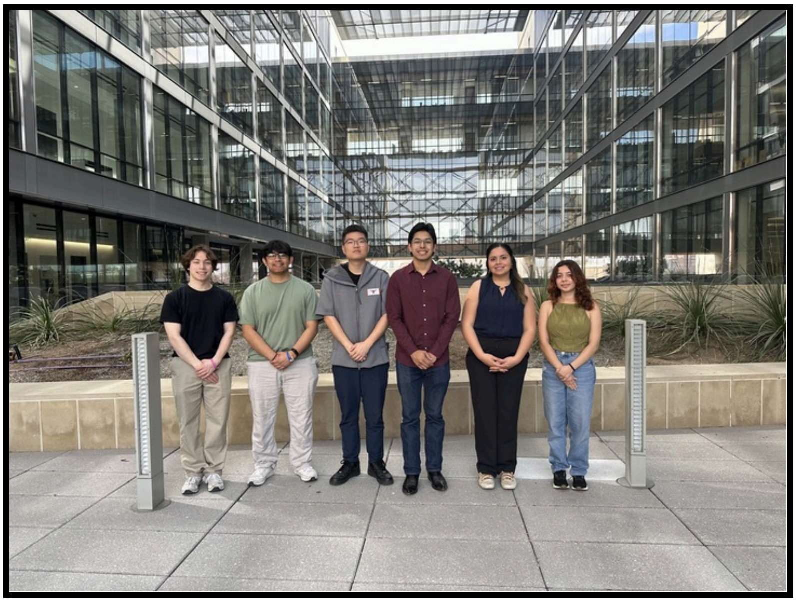
Data Integrated UAV for Wildfire Management

The University of Texas at Austin



(From left → right)

Team Members:
Mateo Renaud - Undergraduate - Mechanical Engineering
Michael Espinoza - Undergraduate - Civil Engineering
Zhixin Huang - Undergraduate - Mechanical Engineering
Enrique Loredo - Undergraduate - Chemical Engineering
Mariana Ponce Ramirez - Undergraduate - Civil Engineering
Lizbeth Martinez - Undergraduate - Chemical Engineering

Faculty Advisor:
Christian Claudel - Civil Engineering, Faculty Advisor
I have reviewed and approved this Proposal Submission for NASA's 2024 Gateways to Blue Skies Competition.

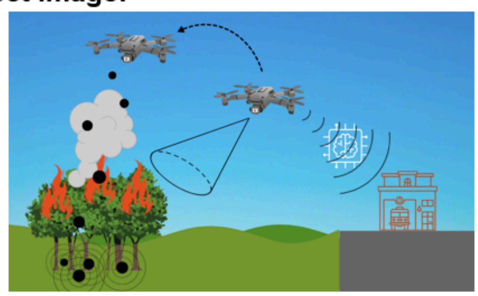
Quad Chart

Data Integrated UAV for Wildfire Management

Project Summary:

- Wildfire – Response
- Lack of situational awareness and visibility in low and high smoke wildfire situations
- VTOL capable fixed wing drone equipped with cameras and disposable in-situ temperature sensors. Data collected from cameras and sensors is transmitted and processed for fire front tracking and prediction

Project Image:



Team Composition/Roles:

- Mariana Ponce Ramirez - Undergraduate - Civil Engineering – Wildfire assessment, ROI, and data processing
- Mateo Renaud - Undergraduate - Mechanical Engineering – Sensor Design, Adoption, ROI, calculations, and media
- Enrique Loredo - Undergraduate - Chemical Engineering – Drone integration, data processing, data processing
- Lizbeth Martinez - Undergraduate - Chemical Engineering – Identifying use case and proposing solution
- Zhixin Huang - Undergraduate - Mechanical Engineering – Connectivity constraints and CAD
- Michael Espinoza - Undergraduate - Civil Engineering – Environmental challenges and agency integration
- We are a team of diverse engineering disciplines with backgrounds in a multitude of technical areas

Proposed deployment timeline:

1. TODAY:
   1. Begin developing sensors and data simulation techniques
   2. Begin gathering data of wildfire behavior
2. 2-5 YEARS (~2029) FROM TODAY:
   1. Begin testing of the physical system in relevant scenarios
   2. Data and pattern analysis begins on wildfires
   3. Begin development of the supporting app
3. 5-10 YEARS (~2034) FROM TODAY:
   1. Begin political process for cross agency collaboration using our solution and plans for fire department integration
   2. Training of firefighters will take weeks to days, this could can wait until 1-2 years before 2035
4. 11 YEARS (2035) FROM TODAY:
   1. Full implementation of technology and training and ready for use in wildfire scenarios

