VIDEO SYSTEMS FOR IMPROVING PORT AND SHIPPING SAFETY

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ABSTRACT

This paper describes how video and digital imaging systems can be used to support safe port operations, especially in developing countries. Digital images of preset video locations can be geo-referenced and then archived for later analysis to improve efficiencies and review any safety threats or breaches occurring inside or outside the port. Significant advances in digital image technology have made it easier to capture, store, transmit and analyze large amounts of information via the recording and manipulation of digital images. The high resolution of the images and the improved capacity and speed of personal computers has improved our ability to handle the large quantities of data contained in the digital images. Smart software has been written to interrogate the images (pixel by pixel) to extract the relevant information, which can then be stored or transmitted via radio or microwave link to conventional telecommunications networks when required.

INTRODUCTION

Despite the success of Vessel Tracking Systems (VTS) and integrated AIS (Automatic Identification Systems) used to control ships in the world's commercial harbours, auxiliary video and digital image systems also play a useful roll in managing maritime operations in ports. This is especially relevant to ports in developing countries where budgets, technology, skills or experience may be limited.

Figure 1. Video Camera on top of the Cape Town Port Control Building

To capture complex coastal processes, which can often vary quite quickly, it is important to ensure continuous video recording of the rapidly changing phenomena. Remote cameras can give continuous coverage, independent of daylight and prevailing weather or sea conditions. As opposed to annual or ad-hoc monitoring, the coastal responses to individual extreme wave events can be recorded at the time when these changes occur.

In 2007, a demonstration system was set up by CSIR / Enviro Vision Solutions (EVS) at the Port of Cape Town in South Africa (Figure 1). This system was then linked by wireless transmitters, to the CSIR in Stellenbosch, to facilitate further development of the system. The approach was to develop the system together with "hands on" input from actual port operators. Software developed for tracking ship motion in small scale physical model tests (Phelp *et al*, 2002) was modified to track prototype ship motions. The basic benefit of the video camera was to automatically provide

Proceedings of the 28th Southern African Transport Conference (SATC 2009) 6 – 9 July 2009
ISBN Number: 978-1-920017-39-2 Pretoria, South Africa
Produced by: Document Transformation Technologies cc Conference organised by: Conference Planners

additional visual information and early warning to harbour masters, vessel traffic controllers and port operators.

COMPONENTS

The video system consists of the following components: The wireless network links (from the port to CSIR) were not necessary for port operations, as supervised from Port Control, but could in future be useful in future expansions of the system, for linking live information to other ports or a Port Headquarters.

System hardware components

The system consists of a Pan Tilt Zoom camera with a 360º rotation (Figure 1), a PC fitted with a video capturing card, a Pelco keyboard controller to allow the port operators to manually control the camera, and LCD screens (Figure 2). At present, this system is linked to a Server at the CSIR via an existing wireless router network (Figure 3) owned by the Rescue and Fire department (RFC) of the Cape Town Metropolitan Council.

Figure 2. LCD Monitors and keyboard at Port Control

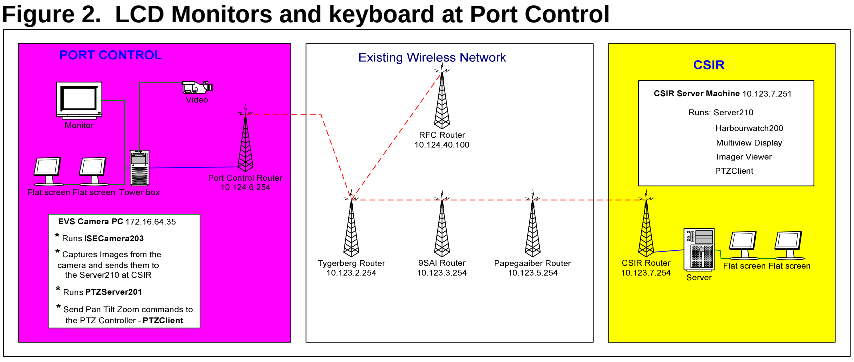

Figure 3. Wireless network configuration

Software components

The Harbour Watch software was develop by EnviroVision Solutions (EVS) and the CSIR and consists of the following suite of functional modules:

- PTZ Server and PTZ Controller – which performs auto and manual camera control functions.
- Image Sampling Engine (ISE) Server and Client – carries out image processing for detection.
- Detection – forms part of the HarbourWatch200 module and was designed to track ship movement. An alarm was activated if there was excessive movement by moored ships.
- GIS map referencing – to link pixels to co-ordinates to allow operators to use the Geo-referenced video to quickly turn the camera to a specific position of interest.
- An offline Image Viewer for reviewing archived incidents at any of the preset stations.
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System features

The system was designed to have up to 100 camera preset viewing positions. Currently at the Port of Cape Town, only 35 are used to focus on each of the existing harbour berths (Figure 4) and other views of interest within the harbour. The camera takes an average 6 minutes to do a full tour of the harbour (approximately 5 presets per minute). The large LCD screen (Figure 2) displays whatever the camera is looking at, which means that port operators can get an automatic 6 minute update of what is happening at each berth, without getting up from their desks. Anything suspicious or unsafe can then be investigated further by manually zooming the camera or using binoculars or carrying out a site inspection if necessary.

As the camera tours around the presets, four images are captured of each berth which are then used by the Image Sampling Engine (ISE) for image processing. These images, taken at 1s intervals are stored on the Server machine and can be recalled later for post-mortems by port operators and other users. Up to a thousand images are stored per preset before they are overwritten by newer images. This translates to about five days of storing capacity as a time history of each berth.

Figure 4. Preset Berth View with Alarm Buttons.

The value in saving four images at 1s intervals, during each harbour tour, was that when these images are played back in sequence, any movement in the picture could easily be detected. This could be used to indicate wave or wind direction at the time of capture. Any loading or unloading activities could also be identified, as well as any small movements of the vessel.

The offline Image Viewer software is used to play-back these images. Regular backups are also made of the stored images. These are then used as input to time / motion studies at each berth, or to examine events which have led to safety or security breaches. Each image has a time and date signature for easy lookup and reference. If the link to the CSIR goes down, images are also stored on the Port Control computer whilst the link is down.

Manual camera control is provided using a joystick or by clicking the mouse on an image of the multi-view display. The latter is made possible by using GIS map referencing software which incorporates a digital terrain map of the harbour and allows operators to quickly move the camera to a specific position of interest. A 5 minute period is allocated to users for manual camera control before control is automatically transferred to the PTZ Controller to continue touring the presets automatically.

MOORED VESSEL MOTIONS

Moored ship movement or ship motion detection is another feature which is currently being developed. This feature is vital to improve safety of port operations in that it assists port operators by activating an alarm if a moored ship moves excessively which might cause mooring lines to break of other damage to the ship or berth.

Physical models of moored ships

One of the main objectives of the system was to track the motion of moored ships in the harbour. Software developed for tracking ship motion in small scale physical model tests (Moes and Hough, 2000) was modified to track prototype ship motions. The model ships were carefully scaled to the same ratio as the undistorted 3D physical models. The calibrated mooring lines and fenders accurately simulated the load-elongation characteristics. Wave generators reproduced both the low-frequency (causing surge, sway and yaw) and high-frequency waves (causing heave, roll and pitch).

Figure 5. Scale Model of a 65 000 DWT Ship.

A remote digital video camera was positioned, almost horizontally, portside onto the ship, with the video image covering the central two-thirds of the ship (Figure 5). Video images of the moored ship were recorded at a standard TV frequency of 25Hz. Accurately dimensioned white strips (contrast strips) were fixed onto the top and either side of the ship, to provide contrast lines for identification of the ship motions perpendicular to these lines. Two mirrors placed at 45° above the bow and stern gave a vertical view of the ship's deck in the same plane as the video image, thereby capturing all six degrees of freedom of ship motion.

Each video image (768 x 576 pixels) was scanned by a number of fixed sample lines of a single pixel width, which crossed the contrast strips (one vertical line at the bow, one at the stern and one horizontal line at bow or stern). These sample lines were scanned simultaneously and were projected as a single vertical line. By stacking these lines side by side (at 25Hz) to form a time stack or keogram, a record of all 6 degrees of freedom could be measured by tracing the dynamics of the appropriate contrast strips.

The ship motion traces could then be stored as a BitMap file for each test, or the pixel coordinates could be stored as an ASCII file. Furthermore, knowing the movements of the attachment points of the mooring lines, the elongation of the lines could be calculated, and thereby the forces in the lines and fenders. In scale-model tests carried out thus far, the accuracies achieved were better than 1 mm ship motion (0,1 m prototype) and 5g mooring force (5t prototype).

