Environment and Natural Resources Trust Fund

2024 Request for Proposal

General Information

Proposal ID: 2024-219

Proposal Title: Innovative Detection-Mapping-Prediction System for Wildfire Smoke and Air-Quality

Project Manager Information

Name: Lian Shen

Organization: U of MN - St. Anthony Falls Laboratory

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Project Basic Information

Project Summary: We propose a novel drone-based technology for autonomously measuring wildfire smoke aerosols and mapping wildfires, and a simulation tool for fast-and-accurate prediction of wildfire and smoke spread and air quality.

Funds Requested: $545,000

Proposed Project Completion: June 30, 2026

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.

Increased wildfire activity is a growing concern across the United States, with the wildfire burn area increased by approximately four times in the past forty years. Minnesota is no exception. During March and April of 2021, our state experienced 819 fires. In the following summer, the Boundary Waters was forced to close for the first time in nearly half a century. The Greenwood Fire burned 27,000 acres and forced the evacuation of 250+ Minnesotans. From tense nights away from home to health implications from smoke to over-taxed firefighting resources, fires are having a larger-than-ever impact on Minnesotans.

Wildfires are a significant source of aerosol emission into the 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) which lodge deep in the human respiratory system. Currently no technology can sample a large near-ground domain with fine resolutions to capture the characteristics of individual particles. The Minnesota DNR urgently needs new tools to quickly and accurately detect, map, and predict the spread of wildfires on-the-ground and the dispersal of wildfire smoke.

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 will combine the wide range of expertise at the St. Anthony Falls Laboratory in innovative drone technology, remote sensing, and computer simulation to develop a novel wildfire detection-mapping-prediction system. We will deploy aerial drones equipped with a holographic imaging sensor to measure air quality associated with the smoke from wildfires. Our drones can autonomously identify new wildfire smoke and fly to its source, and are specially outfitted with equipment to gather real-time data. Utilizing this valuable drone-measured data, together with weather data, we will then use our advanced computer program to simulate the evolution of the wildfire and aerosols influenced by wind, land topography, and canopy, to make accurate forecasts of wildfire and smoke spread. Our system will be tested in the field with help from our project partners, including Travis Verdegan (MN DNR) and Becky Marty (MN DNR Ecologist). The new wildfire detection-mapping-prediction system will help state agencies to: (1) obtain in-situ characterization of wildfire smoke aerosols to yield real-time data from small mobile aerial platforms; (2) provide fast and accurate forecasts of wildfire and smoke spread; and (3) characterize and predict the impacts of wildfires on air quality, human health, and ecosystems.

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?

As demonstrated consistently in recent years, fires are going to be increasingly part of our future here in Minnesota. By investing in a cutting-edge drone-based technology for the detection, mapping, and prediction of wildfires and smoke, the state of Minnesota will be better prepared to protect Minnesotans and their property. The mobile aerial platform-based detection-mapping-prediction system can also help firefighters respond more efficiently and suppress fires before they become catastrophic. The system will serve as an invaluable tool for conserving and enhancing Minnesota's prized forests, and thus protect the natural resources and increase ecosystem health and resilience for the state.

Activities and Milestones

Activity 1: Development of drone-onboard imaging sensor for wildfire smoke assessment

Activity Budget: $109,000

Activity Description:
The proposed project consists of four research activities that are highly collaborative and which together will establish a coherent wildfire smoke detection-mapping-prediction system. The first activity is the development of a digital inline holography (DIH) sensor, built specially for the drone application and for aerosols of interest. Due to the need for lightweight components on the drone, we plan to leverage a lens-less optical design, 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 maintaining high data throughput. The goal is to sample sufficient particulate matter such that we can obtain a representative measure of important particle properties. 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 computer linked to the DIH sensor. Activity 1 will establish a foundation for the development of a drone-based system in Activity 2, provide data to start the predictive model simulation and validate the forecast results in Activity 3, and be tested in the field in Activity 4.

Activity Milestones:

Description	Approximate Completion Date
Initial holographic image sensor design	December 31, 2024
Optimization of holographic image processing for drone-based operation	May 31, 2025
Integration of on-board machine learning-based processing	December 31, 2025

Activity 2: Development of drone-based system for the large area survey during wildfire

Activity Budget: $159,000

Activity Description:
The DIH particle measurement sensor developed in Activity 1 will be integrated 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. Our method will 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, we can enable the drone to follow the smoke to better study aerosol movements. Using drone GPS, a wildfire and air quality map can be generated in real-time, with each drone's onboard computer processing its sensor data. With multiple drones, we can integrate this air quality map into 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 2 builds on Activity 1, providing valuable data for the predictive model in Activity 3 and tested in the field in Activity 4.

