DIGITAL IMAGING PROCESSING TECHNIQUES FOR THE AERIAL FIELD MONITORING OF HARBOUR BREAKWATERS

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Abstract

The entrances to the six largest ports in South Africa are protected by rubble mound breakwaters, which have Dolos armouring. PORTNET, the national Port Authority, have commissioned the CSIR to conduct detailed monitoring of existing rubble mound breakwaters including records of the wave conditions to which they are subjected in service. This paper presents the image processing techniques used to monitor breakwater damage as well as the wave field causing the damage. Wider applications of these techniques have been commissioned during pipeline outfall construction as well as during the design & modelling stage of a proposed new harbour. The image processing techniques have been used to measure both breakwater settling and damage as well as moored ship motion for competing breakwater designs constructed as in scale models, of proposed harbours at the CSIR's physical modelling facilities in Stellenbosch.. The image processing techniques developed by TECHTRIX International are reported here.

Context and Background

Recent trends highlighting the increased use of global satellite mosaics are impacting on the research, infotainment, and animation industries. National Geographic Television have for example, in a joint effort with Jet Propulsion Laboratory, taken over 500 satellite images and stitched them together digitally covering the entire globe at 1km resolution. Cloudy areas are replaced with cloud free data, colours are balanced, and the infrared channels converted from infrared (for vegetation) to natural hues.

This process is now recurring on smaller scales, with image mosaics, recorded from helicopters, aircraft and balloons using GPS to log viewing positions. These images are then projected onto digital terrain models of the area of interest. By repeating flybys at well-chosen intervals, changes, which would otherwise be too slow or subtle for the human eye, are clearly resolved.

In the United States, highway surveys from slow flying helicopters are used for road maintenance programs, and in South Africa annual harbour breakwater surveys use helicopters with differential GPS for imaging. Both digital and analogue images are recorded on pre-determined flight paths. The video sequence is digitised to supplement

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the image sequence recorded using a digital camera. This *current* image sequence can then be compared with archived reference photographs, which are scanned or digitised using a CCD camera. These image sequences are analysed to monitor storm damage and movement of Dolos and more recently Core-loc armour units. A significant data archive, spanning a decade of wave damage to South African breakwaters, can now be analysed using these new image-processing techniques.

Breakwater Imaging

The primary goal of this ongoing breakwater-monitoring project is to quantify damage to breakwaters protecting all major harbours along South Africa's 3000km coastline. Broken and missing armour units, as well as individual displacements of these units are quantified on an annual basis, or more frequently in the case of major storm damage.

Flight paths following GPS stored way stations are flown annually with images typically recorded at 25m intervals along the breakwater from a position, which is normal to the plane, defined by the bank of armour units. Figure 1 illustrates a typical imaging configuration and the position of the photographer on the outrigger

Movement Logging

This image sequence is digitised and stored as the *digital reference breakwater*. This image sequence defines the reference frame against which future breakwater images are compared. Where the flight paths differ despite the deployment of differential GPS, the images are warped in such away as to optimise the fit between the earlier "reference breakwater" images and the more current images. The imaging system then flicks between these two images (the reference and the registered current image) allowing small movements (<10cm) to become immediately apparent to the operator who logs the displacement, damage and disappearance of armour units with a few simple mouse clicks.

Figure 1 illustrating the positioning of the photographer for breakwater imaging. Images are recorded at 25m intervals.

Figure 2a: Model breakwater view with ripples on right hand side barely visible.

In Figure 2a and b the movement of a single armour unit cluster is illustrated using simple image subtraction techniques. Note the barely visible ripples being resolved in this 1:100 scale model. Outdoor harbour surveys often require edge detection techniques in order to resolve small movements despite differing lighting conditions. Typical images as well as the program for illustrating these techniques can be downloaded from http://flyer.ph.und.ac.za/~techtrix/.

