Artificial Vision System for measuring waves level in a wave tank with a real time approach

[1]IBÁÑEZ O., [2]RABUÑAL J.R., [1]DORADO J., [1]PAZOS A., [2]CASTRO A., [3]IGLESIAS G.
(1) Department of Information & Communications Technologies
University of A Coruña, Campus Elviña, 15071, A Coruña, Spain

(2) Centre of Technological Innovation in Construction and Civil Engineering (CITEEC)
Campus Elviña, 15192, A Coruña, Spain

(3) Deparment of Agroforestal Engineering
University of Santiago de Compostela, E.P.S., Campus Universitario S/N, 27002, Lugo, Spain

Abstract: -In this paper we show a new technique for measuring waves, based on artificial vision system to replace traditional methods to measure waves in a wave tank consist on expensive sensors and at the same time intrusive techniques. A procedure for obtaining quantitative wave using video images has been developed. The steps include image capture and data extraction with a real-time approach and non-intrusive method. The method is shown to produce good results as compared to more conventional methods of measuring wave in a wave tank experiment and in addition provides a measure of the wave in all the range of the image (as many points of measurement as the number of pixel in x-coordinate of the image).

Key-Words: - Video-Image Processing, Measuring Techniques, Surface Wave Profile, Computer Vision

1. Introduction

Inside of an European big project "Advanced tools to protect the Galician and North Portugal seaboard against hydrocarbons spills on the high seas" in which, we have to do different measurements in a wave tank like: wave level, oil spill spreading or bodies displacement (containment boom sections). To achieve this, a non-intrusive method it is necessary (due to the presence of objects inside the tank) and the method has to be able to differentiate between at least two different fluids.

These are the reasons why an artificial vision system is being developed because these systems are non-intrusive and can separate a lot of different objects in the image (objects, fluids, etc… anything that a human eye can differentiate).

Other interesting aspects that these systems provide are:

- The cheaper price than traditional systems of measurement.
- Easier and faster to calibrate.
- Don't need to mount an infrastructure to know what happen in different points of the tank (only one camera instead of an array of sensors).
- Provide high accuracy.
- Finally, this system is an innovation idea of applying computer vision techniques to civil engineering area and specifically in ports and coasts field. No similar works have been developed.

In this paper we show an artificial vision system which obtains the height of the wave in all points of the image. Furthermore the same developed system could be used in reflections analysis or in level studios.

1.1. State of the Art

Traditional methods use capacitance and conductivity gauges to measure wave level. One of these gauges only provides one measure in one point and it isn't able to measure two or more phases (water and hydrocarbons for example) and in case two or more different fluids are mixed in the tank, due to their different density, capacitance gauges provide inaccuracy measurements. Moreover these are expensive instruments.

Others works, using image analysis to measure surface wave profile, have been developed for the past ten years [1] [3] [4] [5] [6], but none of them were developed neither with a real-time approach nor a non-intrusive methods. Similar techniques need to dye the water with a fluorescent colour [1], something not possible in many cases or not appropriate if we have to detect two different fluids [7], since dye the water will complicate this task.

2. Laboratory set-up and procedure

The experiment was conduced in a 17.29-m long wave tank at the Centre of Technological Innovation in Construction and Civil Engineering (CITEEC), in the University of A Coruña, Spain. The tank measured 77 cm at maximum depth. Have a width of 59.6 cm and at the final of the tank there is a metal plate which is used as a beach. This plate is 3.04 m length and has a configurable slope for the plate is possible. The experimental set-up is shown in fig. 1.

Solitary waves, generated by a piston-type paddle, propagated along the length of the tank and were measured with a video camera which focuses around 1 m of the tank. To validate the results waves were measured with one conductivity wave gauge situated in the focused area of the video camera. These gauges are estimated to measure with an accuracy of ± 1 mm with a maximum work frequency of 30 Hz.

Two different digital video camera models (Sony DCR-DVD200E and Sony DCR-HC35E) were used to record the waves. Both cameras were of the PAL Western Europe standard with a captured imaged resolution of 704 x 576 pixels the first and 720 x 576 the second, and both works at 25 frames per second.

