IMAGE SEQUENCE MATCHING FOR THE DETERMINATION OF THREE-DIMENSIONAL WAVE SURFACES

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ASTRACT:

Surf zone processes are in the focus of wave research with key words like wave breaking, wave runup and wave overtopping. For coastal management tasks numerical models of the sea surface are required. To serve this purpose the sea surface must be determined in three dimensions. This paper deals with an automatic method for generating such surfaces based on image matching. For data acquisition four synchronised digital video cameras were used. The camera constellation and the expected accuracy are described. The determination of the wave surface results from a least squares matching in combination with a region growing algorithm. Processing principles for image sequence analysis with and without consideration of the surface movement are shown. The research area is a groyne field on a North Sea island in Germany. Due to the progress of the project only first results are presented.

1. INTRODUCTION

The protection of the shore and its population from the mighty impact of floods and huge waves is one of the most important tasks in coastal management. Therefore, the optimisation of constructions like dykes or groynes is of high interest in research and practice. But the design of their shape and surface properties requires detailed information about the waves attacking them. In this context the monitoring and prediction of the sea state in the surf zone is very important.

For almost 100 years photogrammetry has been used for the recording of sea surfaces (Kohlschütter, 1906). However, wave analysis particularly from image sequences using manual measurements is very complex and time-consuming. Present research and developments with regard to automated matching procedures and interpretation of digital images can overcome these limitations. This is important for wave analysis, considering the fact that photogrammetry is the only highly accurate method with a continuous spatial and temporal data acquisition. Also, it has to be pointed out that the photogrammetric results can be applied for the control and verification of numerical models in wave analysis (Strybny et al., 2001).

A number of such numerical wave models to provide time dependent wave information already exists. For the control and validation of these models spatial and time dependent data are needed. Quasi continuous measurement techniques using high resolution digital video cameras are applicable for this purpose.

2. WAVESCAN

WAVESCAN is an interdisciplinary project carried out by the Institute of Fluid Mechanics (ISEB) and the Institute of Photogrammetry and GeoInformation (IPI) of the University of Hannover. The intention of this project is the photogrammetric acquisition and phase-resolving modelling of surf zones on the basis of digital image sequences as well as the combination of the measuring and modelling procedures.

Sites to be studied correspond to typical near shore situations, e.g. a groyne field, the near field of a jetty or breakwater. The selected test area is a groyne field seawards Norderney Island in the coastal waters of the German North Sea. The size is approximately 200 by 200 m^2. The situation is shown in Figure 1. The chosen groyne field is a research groyne field of the Coastal Research Station, equipped with a number of conventional instruments, such as current meters, gauges and wave rider buoys.

Figure 1. Groyne field at Norderney Island

In order to be useful for other sites as well, the photogrammetric data acquisition system must be transferable to different conditions. To record areas of arbitrary size for example, the system prototype of four cameras (see chapter 3) can be extended by adding additional cameras. Also, in terms of accuracy different requirements can be fulfilled.

The requirements on the duration and resolution in time of the project vary, depending on the investigated problem. The minimum period for collecting data is the time needed by the incident wave to cross the surf zone from the seaward boundary to the line of highest wave runup. For this process a duration of about one minute is required (Niemeyer, 1997). Also, the measurements have to be carried out over a period, which is long enough to allow the analysis of the wave crossing and runup. To obtain an acceptable standard deviation of the wave parameters, some 200 waves have to be analysed. Consequently, the chosen measurement system must be able to sample data over a period of up to approximately 20 minutes.

In order to be able to describe the kinematics of the sea surface induced by sea state a high resolution in time must be chosen. The mean wave period in a groyne field near Norderney is approximately 6 s. A sufficient frequency lies between 10 and 20 Hz.

3. IMAGING SYSTEM AND DATA AQUISITION

The measurements at Norderney Island are carried out from the top of high buildings. The cameras II and III are set up in the normal case (see Figure 2). To enlarge the base-to-height ratio and thus to improve the accuracy the convergently arranged cameras I and IV are added. At the same time the recorded area can be increased by successively adding cameras in X-direction.

For data acquisition of the test area digital video cameras with a 2/3 inch interline progressive scan CCD are used. The CCD-sensor has a radiometric resolution of 10 bit greyscale (monochrome) and a geometric resolution of 6.7 x 6.7 µm² per pixel. The sensor size is 1300 x 1030 pixel, the maximum frame rate is 12 frames per second. The system allows a maximum observation period of approximately 20 minutes, the bottle-neck are current disk limitations. The exposure time can be controlled by an external trigger signal. For camera synchronisation IPI developed a wireless system to transmit an external trigger signal from a master station to all slave stations (three in this case) approximately every 1.5 ms.

