Digital image monitoring to optimise safe port operations

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ABSTRACT

This paper describes a low cost video system 'Harbour Watch', which can be used to support safe port operations, especially in developing countries. Preset digital images are geo-referenced and then archived for later analysis to improve efficiencies and review any safety breaches.

1. INTRODUCTION

Despite the success of vessel tracking systems (VTS) and integrated automatic identification systems (AIS) used to control ships in the world's busiest harbours, auxiliary vision 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, thus identifying a need.

The basic idea was to install low cost 'pan/tilt/zoom' (PTZ) video cameras to automatically provide additional visual information and early warning to harbour masters, vessel traffic controllers and port operators. Where there is no prominent port control building, cameras could also be strategically placed to cover the whole port, to make all views easily accessible and recordable, and to raise the alarm on potentially dangerous or unsafe conditions.

In 2007, a demonstration system, called 'Harbour Watch' was set up by CSIR/ Envirovision Solutions (EVS) at the Port of Cape Town in South Africa (**Figures 1 and 2**). This system was then linked by wireless transmitters, to the CSIR in Stellenbosch, to facilitate further development of the system. Images could also be saved to a local network, where they could be viewed by those who may need this visual information. The approach used in this research exercise 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. Besides this, a number of other Harbour Watch applications are discussed in this paper.

Figure 1: Port Control building

Figure 2: PTZ video camera on top of Port Control

2. COMPONENTS

The Harbour Watch system consists of the following components: The wireless network links (from the port to the 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 basically consists of a pan tilt zoom camera with a 360º rotation (Figure 2), 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 3**). At present, this system is linked to a server at the CSIR *via* an existing wireless router network (**Figure** 4) owned by the Rescue and Fire Department (RFC) of the Cape Town Metro.

Figure 3: LCD Monitors and keyboard controller at Port Control

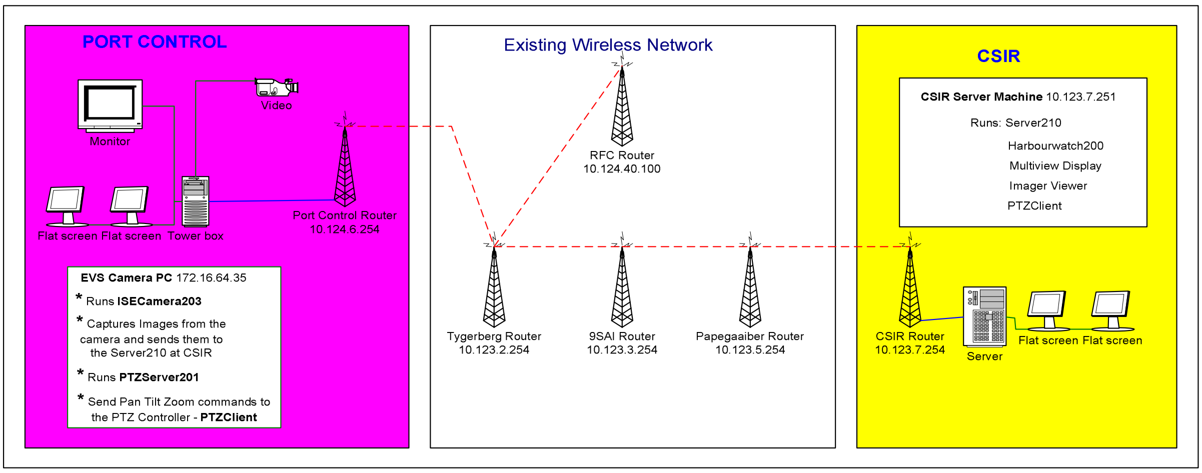

Figure 4: Wireless network configuration

Software components

The Harbour Watch software was developed by 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 design to track ship movement. An alarm was generated to indicate excessive movement by moored ships.
- GIS map referencing – to link pixels to coordinates to allow operators to use the geo-referenced video to quickly tour the camera to a specific position of interest.
- An offline image viewer for reviewing archived incidents at any of the preset stations.

System features

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

Figure 5: Preset berth view image signature and alarm buttons

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

Saving four images at 1s intervals during each harbour tour has an added value in that any movement in the picture could easily be detected when these images are played back in sequence. 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 was used to play-back these images. Regular backups were also made of the stored images. These were then used to drive time/motion studies at each berth or to examine events that have led to safety or security breaches. Each image had a time and date signature for easy lookup and reference. If the link to the CSIR went down, images were also stored on the Port Control computer while the link was down.

