Developing Coastal Video Monitoring Systems in Support of Coastal Zone Management

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ABSTRACT


This paper examines the potential of coastal video systems as a tool to aid effective coastal zone management. The results presented in this contribution are derived from a large-scale international European research programme, the CoastView project. This research focuses on the derivation of simple parameters or 'coastal state indicators' from oblique video images, which can be used in monitoring and managing the coastal environment. Coastal state indicators (CSIs) can be defined as: "A reduced set of issue-related parameters that can simply, adequately and quantitatively describe the dynamic-state and evolutionary trends of a coastal system". A consortium of scientists and national-scale coastal zone managers were formed in order to define a set of CSIs that were clearly aligned with specific coastal management problems. It is shown that potentially CSIs can have a positive impact on management areas such as coastal protection, navigation, recreation and ecosystem protection. Video stations were installed at four morphologically dissimilar field sites, each with their own set of coastal management problems. These sites were used to ground truth and test the utility of video-derived CSIs for coastal zone management. A methodology is presented for clearly associating CSIs with strategic management objectives, setting clear benchmarks beyond which action is required and providing an assessment stage that appraises the result of the action taken. An example case study is presented illustrating how video-derived CSIs can potentially satisfy the strategic objectives set by coastal managers. The example presented here shows how video-derived estimates of the Momentary Coastline (MCL) position can be used to provide cost-effective estimates of shoreline change with higher temporal and spatial resolution than existing survey methods.

ADDITIONAL INDEX WORDS: Coastal state indicators.

INTRODUCTION

This contribution describes how data derived from coastal video systems may be used to support coastal zone monitoring and management. This paper starts by examining the background behind coastal zone monitoring and the scientific contribution of coastal video systems. Next a description is given of the potential of video systems for coastal zone management.

Background

The first major advance in the monitoring of the nearshore environment came with the advent of fast response sensors capable of simultaneously monitoring the water surface displacement due to waves along with the associated flows and sediment suspension. These devices included instruments like pressure transducers, electromagnetic current meters and optical backscatter sensors. In situ measurements like these provide new insight into sediment transport mechanisms and the discovery of new processes (e.g. shear waves) and phenomena which had only been previously supported by theory (e.g. edge waves). Such instruments are still being refined today, and with these refinements we are able to make measurements in new regions of the surfzone. For example the miniaturisation of sensors and development of new technology (e.g. acoustic devices and fibre optic backscatter devices) has allowed measurements to be obtained close to the seabed and within the swash zone. However, a continual frustration with these types of point measurement is the lack of spatial coverage and resolution. This frustration has been partially addressed by simultaneously deploying large numbers of sensors in multi-agency field programs like the C2S2 (WILLIS, 1987), NSTS (SEYMOUR, 1987) and SUPERDUCK86 (MARTENS and THORNTON, 1987) experiments in North America, and European programmes like COAST3D (SOULSBY, 2000) and INDIA (WILLIAMS et al., 1998). A further frustration with the direct deployment of instruments in the surfzone is the lack of temporal coverage as it is usually only possible to maintain sensors for a limited period of time before their signals are degraded or lost in this dangerous and energetic environment.

Over the last two decades there has been considerable effort invested in the refinement of methodologies for the extraction of useful geophysical signals from oblique video images of the coast, and work in this area is still ongoing. The basis for much of this work is the ability to geometrically convert from oblique image data to undistorted plan views of the coast, and work in this area is still ongoing. The basis for much of this work is the ability to geometrically convert from oblique image data to undistorted plan views of the coast, and work in this area is still ongoing. The basis for much of this work is the ability to geometrically convert from oblique image data to undistorted plan views of the coast, and work in this area is still ongoing. The basis for much of this work is the ability to geometrically convert from oblique image data to undistorted plan views of the coast,
Table 1. Management issues - management context matrix displaying some of the key issues experienced at each of the CoastView field sites (defined by coastal managers).