Recording of prototype ship motion

As used in physical models, video imaging could be used to accurately measure prototype ship motions. Time series of digital image sequence data, quantifying the displacement of moored vessels with respect to any fixed objects such as bollards on the quay-side (Figure 6), could be used to alert port operators of dangerous levels of ship motion during storm conditions.

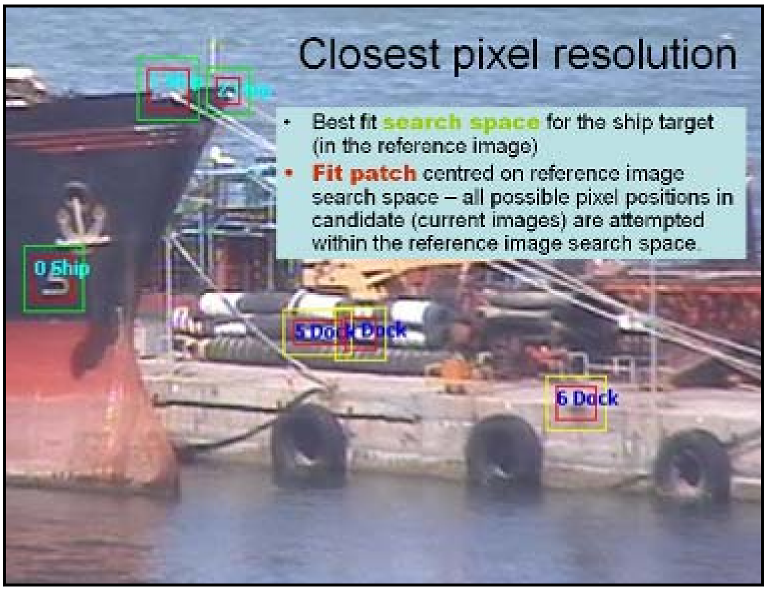

Figure 6. Locking of reference frame onto fixed objects.

Long-wave resonance in harbours could create significant surge and sway motion, on occasion straining mooring lines to breaking point. Early warning from robust multiple target real-time video tracking algorithms could warn harbour masters at an early stage when tug deployments and double mooring lines can be used to prevent damage to both mooring lines and vessels. This could reduce disruption to port operations, and where damage is incurred, accurate visual data could also reduce litigation and provide useful post mortems of accidents and mooring line failures.

Figure 7. Fixed Cameras at Saldanha Bay to Monitor Moored Motions.

For more concentrated monitoring of vessel motions at a particular berth (Figure 7), fixed cameras have been set up with a higher recording frequency (25hz). In a similar fashion to the method shown in Figure 6, fixed points on the quay are used to lock the reference frame, and three points on the ship are used to track the six degrees of vessel motion (surge, sway, heave, roll, pitch and yaw). Reference points are chosen close to light sources for day and night operation.

VESSEL TRACKING

Radar vessel tracking system (VTS)

Figure 8. VTS and Harbour Watch Screens at Port Control.

Most modern ports are equipped with radar vessel tracking systems (VTS). These systems use the automatic identification of ships (AIS) to associate a signature to the blip made on the radar screen. Basic information about the ship is attached to the AIS, including the coordinates of the ship. The VTS screen then shows the ship positions in relation to the port layout marked on a hydro-graphic chart (Figure 8).

By linking the VTS to the Harbour Watch system, the coordinates of the ship on the VTS screen could be sent to the camera, which could then zoom into the ship's position. This gives a visual reference to the ship in addition to the AIS information on the VTS screen. This additional information can be saved for later reference, which is useful, especially if the ship breaches any safety regulations while in the harbour controlled area.

Non-AIS vessels

Not all vessels are AIS equipped. This is especially the case for smaller vessels which are not registered on the VTS screen. Vessel manoeuvres in and approaching the port could be tracked for later analysis, including these non-AIS vessels, thereby aiding or replacing conventional VTS systems. Alarms could also be triggered if a vessel moved out of a designated channel.

Ship Manoeuvring

By using a ship tracker algorithm (Figure 9), a sequence of images could be used to record the ship's track. This has been used in the Port of Durban to monitor the steering angle of ships entering the port as they steer to counter a strong cross current.

Figure 9. Ship Tracking Sequence (Patel, 2001).

