FireCrowdSensing: A Map-Based Web Application for Crowdsensing of Prescribed Fires

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Abstract

Crowdsensing is a promising method for collecting data related to wildland fires due to its combination of accuracy and ease of collection. This paper explores how crowdsensing data for prescribed fires may be collected and categorized to best suit the interests of various technical and general communities and presents a map-based web application dedicated to collecting crowdsensing fire data. The showcased web application allows users to input their own prescribed fire data directly to the database, from where it can be displayed along with other data points on a map and downloaded for personal use. The design of the data categories related to prescribed fires and their metadata is presented along with the implementation of the web application itself.

CCS Concepts

• **Computing methodologies → Modeling and simulation**; • **Applied computing → Environmental sciences**.

Keywords

crowdsensing, wildland fires, prescribed fires, modeling and simulation, web applications

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1 Introduction

Wildfires are natural disasters that are often responsible for significant property damage, destruction of natural resources, and threats to public safety. Recently increasing trends in the number and severity of wildfires worldwide have inspired further research into more efficient ways to mitigate them and to collect more data about them. Besides wildfires, there is also a need to study prescribed fires (also known as prescribed burns or controlled burns), which refer to the controlled application of fire by a team of fire experts under specified conditions to restore health to ecosystems that depend on fire [18]. Prescribed fires can serve multiple purposes, including burning excess vegetation that commonly spread wildfires and promoting the growth of grass to support livestock. Both wildfires and prescribed fires are referred to as wildland fires in this paper.

Data on wildland fires, including pre- and post-fire environmental conditions and information on the fire's spread and area of effect, has proven to be an increasingly valuable resource to technical and general communities alike. Researchers and others in the scientific community can use this data to validate and improve fire simulation models so that they can predict the outcome of wildland fires under hypothetical conditions. Fire managers can benefit greatly from this data as it lets them assess the impacts of fires and plan the best mitigation strategies. When applied to prescribed fires, this data helps landowners and fire operation communities determine whether environmental conditions are safe enough for them to perform prescribed burns. The data can also help fire managers understand the prescribed fires' effectiveness at burning the desired area. Furthermore, wildland fire data is also useful for creating educational resources for the general public and for facilitating public outreach efforts. Government websites like the one for the National Interagency Fire Center use data on the causes and impact of wildfires to better educate the public on ways to avoid accidentally starting wildfires [16]. They also compile the data into easily-understood visualizations to be used for public awareness or specialized education programs.

Despite many benefits of wildland fire data, collecting these data and making them accessible to broader communities have been a challenging task. The current lack of accessible and reusable datasets has proven to be a major problem in the development of more advanced fire simulation models [10]. Collecting integrated data even on planned fire experiments is often difficult due to significant challenges in funding, researcher organization and sensor deployment [12]. Additionally, the collected data may not follow a single standardized format and may require additional potentially resource-intensive steps of quality assurance and processing before they can be used [5]. Particularly for prescribed fires, remote data collection methods often cannot differentiate between a wildfire or

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a prescribed fire, and this makes it harder to evaluate trends in the use of prescribed fires [4].

Developments in crowdsensing methodology can potentially reduce the difficulty of collecting wildland fire data. Crowdsensing refers to the practice of collecting locational data using a large quantity of sensors. Mobile crowdsensing (MCS) is a common variant that derives its data from mobile devices owned by participating users [22]. Similar to crowdsourcing or citizen science, crowdsensing can involve users voluntarily reporting local observations through a mobile application or web portal. However, it is also commonly associated with automatic data reporting from GPS or other sensors on devices owned by consenting users. While crowdsensing data may not always be completely accurate or objective, its low cost and high spatial resolution compared to data from other sources are its best advantages. Previous examples of crowdsensing include mapping urban traffic conditions, disaster management [19], and road quality [6]. This paper explores how crowdsensing may be used for wildland fire data collection, with a focus on data collection on prescribed fires.

To support crowdsensing of prescribed fires, it would be useful to categorize data in an accessible way and support the data with metadata to uphold the FAIR (Findability, Accessibility, Interoperability, Reuse) data management principles. Furthermore, it is important to develop tools that enable data collection from a wild range of potential participants. To this end, we first present a categorization of prescribed fire data and how they may be collected in a crowdsensing environment. Based on the categorization of the data, we then describe the FireCrowdSensing tool, which is a map-based web application that represents an initial effort to enable prescribed fire data collection, data management, and data display. Through this tool, users can input information about local prescribed burns using a data form and make the data accessible for other scientific or data management purposes. Users could also populate the provided input form with images and an embedded video for additional illustration. FireCrowdSensing intends to satisfy the objective of collecting prescribed fire data with crowdsensing by making this process easy for end users and organizing this data in a systematic way. Later, it will be extended with additional features to achieve these objectives more completely.