Appendix

Table 1. Sensor Information

Overall Sensor Mass (m)	0.01 kg
Overall Sensor Radius (r)	0.02 m
Drag Coefficient (C_D)	1.12

$$v_{terminal} = \sqrt{\frac{2mg}{\rho_{air} A C_D}} = 21.545\, m/s \quad Eqn\ (1)$$

$$v_{injury} = 162.1e^{-0.38\sqrt{m}} = 156.056\, m/s \quad Eqn\ (2)$$

Figure (1): Edge Autonomy's Penguin C Mk 2.5

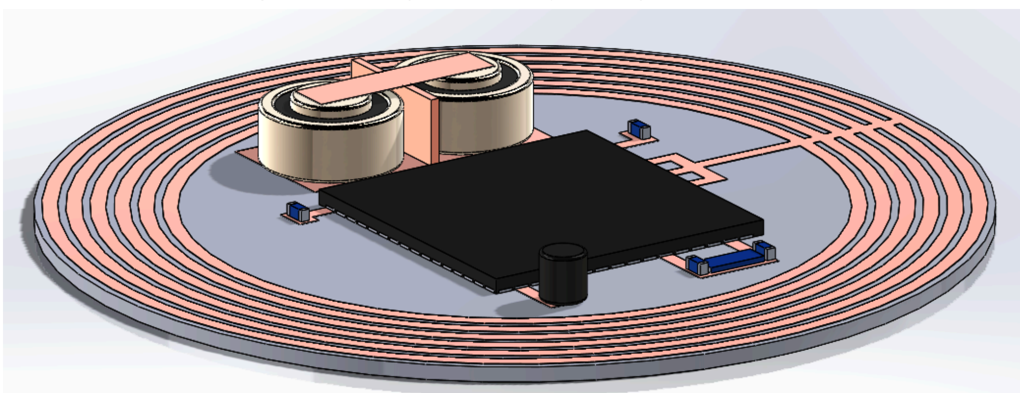


Figure (2): Model of Disposable Sensor

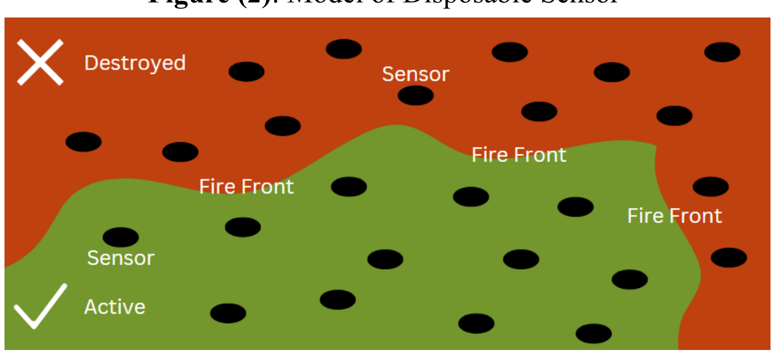


Figure (3): Diagram Illustrating Placement of Sensors

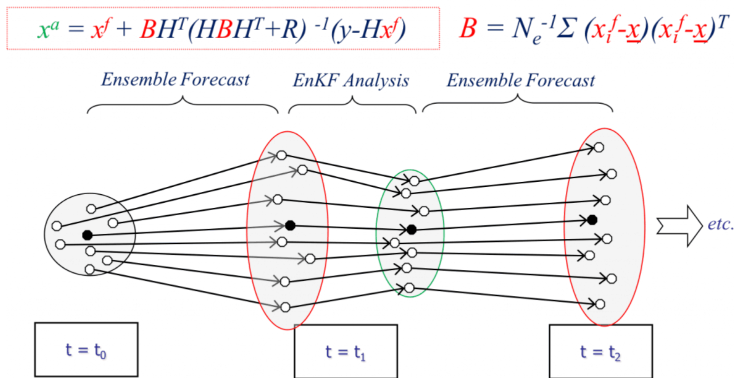


Figure (4): Diagram of Ensemble Kalman Filter (EnKF).

The ensemble forecast and EnKF analysis generate real-time state estimates. They are obtained by selecting ensembles from a set of prior estimates (t=t0). These estimates are propagated forward in time ($t=t_1$) and then combined with measurements obtained at $t=t_1$ to generate new, updated state estimates. These estimates can also be used to perform ensemble forecasts at future times ($t=t_2$), which are useful to predict the future state (location and intensity) of the wildfire

