Environment and Natural Resources Trust Fund
2017 Request for Proposals (RFP)

Project Title: **ENRTF ID: 068-B**

Underwater Robots for Hazard Monitoring in Minnesota Lakes

Category: B. Water Resources

Total Project Budget: $ 442,877

Proposed Project Time Period for the Funding Requested: 3 years, July 2017 - June 2020

Summary:

Based on existing underwater robotic technology, the project aims at developing an autonomous system specialized in monitoring Minnesota lake waters for early identification of potential chemical and biological hazards.

Name: Jiarong Hong

Sponsoring Organization: U of MN

Address: 200 Oak Street SE, Ste 450

Minneapolis MN 55455

Telephone Number: (612) 626-4562

Email jhong@umn.edu

Web Address

Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

The existing underwater robotic technology and cutting-edge optical imaging techniques will enable in situ monitoring and detailed analysis of chemical and biological contents over a large volume of water body in Minnesota lakes.

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ TOTAL	_____%

PROJECT TITLE: Underwater robots for hazard monitoring in Minnesota lakes

I. PROJECT STATEMENT

The ten thousand lakes in Minnesota comprise a significant portion of its water resources, and play important roles in regional climate and ecosystem as well as recreation activities. However, recent evidence indicates ever-growing number of hazards to Minnesota lake waters including sulfate and nitrate pollution, and harmful algal blooms (HABs), etc. The conventional way of water quality monitoring requires sampling water manually at different stations followed by sophisticated lab analysis. This process is usually labor intensive and time consuming, and it is also very limited in providing detailed and timely information on the spatial distribution and the composition of the contaminants and the associated environmental conditions. The lack of such information significantly hinders our ability to determine the cause of these anthropogenic and natural hazards and design science-based preventive and mitigation strategies.

Based on existing underwater robotic technology, the project aims at developing an autonomous system specialized in monitoring Minnesota lake waters for early identification of potential chemical and biological hazards. The proposed underwater robotic system has the following features:
(1) Equipped with versatile sensors including a cutting-edge three-dimensional (3D) holographic microscope for simultaneous measurements of physical, chemical and microbiological contents in water.
(2) Capable of onboard analysis of water quality and provide realtime feedback based on sensor measurements.
(3) Capable of operating autonomously with working span and depth covering all inland lakes of Minnesota, and sampling and analyzing water quality at designated locations and paths.
(4) Relatively low cost (below $3000), affordable for wide use by the agencies and researchers within the state.

The proposed research will achieve the following outcomes:
(1) Providing a powerful tool for state agencies and researchers to monitor Minnesota lake waters;
(2) Helping us determine the cause and examine the impact of growing chemical and biological hazards in Minnesota lakes;
(3) Providing key information to construct the science-based forecast models and preventive and mitigation strategies of potential hazards to improve the ecological and recreational values of Minnesota lakes.

To achieve our goal, a prototype system will be first developed based on the current underwater robots that we have. The prototype will then undergo a series of laboratory tests to improve its design, and undergo field deployments in a number of selected lakes in Minnesota at different seasons to mature its design and improve its functionality. At the end of the project, we will deliver two completed sets of underwater robots to Minnesota Pollution Control Agency (MPCA) and Department of Natural Resources (DNR) for future use.

II. DESCRIPTION OF PROJECT ACTIVITIES

Activity 1: Develop the prototype of lake monitoring robot **Budget: $154,851**

This first stage is to design a prototype robot that is instrumented purposely for water quality monitoring in lakes. We will construct the prototype using the established underwater robotic platforms shown in Figure 1. The current platform is designed to operate down to 200 m deep in water and maneuver with tether continuously for 2 hours. We will equip the robot with various types of sensors for measuring the physical properties, and chemical and biological contents including temperature, conductivity, PH, nitrate and dissolved oxygens, etc., and water sampling devices to collect samples for post chemical analysis in laboratory. In particular, the robot will employ a 3D microscope based on cutting-edge digital holographic imaging developed in PI Hong's laboratory. Such microscope does not require any sample preparation like conventional ones and can perform 3D live imaging of microorganism and abiotic particulates over a wide range shapes and sizes as illustrated in Figure 2. We will build the data acquisition and processing platform to integrate the environmental sensors and other water sampling auxiliaries into the central control processor of the underwater robot.