The camera was mounted on a standard tripod and positioned approximately 2 m from the sidewall of the tank (see fig. 1). The camera was placed so that the field of view was in a parallel plane to the resting water in the tank. This was done to avoid measurement errors when pixels distances are transformed to real distances in mm.

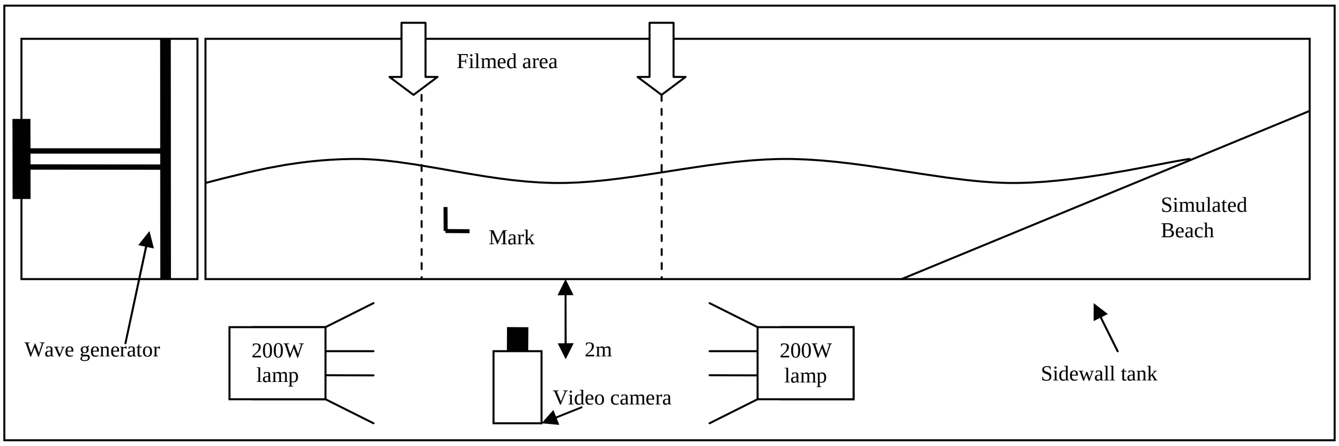

Fig 1. Laboratory set-up diagram.

The procedure developed for this study requires that camera placement remains constant while the camera is turned on. The procedure is as follows:

- Place two marks on the glass sidewall of the tank (see fig. 1);
- Place one horizontal mark on the glass sidewall of the tank; on the bottom of the filmed area (we have used one of the previous marks).
- Position the camera at some distance from the target plane (i.e., tank sidewall) depending on desired resolution;
- Provide uniform lighting on the target plane and a uniformly colored background on the opposite sidewall (to block any unwanted objects from the field of view);
- Start filming.

The two marks (in step 1 of the above list) must size around 5% or 10% of the total filmed area, in our case (1 meter filmed) 10 cm, in order to minimize measurement errors. These marks were placed parallel to x-axis and y-axis, and were used for two aims; have an object with a known size, which allows us making a transformation between real distances in both x,y-axis and number of pixels, that is, know the real distance (in mm) between two pixels in both x,y-axis in the obtained images. If the thickness of one of the marks is big enough to differentiate four control points, this mark can also used to verify that the camera is not moved during the filming. If the pixel location of any of the control points changes from one frame to another in a coherent sequence of filmed frames, then camera movement has occurred and calculates heights could be mistaken.

One of this marks, was placed horizontally on the glass sidewall of the tank, on the bottom of the filmed area to know a real distance between the bed of the tank and this mark, to avoid filming the bed of the tank and filming smaller area (bigger resolution).

With regard to the lighting of the laboratory it is necessary to avoid direct lighting and consequently we can work without gleam and glints.

To achieve this kind of lighting, all lights in the laboratory were turned off and two halogen lamps of 200W were placed on both side of the filmed area, one in front the other (see fig. 1).

3. Video image post-processing

Following filming in the laboratory (also would be possible at the same time), a number of tasks were done to obtain the measurement of the wave in each point of the filming area: image capture and data extraction. These tasks are described in chronological order below.