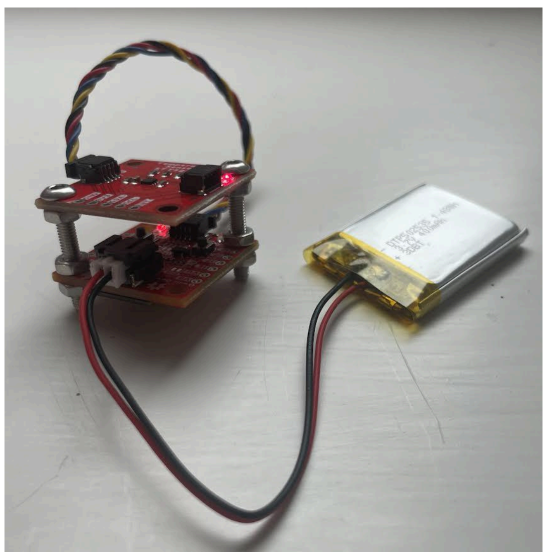


Figure (5): Prototype of Disposable Sensor

Abstract

With the severity of wildfires globally that are expected to worsen due to climate change, advancements in disaster management strategies are needed urgently. This natural disaster is leaving a long-lasting economic, social, and environmental impact throughout the country. The current systems used to address these challenges are limited in terms of time, materials, and communication. These limitations reduce the efficiency and effectiveness of the current firefighting tactics. To address these problems, an aviation-based system that incorporates drones with sensors and simulation technologies is proposed. This system is designed to alleviate some of the stress that responders face by providing real-time data collection, analysis, and predictive modeling capabilities.

This system includes disposable temperature sensors to be deployed by drones. The sensors will offer a better understanding of the fire through real-time data regardless of whether the visibility is limited by smoke. Real-time data will be fed into a recursive model that will continuously improve upon its accuracy to provide a comprehensive predicted path of the fire based on the real-time temperature data, topography, and weather conditions. It is important to note that the system will allow for rapid on-scene scouting and quick temperature sensor deployment due to its long flight times and high speeds. This system will guide the responding agencies, providing strategic paths and resource allocation if needed. Additionally, this proposed system is cost-effective, using existing drone technology and LPWAN communication protocols. Challenges such as extreme environmental conditions and conformity within existing systems are addressed through the designs of this system. The designed pathway takes into consideration predicted technological advancements, the intensification of global warming, and current firefighter training for a proposed implementation of the system by 2035. This proposed aviation-based system represents a direct approach to enhance the reaction time and method of addressing wildfires, ensuring improved wildfire response in terms of time, method, and outcome.

1 - Assess The Situation

Natural disasters around the world are increasing in intensity and frequency, much due to the worsening state of climate change. Wildfires are no exception to this and have become an issue affecting millions around the world. The recent events of the Hawaiian wildfire, Canada/Northeast U.S. wildfire, and frequent Californian wildfires are examples of the worsening effects of this natural disaster. Leaving a long-lasting economic, social, and environmental impact.

In 2022, 7.58 million acres of land were burned due to wildfires, this is directly and indirectly affecting lives (Salas, 2023). This problem is expected to increase by 14 percent by 2030 and even to 30 percent by 2050 (Alves, 2024). This is costing the United States between $394 to $893 billion each year, including damages in real estate value, loss of income, damage to watersheds and aquifers, insurance payouts, evacuation costs, and federal wildfire suppression costs (2023, October 16). However, there are costs that are not fully quantifiable by research, including the loss of agricultural land due to it being harmed. The Thomas Fire in 2018 caused a large amount of damage to farms including thousands of acres of grazing land that was lost. The Camp Fire incident resulted in similar damages, losing approximately 30,000-40,000 acres of grazing land(Front, 2020). This affects crops which affects the availability of food sources for the American population which in turn affects communities and the surrounding economies.

The social impacts of wildfires extend far beyond just the physical damage, indirectly and directly affecting communities, families, and individuals. The emissions resulting from the fire contribute to a significant amount of damage to people in terms of health. The hazardous air pollutants in Wildfire smoke are “associated with premature deaths in the general population, and can cause and exacerbate disease of the lungs, heart, brain, nervous system…” (*Wildfires*, n.d.). In a publication made in 2012, it was found that deaths caused by exposure to the smokes resulted in 339,000 deaths annually (FH et al., 2012). In addition, wildfires have displaced thousands of people, forcing them to move homes. In 2022 alone approximately 228,000 people were displaced and in just Fairview, California alone, 67,000 people were displaced (Salas, 2023).

The environmental toll of wildfires is overwhelming, with long-term consequences affecting the air, soil, and water, negatively impacting the ecosystems. “Wildfires can affect the physical, chemical and biological quality of streams, rivers, lakes and reservoirs" (Mendenhall, 2023). These impacts are noticeable even decades after the fire. The greatest impact is from stormwater caused by the lack of trees burned by wildfires. With the increase in droughts resulting from global warming, it's evident that ecosystems are having a harder time restoring after wildfires due to these conditions. This in turn puts a heavier stress on the ecosystems, increasing worrying delays of ecosystem restoration after the fire. With the increase of droughts, restoration that takes effect after the fire is becoming more difficult, putting harder stress on the ecosystems. The proportion of sites that experience no regrowth after a fire “almost doubled after 2000, from 19% to 32%” (Surtini, 2021).