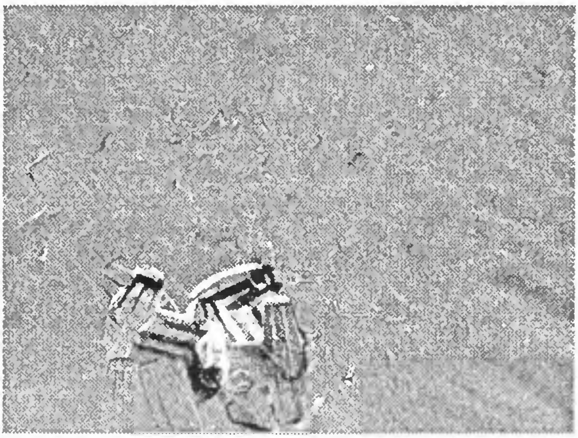

Figure 2b illustrating the registered image subtraction technique which is applied in real-time for identifying significant breakwater movement.

Figure 2c highlight recorded movements during a series of design storm tests in this model application.

Scope of Application

This *Breakwater Monitoring* System is focussed on four specific areas of application:

- Rapid recovery of quantitative breakwater damage from existing photographic archives. In this case a live video digitising station is used to allow freehand movement of the current image until it overlays[3] the reference image (already digitised). The ergonomics of this operation are significantly better than having to pair up common reference positions in every image pair before applying the appropriate image transform. It is however important that the before-and-after image pairs differ only in position and orientation. Should the images differ in size then the zoom has to be adjusted which slows the process down, making it as slow as the cursor controlled "drag and stretch" operation performed on scanned images.
- Real-time multi-camera system for model applications. Both systems, (a 4 CCD camera system for B&W imaging and a 3 camera system for colour imaging) are

[3] This is achieved using either of two methods:

[1] the "blink-comparator" method traditionally used by astronomers when scanning for commits by blinking between two images of a given star fields where fixed stars have been used to register the images or

[2] the "flicker optics" method (South African patent No 94/10303) which interlaces the live video of the current image with the fixed reference image.

used for logging breakwater damage in scale model applications where design storms expose the strengths and weaknesses of different harbour breakwater designs. This kind of work has been labour intensive in the past and has not resolved the details of the breakwater settling process, as well as the myriad of smaller displacements which will propagate over considerable distances from a racking armour unit. The current set-up in the CSIR's model hall in Stellenbosch, SOUTH AFRICA allows for a 10-fold saving in data sampling and processing, making the systematic study of multiple large scale design variations more feasible.

- Off-line digital image archive analysis. When analysing an existing digital image database sampling stations, scanners and digital frame grabbers are not required. These systems are typically run in parallel with the multi-camera sampling systems during a run. In this way several personnel can analyse images pairs as current breakwater image sequences are sampled by running both systems on a common LAN.
- Remote surveillance and environmental monitoring systems. Cameras located on coastal high-points are able to monitor breakwaters and surrounding wave fields during daylight hours. These cameras running at full video frame rates can measure wave orientation and period by continuously sampling video intensities along lines parallel to and at right angles to the nominal direction of wave propagation. Breakwater images can be triggered by wave drawback ensuring image sampling when the bulk of the breakwater is exposed. The research objective here is to log all significant armour movements by time and position and then analyse the statistics as a function of different sea states. The sea-state system has been deployed and a feasibility study undertaken for PORTNET on their Durban Bluff Signal tower – one of the few land based high points with a view of the exposed side of a harbour breakwater. Both modem dial-up for downloading processed data, and microwave links for transmitting live video between camera and frame grabber, have been deployed with reliable performance for environmental monitoring contracts ranging from 2 months[4] to 2 years[5].

Daytime Wave Field Monitoring in the Vicinity of Breakwaters

The *WaveWatch©* system developed by TECHTRIX International is set up during good seeing conditions when the horizon is well resolved. The calibration procedure automatically locates the horizon, and asks the operator to click on the positions of several locations with known GPS co-ordinates within the field of view. This information is used to set up a mapping locating any part of the picture in real-word co-ordinates, allowing any sampling line to resolve true bearing and length. The operator will then position a sampling line, which is roughly orientated along a wave front. Intensity profiles along this wave front are then sampled 25 times a second (using the PAL video standard) and the phase lag between intensity modulations at opposite ends of the sampling line, used to track wave bearing in real-time on an ongoing basis during daylight hours.