Outcome	Completion Date
1. Finalized the design of the hardware framework of the prototype system	9/30/2017
2. Completion of hardware assembly of the prototype system	3/31/2017
3. Completion of basic software platform for sensor control and robot operation	6/30/2018

Activity 2: System improvement through laboratory tests **Budget: $134,258**

At this stage, we will conduct comprehensive tests of the prototype system developed in the Activity 1 using the main flow channel (86 m long, 3 m wide and 1.8 m deep), volumetric tank (7 m deep, 2100 m^3 volume) and outdoor Streamlab at St. Anthony Falls Laboratory (SAFL). The lab tests will help us: (1) improve the mechanical design of the prototype for autonomous maneuver underwater; (2) conduct precise calibration of the underwater positioning system of the robot over a wide range of operational conditions; (3) develop operational procedure and auxiliary components to prevent the system damage and loss when operating in treacherous lake terrain; (4) establish user-friendly software interface and operational manual for potential users.

Outcome	Completion Date
1. Finalized mechanical design of the lake monitoring robot	1/30/2019
2. Completed positioning system, software support and operational procedure of the robot	4/30/2019
3. A complete set of a lake monitoring robot ready for field deployments	6/30/2019

Activity 3: System improvement through field deployments **Budget: $153,768**

The object at this stage is to mature our robot for real-world applications through deployment in a number of selected Minnesota lakes. We will conduct experiments in different seasons throughout the entire year including deploying in the lakes with different levels of chemical pollution and harmful algal blooms. The collected data will be used to develop capability of onboard data analysis capability of water quality in lakes.

Outcome	Completion Date
1. Detailed water quality information for selected Minnesota lakes under different seasons	6/30/2020
2. Developed capability of onboard data analysis and improved robot operation	6/30/2020
3. Two completed sets of lake monitoring robots delivered to the Minnesota state agencies	6/30/2020

III. PROJECT STRATEGY

A. Project Team/Partners

The research will be led by Prof. Jiarong Hong as project manager and the principal investigator (PI) for the system development, which composes the majority part of the project. Prof. Miki Hondzo will serve as co-PI to assist the field deployment, data collection and analysis. Both PIs are affiliated with SAFL. The PIs will be assisted by postdoctoral associate, graduate students, and staff engineer. Details are provided in the Project Manager Quantifications and Organization Description section.

B. Project Impact and Long-Term Strategy

The proposed project will significantly enhance the ability of environmental agencies and researchers to assess the ecological conditions of Minnesota lakes. Specifically, the proposed robot will provide an easy-to-use platform for gathering comprehensive information over a large water body (lateral span and depth) and perform on board analysis of water quality. In long-term, we expect to collaborate with commercial companies within the state to produce a large quantity of such robots at low cost. These robots will be applied to state-wide lakes under different seasons, providing continuous monitoring of the general ecology, the seasonal change and potential hazards in lakes. The valuable datasets obtained with this instrument will allow us to construct the science-based forecast models and preventive and mitigation strategies to deal with hazards in Minnesota lakes.

C. Timeline Requirements

The proposed research requires three years to complete. The detailed timelines are presented in the section describing the research activities.

2017 Detailed Project Budget

Project Title: Underwater robots for hazard monitoring in Minnesota lakes

IV. TOTAL ENRTF REQUEST BUDGET [3 years]

BUDGET ITEM	AMOUNT
Personnel:	
Prof. Jiarong Hong, PI, at 6% time with 74.7% salary and 25.3% fringe benefits (3 years; 1 person)	$ 22,191
Prof. Miki Hondzo, PI, at 6% time with 74.7% salary and 25.3% fringe benefits (3 years; 1 person)	$ 31,026
Post-doctoral Associate at 100% time with 81.7% salary and 18.3% fringe benefits (3 years; 1 person)	$ 198,361
Graduate Research Assistants at 50% time with 58.5% salary and 41.5% fringe benefits (3 years; 1 person)	$ 137,306
Research Staff Engineer Erik Steen ($25.35/hr and 27.4% fringe benefit) for 50 hours/year	$ 4,993
Equipment/Tools/Supplies: 3 sets of robotic platforms (3x$1,000); 3 sets of digital holographic setup ($6,000); $15000 for 3 sets of environment sensors (temperature, PH, dissolved oxygen, chemicals); the 3-year supplies for deployment (3x$3000).	$ 33,000
Travel: traveling to different lakes for field deployment in the last year of the funding period, which including the fuel for the truck and boats and and some accessories	$ 6,000
Additional Budget Items: field deployment boatlrental ($6000), tool and equipment rental ($4000)	$ 10,000
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 442,877

