

Using Vision-Based Wave Height Sensors to Estimate Ocean Wave Field

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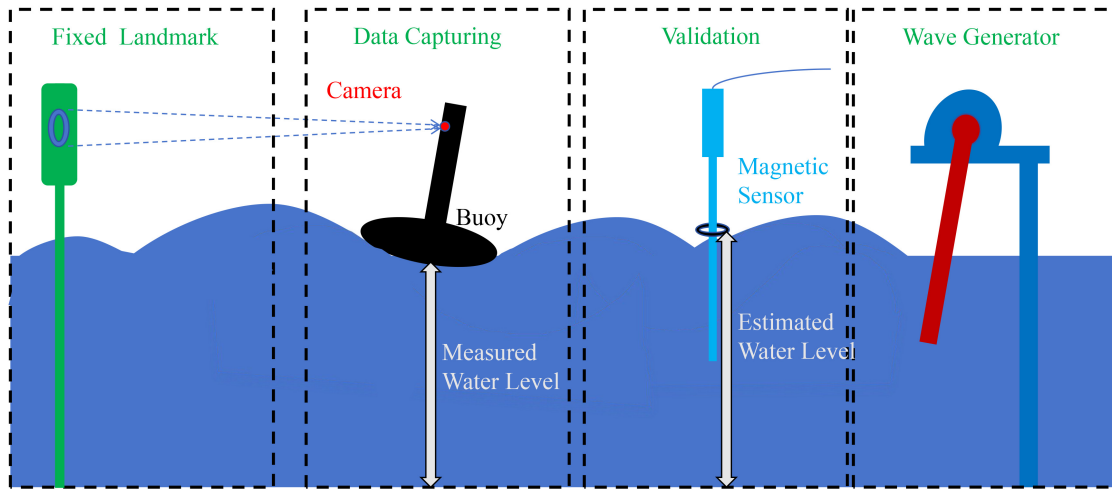
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Abstract

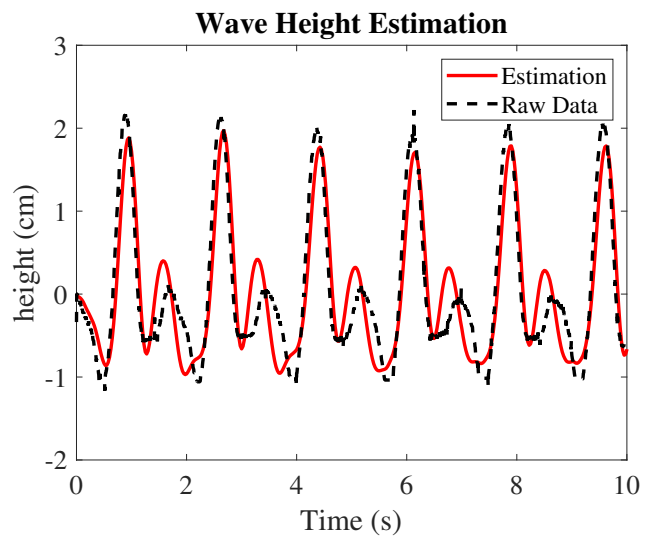
The overall objective of this research is to employ a small array of discrete low cost wave height sensors to estimate the 2D wave field in the vicinity of the sensors. This wave field information is critical for synchronizing the operation of wave energy converters (WECs) within a wave farm, thereby maximizing energy production. Traditionally, the wave height data from an array of locations have been utilized to reconstruct the wave field using a data assimilation approach whereby measured data is used to estimate initial conditions in a CFD computation. Instead of this computationally expensive approach, a Kalman filter based observer was recently developed to estimate the amplitudes and phases of Airy waves in a range of frequencies and direction (ACC-2023). Furthermore, by aggregating the Airy wave components, the comprehensive estimation of the entire wave field can be achieved.

In order to validate this wave estimation approach, we developed a wave height sensor using vision-based buoy localization, which could provide wave height data in real time, in order to estimate the wave profile in a certain region. As shown in figure 1a, the sensing system consists of two parts: 1) a fixed landmark located above the water and in front of the buoy; and 2) a data capturing system mounted on a buoy with a camera viewing the landmark. A n-points perspective (PnP) image processing algorithm, which is based on gradient descent least squares algorithm on the $SO(3)$ manifold, is then used to determine the position and orientation of the buoy relative to the landmark, and hence the wave height. Compared to conventional water level sensors, this vision-based sensor provides a cheaper approach to build up wave sensor network. The experiment results also shows that the vision-based sensor is robust against disturbances from background lighting, which highlights its versatility across various environmental conditions.

Finally, a series of experiments have been conducted in a flume at the St. Anthony Falls Laboratory (SAFL) at the University of Minnesota. In the test, four LEDs arranged in a tetrahedral formation served as the landmark. The LEDs were observed by a camera mounted on a buoy. A Raspberry Pi 4 single board computer (SBC) was used to capture and process the real-time data at a rate of 40 frames per second. This buoy, which can heave and pitch, was placed within a 1-dimensional flume. The flume is equipped with a wave paddle to generate quasi-1D waves, allowing for precise and controlled experimentation within the flume environment. The wave height at the buoy's location, computed from the pose information obtained using the $SO(3)$ gradient algorithm was used to estimate the wave profile. The estimated wave height was finally compared with the data from the conventional magnetic wave sensors placed elsewhere in the flume, which proved that our sensor could get accurate wave profile estimation (Fig 1b). Note that while Fig 1b shows only the wave height trajectory at one location, the estimation algorithm can estimate the wave height trajectory at any location.



(a)



(b)

Figure 1: (a): Schematic of the sensing system, and (b): The wave height estimation compared with the data from the magnetic sensor.