The reminder of the paper is organized as follows. Section 2 presents some related work. Section 3 describes the categorization of prescribed fire data and how they may be collected. Section 4 presents the FireCrowdSensing web application, and Section 5 concludes this paper.

2 Related Work

Crowdsensing had previously been applied to problems like mapping urban traffic conditions, road quality, and disaster management. Mapping applications like Google Maps have implemented crowdsensing-based features to provide information on traffic congestion and potential road hazards. By taking average speed and location data from Android device users, Google Maps can color-code roads on a map by the amount of traffic congestion. Furthermore, users can easily report the existence of hazards like traffic accidents or speed traps to create or remove hazard indicators for other users that are update in real time. As one of many applications of crowdsensing in disaster management, [19] proposed a mobile application that combines GPS data, smartphone photos, and user-submitted information on environmental or traffic conditions to provide high-level real-time information that can inform disaster managers when responding to earthquakes. Applying crowdsensing to measuring road quality, [6] had shown that smartphones using a dedicated crowdsensing application were able to measure road quality similarly to traditional road monitoring techniques, but users of this application can perform these measurements with none of the professional training or equipment needed. Several projects also used web applications to support crowdsensing. For example, NASA maintains a website that links to a variety of webpages hosting different citizen science projects where users can help with collecting or analyzing data to make discoveries in astronomy, environmental science, and other fields [13].

Collecting wildland fire data has been a challenging task. Data on specific fires are usually collected using an array of remote sensors and unmanned aircraft vehicles (UAVs). As part of the Camp Swift 2014 experiment, [11] provided data collected by grounded and aerial sensors before, during, and after each of the three planned burns. Some fuel data also needed to be measured by manually weighing and drying fuel samples. [11] also described the plan followed by the ignition team to start each fire. [8] argued that collecting wildland fire data with enough detail and supporting it with adequate metadata is essential for its usefulness in evaluating operational fire models, especially as they grow more sophisticated and demand more coordination in their datasets. To that end, [8] designed the Fire and Smoke Model Evaluation Experiment (FASMEE) project to collect integrated observations from large wildland fires and to serve as a template for future wildland fire data collection campaigns.

Several works have shown that wildland fire data can be collected using techniques that are assessible in a crowdsensing environment. [17] found that data derived from temperature and relative humidity sensors on smartphones could accurately indicate significant anomalies in vapor pressure deficit that predict oncoming wildfires. They also advocated for an application that allows smartphone users to report these early environmental warnings similarly to applications that already exist for traffic and hiking. The local temperature and relative humidity data collected in this manner could also be used to assess the safety of conducting a prescribed fire in that area. [3] found a way to estimate canopy fuel load (CFL) by taking photographs from smartphones with fisheye lens attachments and processing the results with a free software tool. The resulting estimations had similar accuracy to other photography-based solutions yet could be obtained much more opportunistically. [7] found success in classifying surface fuel types from horizontal-level forest photography using convolutional neural networks (CNNs). [1] also applied this CNN-based method to roadside forest images from Google Earth. These classifications can be taken from crowdsensing photography and inputted into fuel maps to support predictions of wildfires or prescribed fires.

Several map-based web applications also exist to catalog and display wildland fire data. The National Interagency Fire Center maintains an open data site featuring regularly updated data on wildland fire incidents [15]. The Fire Environment Mapping System provides hourly updates on wind conditions, relative humidity, precipitation, and other relevant pre-fire data as recorded by weather stations across the United States [20]. The Fire Information for Resource Management System (FIRMS) combines data from several satellite data sources to detect active fires in the United States and Canada in real time [14]. More regionally, the California Department of Forestry and Fire Protection provides a map of recent wildfires and prescribed fires [2]. However, due to their usage of low-resolution sources like satellite data, most of these applications do not provide highly detailed information on individual fires and how they influence the environment over time. Furthermore, none of these applications are dedicated to recording prescribed fires, and none of them focus on crowdsensing in data collection. The FireCrowdSensing application presented in this paper is different from existing tools because it is designed specifically for the collection of prescribed fire data through crowdsensing. Currently, there are no other applications that have been made with this purpose in mind. Additionally, crowdsensing data can provide more details at higher resolutions compared to satellite data.