3.1. Image Capture

Image capture was carried out on a PC, Pentium 4, 3.00Ghz and 1,00Gb de RAM memory with the Windows XP platform. A Sony DCR-HC35E video-camera record the wave tank, a high-speed interface card, IEEE 1394 FireWireTM, was used to transfer digital data from the camcorder to the computer, the still images were kept in the uncompressed bitmap format so that information would not be lost. De-interlacing was not necessary because of the quality of the obtained images.

3.2. Image Rectification

A .NET routine was developed to physically rearrange the image pixels to correct for intrinsic camera parameters (mostly lens distortion) and camera placement. The basic premise of the method is that the pixels of an image showing a number of control points can be moved to their correct positions if the exact relative locations of the control points are known and with the assumption that the area between the control points is distorted linearly. After use this routine, in both cameras we observed an excellent behaviour of camera lens and were determined not to use this method in order to make a real-time application. Instead of this method, the two marks on the sidewall tank were used to obtain the relation between pixels and real distances.

3.3. Data extraction

An automatic tool for measuring waves from consecutive images was developed. The tool was developed under .NET framework, its interface was done in Visual Basic .Net and all image processing software was done using C++ language and OpenCV (Open Source Computer Vision Library, developed by Intel) library.

The resultant computer vision algorithm accepts as input a video file (.avi extension) and at the same time the video is played, as a result, the program makes two text files with the measurement in all pixels of the image in all frames of the video; one file gives the height in mm and the other in number of pixels. This text files can be used later to make graphics, new videos, etc…

The computer vision procedure is as follows:

- Extract a frame from the video.
- Using different computer vision algorithms get the constant “pixel to mm” in both x-axis and y-axis (only in the first frame).
- Using different computer vision algorithms, the crest of the wave is obtained.
- Work out the corresponding height, for all the pixels in the crest of the wave.
- Supply results.
- Repeat the process until the video finish.

Secondly, with regard to get the constant “pixel to mm”, as was introduced before, two marks (colored black) was placed on the glass sidewall of the tank. These marks appear on the bottom of the extracted frame, so an algorithm look for theses marks in that part of the image. In order to do this search, the image suffering the previous transformations (see fig. 2):

- First of all, the image is split in red, green and blue (RGB) channels.
- The green colour channel is selected because the component green, in black marks, has a big different intensity between the marks and its neighbourhood in the image.
- The green channel is inverted and then, after a histogram analysis, this image is thresholded with a constant value 200 (a manually thresholding is made since there is a big difference in image intensity).
- The result image in the previous step suffers a morphological close by 5x5 structuring element.
- Finally, we do a symmetrical morphological gradient by a 2x2 structuring element, in order to obtain the object with 1 pixel width edge.

- After all, a developed algorithm counts the number of pixels in x-axis inside the horizontal mark and the number of pixels in y-axis inside the vertical mark. As we know the real size of these marks we can obtain the equivalence between pixels and real distances in both axes, dividing the real distance by the equivalence number of pixels.

Thirdly, concerning to obtain the crest of the wave, the process developed is as followed:

- First of all, the image is split in huge, saturation and value (HSV) channels.
- The value channel is selected because is the channel in which differences between water and background are bigger. In fig. 3 (a) a

channel v image from the wave tank is shown.

- After a histogram analysis, the v channel is thresholded with a constant value 105 (a manually thresholding is made since there is a big difference in image intensity). See fig. 3 (b), in which the crest of the wave is clearly recognized.

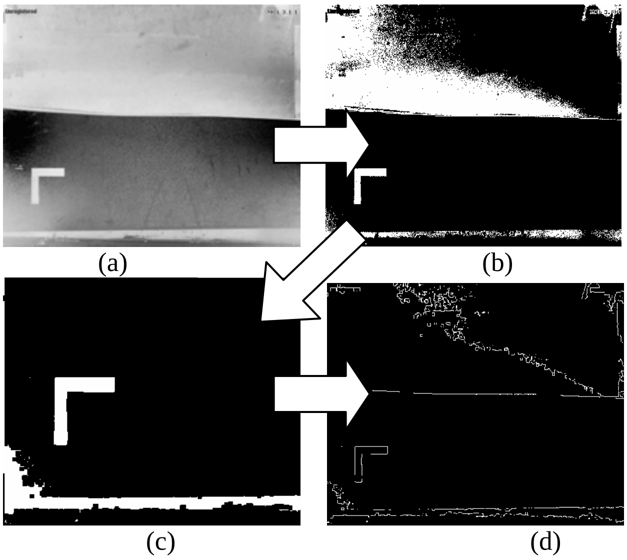

Fig 2. Image sequence of pixel to real distance routine.