Activity Milestones:

Description	Approximate Completion Date
Smoke detection machine learning model development	December 31, 2024
Optimization of optical flow for smoke motion analysis	December 31, 2024
Integration of smoke detection and optical flow with multi-drone swarm	May 31, 2025

Activity 3: Development of a fast-running and accurate predictive tool for wildfire and smoke spread

Activity Budget: $145,000

Activity Description:

Computer simulation has become a powerful research tool for the study of wildfires. Just like a flight simulator, one can use computer calculations to simulate wildfire smoke behaviors under various environmental conditions. Analogous to weather forecasting, which is today mostly done via computer simulation, the spread of wildfires and smoke can be predicted. In this project, we will use state-of-the-art computational software that has the powerful capabilities of simulating the effects of wind, land topography, and canopy on fire and smoke spread. We will develop a fast-running and accurate predictive tool for the spread for wildfires and smoke for Minnesota DNR and practitioners. In our predictive model development, we will work closely with Minnesota DNR experts and practitioners (Travis Verdegan, MN DNR and Becky Marty, MN DNR Ecologist). We have also planned substantial educational and outreach activities for dissemination of our research products. The development of a predictive model in this Activity 3 will utilize the drone-based field data collected in Activities 1 and 2 and will be validated in the field tests in Activity 4.

Activity Milestones:

Description	Approximate Completion Date
Development of an advanced predictive tool for the spread of wildfires and behavior of smokes	March 31, 2025
Validation and improvement of the predictive tool through comparison with Minnesota wildfire and prescribed-burn cases	December 31, 2025
Workshops and seminars for dissemination of research products	June 30, 2026

Activity 4: Field tests in controlled and natural burn settings

Activity Budget: $132,000

Activity Description:

Testing the drone-based measurement (Activities 1 and 2) and computer simulation system (Activity 3) in natural environments is a critical part of developing a usable product. However, the use of such unmanned aerial systems 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. 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, and to improve and validate our predictive model. 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	Approximate Completion Date
Initial field flight testing with single- and multi-drone systems	May 31, 2025
Prescribed burn participation	October 31, 2025
Second generation system based on testing results	June 30, 2026
Natural wildfire deployment, if possible	June 30, 2026

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Travis Verdegan	Predictive Services Coordinator at the Minnesota DNR	Provide insights regarding DNR needs and gaps in existing predictive technologies	No
Becky Marty	Regional Ecologist for the Minnesota DNR	Provide insights about the needs of practitioners, as well as serving as a connecting link to fire personnel in the DNR	No
Lane Johnson	Research Forester at UMN's Cloquet Forestry Center, fire ecologist involved in fire restoration work in northern Minnesota	Provide insights about the needs of practitioners, as well as serving as a resource for outreach and education efforts	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 proposed wildfire detection-mapping-prediction system will yield rapid response data and prediction for wildfire and air quality management, which may be used alongside existing remote sensing tools, such as satellite-based LiDAR measurement. The proposed work leverages the instrumentation and drone infrastructure development already underway, funded through an NSF Major Research Instrumentation grant. Further funding can also be potentially obtained through NSF and EPA. The product is commercializable. Our team is passionate about translating research into commercial products with significant societal impacts. Co-investigator Dr. Jiarong Hong is an innovator and entrepreneur and holds a CTO position in a startup company.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Extraction of Solar Thermal Energy in Minnesota	M.L. 2017, Chp. 96, Sec. 2, Subd. 07a	$250,000
Assess and Develop Strategies to Remove Microscopic Plastic-Particle Pollution from Minnesota Water Bodies	M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 04b	$300,000
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: Lian Shen

Job Title: Kenneth T. Whitby Professor

Provide description of the project manager's qualifications to manage the proposed project.
Dr. Lian Shen will lead the project as the project manager. Dr. Shen holds the Kenneth T. Whitby Professorship in the Mechanical Engineering Department and the St. Anthony Falls Lab (SAFL) at UMN. Dr. Shen is an expert on the study of environmental fluid flows and turbulence in the atmosphere. He has carried out a large number of research projects funded by federal and state agencies, including two previous projects of the Minnesota Environment and Natural Resources Trust Fund.

