will provide information about the area of land monitored by the network of sensors. Second, a collection of automated GIS models based on this data will be curated and made available to collaborating partners. These models will be the result of extensive collaboration and user discovery in order to ensure that models are useful to researchers and first responders. This set of maps will be more comprehensive, updated more regularly, and require less work by human personnel than current maps. Finally, a thorough white paper detailing each development sprint will be written. This white paper will detail the methodology of implementation such that it could be replicated should more networks be deployed.

Methodology

The methodology for this project can be broken down into three main components: hardware, network, and GIS mapping. Each component is based in a different research discipline which requires them to be broken down independently.

Hardware for this project consists of sensor nodes that will be deployed in the wilderness environment of interest. Researchers in Spain, Antonio Molina-Pico et al., detail a methodology in their 2016 paper which consists of central nodes and sensor nodes [4.] A similar hierarchical approach is suggested for use in this project, whereby a pilot network of three central nodes, each equipped with three sensor nodes would be deployed.

Granda et al. propose a design for central nodes to be equipped with an Atmega328 chip to function as the microprocessor; a ZigBee module for wireless data transfer; a GPS module, sensors for temperature, humidity, pressure, $CO2$, $CH4$, CO; and a LiPo battery connected to a solar panel [6.] For the pilot network, the componentry will be mounted onto a breadboard to enable quick design revisions. This project will also implement a wind speed and direction sensor for central nodes, but forego the GPS module. Because nodes will be stationary for the duration of the data collection, the network will include hard coded information about latitude and longitude for each node collected at the time of deployment. Design of the sensor nodes will be similar, but include sensors only for temperature, humidity, and pressure.

Following hardware deployment, a robust network is required in order to ensure seamless data transmission and consistent uptime. The ZigBee devices in each node will be utilized to transmit data between nodes and back to a central processing computer. In 2010 Aslan published a paper which details efficient node placement [7.] This deployment scheme establishes a mesh of nodes, such that no node is isolated. Wenning et al. describe a methodology whereby the network adapts to damaged nodes in order to ensure data transmission [8.] By drawing upon existing scholarly research, it is the aim of this project to establish a pilot network that is fully scalable and maintains robustness.

Once the network delivers the data to the processing computer, modern GIS maps can be rendered using ArcGIS software [9.] Current maps containing fire data rely on difficult to collect data with extraordinarily slow sampling rates. They offer little insightful information to first responders and do not pull from modern data collection methods. Figure 1 (see appendix) is an example of what graphics exist to represent fire danger [10.] Robert Di Paolo, a restoration field technician focusing on the Mono Lake Basin area, cited the Fire Resource and Assessment Program GIS maps as the best GIS data he has been able to find. By feeding the mapping algorithms with live, regularly sampled data, containing discrete information, the maps produced will be more up to date and insightful than existing maps.

Maps will be based on existing maps distributed by the United States Forest Service Wildland Fire Assessment System, as well as information derived by Forest Service partners who will periodically review GIS results of this project [11.] Through a relationship with the Forest Service, the project aims to refine maps based on feedback from professionals about what information is useful (see project members.) By the end of the project, data will be automatically collected, processed, and reported to the forest service partners and first responders.

Methodology Justification

In justifying the proposed sampling design, relevant scholarly research has been referenced and drawn from. The methods proposed are widely accepted and practiced for other applications, and open source documentation for implementing these processes exist for consultation during the project. The project leader has experience designing research including writing documentation for methods, complex data analysis, and reporting findings. The project leader has experience developing circuitry to collect data from sensors, including working with ZigBee modules to transmit data.

Upon successful deployment of the network, project success will depend heavily on generating useful GIS models and getting them into the hands of first responders. In addition to Forest

Service partners, existing maps of fire monitoring are available for reference. By drawing information from a range of sources, a variety of methods of representing geographic data can be generated. From there, it is assumed that successful collaboration with industry professionals will help identify what is useful and what can be revisited.

