WAVE OBSERVATION SYSTEM FOR THE PUERTO RICAN COASTLINE

Mykola Vysotskyy, Robin G. Williams *
University of Puerto Rico Mayaguez, Mayaguez, Puerto Rico

1. ABSTRACT

The National Weather Service in San Juan receives four times a day wave model output for the Puerto Rican regional coastal waters generated by NCEP's WaveWatch III model. These predictions are often unreliable mainly due to the fact that in-situ observations are not available for the coastal regions of Puerto Rico. These observations are required for calibration and validation of the wave model predictions. Over the past several years a group of researchers under Dr. Robert Holman of Oregon State University has developed a technique of using data from video cameras that record conditions in the coastal zone to extract information about wave height, direction, and period. It is proposed to implement a similar approach and develop an algorithm for processing the video data. The data will be recorded in daylight by a video camera and processed by an algorithm in real time. This algorithm will process images of the coastal zone at a specific site and produce output that includes estimates of wave parameters, such as period and direction.

2. INTRODUCTION

Data acquisition, using video capturing equipment, is becoming more and more popular in many areas, especially where it is possible to use automated computer vision systems instead of involving humans in routine work. This research proposes to use remote-sensing techniques on data recorded by video cameras to obtain real-time estimates of ocean-wave parameters in the nearshore zone of Puerto Rico (PR). High-resolution video data will be used to yield estimates of wave parameters that will be more accurate than those that can be obtained from satellite remote-sensing, such as SAR and altimeter data. Satellite data do not adequately satisfy model validation and calibration requirements because they do not have high enough spatial or temporal resolution.

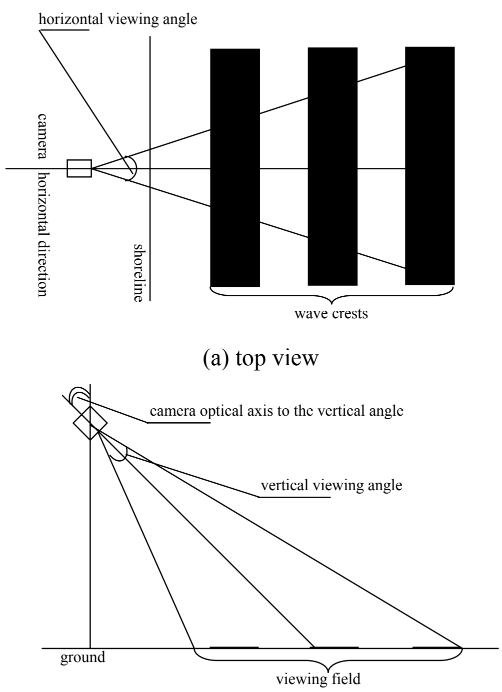
To obtain a useful image of the nearshore zone with well-defined waves (i.e., those that can be classified into objects and noise), the cameras must be located optimally. For example, they must be pointed at areas in the nearshore zone where the waves have not yet been affected by the reefs.

* *Corresponding author addresses:*
Mykola Vysotskyy, UPRM, Dept of Computer Eng., Puerto Rico, 00680; e-mail: mykola.vysotskyy@ece.uprm.edu
Robin G. Williams, UPRM, Dept. of Marine Sciences, Puerto Rico, 00680; e-mail: robin.williams@ece.uprm.edu

In this case it is possible to simplify the image-processing task by setting the video-camera viewing field approximately perpendicular to the shoreline so additional geometric calculations need not be performed. Fig. 2.1 below is as example of an image that can be obtained from a video camera pointed in the right way at the nearshore zone.

Fig. 2.1 Original image

Relatively insignificant roughness of the ocean surface allows us to ignore the vertical dimension and consider it as a flat surface. This is depicted in Fig. 2.2 (b).



(b) side view

Fig. 2.2 Camera orientation

It is also simplifies the task of transforming the video image from perspective to orthogonal.

