Sea State Monitoring From A Mobile X-Band Radar System

Ship and Recreational Vehicle-Based Radar Systems Provide Short-Term, Mobile Monitoring of Sea Conditions

By Li-Chung Wu
Postdoctoral Researcher
Coastal Ocean Monitoring Center
National Cheng Kung University
Tainan, Taiwan
Chia Chuen Kao
Director
Taiwan Ocean Research Institute
National Applied Research Laboratories
Taipei, Taiwan
and
Wen-Hung Yang
Engineer
CSBC Corp.
Kaohsiung, Taiwan

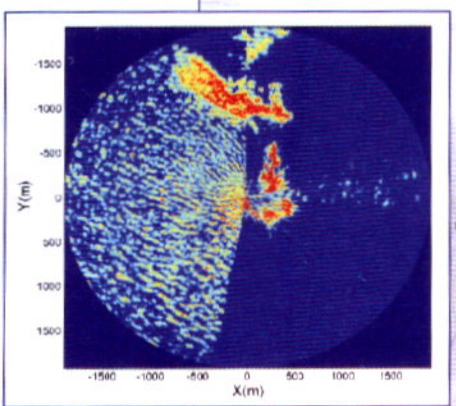
Sea state information is often a requirement for coastal engineering, environmental protection, port operations, disaster prevention, rescue operations and other applications. Methods to monitor sea state generally include *in-situ* or remote sensing techniques. Remote sensing is a useful way to view sea surface features in the spatial domain—the remotely sensed image describes the sea surface based on its backscattering strength.

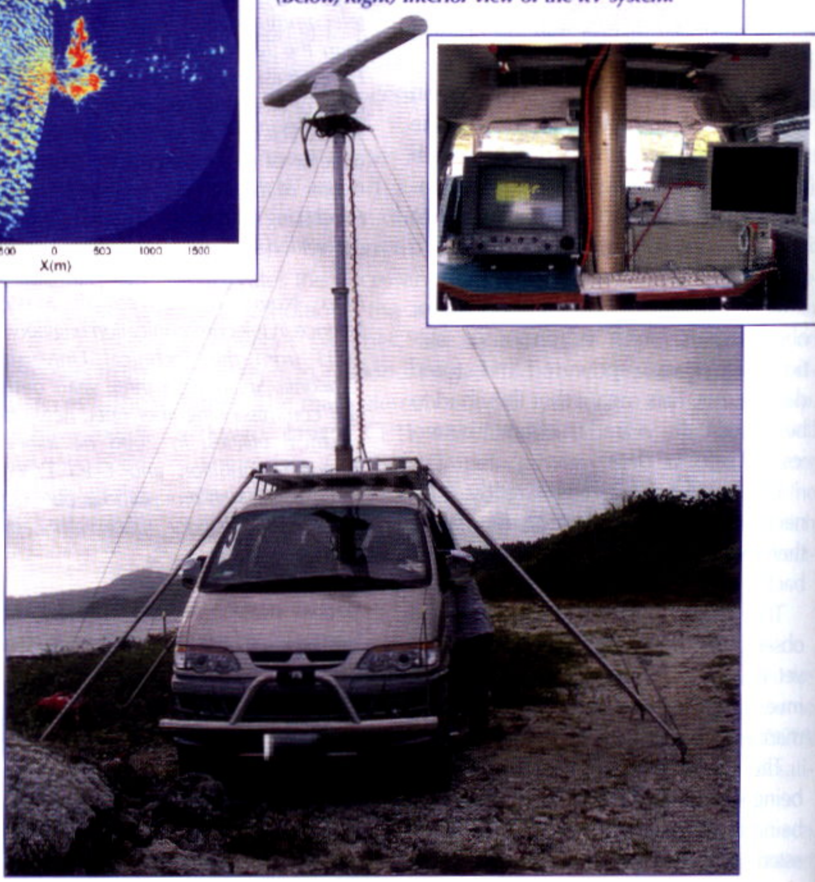
Remote sensing using marine X-band radar has been widely applied in ship navigation, and recently it has begun to be used to measure ocean surface waves and currents. Spatiotemporal sea-surface information can be extracted from continuous X-band radar image sequences.

Most of today's marine X-band radar products operate from land-based stations, but short-term or mobile monitoring stations are necessary for coastal engineering, ocean pollution monitoring and maritime rescue. To meet these mobility requirements, researchers at National Cheng Kung University and the National Applied Research Laboratories integrated a mobile radar monitoring device onto a recreational vehicle (RV) and later to a ship.