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[4] Sappi-Saiccor 6.5km outfall pipeline construction which required pipe-flooding in the event of design storms (1-in-1 year storm from 60° and a 1-100 year storm from 170°) to avoid pipeline displacement on the seabed.

[5] Multi-camera systems using remote cameras on pan-tilt platforms linked by microwave to a central operations centre where digital image processing techniques are used for forest fire detection in forest plantation environments.

Figure 3a illustrates the horizon fix, GPS landmark selection and video sampling line placement. The keograms which follow illustrate the time stack output of the intensity profiles extracted from the sampling line at the full TV frame rate and averaged in order to focus on the phenomena of interest. (For details see the appendix at the end of the chapter.

This time stack is compiled from 576 video images. A fixed video intensity profile running along the shore-line is extracted form each video image and "stacked" from left to right in sequence.

This particular view was selected to illustrate the effect of a rip current near the base of Durban's south breakwater. Surface water is shown converging (through time) on the rip channel. The inset bottom right is 1 (of he 576 profiles) displayed as a plot of intensity for the vertical sampling line passing through the cursor.

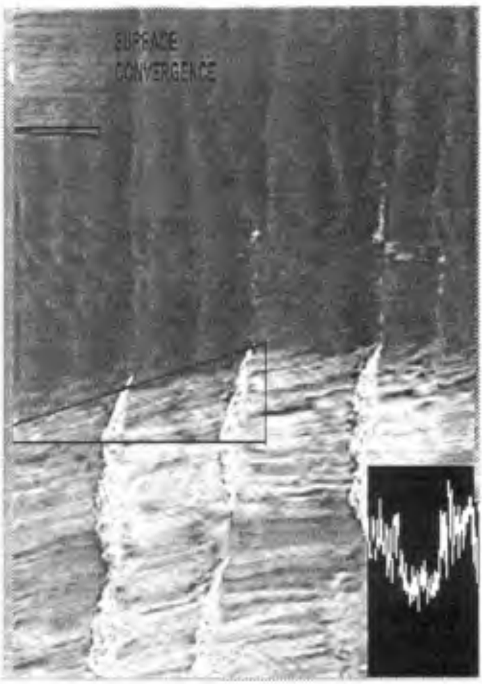

Figure 3b is a time-stack illustrating along shore movements in the vicinity of an off shore rip current near the base of a breakwater in the surf zone.

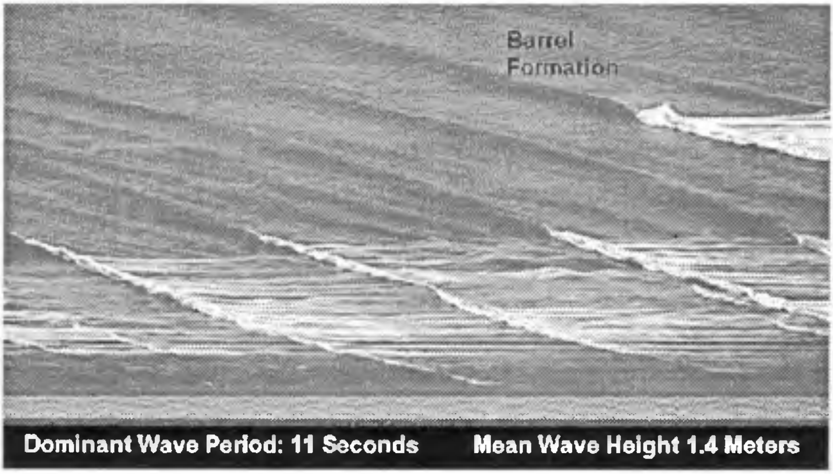

Figure 3c: In contrast to the previous time-stack sampled along a fixed line parallel to the shore, this time stack is sampled from the beach at the base of the breakwater straight out through the surf zone. The shoreward propagation of the swells and the gradual sea-ward drift of the white water is illustrated here. One can clearly make out larger swells "overtaking" smaller swells en route to the beach visible at the base of this video mosaic. On the opposite side of the breakwater ships entering and leaving the harbour can be tracked in this format keeping a record of their arrival and departure times through the harbour mouth.