3. IMAGE PROCESSING ALGORITHM

The concept is to take the image that has just been recorded by video camera and calculate the real-world metric values of the wave, such as wave period and direction. There are three stages in the process:

1) image filtering;
2) image transformation from the perspective projection to the orthogonal projection; and
3) object classification and performing measurements on the transformed and filtered image.

3.1 *Image Filtering*

In this stage the original image from the video camera, shown in the Fig. 2.1, is converted from color to gray scale. The gray-scale image is adjusted by increasing the contrast to highlight shaded regions of the ocean surface and filtered by applying the averaging filter to smooth the image. Fig. 3.1.1 shows the processed image. It can be seen now that the level of the noise is now quite lower. So, the background of the image now seems more homogenous.

Fig. 3.1.1 Adjusted image

To extract the required objects, which are wave-crests defined by shadows, from the image background, the thresholding Otsu's Method is applied, which automatically picks the required global thresholding level for the image and divides image light intensity into two distinct regions. Fig. 3.1.1 shows the result after applying this thresholding method.

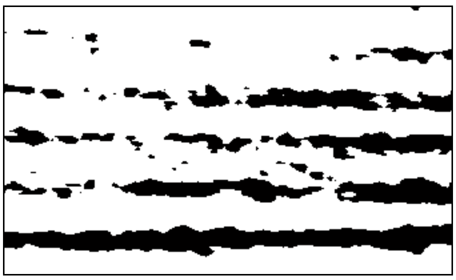


Fig. 3.1.2 Thresholded image

3.2 *Perspective Image transformation*

The processed image is still in perspective projection on the video camera image plane of the real view. In this case it is the 2-D projection of the ocean horizontal surface. In order to reconstruct the original view, it is necessary to perform the perspective view to an orthogonal projection by transformation. It is sufficient to have several explicitly represented waves in the field of view, so it is valid to use the small viewing angle of the video camera. This fact gives us an opportunity to ignore the radial distortion factor. So, it is possible to simplify the 2-D perspective transformation task to a 1-D problem, projecting all the points from each vertical slice of the perspective image to each slice of the real surface. This makes sense, because only vertical adjustment is required, since the horizontal part is not affected by the perspective factor due to the video-camera's direction relative to the ocean surface. The equations relating each pixel on the camera image plane to the real view have been established.

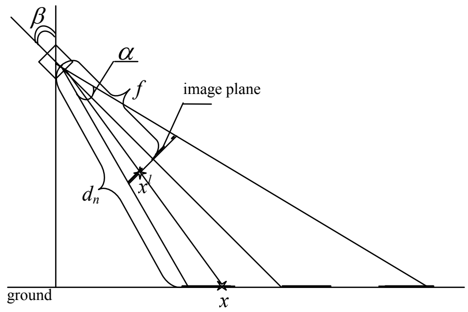


Fig. 3.2.1 Side view

Diagram on Fig. 3.2.1 shows the following main parameters:

α - viewing angle of camera;
β - angle between the camera optical axis and the vertical;
f - camera focal length;
d_n - distance from the camera to the nearest point;
x^1 - some point on the camera image plane;
x - point on the real surface corresponding to x^1.

Each point on the ocean surface can be represented as:

$$x = f(x^1, \alpha, \beta, f, d_n) \quad (1)$$

where f - is geometrically derived transformation function.

The code has been written in MATLAB, where the parameters from equation (1) along with image in Fig. 3.1.2 have been given as input to the program and new projected image has been found. The transformed image is shown below in Fig. 3.2.2. The new image dimension is fully proportional now to the image as if it would have been taken from the top, when the camera optical axis is perpendicular to the ocean surface.