Summary of Outputs and Results:

This project will establish a mesh of sensor nodes in a wilderness environment to aid data collection. This novel method of collecting field data will allow future researchers in the area to collect a range of information about the area within the mesh. By streamlining the process of data collection, researchers will be able to use the existing sensor nodes to collect more data, faster than they have been able to before.

By collecting live field data over the course of six months using this novel method, an improved understanding of the ecosystem within the network will be acquired. A comprehensive data set will catalogue the changes over the wildfire season experienced in the area of study. This information can be used in following years to inform researchers about the nature of the area. By the end of the project, this data will also be available in the form of GIS maps for easy interpretation and dissemination.

Finally, this project will result in a white paper detailing the methodology for implementing a full scale network of sensor nodes. This paper will outline manufacturing processes for full-scale hardware development, network implementation and comments on scalability and robustness, as well as software for effective GIS rendering based on collected data. Ultimately this white paper will outline a process for establishing a wireless sensor network with useful data terminating at a first responder.

Dissemination of Results

During the data collection period, relevant data and collection methods will be shared and reviewed with Forest Service partners. Once the project is complete, the full data set, including GIS models will be publicly available to local researchers and partners. The established network of sensors will continue to automatically generate the data to continue feeding mapping algorithms. The process for delivering the GIS results will remain in place, with local firefighters set to receive notifications about forest fire detection, as well as up to date environmental monitoring results.

The white paper will be made available to the Forest Service for future network developments and project considerations. It is the aim of this pilot project that funding could be acquired to implement a full scale network to monitor broad swaths of land endangered by wildfires. In alignment with this mission, the white paper will contain all relevant information for future grant writers to prepare documentation for a full scale project. Once complete, the paper should contain sufficient novel findings and methodology to be published in a scientific journal for widespread review and consideration.

Success Criteria

In alignment with the proposed timeline, the following metrics for each sprint have been identified as success criteria.

Hardware development: Hardware components should be sourced, assembled, and communicating between nodes by April 15, 2019. This hardware should be robust enough to meet the project needs of collecting data in a wilderness environment for a minimum of six months with minimal human intervention.

Network establishment: Software should be uploaded to the nodes by April 27, 2019. This network must effectively transmit data from the sensor nodes to the processing computer in under 55 minutes in order to provide a more effective sampling time than exists with modern detection methods.

Node deployment: The fully functioning nodes should be securely distributed throughout the wilderness area of interest no later than April 30, 2019. The nodes must receive adequate sunlight to power the LiPo battery. The placement of each node should be as accessible as possible while still meeting network requirements. In the event that a node requires servicing throughout the duration of the project, the field engineer should not be exposed to unmanageable risk due to environmental conditions.

Data collection: Data collection is expected to occur automatically without intervention. Network uptime in critical during this phase of the project. Success in this stage would be reflected by consistent network uptime, frequent and accurate data sampling, seamless data transmission through the node mesh, and collection by a processing computer. From May 1, 2019 to November 1, 2019, field data should be collected and catalogued for processing and analysis. The data set should provide adequate information to compile comprehensive GIS models.

GIS Development: Collected data should be automatically processed into easily interpreted GIS models. Models should be based on existing methods of representing fire related data. Models should also reflect a collaboration with the Fire Service, such that the new method of data collection results in novel models with real world application for first responders. Forest Service partners will be able to comment on the effectiveness of models produced.

White paper: From December 1, 2019 to January 1, 2020 a comprehensive white paper should be drafted and revised. This paper must outline development and deployment methods such that someone with no technical background could replicate the methodology of this project. The white paper should offer insights into project successes and difficulties. It should offer a process for full scale development of a system to report live field data to first responders through GIS models.

External Capacity Development

This project stands to greatly improve wildfire detection methods. Current detection methods are based largely on human observation and lack discrete data for first responders. The proposed network would more reliably inform wildland firefighters about the location and nature of the area they are responding to. Currently, first responders field calls from civilians who spot smoke from a wildfire and must respond with very limited information. Because of the nature of current field data collection, little to no information is available to first responders about the environmental conditions of the area they are responding to.

