SMART FOREST MANAGEMENT SYSTEM

THE CAMP FIRE: EXAMINING INFRASTRUCTURE AND REGULATORY FAILURES IN WILDLIFE PREVENTION

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Computer Engineering

By
Johnathan Mirkovich

November 8, 2024

Technical Team Members: Nathan Yu, Sean Mahoney, Quentin Olsen

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISORS

Ben Laugelli, Department of Engineering and Society

Keith Williams, Department of Computer and Electrical Engineering

Introduction

Electrical infrastructure poses a significant wildfire risk in fire-prone regions, especially in areas where poorly maintained or outdated power lines exist (Morgan & Morgan, 2021). In California alone, there have been several catastrophic fires caused by electrical equipment including the 2018 Camp Fire and 2021 Dixie Fire, two of the most destructive fires in the state's history (Western Fire Chiefs Association, 2024). This socio-technical challenge of preventing fires ignited by electrical equipment is crucial to protecting communities, preserving the environment, prioritizing public safety, and enforcing accountability for utility companies who are responsible.

To decrease this risk, a new solution is needed. Current wildfire detection systems that use satellite imagery and ground sensors lack either rapid detection or broad scale monitoring that is needed to detect fires directly along electrical lines. I will develop a sensor based early detection system that is designed to detect fire conditions along power lines in rural areas. By using infrared (IR) and temperature sensors on each power pole, this system will detect fires instantly. It will use continuous, localized monitoring that will benefit environmental agencies, power companies, and communities at risk.

Both technical and social factors contributed to the Camp Fire, so it is essential to analyze how environmental vulnerabilities, regulation practices, and infrastructure maintenance interact together to allow this failure. My STS project will use Actor-Network Theory (ANT) to examine the network of socio-technical dependencies that contributed to the Camp Fire. This analysis will prove that preventing such fires requires coordinated efforts addressing both technical and social factors

Because the challenge of preventing electrical infrastructure fires is socio-technical in nature, it requires attending to both technical and social aspects to accomplish successfully. In what follows, I set out two related research proposals: a technical project proposal for developing The Smart Forest Management System and an STS project proposal for examining these social factors in the case of the Camp Fire.

Technical Project Proposal

Wildfires caused by electrical infrastructure pose a significant risk to forested regions, especially in rural areas where detection and response times are slow. Electrical lines are a common cause of wildfires due to downed lines, vegetation contact, and equipment failures (Morgan & Morgan, 2021). In 2021, the Dixie Fire, the second largest wildfire in California's history, started when a tree fell onto Pacific Gas and Electric (PG&E) power lines, which led to almost one million acres of forest burned. (Western Fire Chiefs Association, 2024). While current fire detection systems, such as satellite imagery, aerial surveillance, and ground-based sensors, offer large-scale monitoring, they lack the immediacy and precision needed to detect fires directly at their source (Carta el al., 2023). A solution capable of detecting fires directly at their point of origin is needed to minimize the risk of fires caused by electrical infrastructure.

Most existing fire detection systems offer either rapid detection or broad scale monitoring, but very few effectively combine both. Broad scale monitoring technology relies on centralized data processing, leading to delayed response times while most high speed response systems struggle with limited coverage in remote terrain (Barmpoutis et al., 2020). Although some IoT (Internet of Things) based systems have been developed for forest monitoring, they are not specifically designed to monitor electrical infrastructure, which is important for targeting these electrical fires at the source. (Ramelan et al., 2021). Given the limitations of current detection methods, a new solution that can provide quick alerts along power lines is greatly needed. A technical solution that directly monitors power lines and provides rapid alerts would benefit environmental agencies, stakeholders, power companies, and most importantly local communities. This system would reduce critical property damage, environmental harm, and health impacts linked to wildfire smoke.

To address this lack of technology, we propose the Smart Forest Management System, an early warning fire detection system for power companies that have power lines through rural and high fire risk areas. There will be one compact, durable sensor node on each electrical pole, with each node using a Kemet Yageo IR flame detector and an AD7414 temperature sensor to detect both fire and pre-fire conditions. The IR sensor has a scope of up to 90° and monitors thermal change down the electrical line while the temperature sensor acts as a secondary detection mechanism, activating when the threshold temperature is measured at the sensor (Kemet Electronics Corporation, 2020). This dual sensor device is built to ensure reliable detection by allowing the system to monitor the line between each node, providing full coverage of the electrical lines.