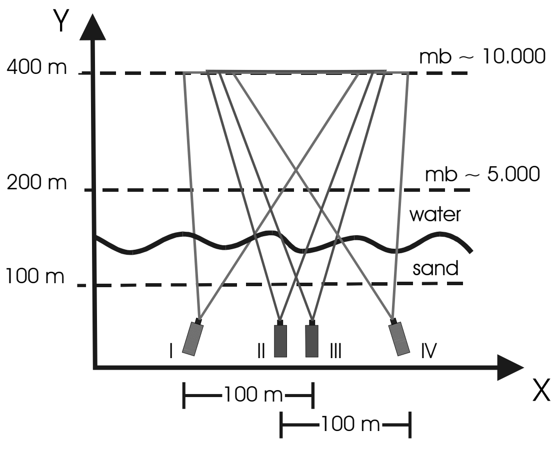

Figure 2. Camera constellation in planimetry

In principle the achievable accuracy is influenced by the object size, the number of available cameras, the focal length and the camera locations. Using a focal length of 50 mm an area of 200 by 200 m^2 can be recorded with an accuracy < 4 cm in X- and Z-direction and < 8 cm in Y-direction at the seaward boundary, assuming an image scale of 1 : 10 000 and an accuracy of the image coordinate measurements of 3.5 µm, corresponding to 0.5 pixel.

The orientation of the images is established manually after data acquisition. The orientation parameters are assumed to be constant for the acquisition of one image sequence.

4. MATCHING METHOD

The 3D recording of the wave surface from images requires the interior and exterior orientation of the images and conjugate points. Therefore, one of the major tasks during the photogrammetric object reconstruction is the search of conjugate points.

Since a number of years automatic matching methods have been investigated as a major issue in digital photogrammetry. The automatic methods for image matching can be divided into three classes, area-based, feature-based and symbolic or relational matching (Schenk, 1999). In area-based matching entities are the grey levels of small areas of two or more images and matching is carried out by cross-correlation or the highly accurate least squares technique. The latter method requires very good initial positions. Feature-based matching determines the correspondence between points, edges (e.g. the wave runup line) or other features derived from the original images. The similarity (e.g. the shape, sign and strength of the runup line) is defined based on a cost-function. The symbolic matching method refers to methods that compare symbolic descriptions of images, for example the breaking waves, and measures the similarity also by a cost function.

These matching methods exist and work well for many photogrammetric applications. Examples for the matching of sea surfaces are given in (Redweik, 1993), (Taguchi, Tsuru, 1998) and (Yamazaki et al., 1998). However, the authors are not aware of any software, which is optimised for the matching of wave surfaces. First tests have been carried out with IPI's matching software DPCOR. This software has been used in a large number of photogrammetric projects before, e.g. (Heipke et al., 1994), (Heipke et al., 1996), (Rieke-Zapp et al., 2001). Conjugate seed points have to be determined manually, then the algorithm follows the region growing principle to match conjugate points in stereo image pairs (Otto, Chau, 1989). Matching is carried out in image space, no orientation parameters are required.

5. IMAGE SEQUENCE MATCHING

During the analysis of image sequences the predictable motion of surface models can be used as additional information. The established temporal correspondence between the subsequent frames of an image sequence can in particular increase the reliability of the results.

The image sequences are obtained with a frequency of 12 Hz. Thus the basic idea of the used processing principle is that subsequent images of one sequence do not change very much. So it should be possible to feed the matching programme with manually measured seed points of just one or a few stereo pairs at the beginning of a sequence, and the program should find the needed seed points of the following stereo pairs on its own. In the following, such an approach is described. First the movement between the subsequent images is assumed to be zero. In an enhancement of this procedure the motion of the wave surface is taken into account (Könnecke, 2002).

5.1 Rigid Transfer of Seed Points

In the first stereo pair the seed points for matching have to be measured manually. Then the matching procedure is executed. This leads to a large number of conjugate points. Because of the small wave motion the conjugate points of this pair (called pair [i] in the following) can be utilized as seed points for the following time step [i+1] (see also Figure 3). In order to reduce the matching effort only a pre-specified amount of seed points is used. Well distributed points with a high correlation coefficient are selected. Then, the matching of the stereo images [i+1] is carried out, the results can then be used in the same way for the stereo images [i+2] and so on.

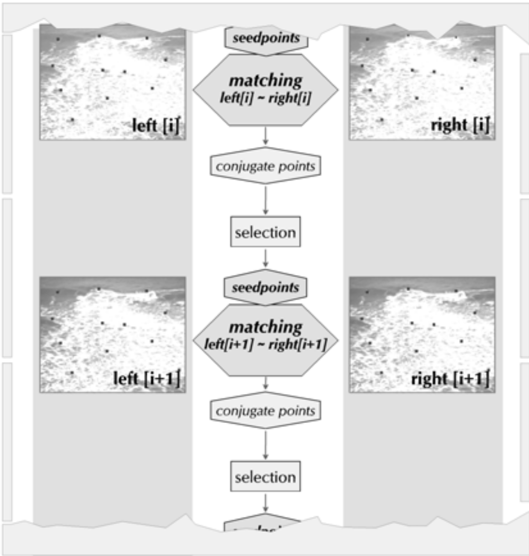

Figure 3. Principle of transfer of seed points

The analysis of image sequences using the rigid transfer of seed points does not take the movement of the sea surface into consideration. Thus a number of seed points for matching the pair [i+n; n≥1] does not lead to successful results. However this loss is compensated by the large amount of available seed points.