Investigations are being carried out at the University of Natal (Patel, 2001) into the spatial structure of cross-currents at the Port of Durban. Digital images (1024 and 767 pixels) of ships entering the port (Figure 9) are used to define velocity vectors and crab angles of the ships, from which cross-currents (drift velocities) are calculated along the ships track. A microwave link is used to transmit live video images while the video camera is remotely controlled by radio telemetry from the university to allow continuous monitoring of all shipping movements. The wind and wave conditions, ship dimensions and loading conditions are also recorded.

An ADCP current profiler and sub-surface wave measuring instrument has been permanently installed close to the channel, which will allow accurate calibration of the system. The added value of the ship tracking system is that the variable drift velocities / cross-currents can be assessed along the entire ship's approach and not just at the ADCP position (600 m off the end of the breakwater). Future investigations will include the recording of the ships speed and heading commands, which will be synchronized with the video recording. This information could be automatically transmitted ashore using an automated information system (Burchell, 2001). As was done in Richards Bay, the use of duel-frequency DGPS instrumentation onboard the ships will be used to check the accuracy of the digital terrain model to track the ships position and heading.

Underkeel Clearance

The first use of digital image technology took the form of digitized photographs. These were used to track the motion of fully laden bulk carriers (Figure 10) leaving the Port of Richards Bay, on the South African east coast. Besides the recorded maximum ship motions, the under-keel clearance was determined, from which computerised decision support systems were developed. Figure 11 shows the resultant plot of increased ship motion due to wave action as the channel depth increases along the ship's track. On-line wave and tide information is used together with the ship dynamics data to predict whether the allowable under-keel clearance would be exceeded (CSIR, 1991). Departure windows can be determined in advance, to allow vessels maximum loading before sailing on the high tide.

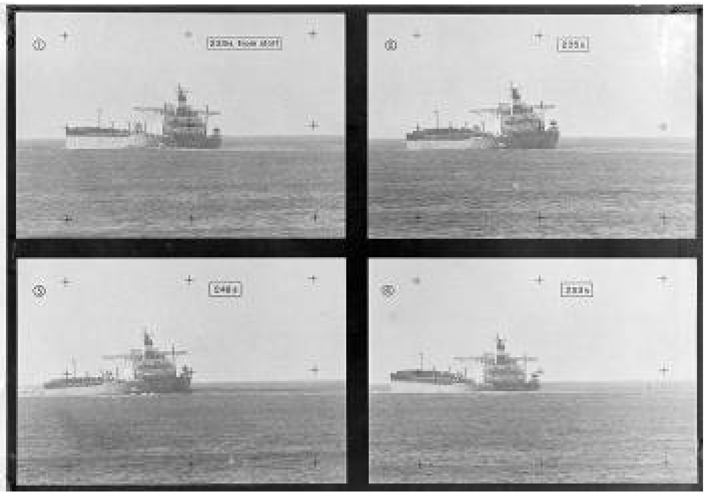

Figure 10. Bulk Carrier leaving Port of Richards Bay

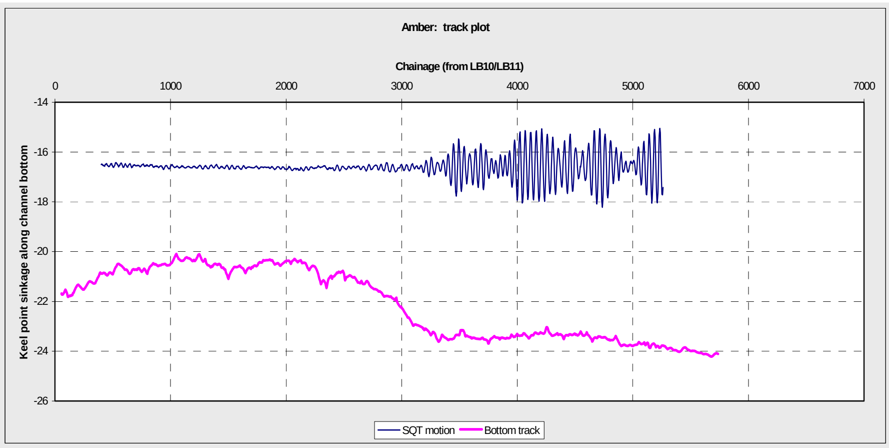

Figure 11. Ship Motion and Channel Depth along ship's track

With the increased need for large and deeper draught ships, and the limited channel depths in existing ports there is a need to optimize the under-keel clearance allowance criteria for safe entry / departure. This optimization involves the accurate measurement of ship motions as a function of tide, wave conditions and ship speed. A recent exercise was carried out for NPA (National Ports Authority of South Africa) at the Port of Richards Bay (Rossouw, 2001), where the motions of fully laden bulk carriers (~180 000 dwt) were accurately recorded (within 3 cm), using 3 dual-frequency DGPS systems mounted onboard ship, with simultaneous recordings of tide and wave conditions. From these results, the relationships between dynamic ship motion and the sea conditions could be established, and the safety margin more accurately determined. A user-friendly ship allowance computer system (DMAX) aids the pilots by giving a "tidal window" within which the ship will meet the under-keel safety criteria.