There are five federal agencies that are responsible for wildland fire management: USDA’s Forest Service and the Department of the Interior’s Bureau of Indian Affairs, the Bureau of Land Management, Fish and Wildlife Service, and the National Park Service (*Wildland Fire Management | U.S*, n.d.). A common problem identified between them is recruiting and retaining wildland firefighters, the main aspect being low pay. Firefighters and public safety are the U.S. Forest Service's top priority in Wildfire response(*Safe and Effective Wildfire Response | US Forest Service*, n.d.). By improving communication and providing precise details of wildfires to the aforementioned agencies and fire departments, we will be able to decrease the amount of damage that is done by this natural disaster.

2 - Identified Use Case[s] & Proposed a Solution

Most of the current tactics that firefighters rely on to fight wildfires are simple if not crude. Bulldozers and masticators are used to remove any potential sources of fuel for the fire in order to create a fire line while larger aircraft such as helicopters are used to drop fire retardant.
However, few fire departments have access to helicopters at all. Despite the fact that 1 in 6 Americans live in an area with significant wildfire risk, only 8% of all fire departments have access to some type of aviation aircraft. This disparity in access to wildfire-fighting aircraft is even more prominent when comparing larger fire departments in cities with bigger budgets and access to more resources versus those in rural areas with significantly smaller budgets. Moreover, these tactics require firefighters to travel long distances into remote areas in order to implement them. This poses significant safety risks to the firefighters who respond. Additionally, firefighters must take into account a multitude of factors when deciding how to approach a fire including topography, types of fuel in the area, and weather. These factors also decide where and how large they will construct their fire lines. Thus, maintaining a steady stream of up-to-the-minute information is vital in order to facilitate coordination between people on the ground. And yet, although communication between firefighters during a wildfire is critical, there are significant logistical challenges that prevent that from happening. Most communication issues arise between firefighters attempting to verbally communicate with one another during a mission. This makes coordination of personnel, such as mapping people out into the right place, more difficult. Moreover, there are important roles in addition to manning bulldozers or dropping fire retardant, such as intel gathering, that require additional manpower. Lookouts are critical in monitoring the fire and advising the crew of any changes in the fire behavior. And yet, many departments are more frequently facing issues with firefighter recruitment and retention. This has a significant impact on how a team will be forced to face a fire given that manpower is a significant restraint for combatting blazes.

Given the current state of wildfire response, it increasingly makes sense to deploy smaller aircraft drones that focus on improving detection and mapping in order to facilitate coordination. Our drone would be designed to arrive well before any firefighters could reach the scene and analyze the fire in order to relay important information about its location, speed, and movement. More specifically, the camera attached to the drone would provide aerial imaging in cases of low-smoke while in high-smoke scenarios the drone would instead switch to using sensors in order to provide the location of the fire without relying on direct visibility. Additional analysis of the fire using AI tools will be able to assist in plotting escape routes, predicting the spread of the fire, as well as detecting the best points to drop fire retardant. More broadly, our drone would also become a part of the greater disaster warning system by alerting relevant fire department stations and updating civilians to any wildfires in their areas that have a drone responding to it. Out of wildfire season, the drone would still be useful as a rescue tool. Often hikers are in inaccessible areas making it difficult for rescue to reach them timely. Our payload-capable drone will be able to locate hikers, easier access routes, and drop utility care packages.

3 - Technical Specifications

3.1 - Drone - Our proposed method of reducing the impact of forest fires heavily relies on long flight times, high speeds, multispectral imaging, and autonomous capabilities of a drone. These requirements can currently be met with the SWAN K1 M1 and Penguin C Mk 2.5 (**Figure (1)**) fixed-wing drones. Although the price of these drones may be considered a financial barrier, we can expect a significant reduction in costs of these drones due to the following: increase in production volume, economies of scale, and gliding technologies, development of new materials, reductions of production costs. Additionally, we can expect software enhancements to allow for simpler hardware designs to further decrease the cost of these drones. Finally, we can expect these drones to transition into broad commercial applications (which will motivate the manufacturers to reduce costs to appeal to a wider audience). Some potential examples of commercial uses would be food/urban package delivery and surveying. These drones are chosen to meet the required specifications in terms of speed, loitering time/endurance, payload (visible and infrared cameras, disposable sensors), and communication systems.

