SSC Project Recommendation for FY 2023

Advanced Fiber Optic Sensing Technologies for Ship Hull Structural Monitoring

Submitted by: Caitlin R.S. Williams, caitlin.williams@nrl.navy.mil, 202-767-9508, US Naval Research Laboratory, Washington, DC

1.0 OBJECTIVE.

1.1 Demonstrate methods of integrating advanced fiber sensor technologies into ship hull monitoring systems, providing data to validate structural digital twin ship model and inform fatigue assessments.

2.0 BACKGROUND.

2.1 Ship structural health monitoring (SHM) systems combined with the development of structural digital twin models (SDTM) enables a shift to condition-based maintenance (CBM) with the installation of hull monitoring systems. Existing hull monitoring systems (HMS) typically comprise a small number (< 50) of sensors that provide global superstructure measurements to estimate ship structure deformation using a SDTM [8.1]. Existing electronic sensors require heavy cabling, are susceptible to corrosion, and require re-calibration during the ship operating life. Fiber optic hull monitoring systems have become commercially available and match the capability of existing electronic systems with reduced cabling and improved reliability [8.2].

2.2 Advanced fiber optic sensor (FOS) technologies can uniquely augment the capability of existing systems to provide a range of new capabilities including: (i) ship detail monitoring, (ii) distributed temperature sensing, (iii) sensitization risk monitoring, (iv) crack detection [8.3], (v) hull pressure measurement, (vi) acceleration, (vii) distributed strain/shape reconstruction. Compared to existing systems, FOSs have very low sensor footprint, enable flexible sensor location, and provide high density of measurement points.

2.3 This new measurement capability enables a data informed SHM approach with comprehensive validation of ship hull structural digital twin models, a capability not possible with existing technology. Additionally, FOSs provide unique, new capabilities, such as real-time shape reconstruction of naval structures, monitoring areas of high thermal and mechanical load to support prediction and monitoring of sensitization risk factors well before stress induced corrosion cracking occurs [8.4], and multi-axis fatigue estimation of individual ship details.

2.4 The proposed study will review relevant fiber optic sensor technologies and show how data is used to provide these new capabilities. A recent installation of distributed FOS on a vessel has generated continuous data for thousands of strain sensors and hundreds of temperature sensors. This data will be used as part of this study [8.5].

2.5 Fiber optic sensor system have been reviewed in the past for their applicability to ship hull structural monitoring. A study by Slaughter, et al. [8.6] detailed a variety of SHM technologies, covering the state of the art in FOS technologies at the time of publication (1997) with a more recent study in 2013 [8.7]. Since this time, considerable advances in FOS have occurred with the development of distributed sensing technologies and advanced ultrasonic FOS detection technologies. With more than two additional decades of FOS technology research and development since the last review by SSC that includes FOS for SHM, an updated study is needed to describe the possible naval SHM applications of state-of-the-art FOS technologies.

3.0 REQUIREMENTS.

3.1 Scope.

3.1.1 The Contractor shall conduct an assessment of state-of-the-art FOS technologies for ship structure monitoring applications.

3.1.2 The Contractor shall review installation design methodologies.

3.1.3 The Contractor shall demonstrate methods for efficient data management and processing, which can be implemented over the lifetime of the vessel and combined with other relevant ship and meteorological data to validate SDTM simulations and provide new SHM capabilities.

3.2 Tasks.

3.2.1 The Contractor shall conduct a comprehensive literature review of state-of-the-art FOS technologies for SHM of vessels, applicable to current and potential future ship structural monitoring applications.

3.2.2 The Contractor shall demonstrate FOS data applications such as SDTM validation, real-time fatigue assessment, shape reconstruction, detail monitoring, crack detection, and thermal loading.

3.2.3 The Contractor shall demonstrate methods for efficient data management and processing, which can be implemented over the lifetime of the vessel and combined with other relevant ship and meteorological data.

3.2.4 The Contractor shall describe the process for integrating these advanced capabilities with existing hull monitoring technologies.

3.3 Project Timeline.

	Month											
Task	1	2	3	4	5	6	7	8	9	10	11	12
3.2.1												
3.2.2												
3.2.3												
3.2.4												
Reporting												

4.0 GOVERNMENT FURNISHED INFORMATION.

4.1 Standards for the Preparation and Publication of SSC Technical Reports.

5.0 DELIVERY REQUIREMENTS.

5.1 The Contractor shall provide quarterly progress reports to the Project Technical Committee, the Ship Structure Committee Executive Director, and the Contract Specialist.

5.2 The Contractor shall provide a print ready master final report and an electronic copy, including the above deliverables, formatted as per the SSC Report Style Manual.

6.0 PERIOD OF PERFORMANCE.

6.1 Project Initiation Date: date of award.

6.2 Project Completion Date: 12 months from the date of award.

7.0 GOVERNMENT ESTIMATE.

These contractor direct costs are based on previous project participation expenses.

7.1 Project Duration: 12 months.

7.2 Total Estimate: $100,000

8.0 REFERENCES.

8.1 For example: "Pioneering ABS and MSC Condition-Based Class Program Showcased at Mega Rust 2019," American Bureau of Shipping, https://ww2.eagle.org/en/news/press-room/abs-msc-condition-based-class.html .

8.2 For example: "Hull Stress Monitoring System," Light Structures, https://www.lightstructures.com/solutions-and-systems/hull-stress-monitoring-system/

8.3 Caitlin R. S. Williams, Meredith N. Hutchinson, Joseph D. Hart, Marriner H. Merrill, Peter Finkel, William R. Pogue III, and Geoffrey A. Cranch , "Multichannel fiber laser acoustic emission sensor system for crack detection and location in accelerated fatigue testing of aluminum panels", APL Photonics 5, 030803 (2020) https://doi.org/10.1063/1.5133040

8.4 C. R. S. Williams, J. D. Hart, M. N. Hutchinson, and G. A. Cranch, "Fiber Laser Sensor Detection of Acoustic Emissions from Stress Corrosion Cracking in Aluminum," in *Optical Fiber Sensors Conference 2020 Special Edition*, G. Cranch, A. Wang, M. Digonnet, and P. Dragic, eds., OSA Technical Digest (Optica Publishing Group, 2020), paper W4.47.

8.5 C. R. S. Williams, J. D. Hart, S. J. Meiselman, S. R. Varma, J. W. Lou, C. G. Pelzman, G. A. Miller, and G. A. Cranch, "Fiber Optic Distributed Sensing for Ship Hull Monitoring on the Expeditionary Fast Transport Ship," in *27th International Conference on Optical Fiber Sensors*, Technical Digest Series (Optica Publishing Group, 2022), paper W2.5.

8.6 S.B. Slaughter, Dr. M.C. Cheung, D. Sucharski, & B. Cowper, "State of the Art in Hull Monitoring Systems," Ship Structures Committee, Report Number: SSC-401 (1997).

8.7 B. Phelps and B. Morris, "Review of Hull Structural Monitoring Systems for Navy Ships," Defence Science and Technology Organisation, DSTO-TR-2818 (2013).