3 Categorization and Metadata for Crowdsensing Data

A prescribed fire is a complex event that is influenced by a variety of factors and generates results (e.g., smoke) that impact the environment. Information taken before, during, and after a prescribed fire must all be considered to fully capture its characteristics. For example, before a fire starts, environmental data like fuel classifications, weather, and terrain conditions can provide useful information for fire managers to assess the risk of spotting fires. When a fire is actively spreading, information about the rate of spread, the number of escaped fires, and the spread process itself can help researchers understand fire behavior and test fire spread simulation models. After the fire finishes burning, additional data can be gained from measuring the completeness of the burn and checking for hot spots and smoldering. The number of hot spots and escaped fires are especially important to record for prescribed fires as they represent the potential risk of uncontrolled burning. Collecting this data is also useful for fuel analysis, identifying early warning signs for wildfires, understanding how an active fire will spread, and predicting the fire's effects on the environment and any nearby communities.

To categorize prescribed fire data in a systematic way, it is important to consider the different factors that influence fire behavior. The three most important factors that influence the behavior of a wildland fire are vegetation, terrain, and weather. Vegetation is described by fuels, which refer to the composite of variables related to the vegetation through which a fire spreads. Fuels can be organized by type and by size. Vegetation data is usually recorded before a fire and several months after a fire to measure fuel consumption [11]. Terrain is described by slope and aspect, where slope is the inclination of a land surface and aspect is the direction the surface faces. Since terrain is unlikely to change between fire incidents, there is not much need to rerecord it in a crowdsensing context. Compared with fuel and terrain, weather is a dynamic factor that changes over time as a fire continues to spread. Wind speed, wind direction, atmospheric humidity, and temperature are major components of weather that can influence fire spread.

While some data can be measured by remote sensing instruments or other sensor devices, other crowdsensing data may be provided by users based on their own observations of a fire. These data are likely to be biased or incomplete. We refer to the data from sensors as hard data and the data from users as soft data. Information like temperature or relative humidity can be comfortably measured by instruments as hard data, but other factors like the fire's rate of spread (ROS) or intensity are harder to quantify exactly in real time. For those factors, users may make either subjective numerical estimations in the case of ROS or categorical ratings in the case of fire intensity. For example, a categorical rating can be done on a three-point scale: "low," "medium," and "high."

Based on the above considerations, this work provides an initial effort to categorize prescribed fire data. Specifically, we group the data temporally into pre-fire, active-fire, and post-fire categories. Each group includes the related data field discussed above, and each field is identified as soft or hard data according to how it is expected to be collected. The pre-fire data refers to the environmental conditions of a fire event before the fire happens, such as vegetation or terrain. Active-fire data concerns the fire's behavior and smoke impact as well as any factors that dynamically influence fire spread (e.g., dynamic wind condition, dynamic fire ignition). Post-fire data characterizes the aftermath of the fire and its immediate impact on the environment. Given a geographical location corresponding to a prescribed fire, this categorization provides information on key pre-fire conditions, active fire data, and post-fire conditions. The categorization also includes a simple metadata format to describe the data pertaining to the fire event.

Figure 1 shows how we organize the prescribed fire crowdsensing data, where event fire event includes four data groups: pre-fire data, active-fire data, post-fire data, and metadata. Each data group includes multiple data points that are called data fields. The underlined values in the diagram represent soft data provided based on participants' personal assessments.

Below we describe each component of the template in detail.

3.1 Metadata

This category describes all the data regarding the creation and nature of the data point. While there exist several well-established metadata formats for documenting professionally-collected geospatial data, we do not expect most users will adhere to those formats in a crowdsensing context. For our purposes, we opt for a comment-based metadata format inspired by [9].

The "Subject" field should briefly summarize the fire event described by the data point. The "Author" field is the name of the author or organization that submitted the data. "Created" and "Modified" refer to the date when the data point was created and the date when it was most recently modified. Lastly, the "Comments" field is intended to be a flexible field where users can write extra information about the data. This can include collection methods, relevant geographical areas, and notes about data modifications or corrections.