3.2 - Disposable fire detection sensors- The primary means of detecting wildfires are visible and infrared (near and thermal IR) cameras. However, these cameras cannot function in all conditions, in particular when smoke is too thick. Our objective is to extend the range of detection to all conditions, including thick smoke. When cameras cannot observe the fire directly, the UAVs will fly over the areas to monitor and drop disposable, disc-shaped (**Figure (2)**) temperature sensors that will serve to monitor the propagation of the front of the fire. These sensors need to be small, light, cheap, and non-polluting. This can be accomplished easily by utilizing a system-on-chip that combines a chip, a radio transceiver, and an internal temperature sensor as a means of monitoring and transmitting temperature. An example system-on chip would be the Espressif Systems ESP32-C3 chip. This chip has an onboard local temperature sensor, microcontroller, and radio transceiver (Bluetooth). The sensor itself will be designed using Printed circuit on Paper (PCP) technology. PCP is the ideal technology since it involves only papers, conductive glues to fix the chip to the circuit board, and conductive inks to design circuits for both the buffer capacitor and for the transceiver antenna. The glues, paper, chip, battery buffer capacitor, and ink can be safely destroyed in the fire with virtually zero pollution (for this particular work, we use alkaline batteries, silicon microchips, and supercapacitors that burn without leaving hazardous residue). A possible CAD design of the sensor is shown below.

The disposable sensors would be dropped ahead of the fire front, with the objective of tracking the propagation of this front. They would measure the rising temperature as the fire gets close to the sensor, before being destroyed by the fire itself. Due to temperature limitations in the chip, we expect the sensors to fail just before the fire burns them (temperature limit of 80 degrees C). Since the sensors are disposable, they can be dropped in large numbers. An example scenario is shown in **Figure (3)**.

This data would allow us to essentially “see” where the firefront is and is spreading without direct visibility. Due to the relatively small dimensions of the antenna (with respect to wavelength), we expect that the antenna will be nearly isotropic (emitting in all directions). Thus, the signals can be received by passing UAVs irrespective of the orientation of the sensor (and the orientation of the UAV).

Due to the expected short lifetime of the sensor, the sensor will be powered by the smallest available battery (two LR44 alkaline button cell batteries to obtain sufficient voltage for the system on chip). The total battery capacity is 155 mAh at 3V, which is sufficient to provide 23 minutes of continuous operation of the reach sensor (in transmission mode). To save energy, we will use the sensor in cycles, operating only for a very small fraction of the time at a time. For example, if we use 1 second of emission every minute (sufficient for transmitting 1 measurement every 10 seconds as a short emission burst), the sensor can last approximately one day. While the batteries can provide sufficient energy, they cannot provide sufficient power in transmission mode (this would require a 3C discharge), and thus a small supercapacitor (of 0.5F capacity, 5.4V max voltage) will be used to power the system during the transmission bursts.

To ensure the safety of the firefighters nearby, the sensors’ falling speed needs to be evaluated. Using the terminal velocity equation, our sensors would have an approximate terminal velocity of 21.545 m/s. According to the formula for the velocity of a falling projectile, of a given mass, to cause injury, our sensor would need to travel 7 times faster than its terminal velocity. Thus, it is safe to be freely dropped.

The terminal velocity speed is also fast enough so that the sensors would be minimally affected by the wind when falling. The high terminal velocity is required to ensure that the sensors are relatively insensitive to wind disturbances, which could blow them away after their deployment.

The sensor data will be received by the UAVs that will keep monitoring them after their deployment. The UAVs will both receive data measurements from each sensor and will locate them (the sensors are not equipped with GPS due to costs and power usage constraints). To monitor the position of each sensor, statistical analysis of sensor detection over time will be used (given the path of the UAV), using measurements of directions of arrival. Each sensor will also ping a unique ID in addition to temperature measurements to estimate the individual position of each sensor. This requires an array of antennas to be deployed on the UAV, for example on its wing.

These disposable sensors are meant to be used in specific high-smoke circumstances; therefore, their use and environmental impact will be limited. Due to the used materials in the sensors, there will be a negligible environmental impact from the use of the sensors. The EPA classifies modern alkaline batteries as non-toxic and pose no significant environmental impact. Inkjet printed circuits are made out of paper and the conductive ink used is not hazardous to the environment. The microcontroller used has a negligible amount of toxic materials and any gasses created that are harmful to humans will not be created in the vicinity of humans to be inhaled.

3.3 - Disposable fire detection sensors prototype- We have created a working prototype, shown in **Figure (5)**, of the disposable sensors. This prototype's primary purpose is to show that temperature measurement and transmission at varying intervals is possible. Due to availability of components we used similar components from the same supplier for this version. The used components were the Espressif Systems ESP32-C6, the Espressif Systems Temperature Sensor STTS22H, and a Li-ion battery that serves the same purpose as the two LR44 batteries. These were chosen for their similar size and cost (as well as shipping availability) to the combined capability of the ESP32-C3 and alkaline batteries. We created a custom program using the Arduino IDE to transmit the measured temperature via low energy bluetooth, powered by the used battery.

