Remote sensing of sea state for ships navigating in arctic waters

The United States has a growing interest in navigating the arctic waters Greenert [6]. The realities of global warming are manifesting in more navigable waters in the arctic, creating growing concerns of national security and increased interest in the economic potential of the arctic. As such, ensuring safe sea travel for vessels in harsh arctic conditions is now a primary concern.

In order to achieve reliable sea-keeping to minimize the risk of capsizing, I am interested in developing a framework to address the potential scenario of ice accumulation on a ship vessel, thus changing the internal mass properties the vessel was designed for or would have without ice accumulation. Previous studies have indicated that the main agent for icing is from sea-spray due to ship motion interacting with ocean waves [4, 11, 12]. It is, therefore, critical to know both the internal mass properties of the ship, as well as the incoming wave or sea state that is providing an excitation to the ship.

The effects of the incoming waves are two-fold: the excitations bear influence on the resulting sea-spray, and the excitations also pose a potential risk for the ship to lose sea-keeping and stability capabilities. The former is a difficult problem to study since the data are difficult to collect in a controlled environment. Many models have been created in order to approximate this, from statistical models to physics-based models. If we take the information from these models as to where like is likely to form, we can focus on the latter and study only the incoming waves and the resulting ship motion, using the ship’s inertial measurement unit. Given that we can properly describe the sea state (wave height, period, direction and velocity of wave), we could compare the actual motion of the ship to a simulated fluid-structure interaction model of the ship in a virtual sea.

In this study, I am interested in investigating the feasibility of recovering the following to use in the described framework: (1) the current sea state in the area surrounding a vessel potentially travelling in the arctic, including wave height and period and (2) the direction and velocity of the waves.

There are several related applications that may provide insight for this project. Concerns about data availability and sea state visibility will be critical. The remote sensing instrument would ideally provide data in high temporal frequency and be made available in near-real-time from the time of collection, and must be readily collected even with significant cloud cover or other obscurities that may occur in the arctic. These preliminary sources indicate that the problem I am approaching is likely to be technologically feasible. The following is a brief synopsis of different remote sensing techniques that have been used to infer sea states.

There are methods to determine the scale and sea state from a standard video, independent of calibration [13, 14]. This method relies on computer vision techniques, along with prior knowledge of wave dynamics and physics, to infer the wave heights and velocities without any formal calibration stage, making this unique from most other techniques. Resolution is in the correct scale, with the studies ranging from 0.1-0.7 meters per pixel. While this study has shown promising results, the use of a normal video is extremely limiting. It is required that the system work both in night time as well as in low visibility scenarios, such as heavy fog. The logistics of directionality would also have to be considered in order to obtain a panoramic view.

Existing data on ocean wind vectors, a parameter closely tied to sea state (a modern version of the Beaufort scale, which relates wind speeds to form and height of waves, along with a qualitative
description of the sea state, has been used to validate wave height results from video recordings of the ocean [14]), is readily available. These measurements are taken by scatterometers such as RapidScat and its predecessor, QuickSCAT [3, 8].

High Frequency remote sensing of sea state via radar is also common, though these instruments are typically mounted to a location on a shore [2]. These systems can reach over ten kilometers offshore and provide high temporal frequency. They are, however, stationary and cannot track a ship beyond a specified distance from the shore, which will often be a place of necessity given the proposed application, in which ships would very possibly be exploring locations outside of the specified range from the shore.

Synthetic Aperture Radar and Radar Altimeters have also been used to infer the sea state [9, 5]. Spatial resolution for SAR instrument used (ERS-1) in [9] is 30m with temporal frequency at 43 orbits in 3 days time, or up to two passes in a day. The temporal resolution would need to be vastly increased in order to be useful for sea-keeping purposes. Further research is needed to determine whether an existing satellite may have better temporal resolution, or if one could feasibly be specified to meet this project’s needs.

Research has also been ongoing in using a marine navigation radar (X-band, around 10 GHz [7]) to measure wave height [16, 10]. An available commercial addition, the WaMoS system connects to existing x-band radar instruments on-board the ship. Resolution for this system has been cited as fine as 5 meters and, though earlier systems (as [16, 10]) were recommended only for lakes or shallow water, this system has been been deployed on ships traveling in deeper waters [7].

Given the preliminary literature review, it seems most feasible to move forward with using the already existing marine navigation radar to conduct this study. This is convenient in that visibility is not an issue, data collection is already ongoing, and the instrument is already installed. Images are also collected for the exact location of interest, with the vessel at the center of the data collection.

The proposed study will require the use of the full-scale R/V Melville. Using its on-board marine radar (X-Band radar), and its IMU, a validation study has been conducted in a real sea-state forcing the vessel. This data has already been collected during a nine-day period in 2013 through an effort by the Office of Naval Research [15, 1]. Though this ship does not have any ice accumulation, this validation provides critical baseline knowledge needed to go further in the study involving ice accumulation on a vessel. In this follow-up study to the 2013 work, I propose that material piles will be placed in areas of likely ice accumulation in order to simulate the build-up of ice, as well as in typical locations below the deck. Since the material pile properties will be known, along with the motion of the ship, as well as an inferred sea state, the study will provide necessary insight to the problem of sea-keeping under potentially uncertain mass properties due to ice accumulation, as well as determining the sensitivity of the sea state and whether such differences in masses can be detected through such a method.

The computational framework envisioned for this problem, that is, model updating due to evolving mass properties from accumulation of sea ice in a fluid-structure interaction simulation is both computationally challenging and computationally expensive, but an important component to understanding sea-keeping in the arctic to ensure safe travel in an increasingly accessible landscape.

References