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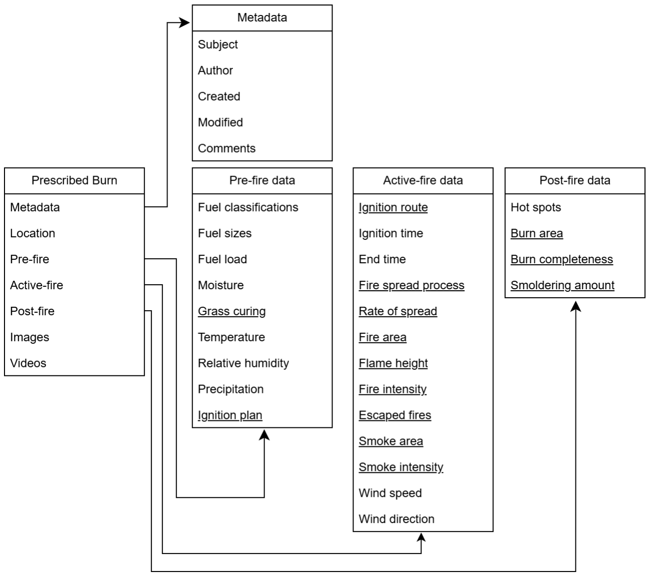

Figure 1: Diagram of the Categorization of Crowdsensing Data

it was most recently modified. Lastly, the "Comments" field is intended to be a flexible field where users can write any information necessary to fully understand the data. This can include collection methods, relevant geographical areas, and notes about data modifications.

3.2 Pre-fire Data

This category contains fuel and environmental conditions recorded before ignition. It has been shown that temperature, relative humidity, and fuel classifications can be measured through sensors and photography from smartphones with little preparation necessary from users. In particular, fuel classifications could be taken automatically from forest photography from specially-equipped cars like the ones used for Google Earth. Measuring other quantities such as fuel moisture or precipitation in a local area would have to be done using dedicated pocket weather meters or other specialized equipment. If necessary, any remaining pre-fire environmental conditions can also be determined from the measurements of local weather stations or satellites. Unless otherwise specified, each field involving geospatial data is defined by taking an average measured across the relevant area; e.g., the "Fuel load" field is understood to be the average fuel load across the area represented by the data point.

"Fuel classifications" consists of four different percentage values estimating the frequency of four major classifications of fuel in the given area. In other words, they measure what percentage of the land consists of grass, shrub, litter, and slash fuels. Similarly, "Fuel sizes" consists of four percentage values, each stating what percent of the land consists of 1-hour, 10-hour, 100-hour, and 1000-hour fuels. Currently, these two fields can be measured manually, but estimations using the previously described smartphone photography techniques could also be viable.

"Fuel load," which measures the amount of fuel in an area in tons per acre, can be measured using either satellite data or ground samplings.

"Moisture" and "Grass curing" are average percentages of fuel moisture and grass curing in the area, respectively. Fuel moisture could be measured with a hand-held weather meter, but grass curing is expected to be assessed as soft data. "Temperature," "Relative humidity," and "Precipitation" can all be measured locally with hand-held instruments as well.

Lastly, "Ignition plan" is a textual description of the planned route for the ignition team(s) to take when they ignite the fire.

3.3 Active-fire Data

The "Ignition route" field is a text field describing the actual route taken by ignition teams, which can sometimes differ from the intended ignition plan. Similarly, the "Fire spread process" field is a textual description of the fire's spread over time, which can include information on the path of the fire front or the trajectory of the smoke plume. "Ignition time" and "End time" are the times at which the fire was first ignited and finished burning, respectively.

While measurements like the fire's rate of spread, fire area, flame height, and the smoke plume's area and trajectory can usually be estimated as soft data, they can be assisted using additional instrumentation or imagery from UAVs. Similar to what is done on applications like Google Maps, we would most likely have to make an estimation based on many user-submitted values for the fire's route, area, height, intensity, and other related data in order to quickly produce crowdsourced measurements.

"Escaped fires" is the number of fires that had escaped the boundaries of the prescribed fire during the burn and needed to be extinguished. "Fire intensity" represents the average amount of heat released by the fire while it is burning, while "Smoke intensity" refers to how thick or heavy the smoke plume is. Both measures of intensity are defined as categorical ratings. Lastly, "Wind speed" and "Wind direction" are average values which can be measured with handheld weather meters. Notes about dynamic changes to wind conditions or any other data field can be included in the "Fire spread process" field.