<table>
<thead>
<tr>
<th>Field Site</th>
<th>Coastal Protection &amp; Maintenance</th>
<th>Navigation &amp; Shipping</th>
<th>Recreation &amp; Tourism</th>
<th>Ecosystem Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egmond, Netherlands</td>
<td>- Is the coastal zone stable?</td>
<td>- Is navigation safe in the area?</td>
<td>- Is the beach suitable for tourism?</td>
<td>None addressed</td>
</tr>
<tr>
<td></td>
<td>- What is the position of the coastline?</td>
<td>- Are there navigation traffic queues?</td>
<td>- Is there enough space for tourism?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Is the strength of dykes and dunes OK?</td>
<td></td>
<td>- Is it safe to swim</td>
<td></td>
</tr>
<tr>
<td>Teignmouth, UK</td>
<td>- Is the coastal zone stable?</td>
<td>- Is the shipping channel safe?</td>
<td>- Is it safe to bathe?</td>
<td>None addressed</td>
</tr>
<tr>
<td></td>
<td>- Where are the erosion 'hot-spots' located?</td>
<td>- Where are hazardous sandbars located?</td>
<td>- Where are bathing hazards located?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Are sea defences adequate?</td>
<td>- Is the navigation channel marked accurately?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>El Puntal, Spain</td>
<td>- Is dredging adversely affecting the beach?</td>
<td>- When should dredging occur?</td>
<td>- Are swimmers at risk?</td>
<td>- Are the dunes on the spit stable and recovering?</td>
</tr>
<tr>
<td></td>
<td>- Is replenishment of dredged sand carried out adequately?</td>
<td>- How much should be dredged?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lido di Dante, Italy</td>
<td>- Is the coastal zone stable?</td>
<td>None addressed</td>
<td>- Is there enough space for tourism?</td>
<td>- Is the beach polluted?</td>
</tr>
<tr>
<td></td>
<td>- Are buildings, beaches &amp; dunes stable?</td>
<td></td>
<td>- Is it suitable &amp; safe to swim?</td>
<td>- Is the beach crowded?</td>
</tr>
<tr>
<td></td>
<td>- Are the coastal defences adequate?</td>
<td></td>
<td>- Is there a biochemical swimming hindrance?</td>
<td>- Is the dune ecosystem healthy?</td>
</tr>
</tbody>
</table>

The information currently available to the coastal manager about the physical state of the coastline from observations, models and scientific interpretation is often too complex and difficult to be of direct use. In order to assist the decision making process this complex information needs to be delivered promptly and in a simplified form, i.e. reduced to a limited set of 'Coastal State Indicators' (CSIs) upon which management decisions can be based. Here we define CSIs as, 'A reduced set of issue-related parameters that can simply, adequately and quantitatively describe the dynamic-state and evolutionary trends of a coastal system'. The CoastView project has two main objectives:

- To develop and verify video-based monitoring methods and associated analysis techniques for the accurate estimation, monitoring and interpretation of the dynamic significance of these CSIs.
- Four diverse field sites (Figure 1) form the focus of the CoastView project. These are a continuous undefended coastline (Egmond, Netherlands), a coastline defended by offshore breakwaters (Lido di Dante, Italy), a busy coastal inlet with a dynamic spit (El Puntal, Spain) and an inlet with multiple dynamic offshore sandbars (Teignmouth, UK). Video stations have been established at all four sites. Each of the CoastView field sites experiences different management issues and therefore formed an interesting 'test-bed' for the CoastView project. The key issues that resulted from the discussions amongst coastal managers from each of these sites are summarised in Table 1.

The CoastView project approach to the problem is to establish a consortium of scientists and national-scale coastal managers that meet regularly within the framework of the three-year project. The project recognises issues that fit into four distinct management contexts: including, coastal protection, navigation, recreation and ecosystem protection.

The role of the managers is to define the key management issues that commonly exist around the world's coastlines (e.g. Table 1). The scientists' role is to define appropriate video-
Table 2. Examples of potential video-derived variables defined by scientific project partners (these are the building blocks of CSIs).

<table>
<thead>
<tr>
<th>Relevant Area</th>
<th>Video-derived parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beach State</td>
<td>Beach volume, Beach elevation, Beach width, Beach contours, Sandbar height, Sandbar location</td>
</tr>
<tr>
<td>Dune condition</td>
<td>Dune height, Dune foot position, Dune flora (extent, health), Over-wash locations</td>
</tr>
<tr>
<td>Beach safety</td>
<td>Surface current speeds, Rip-current locations, Location of bathing hazards, Beach classification</td>
</tr>
<tr>
<td>Beach use</td>
<td>Location of users, Density of users, Duration of visit, Nature of use</td>
</tr>
<tr>
<td>Wave climate</td>
<td>Wave height, Wave period, Wave direction</td>
</tr>
<tr>
<td>Shipping activity</td>
<td>Location of shipping channel, Depth of shipping channel, Location of channel markers, Number of vessels passing, Types of vessels, Dredging / dumping frequency, Dredging / dumping location</td>
</tr>
<tr>
<td>Algal bloom / seaweed</td>
<td>Maps of seaweed / algal blooms</td>
</tr>
</tbody>
</table>

Table 3. The frame of reference approach to swimmer safety.