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

Moored ship movement or ship motion detection is another feature 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.

3. MOORED VESSEL MOTIONS

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 (CSIR, 2004) 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).

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 6). 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. 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.

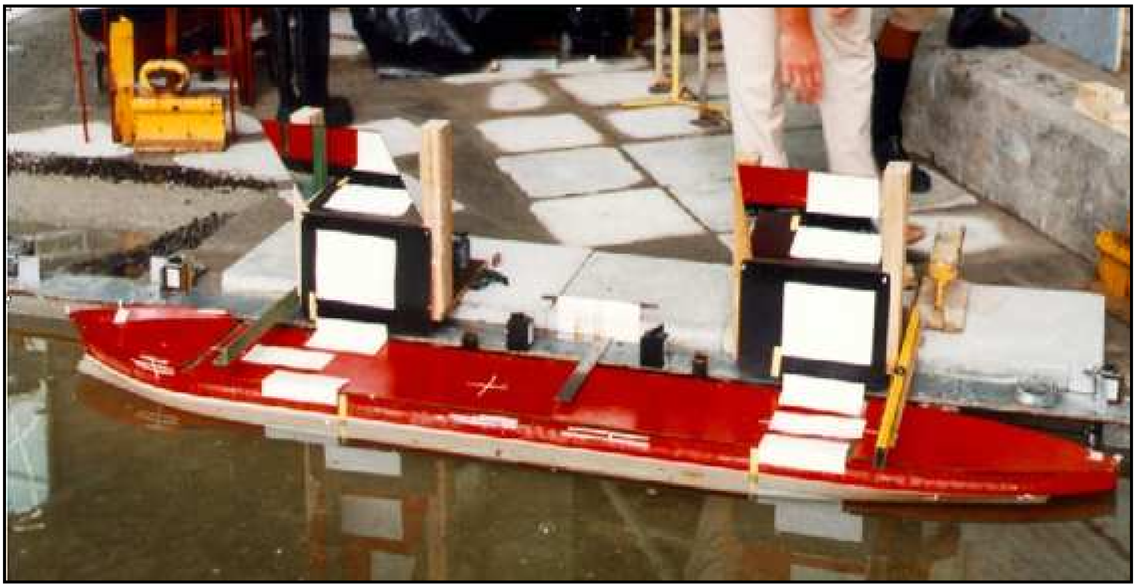

Figure 6: Scale model of a 65 000 DWT ship

Each video image (768 x 576 pixels) was scanned by a number of fixed sample lines of a single pixel width, which cut 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° 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 5 g mooring force (5t prototype).

Recording of prototype ship motion

As used in physical models, video could be used to accurately measure prototype ship motion. Time series digital image sequence data, quantifying the displacement of moored vessels with respect to any fixed objects such as bollards on the quay-side (**Figure 7**), could be used to alert port operators of dangerous levels of ship motion during storm conditions.

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.