3.4 Post-fire Data

This category contains relevant data that can be collected immediately after a fire had finished burning. "Hot spots" is the number of spots on the burned area that are still actively burning after the main fire had finished burning. "Burn area" and "Burn completeness" both measure how much of the area was actually burned by the fire. "Smoldering amount" estimates how much of the burned area is still smoldering using the categorical rating discussed above.

4 The FireCrowdSensing Web Application

To enable crowdsensing from a wild range of potential participants, we developed the FireCrowdSensing tool, which is available at http://firesim.cs.gsu.edu:3000/crowdsensing. FireCrowdSensing is a client-server system that was developed using frontend and backend technology similar to what was used for the web application for the DEVS-FIRE model [21]. While users can log in to enable additional functionality, the basic features can still be accessed without logging in. A mobile version of this application will also be produced once the web application is made more robust. We developed the web application first because it is easier for users to navigate the map through a webpage. Our ultimate goal is to support both the web application and a mobile application.

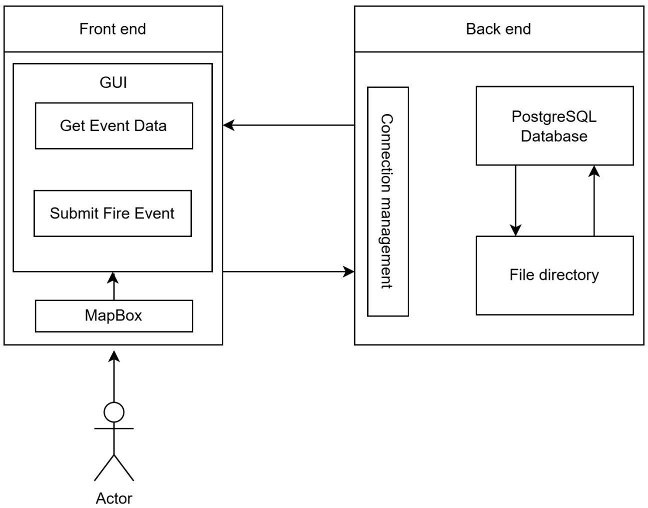

Figure 2: System Architecture Diagram for the FireCrowd-Sensing Web Application

Figure 2 shows the system architecture diagram for the Fire-CrowdSensing web application. Actors on the front end can click "Get Event Data" to view fire events submitted by other users using the map-based GUI powered by the MapBox API. They can also click "Submit Fire Event" to submit fire data to the back end. All event data are stored in a PostgreSQL database, but image and video attachments are stored separately in the server's filesystem. The connection management component handles user authentication as well as the reading and modification of event data.

Figure 3 shows the current version of the main page of the web tool. After clicking "Get Event Data," the map populates with green markers representing reported prescribed burns.

Clicking "Input Burn Information" reveals a form where users can write a description of the burn, attach images, embed a video from either a .mp4 file or a YouTube link, and fill out a form of data pertaining to the burn. Any external files attached this way will be stored on the server. There is also an "Add Ignition Points" button to allow users to draw lines on the map corresponding to the locations and routes of ignition teams in a similar manner to the web application for DEVS-FIRE. To support cases where the user does not know some of the information that the template asks for, it can be submitted while it is still incomplete. Note that the form will be updated in the future so that the data is organized according to Figure 1.

In addition to submitting data, users can click on individual points to reveal the data and metadata corresponding to them. This view will also display any attached images or videos.

Users can also filter the displayed data by specifying which user to seek data from, defining limits for most or least recently created