<table>
<thead>
<tr>
<th>Management context</th>
<th>Recreation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic objective</td>
<td>To preserve swimmer safety at all times</td>
</tr>
<tr>
<td>Operational objective 1:</td>
<td>Avoid swimming when wave heights or currents are excessive</td>
</tr>
<tr>
<td>Quantitative State Concept 1:</td>
<td>Knowledge: Swimming is dangerous when significant wave heights ($H_s$) exceed 1 m or resultant currents ($u$) exceed 0.5 m/s in the swimming zone. ($H_s = 1 m$, $u = 0.5 m/s$)</td>
</tr>
<tr>
<td>Video-derived variables:</td>
<td>Wave height ($H_s$), Resultant current ($u$)</td>
</tr>
<tr>
<td>CSI = $max(H_s/H_s, u/u)$</td>
<td></td>
</tr>
<tr>
<td>Benchmarking 1:</td>
<td>Current state: $max(H_s/H_s, u/u)$</td>
</tr>
<tr>
<td>Reference State:</td>
<td>$max(H_s/H_s, u/u)$</td>
</tr>
<tr>
<td>Intervention procedure:</td>
<td>Fly the red flag &amp; stop bathing if $max(H_s/H_s, u/u) &gt; 1$</td>
</tr>
<tr>
<td>Operational objective 2:</td>
<td>To alert the general public to the location of bathing hazards.</td>
</tr>
<tr>
<td>Quantitative State Concept 2:</td>
<td>Knowledge: Swimmers are frequently cut-off by the tide on offshore sandbanks and get into difficulty in the strong flows between sandbars.</td>
</tr>
<tr>
<td>CSIs:</td>
<td>A publicly displayed video-derived map showing the location of hazardous sandbars, regions of strong flow and shipping hazards.</td>
</tr>
<tr>
<td>Benchmarking 2:</td>
<td>Current state: Current hazards</td>
</tr>
<tr>
<td>Reference State:</td>
<td>Hazards absent</td>
</tr>
<tr>
<td>Intervention procedure:</td>
<td>Warn public of the existence &amp; locations of hazards</td>
</tr>
<tr>
<td>Evaluation procedure:</td>
<td>Assess public awareness of hazards (questionnaire)</td>
</tr>
</tbody>
</table>

### An operational objective: that describes how the strategic objective will be achieved in a four stage process:

01 - Quantitative state concept: a means of quantifying the problem in hand. The application of CSIs is relevant at this stage of the process.

02 - Benchmarking process: a means of assessing whether or not action is required. At this stage CSIs are compared to a threshold value.

03 - Intervention procedure: Defines in detail what action is required if the benchmark values are exceeded.

04 - Evaluation procedure: Assesses the impact of the action taken. If the action has not been successful it may be necessary to revise the strategic/operational objectives and hence the feedback loops indicated in Figure 2.

There are several important advantages gained through invoking the frame of reference approach:

- The frame of reference approach facilitates clear, unambiguous communication between coastal scientists and managers.
- The CSIs are clearly linked to the overarching strategic objective and therefore the relevance of the indicator is clear to the coastal manager.
- The CSI is clearly embedded within a broader framework that has a well defined response and assessment procedure.
- The framework ensures a rigorous definition of CSIs, the required accuracy and the associated benchmark values.

### Aggregation of CSIs

Sometimes video-derived variables like those listed in Table 2 must be aggregated in order to address a certain issue and satisfy the definition of a CSI. For example, a strategic objective at the Teignmouth site that falls under the navigation heading is,
'to maintain a safe, navigable shipping channel'. One operational objective is, 'to ensure that navigation buoys adequately mark the channel'. The base level variables that relate to these issues are the channel position (as identified by evaluating the intertidal morphology and wave breaker patterns shown in time-averaged images) together with the video-derived buoy positions. The relevant CSI (and quantitative state concept) in this case is the buoy-channel marker inter-distance, which is an aggregate of the base level variables. To complete this example, the benchmarking process would ensure that the marker buoys are sufficiently close to the perimeter of the dynamic shipping channel. That is the buoy-channel marker inter-distance is below a predefined threshold value which is based on expert knowledge of the area. The intervention process in this case is to move the buoys and then reassess their location with the same quantitative state concept (the evaluation procedure).