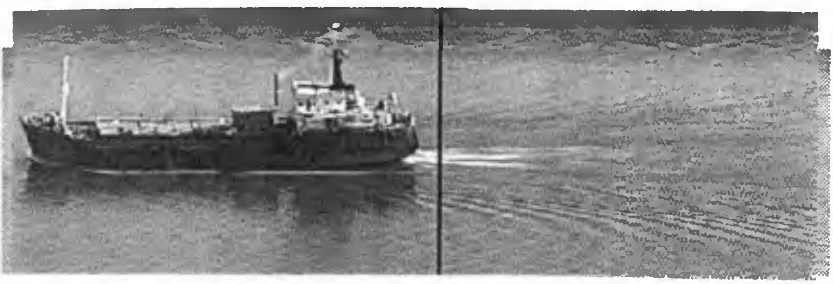

Figure 3d displays the digital video record (in time stack mosaic form) of ships entering and leaving the harbour.

Decision Support for Harbour Breakwater Management

Breakwater movement after the settling stage following construction is required when compiling a set of practical management directives supported by the emerging trends in breakwater damage (when is it best to repair the breakwater?). Early repairs may be too frequent and therefor expensive while late repairs stand the risk of having to repair runaway damage events like leading to total breakwater failure. The current directive is for immediate repairs when displacement, loss and breakage approach 30% of armour units along any given section. Historical records do however include results where these directives were not applied in the past ensuring that management evaluation data is available over a wide range of management regimes (*CSIR reports .....1987-1997)*.

Once the repair has gone ahead, its implementation can be significantly improved with the used of GPS assisted armour placement cranes, streamlining the process from movement detection to the physical positioning of the replacement armour unit (*Phelp et al 1998*).

Ship Dynamics in the Vicinity of Breakwaters

The recent advent of wave field monitoring with view to highlighting the risks associated with specific storms on a more quantitative bases, has been focussed on developing operational criteria for storm related port closure to shipping. The narrow Durban harbour entrance, which only exceeds the large ship beam by a factor of three, is monitored for wave sea conditions impacting on the safety of the ships approaching the harbour entrance. As vessels enter the lee of the south breakwater strong yawing motion as well current shear have been measured. The figure below is a time-stack montage illustrating the cross-current in the vicinity of the harbour entrance displacing the ship's wake from the path followed by the ship's bow through the water.

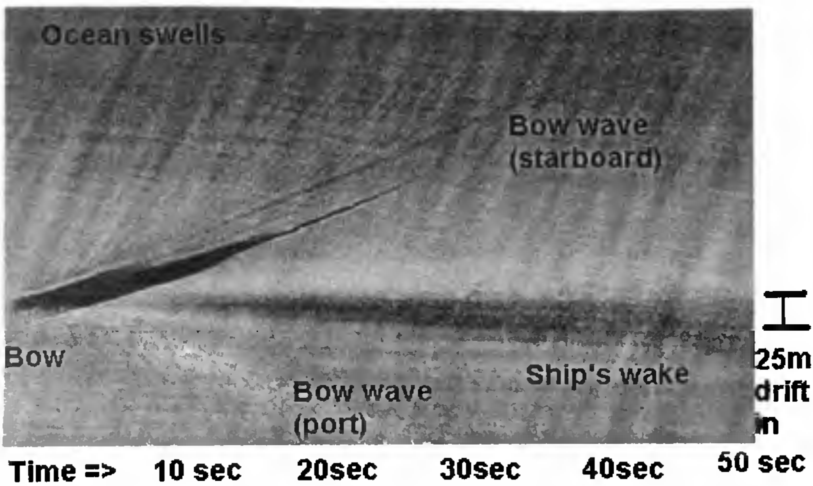

Figure 4: This remarkable keogram of a ship approaching the harbour entrance from a distance of 2 nautical miles. The cross-current in the surface layer is evidenced by the gradual sideways drift of the wake (by 25m over 50 seconds) resolved here at progressively lower positions towards the right hand side of this time stack mosaic.