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ Being Applied to Project During Project Period: N/A	$ -	N/A
Other State $ Being Applied to Project During Project Period: N/A	$ -	N/A
In-kind Services During Project Period:	$ -	N/A
Unrecovered UMN Indirect costs (52% MTDC)	$ 202,371	*Secured*
Funding History: **National Robotics Initiative funding on "Robotics 2.0 for Disaster Response and Relief Operations" (2014-2017).** The proposed project will leverage the resources developed from this project which will end in summer, 2017.	$ 1,000,000	ongoing and end in summer 2017

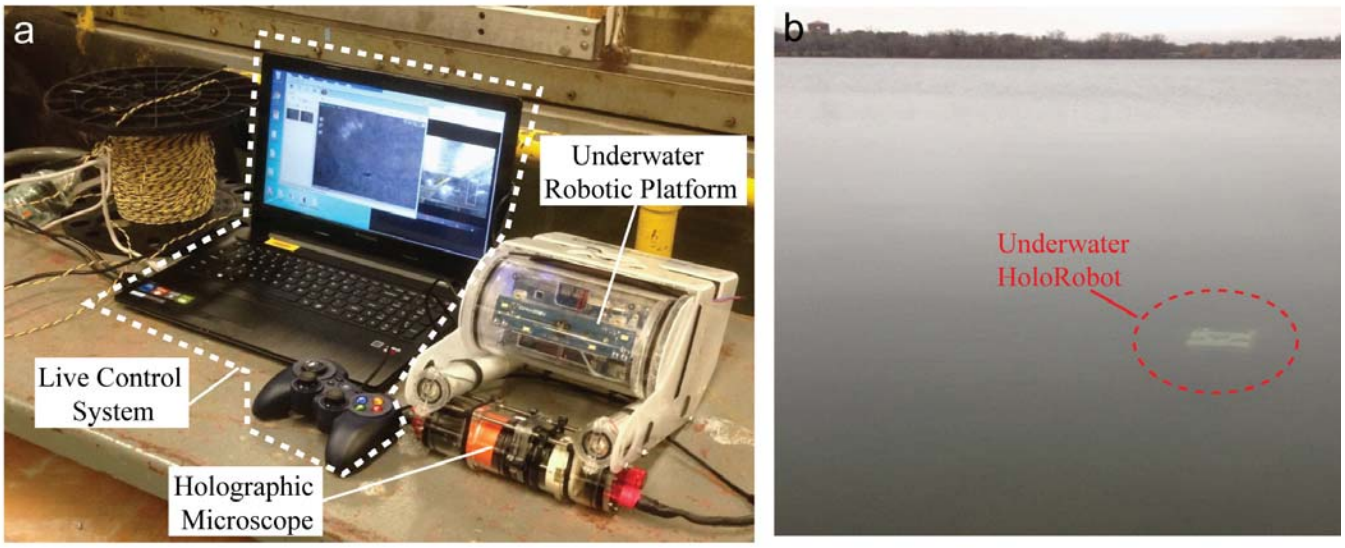

Figure 1. (a) The underwater robotic platform "HoloRobot". The robot is equipped with a three dimensional (3D) digital holographic microscope which allows 3D live imaging of microscopic particulates. This platform will serve as the basis for the development of the proposed robot for lake monitoring. (b) The field deployment of "HoloRobot" in Lake Johanna, Arden Hills, MN.