- A symmetrical morphological gradient is applied to obtain the crest of the wave, as can be seen in fig. 3 (c). The structuring element used was 2 x 2 as we prefer a one-point thickness curve to achieve accuracy results. A morphological opening is done (with a 3 x 3 structuring element) before the symmetrical morphological gradient, fig. 4 (b). We use this operator to mitigate the error in not de-interlaced videos (real-time process), since this operator removes from the crest of the wave the uncertainty zone. This uncertainty zone (fig 4. (a) on the top of the wave) appears because of the high speed of the wave in relation to capture rate of the camera (interlaced problem). Final result is shown in fig. 4 (c).
- Finally, a routine to find the wave returns all the crest points, which are transformed to real heights (distances in mm). This routine takes decisions about the direction to follow to try to obtain the more real shape of the wave. If computer vision operators don't achieve the entire crest of the wave (because of gleams in the record process), this algorithm search in a defined neighbourhood to continue the curve and fill these hollows interpolating between the extremes of the hollow.

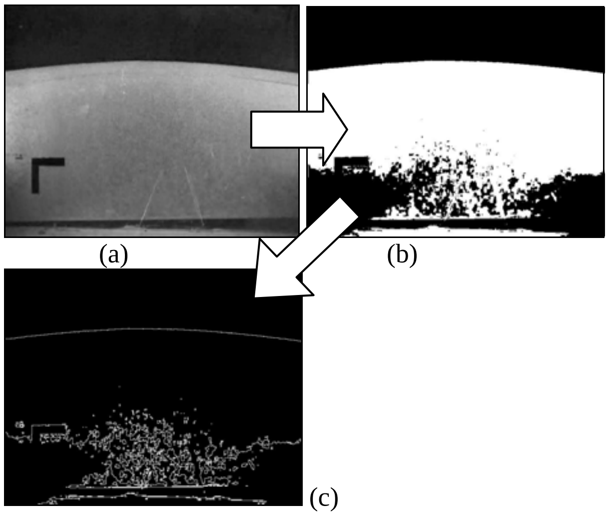

Fig 3. Image sequence of the algorithm which obtains the crest of the wave.

4. Results

A comparison of data extracted from video images with data measured by conventional instruments was done to ascertain the approximate accuracy of the data extraction process described in Section 3. The comparisons are not necessarily meant to validate the procedure as there are inherent errors with conventional instruments, as well; rather, the comparisons aim to justify the use of video images as an alternative method for measuring wave and profile change data.
Different isolated measurements with conductivity gauge were done at the same time the video camera was recording. Then results from both methods were compared.

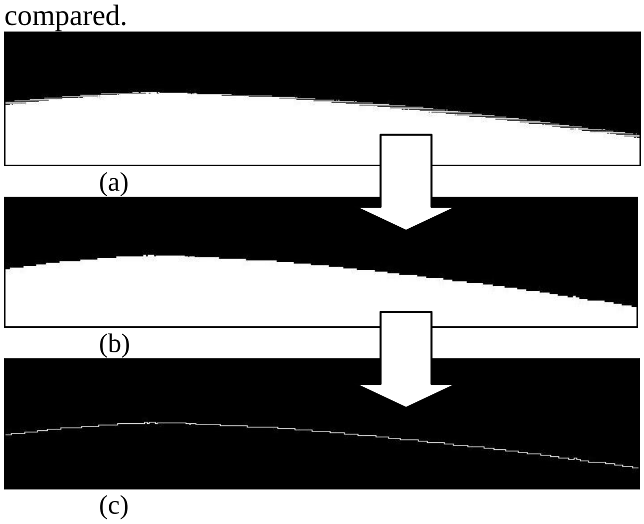

Fig 4. Image sequence of the algorithm which obtains the crest of the wave in interlaced images.

