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United States Department of Agriculture
Project Initiation

Project Data for Accession Number 1027622

Project Title

Collaborative Research: NRI: Ocean-Powered Robots for Autonomous Offshore Aquaculture

Project Details

Sponsoring Institution National Institute of Food and Agriculture	**Project Status** COMPLETE
Funding Source NIFA Non Formula	**Grant Year** 2021
Grant No. 2021-67021-35975	**Cumulative Award Amt.** $250,000.00
Proposal No. 2021-10978	**Multistate No.** (N/A)
Project Start Date Sep 01, 2021	**Project End Date** Aug 31, 2025
Program Code [A7301] National Robotics Initiative	

Project Director

Furukawa, T.

Recipient Organization

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Performing Department

Mechanical and Aerospace Engineering

Non Technical Summary

According to the United Nations Food and Agriculture Organization (FAO), 76% of the 600 fish stocks they track are either fully exploited, overexploited, or depleted. The fishing industry has been forced to turn to aquaculture, an alternative means ofproduction. Aquaculture has been the fastest-growing source of animal protein since 1990. In 2018, global fish productionreached 179 million tons, 45% of which, valued at $250 billion, came from aquaculture production. The FAO has predicted that by 2030 the global aquaculture market is projected to be more than $529 billion. Aquaculture production has increaseddramatically to five times the level of production in the 1990s, while wild fish production has decreased. Compared with coastalinshore aquaculture, offshore fish farming may yield 10-100 times the fish production, and is an effective strategy to decreasepressure on wild natural resources, with lower environmental impact.However, the U.S. globally remains a relatively minor aquaculture producer, ranked 16th in 2018 on a global scale, although it isthe leading global consumer of aquaculture products, importing 90% of its seafood

from abroad. Blue Ocean Mariculture Inc.(HI) remains the only ffshore aquaculture farm in operation in the USA. In 2020, Presidential Executive Order 13921 onseafood was signed to boost the infant US aquaculture industry. This Executive Order prioritized aquaculture development inocean waters, especially in the U.S. exclusive economic zone. It is pivotal to develop and implement advanced technologies toaccelerate domestic aquacultural production.Huge challenges exist for offshore aquaculture operations and maintenance. Preliminary research was performed by the projectteam by interviewing offshore fish farm industry leaders and reviewing the available literature on offshore fish farms. Among themost labor-intensive and high-risk tasks are cleaning and dead fish removal. According to Open Blue Sea Farms, Inc., humandivers are sent to fish pens to remove dead fish every day, since dead fish will attract sharks and marine mammals, anddamage the fish pens. They also conduct monthly cleaning work to mitigate biofouling of the metal fencing comprising the pens.Needless to say, the offshore environment is subject to high waves and more aggressive sea creatures, which increase both theworkload and danger of human divers.These challenges motivate us to develop a sustainably powered autonomous robotic system, including both an autonomoussurface vehicle (ASV) and an autonomous variant of a tethered remotely operated vehicle (which we term AROV), to improvethe operation, maintenance, and monitoring processes and increase overall fish production at offshore fish farms.

Animal Health Component

Animal Health Component: 0%

Research Effort Categories

Basic	0%
Applied	50%
Developmental	50%

Classification

Knowledge Area (KA)	Subject of Investigation (SOI)	Field of Science (FOS)	Percent
601	7210	2080	40%
601	7210	2020	60%

Knowledge Area

[601] Economics of Agricultural Production and Farm Management

Subject Of Investigation

[7210] Remote sensing equipment and technology

Field Of Science

[2080] Mathematics and computer sciences

[2020] Engineering

Keywords

United States Department of Agriculture
Project Initiation

Agriculture, Aquaculture, Control, Design, Mechanisms, Perception, Planning, Dynamics, Manipulation, Field Robots, Marine Energy