This will use LoRa (Long Range) communication technology to transmit data over a large distance with minimal power consumption. Each node will work to form a mesh network, where each node acts as a relay for nearby nodes so they can all share their data with a central control unit at the end of the electrical line via a LoRaWAN (Wide Area Network) protocol. This design will have quick data transmission across large distances and enhance network reliability while maintaining low power output (The Things Network, 2023).

Testing will initially focus on verifying sensor accuracy, signal range, and battery life in a controlled environment before conducting tests out in the forest. Field tests will evaluate the system's performance in real world fire conditions and verify the accuracy of both sensors. Threshold settings will likely need adjustments to minimize inaccurate readings and ensure reliable detection. For communication testing, each node will send a single byte of data down the mesh network to the central unit only if one of the sensors is triggered. To ensure full functionality, each sensor will also transmit a data byte daily to confirm operational functionality. Our goal is to create a prototype with battery life of at least one year, which would allow for long term, low maintenance deployment. Field and controlled tests will assess these metrics, demonstrating the system's effectiveness and value to stakeholders.

STS Project Proposal

The 2018 Camp Fire, which was started by a malfunction in PG&E's electrical infrastructure, became the deadliest and most destructive wildfire in California's history, killing 85 people and destroying over 18,000 structures (Butte County District Attorney, 2020). Investigations concluded that the fire was caused by deteriorating power lines that PG&E failed to upgrade or maintain to withstand environmental risks (O'Brien et al., 2022). This disaster highlighted several socio-technical factors, including aging infrastructure, poor management decisions, and not following protocols which together contributed to this preventable tragedy.

Previous analyses of the Camp Fire have often focused on the aging infrastructure of PG&E along with California's lack of strict regulatory enforcement. Many reports attribute the fire to physical variables such as outdated towers, failure to manage overgrown vegetation, and high wind. Furthermore, investigations exposed PG&E's prioritization of profit over safety. The company was notified that a transmission tower, one over a quarter-century beyond its useful lifespan, was at risk of collapse due to strong winds; the same winds that allowed the fire to spread so quickly (Penn et al., 2019). These analyses normally treat each factor as a separate issue, leading to independent solutions such as stricter regulations and infrastructure upgrades. However, addressing these factors as isolated issues leads to reports overlooking the interconnected dependencies that heightened the fire's risk. A more comprehensive approach will, over time, help create policies that require more urgent infrastructure upgrades, better regulatory oversight, and increased assessments of environmental risk to help decrease the risk of these disasters.

Viewing these factors as parts of a single, interconnected network allows for a stronger understanding of the Camp Fire. The disaster did not start from isolated issues but from a lack of coordination and dependency among key factors where regulatory leniency, environmental challenges, and PG&E's limitations reinforced one another, increasing the risk. For example, California's fines-only approach to infrastructure upgrades allowed PG&E leave its outdated system unaddressed as the company could easily afford the fines (Taylor, 2016). The results of ignoring these interdependent factors can be significant and lead to crucial vulnerabilities that would not be seen. I believe that the Camp Fire was not the result of isolated failures but of a complex network of socio-technical dependencies, where PG&E's outdated infrastructure, failure to manage environmental vulnerabilities, and regulation collectively all led to the conditions of this disaster.

To analyze the Camp Fire's interconnected causes, I will apply the Actor-Network Theory. Created by Bruno Latour, Michel Callon, and John Law, ANT is a framework that examines how networks of human and non-human actors shape outcomes through their interrelationships and dependencies. A key concept in ANT is translation, which is the process by which actors align or fail to align within a network, which directly impacts success or failure (Thrift et al., 2009). ANT emphasizes the role of network builders, who construct heterogeneous networks comprised of human and non-human actors to solve a specific problem. In the Camp Fire case, PG&E acted as the network builder by creating a network of infrastructure, regulations, and environmental considerations with the goal of providing safe and reliable electricity. However, this network failed to align as the aging infrastructure, inadequate regulatory oversight, and unmanaged environmental risks combined to increased wildfire risk.