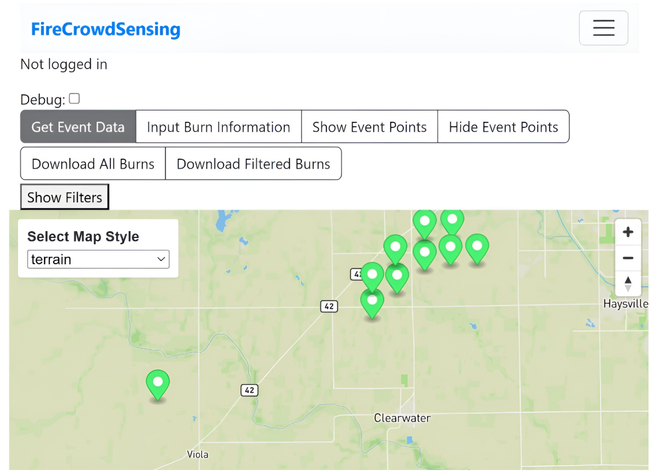

Figure 3: FireCrowdSensing Map Populated with Example Prescribed Burn Reports

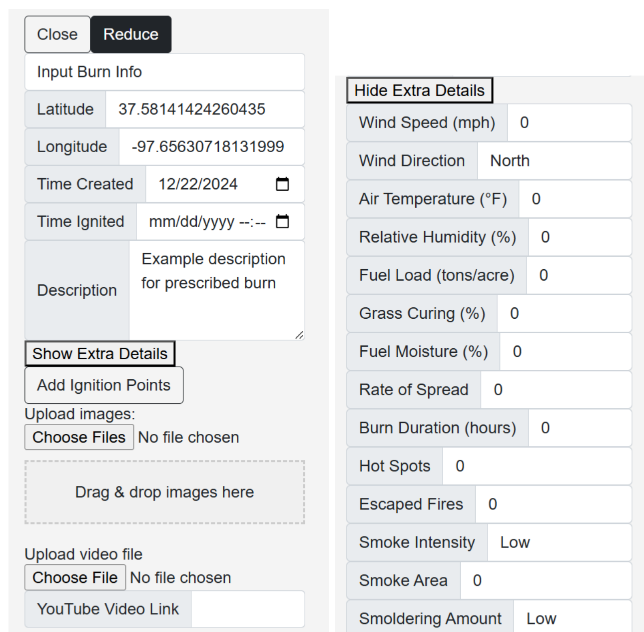

Figure 4: Working Model of the FireCrowdSensing Input Form

data, or highlighting an area of interest on the map. These filters can be displayed by clicking "Show Filters."

Clicking "Download All Burns" downloads a .xlsx file with a spreadsheet of all the prescribed burn events currently recorded in the database. The spreadsheet file contains all of the data in the "Extra Details" section along with the text descriptions, the emails of the users who submitted the data, and the line segment data for all the ignition team lines corresponding to each data point. The ignition team data is stored in a separate sheet on the file, and they

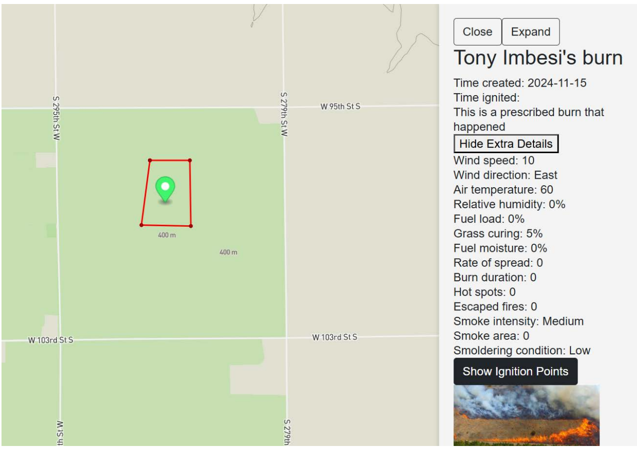

Figure 5: Example Data Point in FireCrowdSensing with Attached Media

are joined to their corresponding burn through an automatically-generated UID. If the data was filtered through the provided filters, then that subset of data can be downloaded by clicking "Download Filtered Burns."

A demo video showing basic functionality of the FireCrowdSensing application can be viewed at https://sims.cs.gsu.edu/sims/research/DEVSFIREVideos/FireCrowdSensing_demo.mp4.

5 Conclusion and Future Work

This paper presents an initial effort to facilitate the collection of crowdsensing data for prescribed fires. The FireCrowdSensing web application was presented to show how users might input and interact with prescribed fire data. Future research of this work will be carried out in several directions. First, we will work on refining the categorization of the prescribed fire data by consulting with prescribed fire managers and other researchers. Second, we will continue developing the FireCrowdSensing tool to improve its functionality and look into privacy concerns that can arise when sharing the data. Third, we will reach out to prescribed fire communities and distribute the tool to community participants to collect prescribed fire data.

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A Appendix

The FireCrowdSensing web application can be visited at http://firesim.cs.gsu.edu:3000/crowdsensing.

The demo video for the web application can be viewed at https://sims.cs.gsu.edu/sims/research/DEVSFIREVideos/FireCrowdSensing_demo.mp4.