4 - Conceptualize Implementation

4.1 - Summary of Data Processing - Wildfire fighting can largely benefit from having predictive guidance from a simulation to better understand each wildfire's behavior and propagation in real-time. These simulations require an estimate of the current position of the fire front, and the location of burnt areas. Our UAVs will collect data required for the predictive simulation, from a combination of visible camera, infrared camera, and disposable temperature sensor data (as required by visibility limitations). While this data is extremely useful, it is not sufficient in general to accurately map the position of the fire front line, since it is incomplete (particularly if smoke is very dense and the fire becomes invisible).

In the case of dense smoke being present, the presence of fire is only obtained indirectly from the measurements of the disposable sensors, and it is important to generate usable maps, in real-time, from these measurements. Generating maps in real-time amounts to estimating the state at every location of an entire geographical area as one of the following states: unburned, burned, and currently burning. This estimation can be achieved using sensor fusion, that is, combining models of fire propagation with incomplete (partial) sensor measurements (temperature/camera data) at specific locations. The most commonly used method to achieve this type of data processing is the Ensemble Kalman Filter as used for weather forecasting and air quality monitoring to increase accuracy and better handle incomplete data (Houtekamer, 2005).

The Ensemble Kalman Filter (EnKF, detailed in **Figure (4)** (Nystrom, n.d.)) is a data assimilation process that requires both a physical model (in the present case a model of wildfire propagation) and real-time measurement data. This method is recursive, in that we start with an estimate state (or guess of the current situation), and gradually improve this estimate using new measurements. As previously mentioned the model could be developed using the temperature sensor data (low-resolution/incomplete when visibility is low), but also by implementing the data from cameras (visible and infrared when visibility is high). Through the use of the collected data, the AI model can be trained with high resolution data to provide more granular fire behavior predictions (predictive fire map) relative to current approaches.

The states considered are the status of each location on the map being unburned, burning, or burned. We begin the estimation process by drawing a set of random possible fire maps, around our initial estimate of where the fire actually is (which is unknown). Each possible fire map is then used to obtain a forecast of what the situation will be (for this particular fire map) at the next time step (for example in the next 5 minutes). For each possible map, this forecast is computed using the fire propagation model, which accounts for the location of the fires on this particular map, wind, location of wooded areas, probability of fire propagation in a particular direction, and more. Once each fire map from this set of possible fire maps has been updated to the next time step, the predictions of each of these maps are compared with the actual measurements obtained from the sensors. This comparison allows us to select the most likely scenarios that are currently happening, and use them to generate the new estimate state which corresponds to the update phase. This process is continuously performed to continuously reduce error and obtain accurate real-time maps of fire propagation that are compatible with all measurements.

Additionally, our artificial intelligence model would greatly benefit from having accurate topography which is readily available in the United States via the NED (National Elevation Dataset). The NED has high-resolution data for many remote areas but the level of detail and accuracy vary. However, our drone would be able to provide accurate topography mapping during the non-fire season. The use of drones for the development of accurate topography maps would allow for continuous improvement of our simulation (topography is essential in predicting fire behavior). In addition, initial training for the model could begin with modeling prescribed burns to allow for strong baselines when applying the model for large wildfires. It is important to note that "each minute of delay is critical to the safety of the occupants and firefighters, and is related to the property damage" (quote by Averill, NIST's Engineered Fire Safety Group Lead retrieved from NIST, 2010). Therefore, accurately forecasting the future spreading of a wildfire (with the model described), can decrease response time and increase effectiveness of the fire departments' plan.

The simulation will allow our model to analyze a variety of fire scenarios and identify trends to then translate into effective strategies for the mitigation of wildfire damage. Through rigorous training and refinement, the artificial intelligence model would be instrumental in optimizing response strategies against wildfire by allowing for an accurate predictive fire map. However, it is important to note that the volume of data collected by the UAVs' (due to its long flight-times) would be significant in volume and require high performance computing resources. To accomplish this a robust and established database would be used. Some examples for applicable databases are Microsoft, Google, and NVIDIA. Additionally, data encryption and secure access controls would be implemented to ensure integrity of the collected data.

4.2 - Minimal barriers to adoption/use (i.e. effectiveness, simplicity, high reliability, user-friendliness, computer-controlled) - Due to the circumstances our solution is used for, it needs to be effective, reliable, and easy to operate. Current drone technology and software allow for automatic take-offs and landings. They are also capable of flying to predetermined locations with obstacle avoidance. These are currently commercially available tools that have been rapidly increasing in efficiency and reliability in recent years. This allows for minimal training and nearly completely hands-off operation. This is a key requirement for firefighters due to the low number of available staff. For information availability and control to the firefighters on the ground, a person with training will have access to a tablet that can provide live view, and the prediction analysis made with our system. They are also given the option to manually control different functions of the drone (although due to the autonomy, this would usually be unnecessary).