Van Koningsveld et al. (2003) discuss other cases where it is inappropriate to aggregate CSIs which relate to a common strategic objective under the same operational objective. The example given below is related to swimmer safety under the recreation heading (Table 3).

In this example there are two distinct operational objectives involving different and incompatible CSIs. The first CSI is a numerical aggregation of wave height and current strength that is designed to prevent swimming when either waves are too large or currents are too strong. The basic knowledge used is that it is unsafe to swim when surface currents (due to longshore currents, rip currents or tidal flow) or wave heights exceed certain critical values ($H_{sc}$, $u/c$).

Mathematically this benchmarking process is assessed by the equality: $\max(H/H_{sc}, u/c) \leq 1$.

The second operational objective is concerned with educating the general public about the location of bathing hazards and where it is safe to swim using a video-derived map that displays the spatial location of the dangerous sandbars, strong currents and shipping hazards. Due to the diverse nature of the base level CSIs involved in this problem it is inappropriate to aggregate them in a single CSI. The frame of reference approach handles this incompatibility between CSIs by defining separate operational objectives that deal with wave height and current strength and the spatial location of hazards separately under the same strategic objective (Table 3).

The swimmer safety example given here shows that the form of CSIs may be quite diverse, ranging from a single numerical parameter to a map that quantifies the location of bathing hazards. Notice that the frame of reference approach outlined above is not limited to video-derived CSIs and opens the possibility of effectively combining additional data with video data. E.g. in the swimmer safety example, if direct measurements of wave height are available they may well be more reliable than video-derived estimates. Also notice how efficiently expert knowledge can be integrated into the decision making process.

In the following section we explore the application of video-derived CSIs and the frame of reference approach to a well-established coastal management problem.

RESULTS

Coastal Management at Egmond

The example illustration chosen here fits within the management context of coastal protection and relates to the Egmond field site. In 1990 the coastal managers in the Netherlands made a historic decision, which stated that the coastline should be maintained at the position of that date. A new policy was adopted called the 'Dynamic Preservation Policy', (MIN V and W, 1990). The objective of this policy is to provide safety against flooding in combination with sustainable preservation of the functions and value of the dunes and beaches. The 'Dynamic Preservation Policy' aims to take advantage of the natural dynamic processes; therefore the principle intervention procedure involves sand nourishment. In order to implement this policy a quantitative measure of the shoreline position was required, and the concept of the Momentary Coastline or MCL was developed. The momentary coastline position is an aggregated measure of the $H_{mlw}$ coastal contour. The MCL position is quantified from the sand volume in the beach profile between the dune foot elevation $H$ above $MLW$ and the depth contour at an equal depth $H$ below $MLW$. (Figure 3). The MCL is located a distance equal to the area ($A$) of the shaded triangle in Figure 3 divided by $2H$ and is measured from a constant reference location to this position.

The location of the MCL at a particular point in time may be subject to inter-annual variability and therefore is not a good indicator of the longer term trends in coastal behaviour. For this reason a Testing Coastline (TCL) was defined using the linear
The trend of the MCL over the ten previous years.

The Basal Coastline (BCL) is the benchmark to which the TCL is compared. The BCL is calculated in the same way as the testing coastline using the previous ten years (1980 to 1989) of MCL estimates prior to the reference date (1 January 1990). A full and more detailed description of this procedure can be found in van Koningsveld and Mulder (2003). Table 4 shows how this problem can be defined within the frame of reference.

Generally the frame of reference approach detailed above is implemented using extensive aerial beach and sub-tidal surveys. The considerable cost and manpower involved in these surveys limits the spatiotemporal resolution of the surveys and hence, the assessments of beach-state. The implications of this are that there could be severe erosion between surveyed locations, or the measured trend in the TCL position could be affected by the seasonal cycle in beach volume. The implementation of video-derived CSIs will provide a cost-effective way of increasing both the spatial and temporal resolution of the assessment of beach-state and avoiding the problems associated with conventional surveys.