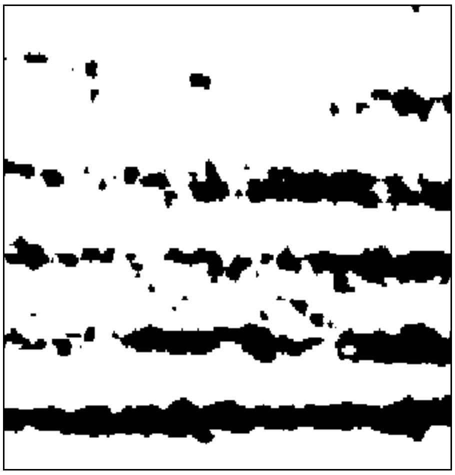


Fig. 3.2.2 Projected image

3.3 *Object Classification*

To perform this task, it is first necessary to clean the noise from the image. But how is it possible in this case? It is proposed to find the total number of objects and the total number of foreground pixels in the image, then the average number of pixels per object is calculated, and objects, which have fewer pixels, than average are considered to be as a noise and deleted from the image. The cleaned-up image is shown in Fig. 3.3.1. The foreground that remains is classified as the most explicit waves that can be processed.

Fig. 3.3.1 Cleaned-up image

3.4 *Measuring Parameters*

In order to find period of waves, which is the distance between them, it is sufficient to find the mean center lines of each object, which are shaded from the wave crest, and calculate the average distance between neighboring lines. The image shown in Fig. 3.4.1 shows the calculated mean center lines, after applying the morphological function, that connects objects, those locations are close enough to each other. To get this result the morphological function that thins objects to lines is applied.

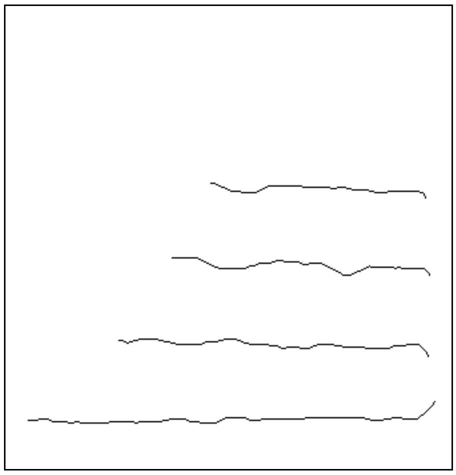


Fig. 3.4.1 Mean centerlines of the waves

The proposed concept to measure period is to find all distances between pixels of neighboring lines within the same column, and then to calculate the average value. Since the coefficient that transforms pixels to meters is known, it is possible to obtain the approximate period of the waves. The diagram in Fig. 3.4.2 represents the approach described above to calculate period.

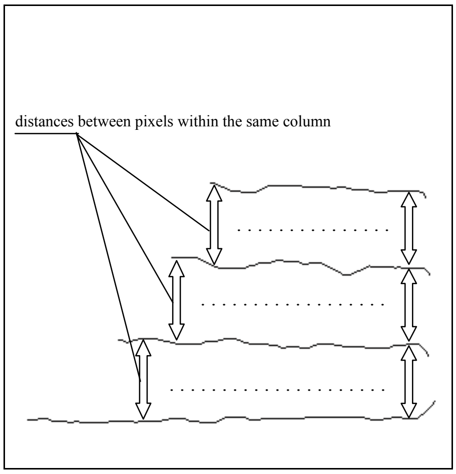


Fig. 3.4.2 Wave period calculation

In case of wave direction the proposed method is the following:

- approximate the curves representing the waves to corresponding lines;
- obtain the average angle between all calculated lines and the image vertical axis, equation (2);
- transform the average angle to real-world angle, since the direction of video camera is known.

Diagram in Fig. 3.4.3 shows this approach, where γ_i - is the angle between approximate line of wave and the vertical axis of the image.

$$\gamma = f(\gamma_1, \dots, \gamma_n) \quad (2)$$

where *f* – averaging function, *n* – number of recognizable waves.