Before talk about the results, is very important to comment on the inherit errors between both methods:
The first problem refers to the synchronization between the sampling frequencies of both methods. Sensors used have different frequencies of work but none of them match with the frequency of the image capture. The sensor sampling frequency was 30 Hz in front of the 25 Hz in video analysis, and to synchronize this manually, one per six samples were removed from sensor measurement. Doing this, we are introducing an error between video and sensor measurements because obtained data come from different moments of time, however they are very similar moments of time and synchronize each second.
As we can see in the pictures below, before synchronization (fig. 5) we have different numbers of measurements and in different moments of time. After synchronization (removing one per six samples from sensor measurement) data measurements are nearly equals (fig. 6) not as before synchronization.

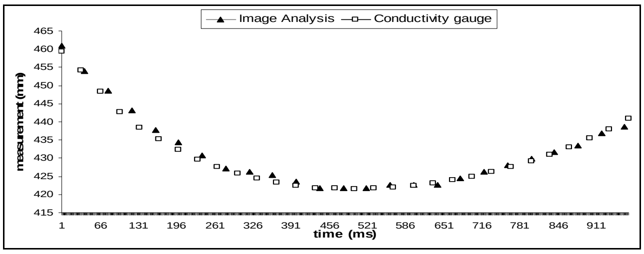

Fig 5. Sensor and image measurements before synchronization. Different time space.

The second source of error is due to the sensor measuring near the centre of the tank while de images are determined from the profile along the glass wall of the tank. It was assumed that profile changes were uniform across the tank; this was visually observed to be true in many but not all cases where waves weren't regulars.
Another error in both measurements can comes from the fact of that the sensor does a previous filtering of samples integrating averages (return the middle point from a continuous line), and the video analysis technique return discrete measurements.
Finally, we have to take into account that the measures were distorted because of the fact that the sensor is an intrusive element.

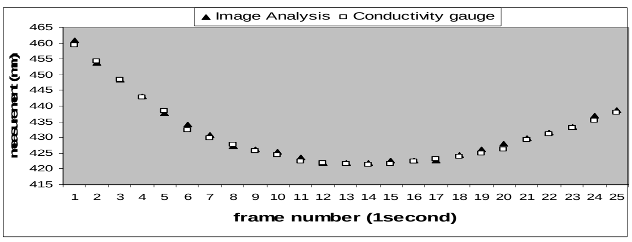

Fig 6. Sensor and image measurements after synchronization. The same time space.

In fig. 7 we can see the correlation line in which we can observe that R2 is 0.994.

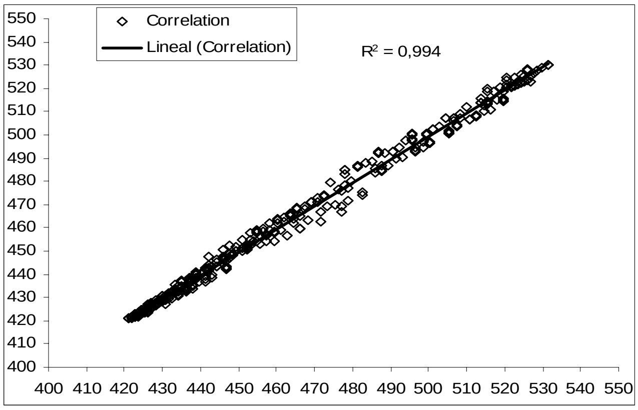

Fig 7. Correlation line.

In fig. 7, we can observe a bigger error in the middle of the line, that is to say, when the wave is growing up and going down. This error is due to the bigger speed of the wave at these points and the problem of synchronize measurements between sensor and image, which increase with this.