4.3 - Cost/Return on Investment - The cost of our solution is important as many local fire departments do not have the same budget as the larger ones. After speaking with large and small fire departments, we came to an estimate of a total of $15,000 as a soft limit per fire department for a total cost. As mentioned, drone costs are high as of now but are expected to decrease, and with our requirements, this should not be an issue. The disposable sensors are negligible in cost due to their cheap components. The largest cost is the database and leased-out GPUs. When reviewing all of the costs associated with this system, it is estimated at around $300,000 each year. This cost comes from an estimate from providers such as Google and Microsoft for a database infrastructure, AI capable GPUs, data center costs, maintenance and support, and development and integration. This cost would be spread across each user, and with thousands of fire departments in the U.S. that interact with wildfires, this cost would be manageably embedded into each of their costs resulting in only hundreds of dollars. A return on investment (ROI) is untraditional, as the people involved in this are non-profiting. When speaking with fire departments it became clear that to justify the investment of their budget into a drone it had to be multipurpose. A primary source of ROI for our solution is its camera and payload capability. This allows for wildfire use; as well as, use throughout the year. The firefighter specified that a drone capable of locating and aiding lost or injured hikers would be valuable. Now people not easily accessed by rescue teams can be helped by providing a care package of basic utilities decided by the rescue team. The team would also be able to locate routes to easily access them. The damage that is being prevented, including damage to crops, land, and property is another source of predicted ROI. This system will increase firefighting efficiency dramatically. As mentioned before in Section 1, the U.S. government pays millions to even billions in damages caused by wildfires. Even a 1-3% improvement dramatically outweighs the cost of our solution.

4.4 - Support system requirements -The fire station will have a support hub to help the firefighters while they are on duty. These hubs will be installed on the fire truck in order to charge and get the drone ready for operation. The hub would also make it easier for fire departments to communicate with one another, allowing for data sharing and collaborative operations. The device can function even in the event of low internet thanks to offline features incorporated into the design. The drone's ability to deploy antennas and collect temperature data minimizes the need for human involvement in areas where smoking occurs. Because the device transfers data through Bluetooth from antennae, it will consume less power than other mentions of data transmission. Furthermore, simultaneously tracking features will also be incorporated into drones ensuring proper maintenance and that batteries are changed when needed. Real-time drone status monitoring is another feature that the system will include, allowing firefighters to quickly assess and utilize the drone as needed. These support systems will, in general, be very helpful in integrating drones into firefighting operations. If the fire department integrates these support technologies into its infrastructure, drone-based wildfire monitoring could be the most efficient and successful method available.

4.5 - Connectivity constraints (lack of internet, power, GPS, etc.) - During a wildfire, the system will communicate via Low-Power Wide-Area Network technologies like LoRa to overcome connectivity limitations. Because LoRa provides long-range communication, it can be used in locations with poor communication. In addition, the drone will be placing single-use antennas with temperature sensors around the wildfire. Through Bluetooth, these sensors will send temperature data to the drone. After that, the drone will upload this data to a database so that simulations may be run to predict the spread of wildfires. Firefighters will receive real-time updates on their tablets with this information. By ensuring that data is gathered and transferred even in isolated locations, this technology improves the effectiveness and security of firefighting operations.

The drone will also operate on autopilot. Using the data simulations, the drone will fly around the region on its own and provide real-time information to the firefighters. Even in locations with poor connectivity, the system will monitor the drone's power output to each motor. If the drone goes outside of the connection area, it will automatically retrace its route until it regains communication.

4.6 - Challenges posed by adverse environmental conditions (wind, rain, smoke, etc.) - The main challenge we face for our drone is the issue of smoke and its effect on visibility. However, our sensors will work around that and use it to our advantage by providing data through the smoke. Our drone, like many available today, is wind resistant, so the adversity of wind will not pose much of a threat to us. Furthermore, the sensors we will be using will have a fast enough terminal velocity that most wind speeds will not significantly affect them.

4.7 - Interoperability with existing people, processes, organizations, solutions, and technologies - Our drone is designed for the purpose of being used by local fire departments to tackle wildfires in a more head-on approach. The fire station would have a drone at their disposal, with a charging station in place to keep them prepared. When they are made aware of a wildfire, they'll send out a drone to assess the situation and retrieve data far in advance of the firefighters. Once the data is received and a solid prediction of the severity of the wildfire is made, the fire department will send it to surrounding emergency alert agencies like the National Weather Service, where they can alert nearby civilians of the danger and estimate the time it will take for the fire to spread, if necessary.