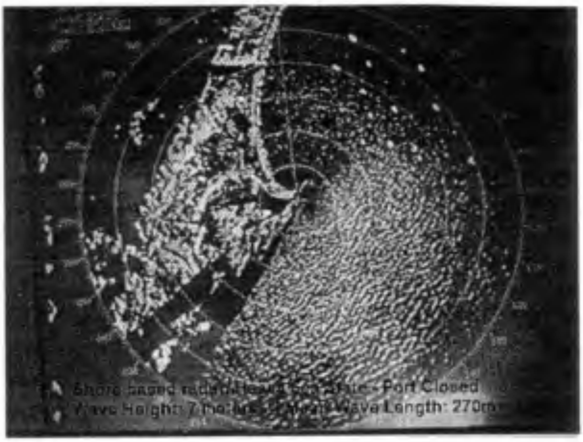

Figure 5a displays a single sweep of the radar field. This is digitised and analysed over any portion of the wave field for wave propagation speeds, wavelengths and periodicity. Qualitative wave amplitude estimates can also be made.

24 Hour Monitoring of Wave Fields in the Vicinity of Breakwaters

Machine vision based ship tracking and wave field sampling are limited to daylight hours and can be effected during heavy sea conditions when visibility can deteriorate. For this reason radar data have been digitised enabling around the clock monitoring of storm-time wave fields up to a distance of 6 nautical miles from the bluff signal station. The radar field is digitised in time series allowing for accurate wave celerity, wavelength, period and *qualitative wave height variation* measurements to be made. The radar image mosaic below illustrates in space-time (or time-stack) format, how wave length and period as well as phase velocity can be measured. It is interesting to note that the "envelope" modulating the amplitude propagates at close to half the phase velocity. This allows one to estimate the group velocity, which is effected by both the surface current and bottom topography.

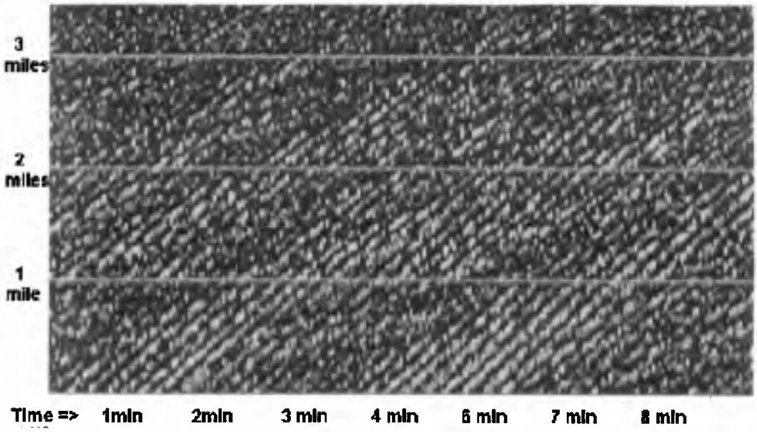

Figure 5b illustrates the propagation of individual wave fronts during heavy sea conditions which necessitated the closure of the Durban port during May 1998.

Breakwater Design and Moored Ship Dynamics

Remote measurement of moored ship movements is illustrated below allowing for the quantitative comparison of different design storms and breakwater designs in the model environment, as well as useful information for harbour records and container loading availability on a daily basis in the port environment. The most recent system can measure all 6 degrees of freedom with a single camera in the model environment.

Figure 6a showing the model ship with all the attachments required for performing conventional measurements of model ship dynamics. This is contrasted with the techniques deployed here where images are analysed and displacement profiles are measured at 25 or 30Hz. These techniques have been scaled up to field trials with change in hardware or increase in cost.

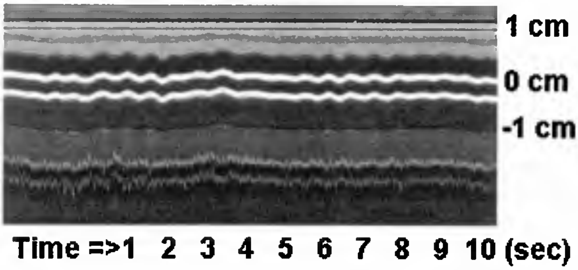

Figure 6b showing a typical feature trace, which is automatically tracked when extracting displacement time series data. One or more sets of data can be sampled for each degree of freedom.

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