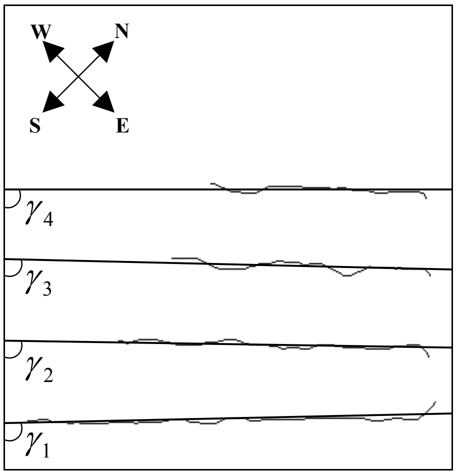


Fig. 3.4.3 Wave direction calculation

In applying this approach, a 5-10% error is expected, which is insignificant in this case, since the direction of the waves is usually given in one of eight possible directions: N-W, N, N-E, E, S-E, S, S-W, W.

4. OBSERVATION SYSTEM

In the above the approach for automatically obtaining the necessary wave parameters from the image, taken by video camera is described. Another problem that must be addressed is camera installation and connection to the main computer, where the images will be processed. Two steps must be performed:

1) defining the location of video camera installation; and
2) transmission of video data to the computer.

4.1 *Defining the Location*

It is proposed to install a camera at the one of three locations that NWS (San Juan) is interested in. They are shown in Fig. 4.1.1, two on the north side of PR, and one on the south side of PR. One of the possible locations is the El Morro castle in Old San Juan. This site is under the control of the U.S. National Parks Service. Scott Stripling (our collaborator at the NWS in San Juan) has already negotiated approval for the location of one of the cameras at this site. It has the advantages of having good security, readily available power, and good communication infrastructure, such as telephone lines.

Fig. 4.1.1 Possible location for camera installation

4.2 *Transmission of Video-Data*

Diagram in Fig. 4.2.1 shows the principle of the connection between video camera and the destination server if there is no phone line available at the site. The Internet Gateway is a server that will connect the video camera to the Internet. The destination server is the computer, connected to the Internet, receiving images every 10 minutes and processing them, most likely at UPRM.

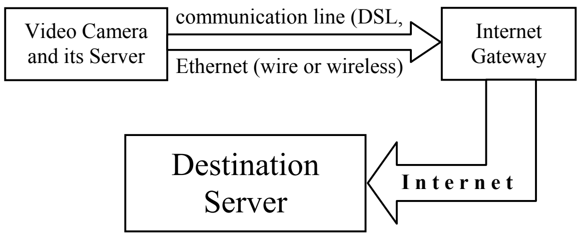


Fig. 4.2.1 Connection if phone-line is N/A

Diagram on Fig. 4.2.2 shows the principle of the connection between video camera and the destination server if there is phone line available at the site.

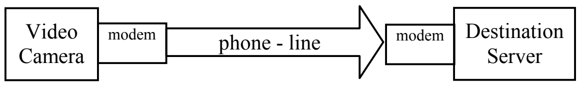


Fig. 4.2.2 Connection via phone – line

5. FUTURE WORK

The next step is to perform the fieldwork, which involves installing the video camera, which was provided by NWS in San Juan. The video camera has a high-resolution matrix, and comes with its own special server with an IP address, which is operated remotely via its own Web server, and can be connected to the Ethernet network or phone line.

In the future it is planned to extend the algorithm in order to process images taken not only in any vertical plane, but also in any horizontal direction of video camera to the ocean surface, and to try to extract the information about relative wave-height, based on the shadows of the wave crest caused by the sun, considering the fact that shadows depend on the sun's position during the day.

6. CONCLUSIONS

This proposed work describes the development of an automated observation system to retrieve wave parameters from the nearshore zone of ocean. The system's main components are a video camera with its server and computer with the application software running on it. This software will process video imagery of nearshore waves, and give output that describes real wave parameter (wave period and direction) estimates. This software will use the proposed algorithm to obtain real wave information, which is based on different image processing techniques described in this paper. This algorithm is already implemented and tested with example picture of ocean waves in MATLAB environment. The results are shown in the above figures.

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http://cil-www.coas.oregonstate.edu:8080/, Coastal Imaging Lab, in the College of Oceanic and Atmospheric Sciences at Oregon State University.