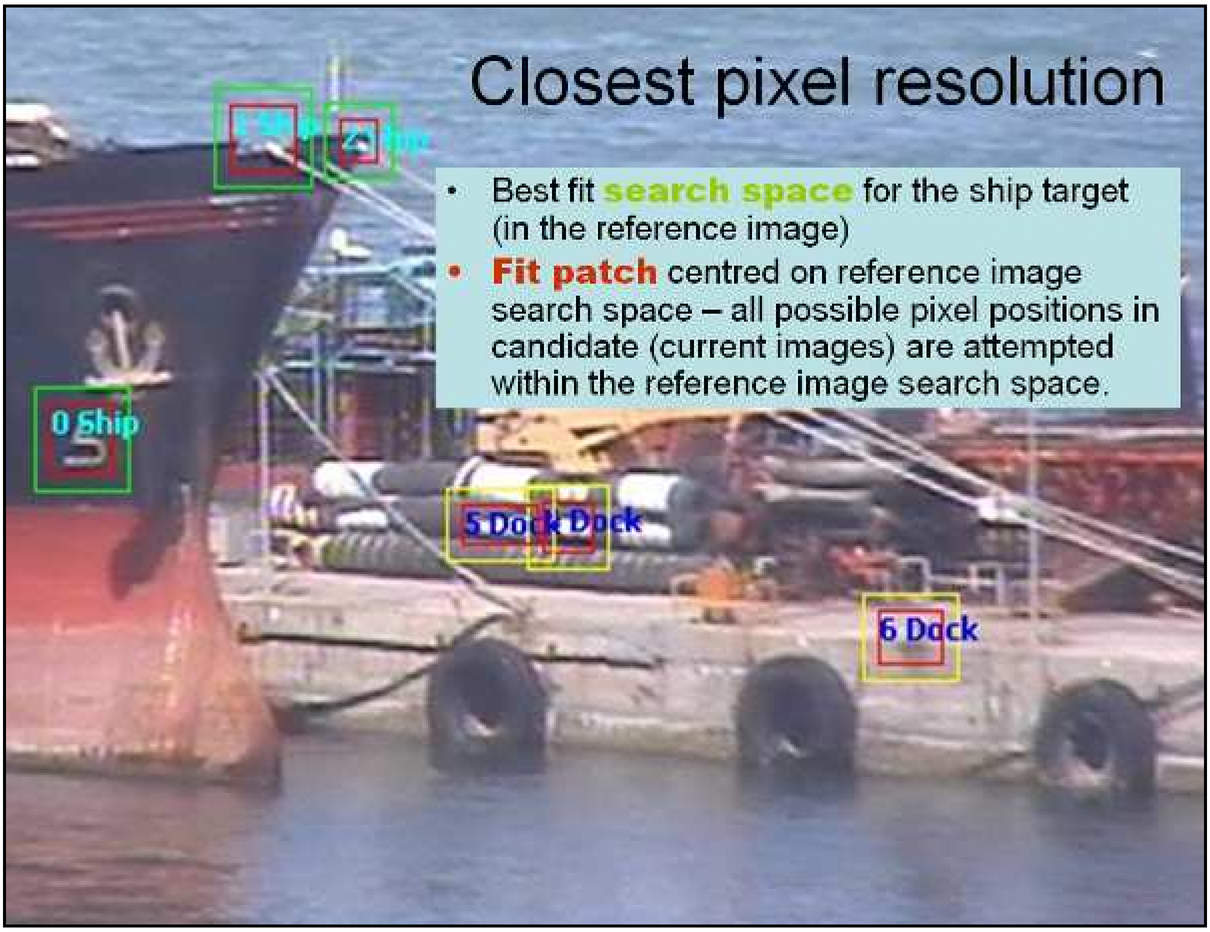

Figure 7: Locking of reference frame onto fixed objects

4. IMAGES GEO-REFERENCED TO A PORT LAYOUT MAP OR DIGITAL TERRAIN MODEL

Geo-referencing

The video camera 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 (**Figures 8 and 9**), with the camera's field of view shaded in red.

This was useful for identifying things such as bollard numbers and exact positioning of any recorded incidents. 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 8**) 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.