In regards to the Camp Fire, I will use translation to argue how PG&E's outdated infrastructure, regulation practices, and failure to manage environmental vulnerabilities failed to align towards preventing this disaster (Latour, 2005). An approach that identifies the interdependencies of these causes would allow for quicker identification and keep the electrical companies more reliable. Having a single, unified policy that outlines detailed infrastructure assessments, mandatory safety protocol, and independent audits would help ensure that all factors are aligned towards preventing a fire. To support my analysis, I will use several different sources including Cal Fire's incident reports, California Public Utilities Commission's (CPUC's) regulatory documents, and news reports related to the Camp Fire to support my analysis. Together, these sources will show that the interaction of the different causes of the fire created an interdependent network of vulnerabilities that led to the Camp Fire.

Conclusion

While considering the critical wildfire risk from electrical infrastructure, this prospectus proposes a combination of both a technical and STS project in which to address this socio-technical challenge. The technical project, Smart Forest Management System, is designing an early detection system for rapid, at the source monitoring along the lines of electrical poles in fire prone areas, providing community and stakeholder safety and reliability. The STS project uses Actor-Network Theory to explore how infrastructure vulnerabilities, regulation practices, and environmental influences contributed to the Camp Fire, designing a detailed understanding of how these factors interact with each other to increase wildfire risk.

Together, these projects emphasize that preventing electrical fires require technical improvements along with insight of how different social and regulatory factors work together. By addressing each point, this prospectus outlines a path towards an efficient and coordinated approach in reducing the risk of wildfire across vulnerable regions.

References

Barmpoutis, P., Papaioannou, P., Dimitropoulos, K., & Grammalidis, N. (2020, November 11). *A review on early forest fire detection systems using optical remote sensing*. MDPI. https://doi.org/10.3390/s20226442

Butte County District Attorney. (2020, June 16). The Camp Fire Public Report. https://www.buttecounty.net/DocumentCenter/View/1881/Camp-Fire-Public-Report---Summary-of-the-Camp-Fire-Investigation-PDF/

Carta, F., Zidda, C., Putzu, M., Loru, D., Anedda, M., & Giusto, D. (2023, July 24). *Advancements in forest fire prevention: A comprehensive survey*. MDPI. https://doi.org/10.3390/s23146635

Kemet Electronics Corporation. (2020, September). *SMD I2C Pyroelectric Infrared Sensor Reference Manual*. SMD Sensor Reference Manual. https://www.kemet.com/content/dam/kemet/lightning/documents/ec-content/KEMET-SMD-Sensor-Reference-Manual-V1.2.pdf

Latour, B. (2005). *Reassembling the social: An introduction to actor-network-theory*. Oxford University Press.

Morgan & Morgan. (2021). *How power lines can spark devastating wildfires: Fire lawsuit*. Fire Lawsuits - West Coast Wildfire Damage Attorneys. https://www.firelawsuit.com/latest-news/how-power-lines-can-spark-devastating-wildfires/

O'Brien, W., & Envista Forensics, Inc. (2022, July 6). Root Cause Analyses: 2017-18 Wildfires. https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/safety-policy-division/reports/root-cause-analyses-of-the-2017-18-wildfires.pdf

Penn, I., Eavis, P., & Glanz, J. (2019, March 19). *California wildfires: How PG&E ignored risks in favor of profits*. The New York Times. https://www.nytimes.com/interactive/2019/03/18/business/pge-california-wildfires.html

Ramelan, A., Hamka Ibrahim, M., Chico Hermanu Brillianto, A., Adriyanto, F., Rizqi Subeno, M., & Latifah, A. (2021). A preliminary prototype of Lora-based Wireless Sensor Network for Forest Fire Monitoring. *2021 International Conference on ICT for Smart Society (ICISS)*, 1–5. https://doi.org/10.1109/iciss53185.2021.9533237

Taylor, M. (2016, January 5). *Improving California's Criminal Fine and Fee System*. Legislative Analyst's Office. https://lao.ca.gov/Publications/Report/3322

The Things Network. (2024, March). What are Lora and Lorawan? https://www.thethingsnetwork.org/docs/lorawan/what-is-lorawan/

Thrift, N. J., & Kitchin, R. (2009). *International Encyclopedia of Human geography*. Elsevier.

Western Fire Chiefs Association. (2024, June 25). *The Link Between Power Lines and Wildfires*. WFCA. https://wfca.com/wildfire-articles/power-lines-and-wildfires/