4.8 - Expected improvement over existing practices - One of the main challenges of firefighting drones right now is analyzing and determining where the fire is starting from, and creating an accurate prediction of where the wildfire is heading. Our sensors aim to improve that, which will be heat sensors that will be able to detect critical temperatures and the direction of the fire front. These sensors will be disposable, so we won't have to worry about the fire's effect on them as much, and based on where the fire is getting hotter, will determine what location the fire department will need to focus on. This data will be transferred at higher speeds than before, which will provide more time for warning and evacuation for nearby residents.

4.9 - Developing Understanding of Mechanism for Fire Spread - After the wildfire has been extinguished, the data that has been collected can still be leveraged to identify crucial trends. This data can be implemented to create an agent-based simulation similar to FSim which maps a simulation of wildfire spread and FlamMap which details fire behavior over complex terrain. Using the drone's multispectral imaging and disposable temperature sensors, the leading edge of the fire can be modeled (while incorporating geographical context: elevation, vegetation, and historical fire patterns). The proposed simulation can initially be an agent-based modeling (ABM) while training data can be collected for training of a deep learning simulation. Through the usage of ABM, we could develop insights into wildfires, collect data for future validation of a deep learning model, and understand mechanisms that drive fire spread (which can aid in identifying biases and limitations of deep learning models). ABS will be a complex model and computationally demanding but will be instrumental in optimizing repose strategies for wildfires. After the ABM has been started and training data has been collected, we can develop, refine, and validate a deep learning model.

5 - Path to Deployment

The pathway to deployment for our solution is streamlined and considers all major factors. Beginning today (2024), the drone and camera technology is TRL 9 and will only get cheaper and more effective over the next 11 years. The main components of a drone are the battery, motor, and frame. As the raw materials, such as lithium and aluminum, become cheaper, the cost of drones will also decrease. Drones will be purchased from different companies to find the best one that can operate effectively over fires. They will be tested under high temperatures and low oxygen conditions to determine the most suitable option. AI and data simulation are in the area of TRL 4-5 as their techniques exist but the exact use case has not been as explored. As the world enters an AI era, the precision of simulations has greatly increased from data collected by AI software, as well as the speed of their development, examples being OpenAI, xAI, and Gemini. This data serves as the foundation for simulations, making the models accurate and closer to real-life scenarios. Our sensor technology is TRL 3-4, research that presents similar technology exists but varies in goals and details. The gathering of wildfire behavior data will begin as soon as possible. In the next 2 to 5 years (up to 2029) more milestones will be reached. With continued research, our sensors could reach up to nearly TRL 8 and thus the entire physical system would begin testing in relevant scenarios. Beginning data analysis would start with wildfire data. In the following 5 to 10 years (up to 2034) data analysis and prediction methods have been refined and are nearly ready for use in real-time scenarios. In the first 5 years, wildfire data will be collected and stored along with related data such as the wind speed and landscaping, this data will serve as the foundation for simulating and predicting the movement and expansion rate of future fires. Early in these 5 to 10 years, the process for approval and use by the government would begin. The process of cross-agency information sharing would begin implementation to ensure minimal miscommunication between agencies later on. Integration into the fire departments begins. This includes the necessary equipment, such as charging stations and batteries, and training of firefighters; due to the highly automated nature of our solution, this would take weeks to days.

Finally, in 2035, full integration of technology would be ready across all stakeholders. Equipment will be deployed into every fire station, software will be developed with 10 years of stored detail to perform simulations and share information between fire departments. The cooperating and collaborating agencies are aware and ready to receive any information in the case of a rampant wildfire. This timeline provides a clear and gradual implementation across all factors and allows for use beginning in 2035.

6 - Conclusion

Wildfires are becoming more frequent and impactful in people's lives than ever. Our solution aims to support the firefighters who combat these natural disasters by improving situational awareness and providing fire detection and predictive modeling. Our drone design allows for access to situational information far ahead of personnel arrival. Our advanced sensors in combination with data processing/predictive analysis allow for more informed decision making and efficiency of firefighters. With the scalability and simple plan for integration, our solution has the potential to aid firefighters across the nation.

Our path to deployment considers TRLs, stakeholder integration, and training of firefighters. This creates a streamlined approach to full integration with all involved agencies by 2035. The collective efforts of everyone this solution involves will lead to a safer and more sustainable future.

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Our concept utilizes a eVTOL drone to quickly respond to wildfire alerts ahead of fire fighters. This will provide live aerial information of the current state of a fire. Our drone will also be carrying disposable temperature sensors that can be airdropped in high density smoke situations that render the camera useless. These sensors will be able to provide a “view” of the fire front by intermittently transmitting data back to the drone. Lastly the live data collected from the drones camera and sensors will be used for live predictive analysis for fire mapping and behavior.