Co-investigator Jiarong Hong is a Professor in the Mechanical Engineering Department and SAFL at UMN. He is an expert in fluid flow imaging and particle diagnostics. His research has been broadly reported by media. Particularly, his recent work on air quality and COVID-19 transmission has been on the front page of Star Tribune multiple times. He is passionate about translating fundamental research into commercial products and he is holding a position as the Chief Technology Officer of Astrin Biosciences, Inc.

Co-investigator Ardeshir Ebtehaj is an Associate Professor in the Department of Civil, Environmental, and Geo-Engineering at UMN. He has published more than 40 peer-reviewed papers on environmental remote sensing and weather forecasts. He is a recipient of NASA's new investigator award in 2018 for his contribution in remote sensing sciences and weather forecasts.

This project will be assisted by Clare Boerigter, Communications Manager at SAFL. She fought wildfires as a wildland firefighter for the U.S. Forest Service in 2012, 2013 and 2015. She holds a Master of Fine Arts in Writing and specializes in writing and outreach around wildfire. Previously, she worked for the Minnesota Forest Resources Council, UMN's Cloquet Forestry Center, and the Forest Service's Northern Research Station. She is well connected within the Minnesota fire community.

Organization: U of MN - St. Anthony Falls Laboratory

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 St. Anthony Falls Laboratory (SAFL, http://www.safl.umn.edu) at the University of Minnesota. SAFL is an interdisciplinary fluid mechanics research and educational institution. It situates right next to the St. Anthony Falls in Minneapolis and has many unique research facilities. It has 18 faculty members and 42 research and administrative staff members. SAFL is a world-renowned research laboratory specializing in environmental and geophysical fluid mechanics studies. SAFL researchers have performed many innovative environmental studies for the state of Minnesota. Some of the projects were or are funded by the Minnesota Environment and Natural Resources Trust Fund. The proposed research leverages the unique and advanced capability of simulating and measuring environmental flows at SAFL, which has 16,000 square feet of space dedicated to research.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Project Manager - Lian Shen		Oversees the whole project; responsible for the research planning and reporting; leads the research on fire and smoke simulations			26.9%	0.12		$38,241
Co-investigator - Jiarong Hong		Leads the research on drone-based diagnostics and air-quality measurements			26.9%	0.16		$39,701
Co-investigator - Ardeshir Ebtehaj		Leads the research on assimilation weather data into the prediction model			26.9%	0.08		$17,217
Researcher - Richard Christopher		Field deployment of drone-based system			26.9%	0.32		$35,127
Staff - Clare Boerigter		Communications Manager with a fire background to oversee educational and outreach component and facilitate relationships between researchers and fire personnel			24.2%	0.5		$41,405
Postdoctoral Researchers		Develop drone-based diagnostics for wildfire aerosol mapping; develop wildfire smoke predictive model			20.4%	4		$280,688
Undergraduate Student Assistants		Assist data analysis and model validation			0%	1		$31,668
							Sub Total	**$484,047**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Equipment	Data storage	To save the data of measurements and simulations					$3,000
	Equipment	Drones	Includes primary hardware components (frame, GPS, batteries, flight controllers, etc)					$30,000

	Tools and Supplies	Drones 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	**$49,465**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	Field experiment	Miles and meals to conduct field experiments					$6,000
	Conference Registration Miles/ Meals/ Lodging	Workshop and seminars	Cost of conferences, workshop, and seminars					$2,488
							Sub Total	**$8,488**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
	Printing	Outreach materials	Print outreach materails					$1,500

	Publication	Publication of research results	Cost of publishing research in professional journals					$1,500
							Sub Total	**$3,000**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$545,000**

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				
In-Kind	Unrecovered F&A	Support of SAFL facilities where research will be conducted.	Secured	$299,750
			Non State Sub Total	**$299,750**
			Funds Total	**$299,750**

Attachments

Required Attachments

Visual Component

File: 86ca4a3c-657.pdf

Alternate Text for Visual Component

The visual summarizes the problem, proposed solutions, and outcomes of the project for improved prediction of the spread and air pollution of wildfires in Minnesota....

Optional Attachments

Support Letter, Photos, Media, Other

Title	File
UMN SPA letter	2f07dbb5-cbd.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?

No

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

N/A

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

N/A

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Does your project include the design, construction, or renovation of a building, trail, campground, or other capital asset costing $10,000 or more?

No

Do you propose using an appropriation from the Environment and Natural Resources Trust Fund to conduct a project that provides children's services, as defined in Minnesota Statutes section 299C.61 Subd.7?

No