Mobile X-Band Operation

Marine X-band radar images the sea surface through the Bragg resonance process—electromagnetic waves launched from a radar antenna are strongly backscattered by ocean surface waves at half the electromagnetic wave length, then

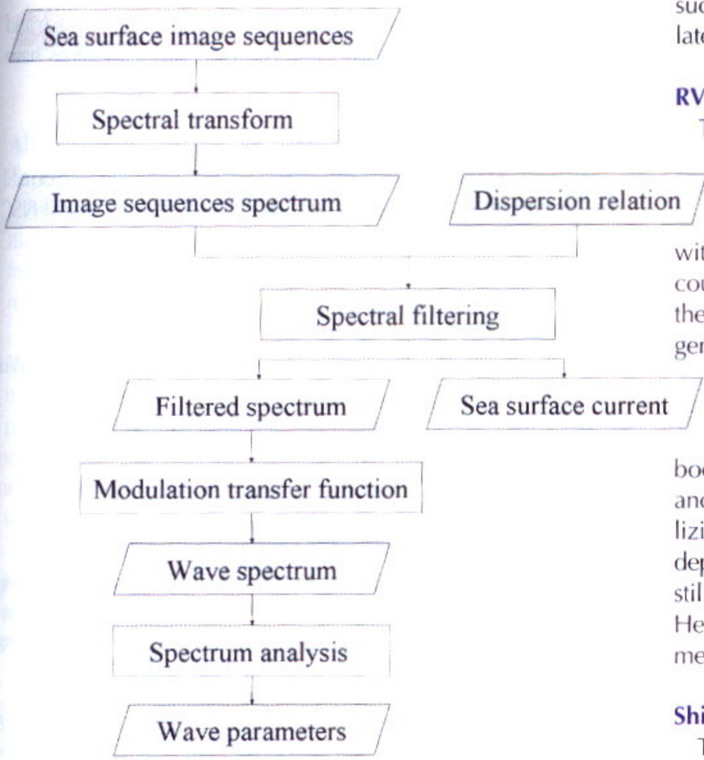




The mobile X-band radar system operated on an RV.

(Left) X-band radar image.

(Below, Right) Interior view of the RV system.



Results of an inhomogeneous sea-surface image analysis.

detected by the system. After collecting the sea-surface image signals from the radar system, different algorithms for image analysis are applied to extract sea-state information.

The functional core of the mobile X-band radar system includes an analog-to-digital system with a 20-megahertz sampling rate and 12-bit resolution. The spatial resolution of the radar image is 7.5 meters per pixel under this sampling rate. At 42 revolutions per minute, the radar acquires 42 continuous sea-surface image sequences every minute and the image sequence has a temporal resolution of 0.7 hertz.

After monitoring the same sea area continuously, radar image sequences can be processed to obtain information about the sea surface.

The first step to derive the sea-surface wave and current information from the radar image sequences involves spectrum transformation. Fourier transform, which is suitable for homogeneous image analysis, is the most common and useful tool to extract the image sequence spectrum from the homogeneous radar image sequence.

Recently, studies have shown the inhomogeneity of nearshore sea surface patterns. Different solutions based on the algorithms of the dispersive surface classificator and wavelet transform have been used to analyze the inhomogeneous sea-surface features from radar images.

Eliminating background noise is necessary to capture accurate sea-state information. The theory of dispersion relation is applied to filter noise from the spectrum.

Once the noise has been filtered, operators can extract sea-surface current information from the image sequence spectrum using Doppler-shifted dispersion calculations.

To obtain the ocean wave spectrum, the modulation transfer function is recommended as a means of establishing the relationship between the filtered image-sequence spectrum and the ocean wave spectrum. Significant wave parameters, such as the wave period and wave height, can then be calculated from the wave spectrum.

RV-Based Radar System

To operate safely and effectively, the mobile X-band radar system required sufficient height, power and stability. The shadowing effect of electromagnetic waves caused by a low grazing angle was avoided by equipping the RV with a seven-meter boom, powered by an oil pump, that could lift the radar antenna to a sufficient height. Powering the radar and supporting equipment required a 1,000-watt generator in the RV.

The added height and weight of the X-band radar on the boom required the RV to be stabilized. Four jacks were placed under the vehicle, and the seven-meter boom was stabilized with four four-millimeter cables anchored to 3.5-centimeter steel piles. Even with these stabilizing features, the system still takes less than 30 minutes to deploy and operate after arriving on site, and the system can still operate safely in severe weather: During a typhoon on the Hengchun coast in Taiwan with wind gusts of more than 35 meters per second, the system remained stable.