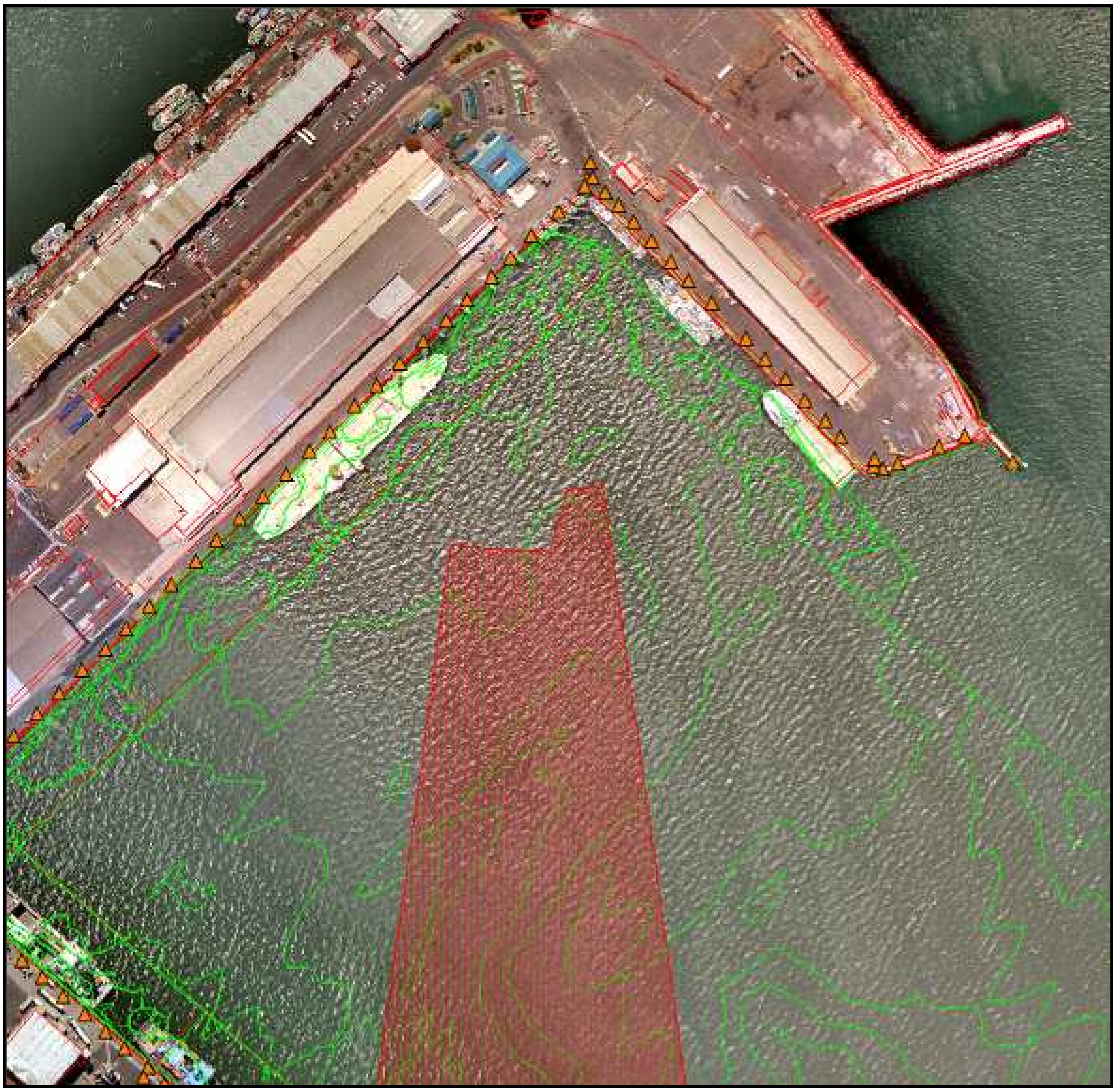

Figure 8: Image linked to digital terrain model and Google picture

By overlaying the latest hydro-graphic survey chart (shown as green in **Figures 8 and 9**), 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.

Figure 9: DTM view of Port of Cape Town

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.

5. VESSEL TRACKING

Radar vessel tracking system (VTS)

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 10**).

Figure 10: VTS and Harbour Watch screens at Port Control

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 that 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.

By using a ship tracker algorithm (**Figure 11**), a sequence of images could then be used to record the ships track.

Figure 11: Ship tracking algorithm

Berthing information for shipping agents

The arrival and departure of vessels, which is captured on the latest view of a particular berth, can be saved for automatic access *via* cell phone modem. With the name of the vessel or berth identifying the image, a shipping agent could receive an updated SMS image to provide the latest information on the vessel's movements. Passwords could be used to restrict access to general public.

Policing of incidents

An example of the usefulness of the Harbour Watch system can be illustrated by an incident recently recorded at the Port of Cape Town. A small private motor boat was seen circling close to a whale near the entrance to the port, which is illegal in terms of Nature Conservation Regulations. After ignoring calls on the radio from Port Control, the harbour pilot boat was dispatched for further investigation. This information was captured on one of the touring cameras looking at the entrance to the port. Captured images, with a date and time register, were later used as evidence in a legal hearing (**Figure 12**). This visual information would not have been available without the Harbour Watch system being in operation at the time.

Figure 12: Archived images of boat and whale, then Harbour Pilot Boat

6. OTHER APPLICATIONS

Tracking progress

A video camera installed at the Port of Durban has been successfully used to monitor the progress of the construction of a new quay wall and back-up area. Besides the berths, views of the navigation channels and construction areas were easily be included in the Harbour Watch data, for time/motion studies.

Conclusions

In conclusion, there are a multitude of applications that have successfully been added to the installed system. At reasonably low cost, the Harbour Watch system can thereby improve the safety of port operations. A number of critical port operations that 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.

This has led to other South African ports, namely Durban and the new Port of Ngqura to request Harbour Watch to be installed at their Port Control towers.

7. REFERENCES

PHELP, D., AUTHOR, VAN ASWEGEN, J., MOES, H. AND HOUGH, G. (2002): Applications of Digital Image Technology to Port Operations and Coastal Monitoring, ICCE'02 Cardiff, UK.