The process proposed by this project would greatly improve the information available to first responders. With comprehensive GIS models available at the time of fire detection, firefighters could respond quicker and more deliberately to emergency situations. This increased response efficiency stands to save time, resources, and lives.

Additionally, discrete data for a wide range of wild land could be used in a variety of research projects. While it is outside the scope of this project, advances in neural network analyses of large data sets have proven to be incredibly effective in generating new insights. The sorts of data sets generated by broad networks of sensors may have incredible application to future researchers.

Project Members

Mentor
Name:
Email:
Current Institution:
Department:

Forest Service Collaborators
Name:
Email:

Current Institution:
Department:

Name:
Email:
Current Institution:
Department:

Project Timeline

10/2/2018 - 4/1/2019 Grant Dispersal and Funding
4/5/2019 - 4/15/2019 Hardware Development
4/16/2019 - 4/27/2019 Network Establishment and Testing
4/27/2019 - 4/30/2019 Node deployment
5/1/2019 - 11/1/2019 Data Collection
6/1/2019 - 11/1/2019 GIS development
7/1/2019 - 11/1/2019 First Responder Integration
8/1/2019 - 12/1/2020 White Paper Writing

Project Budget

Total Project Outline

Description	**Justification**	**Total**
Lodging + Food	Food for principle researcher	$2,800
Lodging + Food	Lodging for principle researcher	$2,000
Equipment + Supplies	Research laptop	$1,300
Equipment + Supplies	Central Node Hardware (x3)	$750
Equipment + Supplies	Sensor Node Hardware (x9)	$1,500
Equipment + Supplies	Transportation: Gas	$500
Laboratory Costs	ArcGIS software	$500
Total Project Budget		$9,350

Preliminary node BOM for budget analysis.

Item	Source	Cost
Temperature and humidity sensor	https://www.adafruit.com/product/385	8.96
LiPo battery	Lipolbattery.com	30 ea + 90 shipping
Solar panel	https://www.adafruit.com/product/1525	59
ZigBee + antenna	https://www.sparkfun.com/products/11216	37.95
Atmega	https://www.digikey.com/product-detail/en/microchip-technology/ATMEGA328-PU/ATMEGA328-PU-ND/2271026	1.96
Breadboard	https://www.jameco.com/z/WBU-301-R-400-Point-Solderless-Breadboard-3-3-Lx2-1-W_20601.html	4.95
Wire	https://www.amazon.com/StrivedayTM-Flexible-Electric-electronic-electrics/dp/B01LH1FYHO/ref=asc_df_B01LH1FYHO/?tag=hyprod-20&linkCode=df0&hvadid=194019628201&hvpos=1o1&hvnetw=g&hvrand=7008238163886326678&hvpone=&hvptwo=&hvqmt=&hvdev=m&hvdvcmdl=&hvlocint=&hvlocphy=9033151&hvtargid=aud-467077737785:pla-309338056031&psc=1	16.09 (one time purchase)
Case		$20
Total Sensor Node Cost		162.82
Wind speed sensor	https://www.adafruit.com/product/1733	44.95

Total Central Node Cost		207.77

Funding Sources

National Geographic grant
https://www.nationalgeographic.org/grants/grant-opportunities/

Forest Service grant
https://www.fs.usda.gov/detail/prc/tools-techniques/funding/?cid=STELPRDB5200611

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9. Arcgis mapping software https://www.esri.com/en-us/arcgis/products/arcgis-online/pricing
10. Wildfire maps http://frap.fire.ca.gov/data/frapgismaps-subset
11. Fire metrics and graphs? https://en.m.wikipedia.org/wiki/National_Fire_Danger_Rating_System

Appendix

Figure 1: Existing wildfire management graphic