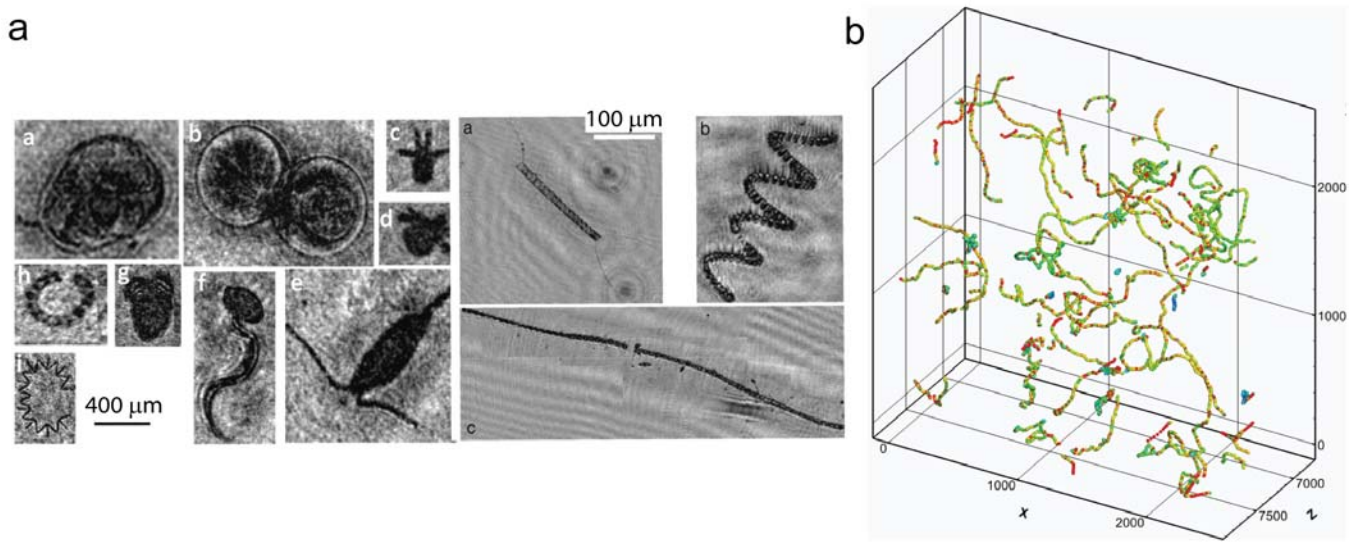

Figure 2. (a) Selected sample images of live microorganisms in water recorded by digital holographic microscope. (b) The 3D motions of microscopic particles captured by digital holographic microscope underwater. The color on the trajectory of individual particles marks their instantaneous speed.

Project Manager Quantifications and Organization Description

Project manager: Jiarong Hong

Benjamin Mayhugh Assistant Professor in Saint Anthony Falls Laboratory (SAFL) and Department of Mechanical Engineering at University of Minnesota
B.S., Mechanical Engineering, University of Science and Technology from China, 2005
Ph.D., Mechanical Engineering, Johns Hopkins University, 2011

Research Focus: Hong's research across a wide range of areas involving flow mechanics, limnology, optical sensing and robotics. He has substantial experience in the field and laboratory study of harmful algal blooms (Hong et al. 2012, PLOS One *7*(5) and Talapatra & Hong 2013, MEPS, 473, 29-51). His work has been widely reported by major international media including *Nature, National Geographic, and Yahoo News, etc.*

Awards: Robert T. Knapp Award from the Fluids Engineering Division of American Society of Mechanical Engineers (2011), Corrsin-Kovasznay Outstanding Paper Award (2012), CAREER award from National Science Foundation (2015), McKnight Land-Grant Award (2016), and Office of Naval Research Young Investigator Awards (2016).

Co-investigator: Miki Hondo

Professor in SAFL and Department of Civil, Environmental, and Geo- Engineering at University of Minnesota.
M.Sc., Surface Water Hydrology, Free University of Brussels, 1988
Ph.D., Civil Engineering, University of Minnesota, 1992

Research Focus: Hondzo's research lies in the areas of water quality and physical processes in aquatic ecosystems. He has over 20 year experience in conducting field and laboratory research on harmful algal blooms and water quality in rivers and lakes.

Awards: Founders Award for the best paper "Long-term lake water quality predictors" (1996), CAREER award from National Science Foundation (1997), Rudolph Hering Medal (2000) and Arnold Greeley Award from Environmental Engineering Division of American Society of Civil Engineers for most valuable contribution to the increase of knowledge in the environmental branch of the engineering profession (2008).

Organization Description:

Prof. Jiarong Hong will serve as the project manager and carry out the majority of the development in the proposed project. Prof. Miki Hondzo will serve as the co-PI to assist the field deployment, data collection and analysis part of the project. Both PIs are affiliated with SAFL (http://www.safl.umn.edu), a world-renown research laboratory in environmental engineering and water resources. The lab has a large number of faculty and research engineers who have contributed to the projects related to water resource and management across the state. Instrumentation development is a significant part of the lab. In the past, the lab has developed automated data collection, sampling protocols, wireless data transfer and storage for several state agencies. SAFL provides a number of unique facilities for the proposed research. These facilities include an 86 m long flume using Mississippi river with well-controlled flow rate, outdoor stream lab (an artificial river for sediment and chemical transport in river and alluvial plain), 2100 m^3 volumetric tank for testing submersible devices. The EcoFluids Lab, nested in SAFL and developed by PI Hondzo, allows researchers to study the interactions among fundamental fluid mechanics, microalgal metabolism, and chemical processes in aquatic environments. In addition, both PIs are co-investigators for two major robotics grants from National Science Foundation including $ 1 million National Robotics Initiative funding on "Robotics 2.0 for Disaster Response and Relief Operations" and $ 1.5 million major Research Instrumentation funding on "Development of a Solar UAV Instrument". The proposed project will significantly leverage the resources from these federal grants.