In graphics 8 and 9, we can observe the error between both methods. The curve from the sensor measurements is smoother than the one from the video analysis due to the last point commented previously. In many points of both curves we can observe measure gap due to the different frequency sampling, bigger in crests of wave were water speed is bigger.
In spite of these sources of error, the average error between conductivity sensor measurements and video analysis is 1.84mm, a lot better compared with the 5mm average error obtained in the best work done until this moment [1]. But it isn't an indicative error because of the commented source of errors took into account in this study, however the estimated real error from this video analysis system is 1mm, that is to say, the equivalence between one pixel and a real distance, and in our case (with the commented video camera and distance from the tank) one pixel is equivalent to nearly 1mm. This error could be improvable with a camera which avoids a better resolution or focusing a smaller area.

5. Future works

This is the first part of a bigger system which would be capable of measure displacements of a containment boom section in the vertical axis and measure the slope angle [2]. Furthermore the system would be capable of making a distinction between the water and a containment fluid and would identify each zone for each fluid.

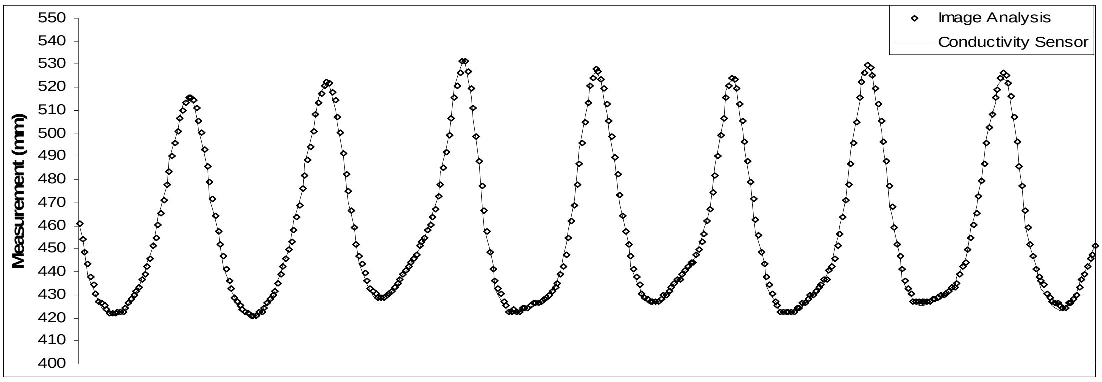

Fig 8. Temporal sequence of measurement by sensor and image analysis.

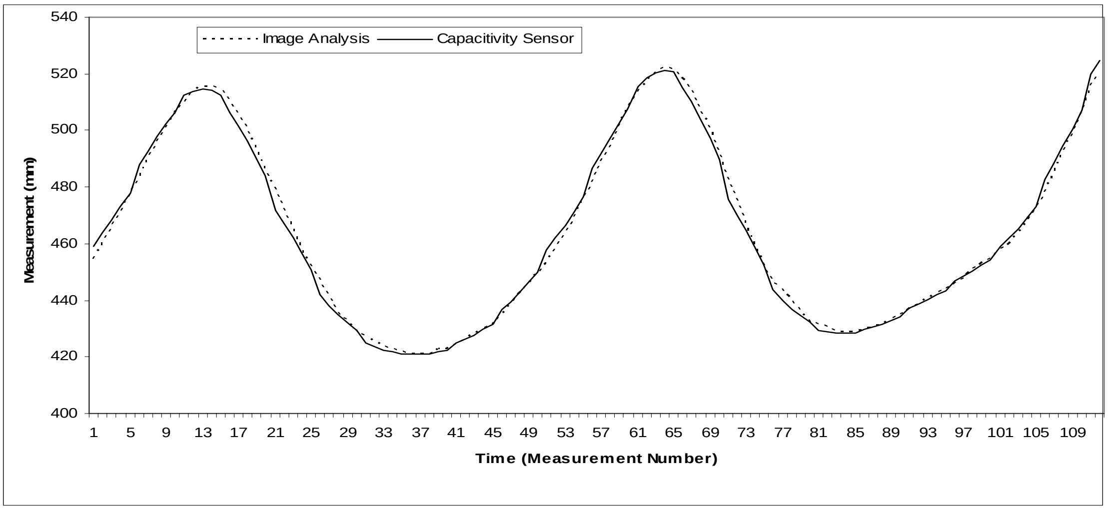

Fig 9. Zoom from one part of fig. 14.

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