Sub-tidal Beach Mapping Using Video

There are two methods for surveying the sub-tidal beach using remotely sensed video data. The first utilises the time-domain and evaluates the phase-speed of surface gravity waves using the rapidly sampled intensities from an array of pixel elements within an oblique image (Stockdon and Holman, 2000). The wave phase-speed can be inverted to yield the water depth since the theory linking wave speed and water depth is well established. The methodology detailed in this contribution provides an inverse modelling approach to extract the sub-tidal profile. An inverse modelling approach to extract the sub-tidal profile. A typical estimation of bathymetry from the sub-tidal beach mapper (SBM) is shown in Figure 4. The lower panel shows a time-stack of the profile estimated using the SBM. The upper panel shows an arbitrary initial profile measured at the start of the 8-day period, from which the SBM estimate is evolved (dashed line). Also shown in the upper panel are the surveyed profile (thin line) and the SBM estimate (bold line) for the end of the 8-day period, and the difference between the measured and estimated profiles (small dots). It can be seen that there is excellent agreement between the survey and the video estimate with vertical error that is small (<1m) compared to the scale of the profile change under investigation.

The video-derived position of the MCL at both profile locations together with the position of the MCL derived from traditional infrequent surveys in May and September 2000 are shown in Figure 6. It can be seen that there is reasonable agreement between the video-derived and surveyed MCL estimates with deviations of generally less than 10 m at the time of the infrequent surveys. Between surveys the deviations can be much larger indicating the value of the video sampling method.

The video-derived MCL time-series shows a high degree of inter-annual variability and a clear response to beach and shoreface nourishment works. There is a seaward shift in MCL of +35 m and +15 m at y = -130 m and -1500 m respectively. This net accretion over the first six months corresponds to the completion of the combined beach and shoreface nourishment. At y = -130 m this accretionary phase is followed by a period of stabilisation during spring, and further period of accretion during the summer months. The trend is similar at y = -1500 m but with slight erosion following the accretionary phase in spring followed by a period of stabilisation during the summer months.

DISCUSSION

The methodology detailed in this contribution provides an...
effective mechanism for communication between coastal scientists and managers (the ‘frame of reference’) and clearly links video-derived CSIs to management issues. The example given here uses an established methodology from the Netherlands that addresses a coastal erosion problem. This procedure normally involves monitoring the coastline using traditional surveying techniques in order to evaluate the Momentary Coastline (MCL) position and hence the Testing Coastline (TCL). The advantage of complementing traditional surveys with video-derived parameters is not just economic; video surveys also yield improved temporal and spatial resolution. Thus, erosion hotspots that potentially occur in between survey lines will be picked up using the video method. Additionally, the video method has the advantage of resolving the higher frequency, seasonal trends in the sand volumes (and MCL position) commonly observed on many natural beaches, which are aliased by lower frequency surveys. Thus, it is possible to more accurately separate the long-term trends in the MCL position from the inter-annual variability.

The example of the MCL given here illustrates that it is not just the instantaneous values of CSIs that are of value but also the extrapolated trends in these parameters. Another objective of the CoastView project is to examine the utility of data driven models for forecasting the evolution of coastal state.

However, the development of video-derived CSIs is still in its infancy. Ongoing research within the CoastView project will focus on the development of robust, well-tested algorithms that automatically and promptly deliver reliable video-derived CSIs to coastal managers. The World-Wide-Web is one method of dissemination that is currently being used by the Water Research laboratory in the University of New South Wales (School of Civil and Environmental Engineering) to deliver video information directly to their commercial clients in a fast and effective manner. (http://www.wrl.unsw.edu.au/coastalimaging/index.php). This dissemination methodology is also under investigation within the CoastView project.

In addition to the established operational objectives (e.g. MCL method) discussed here it is also apparent that there are many other new video-derived parameters that may assist in the coastal management process. For example, with regard to recreation, a new operational objective might be formulated as follows: ‘near coastal resorts, a minimum beach width of 75 m will be maintained during the entire tourist season’. This would directly contribute to the Netherlands strategic objective of, ‘...sustainable preservation of values and functions ...’ Effective implementation of such a new operational objective again
Coastal video systems have demonstrated the capability of accurately monitoring hydro- and morpho- dynamic parameters, which have value to both science and coastal zone management.

The spatiotemporal resolution and coverage of video-derived information (e.g. morphology) often exceeds that obtained using traditional methods.

Accurate monitoring of hydro- and morphodynamic parameters, which have value to both science and coastal zone management issues. The procedure involves a careful benchmarking process, definition of the appropriate corrective action if threshold values are exceeded and a method assessing the effectiveness of this action. The methodology also allows for the integration of specialist knowledge and non-video-derived data into the decision making process.

Coastal video monitoring systems show great potential as an aid to coastal zone monitoring and management.

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