Environment and Natural Resources Trust Fund

2023 Request for Proposal

General Information

Proposal ID: 2023-235

Proposal Title: Wildfire Air Quality Mapping Using Real-Time Drone-Based Diagnostics

Project Manager Information

Name: Jiarong Hong

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: Our aim is to develop a novel drone-based tool for autonomously measuring wildfire smoke aerosols, tracing them from the emission source, with the goal of improving air quality management capabilities.

Funds Requested: $304,000

Proposed Project Completion: June 30, 2025

LCCMR Funding Category: Air Quality, Climate Change, and Renewable Energy (E)

Project Location

What is the best scale for describing where your work will take place?

Statewide

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

During the Project and In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Wildfires are a significant source of aerosol emission into our atmosphere, where they can have immediate impacts on air quality and public health as the aerosol concentrations increase. In particular, aerosol emissions from biomass burning can introduce significant loading of fine particulate matter (e.g., PM2.5) that lodge deep into the human respiratory system. It is therefore important to be able to both monitor and predict how the aerosols emitted during wildfire events will disperse in the atmosphere, as they are transported to communities downwind, and how their properties (e.g., concentration, morphology, and composition) may change during these very dynamic early stages. Existing aerosol measurement technologies are unable to provide in situ, real-time data on these important aerosol characteristics, and are also unable to map the variation in aerosols in relation to the source of emission. Developing the capability of providing this data is crucial in the modeling of the spatial and temporal change of air quality and related management efforts.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

We propose to combine aerial drone technologies with holographic imaging methods developed in our lab in order to measure air quality associated with smoke from wildfires. Furthermore, we propose to use computer vision technology integrated with the drone such that the drone can autonomously identify a smoke plume, fly toward its source, and then follow along the motion of the smoke plume, all the while measuring local aerosols with the holographic imaging sensor. This will enable unprecedented in situ characterization of wildfire smoke aerosols during emission and dispersion downwind in a manner that yields real-time data for air quality management, as well as larger datasets towards the improvement of air quality modeling efforts. This work is possible due to digital inline holographic (DIH) imaging technology developed in our lab, which provides a way to obtain comprehensive information (e.g., concentration, size, morphology, and composition) of suspended particles in air within a compact form factor. The system will be tested with help from our project partner, Travis Verdegan, from the Minnesota Department of Natural Resources (DNR), who will coordinate participation in prescribed burn activities in natural settings and also serve as a fire management Subject Matter Expert.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

We will develop a new tool for characterizing air quality associated with wildfire emissions. This tool may be deployed to provide immediate data on the aerosols being emitted from a new wildfire, and thus in concert with other measurement tools provide an assessment of public health risks. This technology also enables us to collect field datasets that may be used to improve our understanding of the deficiencies of air quality modeling efforts. The technology we develop will have been tested in natural burn settings through our partnership with Travis Verdegan from Minnesota DNR.

Activities and Milestones

Activity 1: Development onboard imaging sensor for air quality assessment

Activity Budget: $100,000

Activity Description:
To measure smoke aerosol properties, we will develop a digital inline holography (DIH) sensor, built specially for this drone application and for these aerosols of interest. Due to the need for compact, lightweight components on the drone (to minimize payload and increase flight time), we plan to leverage the lens-less optical design approach, which has been used in our lab for other applications. The design of this new sensor will be aimed at optimizing the image resolution of the individual particles while also maintaining high data throughput. The goal therein is to sample sufficient particulate matter such that we can obtain a representative measure of important particle properties such as concentration, size, morphology, and composition. This will provide a comprehensive characterization of the aerosols affecting air quality associated with wildfires. Furthermore, by developing our data processing techniques with efficient, machine learning approaches, we can output such measurements in real-time using a dedicated computer linked to the DIH sensor. Obtaining such real-time information is a key part of providing actionable data for air quality management.

Activity Milestones:

Description	Completion Date
Initial holographic image sensor design	December 31, 2023
Optimization of holographic image processing for drone-based operation	May 31, 2024
Integration of on-board machine learning-based processing	December 31, 2024

Activity 2: Development of drone-based system for the air quality survey during wild fire

Activity Budget: $104,000

Activity Description:
The technology proposed involves the integration of the DIH particle measurement device onto an autonomous drone platform. This self-guided operation of the drone, intended to optimize the sampling of aerosols as they are traced from the source and along their dispersion path, necessitates a smoke recognition and flight planning algorithm. We plan to use artificial intelligence (AI) methods in order to visually recognize smoke plumes, from which a flight can be charted toward its source. Furthermore, by quantifying the motion of the smoke using the drone camera, and leveraging similar AI methods, we can enable the drone to follow the smoke, matching its motion, to better study aerosol movements. Using drone GPS, and the sensor described in Activity 1, an air quality map can be generated in real-time, with each drone's on-board computer processing its sensor data. With multiple drones, and by using each drone's initial view of the smoke plume itself, we can integrate this air quality map around a computer-generated reconstruction of the smoke plume location. This will help us to understand how wildfire emissions influence the surrounding environment's air quality, and in particular how this develops relative to its source as it moves into downwind regions and communities.