Ship-Based Radar System

The sea-state monitoring system was most recently modified to operate on a container vessel with a 6,600 20-foot-equivalent-unit capacity. Mounting the system on a moving vessel requires a global positioning system and compass to correct the radar image signals.

While being used for sea-state monitoring, the X-band radar retains its navigational functionality; radar image, ship tracking and heading continue to be presented on screen.

The influence of pitch and roll of the moving ship required the team to develop an algorithm that would calculate the wave parameter based on the radar image. The algorithm is based on the statistical analysis of the Weibull probability density function.

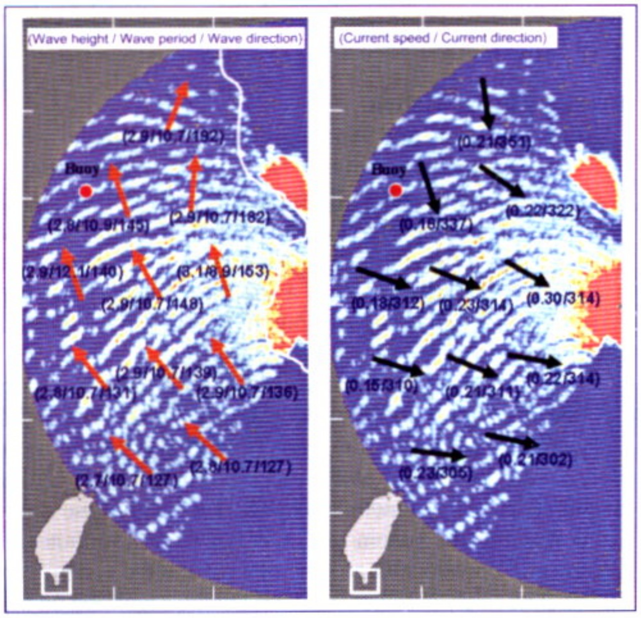
Results

In one example of a radar image sequence taken from the RV-based system, refraction and diffraction phenomena were observed. In this example, a moored buoy collected wave data information three kilometers from the coastline at a water depth of 45 meters. The moored buoy found a significant wave height of 3.2 meters and a dominant wave direction of 158 degrees. The RV-based X-band radar imaged this same area to determine spatial waves and current fields of the waves.

The results calculated by the wavelet transform show the wave direction changes from 127° to 192°. The results fit the pattern of refraction and diffraction waves. The calculated wave heights varied between 2.7 meters and 3.1 meters, current speeds measured between 0.15 meter per second and 0.3 meter per second, and current directions were between 302° and 351°.

For the ship-based system, the results were also successful. The average difference in wave height between the ship-based radar system data and an *in-situ* data buoy was less than 0.2 meter, showing that the ship-based system is also accurate.

These results reveal that the mobile system is a viable method of measuring the sea-surface state.



A sample screen of the ship-based radar monitoring system.

Conclusions

This article presents a mobile X-band radar system that can be integrated into an RV or a container ship as a sea-state monitoring device. Operators using the marine X-band radar and a computer with high-speed data acquisition can extract continuous sea-surface image sequences. Operating the radar on an RV requires a generator, an elevated boom and a stabilization system. To operate on a moving ship, algorithms must be applied to compensate for the influences of pitch and roll. Both the RV-based and ship-based radar systems have been operated successfully.

Acknowledgments

This study was supported by the National Science Council in Taiwan (grant numbers NSC 98-2221-E-006-251 and NSC 98-2218-E-006-236). Field work was supported by CSBC Corp. (grant number CSBC-RD-567.1).

References

For a full list of references, please contact Dr. Li-Chung Wu at jackalson18@gmail.com. ■

Visit our website at www.sea-technology.com and click on the title of this article in the Table of Contents to be linked to the respective company's website.

Dr. Li-Chung Wu is a postdoctoral researcher at National Cheng Kung University in Taiwan. His research includes applying the wavelet transform process to analyze wave and current fields from remote sensing images.

Chia Chuen Kao is the director of the Taiwan Ocean Research Institute/National Applied Research Laboratories. He is also a professor in the department of hydraulic and ocean engineering at National Cheng Kung University and specializes in marine engineering and observation.

Wen-Hung Yang is an engineer at CSBC Corp. He specializes in the basic design of container vessels.