Goals / Objectives

Broad Goals of the Collaborative ProjectThe United States is a minor aquaculture producer, while it is the leading global importer of fish and fishery products. The aim ofthis project is to develop an autonomous, ocean-powered robotic system to support offshore fish farming, which opens newpossibilities for advanced technology to aid the proliferation of domestic aquaculture. To operate sustainably far offshore, thesystem will power itself by harvesting energy from ocean waves. An autonomous surface vehicle (ASV) will serve a dualpurpose as both a mission management system and a wave energy converter. The ASV will deploy an autonomousunderwater robot embodied in a tethered, omnidirectional remotely operated vehicle (ROV), which will be termed anautonomous remotely operated vehicle (AROV). The AROV will address two of the most labor-intensive and time-consumingtasks associated with the maintenance and upkeep of an offshore fish farm: persistently cleaning fish pen fencing to avoid theaccumulation of biofouling, and frequently removing dead fish from the mort traps at the bottom of their pens. The ASV's noveldesign and energy-efficient control will permit it to harvest energy while supporting the AROV's subsea tasking. The AROV,equipped with continuum manipulators and novel sonar-based perceptual capabilities, will be uniquely capable of conservingenergy while cleaning by climbing along a fish pen's fencing, minimizing its use of thrusters. The project will be executed by anexperienced team with diverse expertise spanning wave energy harvesting, target tracking and control, grasping andmanipulation, underwater perception and navigation, and fisheries ecology and management.Goals of the UVA TeamFurukawa will lead the project as the Lead PD. Furukawa's first goal is toadminister the project as the Lead PD and lead the project successfully to produce the expected outcomes. Technically, the UVA team will be in charge of the development and navigation of the ASV. The ASV will serve as a wave energy converter (WEC) to harvest ocean energy. Since the WEC will be designed at Virginia Tech (VT), the UVA team will collaborate with the VT team and complete the development of the ASV. The mission of the ASV is to allow the AROV to localize and navigate itself autonomously to perform both dead fish removal and cleaning path following. Since the Stevens Institute of Technology (Stevens) team will develop the AROV and its autonomous navigation scheme, the UVA team will collaborate with the Stevens team and develop an autonomous navigation scheme for the ASV.

Project Methods

Overall MethodThe entire system will consist of an ASV and an AROV. The ASV will serve as a WECto harvest oceanenergy, supplying power to itself and to the AROV for its mission. The AROV will localize and navigate itself autonomously to performboth dead fish removal, and to execute cleaning paths along the boundary of the fish pens (typically30-70 meters across). The AROV will perform frequent, light-duty cleaning of the fish pen fencingand dead fish collection with unprecedented energy efficiency, using low-cost modular continuummanipulators to grip the surrounding fencing. As the AROV may travel beyond the length of itstether cable, the ASV performs "mild" autonomous following.Each of the proposed technologies isstrongly coupled with the expertise of a PD. For ASV development, PD Zuo will work on power generation with his ocean energy harvesting expertise. PD Englot will work on AROV navigation with his underwater vehicle autonomy expertise. Co-PDWang will work on AROV manipulation with his robotic armdesign expertise. PD Furukawa will work on ASV navigation with his multi-robot cooperation expertise. Co-PD Jiaowill work on technology assessment with her fishery quantitative assessment expertise. Senior Personnel (SP) Cordero willserve as Chair of an Industry Advisory Board (IAB) formedwith representatives of leading fish farm companies. Furukawa will serve as the Lead PD for thisproject due to his robotics research experience over two decades and extensive experience in leadingindustry-funded projects.ASV Integration and Navigation (UVA Team) The proposed WEC simultaneously serves as an ASV, harvesting energy both to operate the AROV, and to control the ASV as it follows theAROV with minimal energy consumption. The state constraint to satisfyis that the distance between the ASV and the AROV must be less thana threshold distance, which is well less than the maximum cable length.The proposed control scheme is as follows. If the AROV is on afence-cleaning or dead fish collection mission,

the ASV will be connectedto a rail installed along the circumference of the fish pen while keepingoriented tangentially to the circumference. The ASV is stationary unlessthe ASV-AROV distance exceeds the threshold, in which case it moves further along the circumference. This kinematic constraint simplifies theASV control by making it a 1-D problem. The ASV control becomes fully two-dimensional when the AROVmoves from one fish pen to another. Given the state of the AROV at the current step, the state of the AROV at future steps can be probabilistically predicted using the Chapman-Kolmogorov equation. In order tominimize the energy consumption, the simple solution proposed for ASV control is linear motionto the peak of the belief at the predefined multi-step lookahead, based on receding horizon control (RHC). This simple linear servoing can be revisited as a non-trivial control solution when energyefficiency is concerned. It is to be noted that the control scheme can also be used for engaging witha target, such as a fish pen's rail, if the target can be localized by the ASV.Lastly, the localization of the ASV as well as its target should be discussed. Simultaneouslocalization of the ASV and any target is classified as a tracking-and-localization (TAL) problem andhas been solved previously using an Extended Kalman Filter (EKF) based multi-stage localizationtechnique by PD Furukawa. Since it is on the surface, the ASV will be equipped withstandard localization sensors including a GPS, an IMU, a LiDAR and a stereo camera, which areneeded for the proposed multi-stage localization technique. The proposed technique will be usedto estimate the ASV pose and the target pose.