Activity Milestones:

Description	Completion Date
Smoke detection machine learning model development	December 31, 2023
Optimization of optical flow for smoke motion analysis	December 31, 2023
Integration of smoke detection and optical flow with multi-drone swarm	May 31, 2024

Activity 3: Field deployments in controlled and natural burn settings

Activity Budget: $100,000

Activity Description:

Testing the drone-based measurement system in natural environments is a critical part of developing a usable product. However, the use of such unmanned aerial systems (UAS) necessitates consideration of safe implementation of the drones around the wildfire itself, firefighting personnel and equipment, and also nearby wildlife. Our project partner, Travis Verdegan at the Minnesota DNR, will coordinate with us and advise in pursuit of these efforts. Although drones introduce a number of logistical challenges, they are at the same time incredibly useful tools for scientific research, of which this project is but one example.

Field testing will also give us the opportunity to refine the flight automation of the drone such that it can appropriately position itself for optimal mapping of air quality. Initial efforts will focus on ensuring our tools can operate at full scale, in terms of both operating time and communication distances, as well as safety. Synthetic smoke generation can enable safe testing of aerosol measurements, before moving on to participating in prescribed burn activities where conditions are still relatively controlled. Finally, we envision testing the device under natural wildfire conditions, if possible, in partnership with the Minnesota DNR.

Activity Milestones:

Description	Completion Date
Initial field flight testing with single- and multi-drone systems	May 31, 2024
Prescribed burn participation	October 31, 2024
Second generation system based on testing results	June 30, 2025
Natural wildfire deployment, if possible	June 30, 2025

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Nathaniel Bristow	University of Minnesota	Nathaniel will be in charge of developing the software and hardware components of an integrated system for drone-based particle measurement. This includes the particle measurement instrument, drone autonomous navigation technology, and drone swarming methods. He will also oversee the GRA in their work, and lead field testing, as lead pilot.	Yes
Graduate Research Assistant	University of Minnesota	The graduate research assistant will develop the holographic imaging sensor used in particle measurement on the drone and in the development of image processing of acquired data. They will also participate and assist in field testing, serving as a secondary pilot.	Yes
Travis Verdegan	Minnesota Department of Natural Resources	Travis will provide fire management subject matter expertise, and coordinate prescribed burn activities	No

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?

The product we develop will yield rapid response data for air quality management strategy, which may be used alongside existing remote sensing tools, such as satellite-based LiDAR measurement. The unique data we collect will also be used to develop larger datasets that may be shared with subject matter experts in the field of air quality modeling to improve predictive accuracy. The proposed work leverages the instrumentation and drone infrastructure development already underway, funded through a National Science Foundation (NSF) Major Research Instrumentation grant. Further funding can also be potentially obtained through the NSF or the Environmental Protection Agency.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Remote Sensing And Super-Resolution Imaging Of Microplastics	M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 08j	$309,000

Project Manager and Organization Qualifications

Project Manager Name: Jiarong Hong

Job Title: Professor

Provide description of the project manager's qualifications to manage the proposed project.

PI Jiarong Hong is a professor from the Mechanical Engineering Department and St Anthony Falls Laboratory at the University of Minnesota (UMN). He is one of the leading experts in experimental fluid dynamics, flow imaging, and particle diagnostics. He has published more than 100 peer-reviewed papers and holds eight patents on the relevant topics. His work on wind energy, cavitation, indoor air quality, and COVID-19 transmission has been broadly reported by international media including National Geographic, Nature, New York Times, Smithsonian, Washington Post, The Atlantic, Economist, Forbes, Daily Mail, NBC, CNN, CGTN, Fox News, and many others. Particularly, his recent work on indoor air quality and COVID-19 transmission has been on the front page of Star Tribune multiple times and his collaboration with Minnesota Orchestra focusing on transmission risk assessment during music instrument plays has made direct impact on CDC policies and social safety guidelines. PI Hong is a recipient of National Science Foundation

(NSF) CAREER award, Office of Naval Research (ONR) Young Investigator award and McKnight Land-grant Professorship from UMN. His research has been broadly funded by many federal agencies including NSF, ONR, Army Research Office, and National Oceanographic and Atmospheric Administration and industry including WinField United, Xcel Energy, Ford, and Donaldson. He is currently the PI of a large NSF major research instrument grant focusing on developing diagnostic approach for imaging atmospheric flow and particle transport. This project involves the collaboration of more than 20 experts from 11 universities, two national labs and industries across the globe (i.e. U.S., Europe, Australia and Asia), providing direct support to the proposed research. PI Hong is also an innovator and entrepreneur who is passionate about translating fundamental research into commercial products that generate significant societal impact and he is holding a position as the Chief Technology Officer of Astrin Biosciences, Inc.