Because of the high cost of deploying (and recovering by helicopter) the three DGPS instruments on the laden bulk carriers leaving the port, it was decided to check the use of a permanent video recorder set up at port control. Trial runs have been carried out at Richards Bay, and a permanent camera, with remote pan, tilt and zoom capabilities, has been set up at port control on the Bluff at the entrance to the Port of Durban (100 m above sea level). A digital terrain model of the field of view is set up from known reference points (e.g. breakwater light) so that the recorded movement of the ships can be calibrated to the ships position. Early studies carried out by CSIR in Richards Bay (CSIR, 1981) used a still camera mounted on the north breakwater. Images of ship motion (Figure 10) were digitized from photographs taken at 1Hz giving an accuracy of 0,2 m for vertical motion. Besides the disadvantage of the reduced accuracy, the main advantage of the photographic and video systems is that no equipment is needed onboard the ship.

IMAGES GEO-REFERENCED TO A PORT LAYOUT MAP OR DTM

Geo Referencing

The video camera, installed at the Port of Cape Town, was accurately orientated and mounted on referenced coordinates so that each pixel in the field of view could be linked to an x,y position on the port layout map. This digital terrain model (DTM) was displayed on a separate screen (Figure 12), with the camera's field of view shaded in red.

This was useful for identifying such things as bollard numbers and exact positioning of any incidents which were recorded. By moving the cursor on the large LCD screen view image, the corresponding point was highlighted on the DTM. Features such as boundaries (red lines), buildings, services and even bollard positions (shown as orange triangles in Figure 12) could be overlain on the DTM. This assisted with the berthing of vessels, by being able to identify bollard numbers from Port Control, and thereby to give the correct instructions to the berthing master.

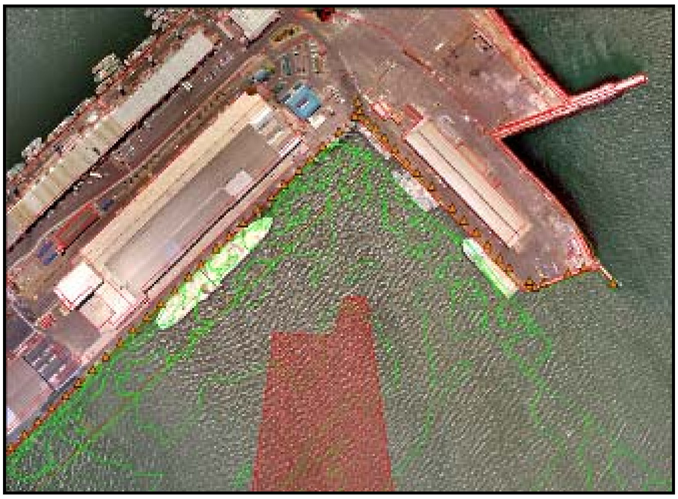

Figure 12. Locking of Reference Frame onto Fixed Objects

By overlaying the latest hydro-graphic survey chart (shown as green in Figure 12), depth information around the harbour and at each berth was also readily available to the operators at Port Control. Depth information is important to port operators when a vessel, which is close to the design depth, needs to be manoeuvred into a particular shallow berth.

Plume tracking

Similar technologies applied to key environmental monitoring points within the harbour could be used to maintain visual surveillance of oil spills or dredging plumes. Because the DTM gives an undistorted plan view, the position, area and growth of a plume can be tracked over time (updated automatically at specified intervals). Linked to prototype wave, wind and current measurements, this spatial data is geo-referenced and could then be used to calibrate numerical dispersion models.

CONCLUSIONS

In conclusion, there are a multitude of applications which have successfully been added to the installed HarbourWatch system. At reasonably low cost, the video system can thereby improve the safety of port operations. A number of critical port operations which have been automatically recorded by the newly installed system, have already been used by harbour managers as legal evidence for carrying out post-mortems of incidents and to train relevant staff.

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