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Air Quality (AQ) Sensors for Early Warning of Wildfires

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Summary:

Over the past few decades, the number of wildfires and the damage caused by them has steadily increased throughout the world. The loss of lives and the cost in damages could be avoided by using low-cost, low-power, tiny but sensitive AQ sensor arrays capable to detect the environmental changes induced by wildfires. Here we report the use of such an array built from selective electrochemical sensors to detect these changes in AQ related to fires. We describe the calibration and field data for electrochemical and other AQ sensors in widespread networks for early warning systems for wildfires.

Keywords: wildfire detection, environmental sensors, electrochemical sensors, CO, particulate matter

Background, Motivation and Objective

According to the National Oceanic and Atmospheric Administration, the U.S. has suffered $553 billion in damage in weather and climate disasters since 2015. These damages were partially amassed during 79 billion-dollar disasters, 10 of which happened in California resulting in up to $100 billion in damages in California alone. Wildfires were the cause for half of these billion-dollar disasters [1]. In 2021, a total of 58,985 wildfires was recorded that caused roughly $11.2 billion in damages not accounting for the loss of life or personal traumas in affected communities and families [2]. According to the Insurance Information Institute, wildfires caused $20.8 billion in economic losses in 2021 [3]. The constant increase in number of wildfires (+223 % since 1983 [2]) and the damages caused by them led the Investor-Owned Utilities to spend $11 billion for mitigation strategies in 2021 and 2022 to prevent wildfires [4]. While the mitigation strategies are important to prevent fires from happening and to stop them once started, a system is needed additionally to detect wildfires early on when they are small and can sometimes be stopped before causing vast damage. Current methods of wildfire detection include satellite imaging, ranger eyesight and reports by civilians. Satellite imaging requires expensive instrumentation, especially with the suggested improvement discussed by the NOAA [5] where satellites rotate with the earth so they can stay focused on the most endangered parts of the earth (continuous imaging from the same area to be able to detect changes right away). Reports by civilians are chance-detections and somewhat unreliable. Similar issues are observed with detection by ranger eyesight. Rangers constantly check for fires; however, a fire often must spread before rangers are able to observe it if it started in areas that are not easily accessible for the rangers.

Since wildfires produce several different gaseous species like NO_x, CO, VOCs in addition to particulate matter [6], environmental sensors should be able to detect wildfires in their vicinity. Satellite data from 2018 has shown a severe increase in CO in areas with wildfires [7]. The same is true for PM2.5, particulate matter of 2.5 µm and smaller [5]. In a recent study, we were able to show that environmental sensors can indeed be used to detect wildfires [8]. Furthermore, we found that a mini array consisting of a CO sensor and a particulate matter sensor for PM2.5 are sufficient to obtain information on wildfires in their vicinity [8]. Data from the multiple burn events over a two-week period using a variety of wood fuels, loadings and moisture contents were monitored [8] and evaluations provided confirmation of our hypothesis that AQ changes do occur and can be detected from very small burnings at some distance, It may be possible to build effective networks with AQ sensors for early wildfire detection. The following results show some additional interpretations of the data set that reveal correlations between CO, PM2.5 and the presence of fires as well as possibilities to improve selectivity and obtain a practical deployment strategy

However, we also realized that there are several issues that need to be addressed before this technology can be used as an actual early warning system for wildfires. First, the sensors must be connected to nodes that can communicate continuous status of the background pollutants. Second, the nodes have to be very low-cost and low-power so they can be deployed in large quantities to cover areas prone to fires. Third, sensitivity must allow for low-level detection since dilution of the fire's emissions will produce only small changes above AQ background levels in early stages of fire. We will describe the development of sensor nodes based on electrochemical sensors for the detection of wildfires, and what we have learned from their deployment including their advantages and their shortcomings. Further, the benefit of combining electrochemical sensors with a particulate matter sensor is discussed for increased selectivity, reduction of potential false alarms.

Experimental Methods

An array of electrochemical sensors (CO, SO_2, NO_2, O_3, …) and a particulate matter sensor (PM2.5) was packaged in a device (Thingy, LLC [9]) and used together with pollutant and local weather station data from nearby EPA monitoring stations. The data was analyzed to show how fires are followed using AQ measurements.

Results

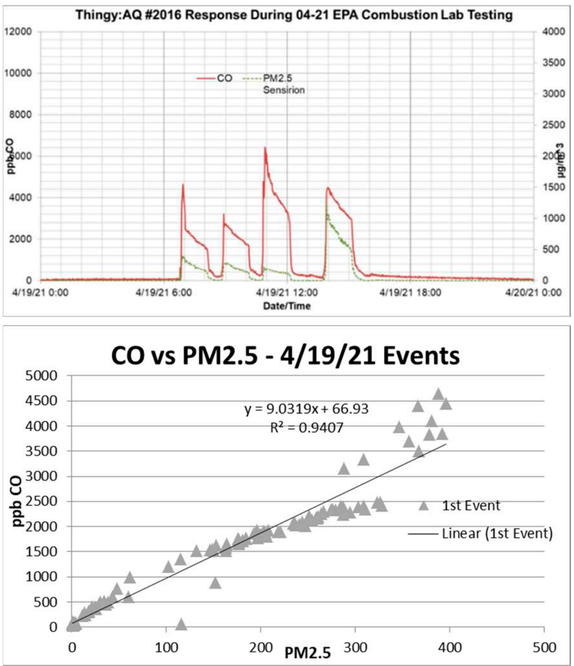

Figure 1: top: output of the respective sensors (CO: red; PM2.5: green) in four subsequent test events. Bottom: output of the CO sensor plotted against the output of the PM2.5 sensor during the first of four events shown at the top.

Figure 1a (top) shows the raw data of a particulate matter sensor (PM2.5) overlain on data from a CO sensor, Figure 1b (bottom) illustrates the linear correlation between the CO and PM2.5 for the first simulated fire event.

The comparison of the sensor data of the mini array with the reference sensors revealed: 1] while virtually all AQ parameters [T, P, RH, CO_2, CO, PM, SO_2, NO_2, O_3] varies during test burns, a single CO sensor and PM2.5 sensor could be sufficient for unambiguous detection wildfires; and 2] AQ readings from the sensor nodes were correlated to the local EPA measurements from 1- 4 miles away. This data analysis, together with the low cost of the nodes, support the hypothesis that sensor-based early detection of wildfires may be cost effective since prevention of just one big fire could save significant suffering/cost.

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