Organization: U of MN - College of Science and Engineering

Organization Description:
The University of Minnesota-Twin Cities campus, spanning the East Bank, West Bank, and Saint Paul Campuses, is the flagship campus of the University of Minnesota system, with nearly 48,000 students and ~3,800 academic staff. Its educational and research programs in science and engineering consistently rank in the top 25 in nearly all disciplines. This project in particular will be housed within the Department of Mechanical Engineering and St. Anthony Falls Laboratory.

Founded in 1889, the Mechanical Engineering department has 44 active faculty, 50+ staff members, 300+ graduate students, 74 postdoctoral associates, research associates and visitors, and about 560 undergraduate students. Aerosol and Particle measurement techniques, leveraged heavily in this project, were originally developed in the University of Minnesota Mechanical Engineering Department in the 1950s, and leadership in aerosol and fluid mechanics measurement continues in the department to this day.

St. Anthony Falls Laboratory (SAFL) is one of the leading institutes in the field of environmental fluid dynamics. It situates right next to St. Anthony Falls in Minneapolis and has many unique research facilities including outdoor stream labs, 90 m long main channel, atmospheric boundary layer wind tunnel, etc.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Nathaniel Bristow		Post-doctoral associate			23.6%	2		$126,072
Graduate research assistant		Research assistant			23.6%	2		$100,975
Professor Jiarong Hong		PI			33.5%	0.08		$12,444
Benjamin Erickson		Engineer			28.7%	0.18		$15,044
							Sub Total	**$254,535**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Equipment	Drones	Includes primary hardware components (frame, GPS, batteries, flight controllers, etc)					$30,000
	Tools and Supplies	Sample collection tools and supplies	Aerosol sampling					$1,000
	Equipment	Cameras	Drone navigation with smoke detection					$4,000
	Equipment	Particle measurement sensors	Holographic imaging, including camera sensors, lasers, enclosures					$2,000
	Equipment	On-board computers	Data collection on drone, real-time processing					$5,000
	Equipment	Base station computer	Processing computer for field deployments and integrating data from drones					$3,000
	Tools and Supplies	Miscellaneous hardware	Building and integrating drone and sensor hardware components					$1,465
							Sub Total	**$46,465**

Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	Travel to and from flight testing locations	This includes shorter, more frequent trips for drone development phase, as well as farther travel to field deployments for prescribed burn activities and other field testing					$3,000
							Sub Total	**$3,000**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$304,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**-**

Attachments

Required Attachments

Visual Component

File: a82b5392-59c.pdf

Alternate Text for Visual Component

The visual depicts the drone-based system on the backdrop of a wildfire, illustrating how the drone will be equipped with a holographic imaging sensor, with some sample images, and a smoke recognition software, also illustrated with a sample view of a forest fire....

Optional Attachments

Support Letter or Other

Title	File
Support Letter	c0d1a9d9-3d0.doc
Project summary figure	f889129d-5e7.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have potential for royalties, copyrights, patents, or sale of products and assets?

Yes

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

Yes

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

No

Does your project include original, hypothesis-driven research?

No

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Wildfire Air Quality Mapping using Real-time Drone-based Diagnostics

PROBLEM

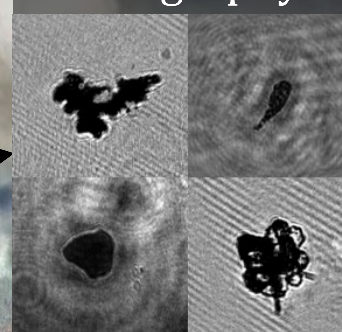
- Wildfires are increasing with climate change, and emit large amounts of harmful aerosols into atmosphere
- Existing measurement tools are incapable of providing real-time, particle-resolution aerosol data

SOLUTION

- Leverage compact holographic imaging for comprehensive particle-level information
- Using drones, autonomously track and measure smoke from source, providing rapid *in situ* measurements

Drones

Holography



Computer vision

OUTCOMES

- New technology, providing unique data for both real-time aerosol monitoring and for developing predictive models of air quality

PARTNERS

Jiarong Hong, UMN
Nathaniel Bristow, UMN
Travis Verdegan, DNR