5.2 Motion Analysis

It is also feasible regarding image sequence analysis to take the movement of the sea surface into account, for example based on a vector field modelling motion from one time epoch to the next (Jähne, 1991). The vector field provides information about the direction and velocity of the movement.

5.2.1 Motion Models: Assuming a successful matching between an image [i] and its successor [i+1] of one image sequence taken by one camera, a large set of conjugate points in both images is available. Since these images represent one view at consecutive time steps, the position difference of any of the matched conjugate points in image space can be interpreted as a displacement or movement vector of that point. All displacement vectors of all conjugate points form the vector field, which represents a model of measured pixel movements.

Since the time interval between image [i] and [i+1] is not only the same as between image [i+1] and [i+2] but also very small, the assumption of a linear approximation of the water mass movement during the period [i] to [i+2] is assumed to be valid for a significant number of points. Therefore the position of a point at time [i+2] can be predicted by extrapolation of the movement measured between [i] and [i+1] (see Figure 4). This results in a large variety of potentially corresponding points between the images [i+1] and [i+2]. Out of them a new set of seed points is chosen. Then, the matching [i+1] and [i+2] is performed. This yield a new set of corresponding points in [i+1] and [i+2].

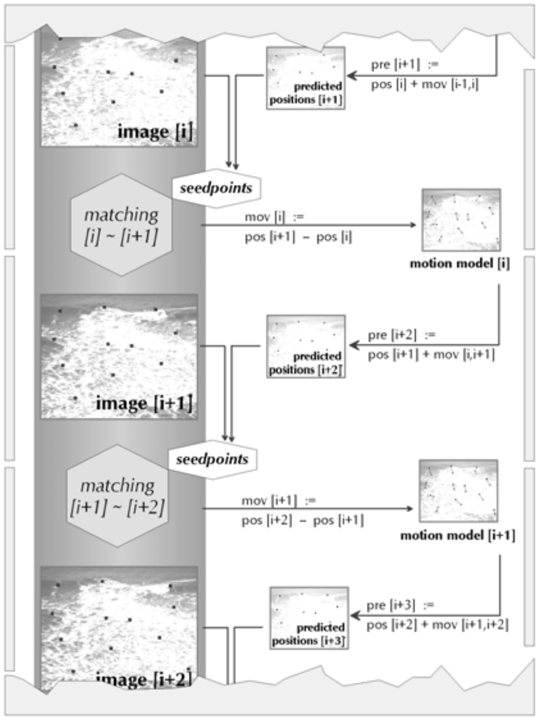

Figure 4. Principle of motion models

It is possible to match any image [i+n] with its successor [i+n+1] as long as the matching with the predecessor [i+n-1] was successful as well. Combining this knowledge with the fact that the very first matching step [0] to [1] of this image sequence can be done with manually measured seed points, it becomes obvious that all images of this sequence can be linked together by matching. Therefore a set of conjugate points and motion models can be derived for that sequence.

5.2.2 Stereo Models: If a matching between a stereo image pair of time [i] is carried out, a set of conjugate points is the result. There exists no functional context between this stereo point set and the sets of conjugate points of the temporal matching within the left and right image sequence, but both sets refer to the same image space.

After every motion model calculation a connection between the corresponding stereo images must be established. One opportunity to solve this problem is provided by using the motion model [i, i+1] for a stereo sequence of two images [i] and [i+1] and the subsequent stereo matching. In both images of the stereo pair [i] seed points are available from earlier computations. For the calculation of the vector field of the motion model in the left and right image sequence the same seed points have to be determined in the image [left, i+1] and [right, i+1]. The matching procedures for the stereo pair [i] and the motion models [left i, i+1] and [right i, i+1] are carried out. Then, the conjugated points of the stereo pair [i] are transferred by the use of the motion models into the images [i+1]. A matching of the image sequence [i+1] is carried out. From the acquired conjugate points of the stereo matching [i+1] suitable seed points can then be selected for temporal matching to determine the motion model [i+1, i+2]. In this way at every time step the motion and stereo model are related.

6. RESULTS

Up to now only first analysis of the normal case images has taken place (see chapter 3). Because of the poor base-to-height ratio a low accuracy in Y-direction is expected. As mentioned before, the accuracy can be improved by additional use of the two convergent image sequences.

Figure 5 shows the manually measured seed points of the first stereo pair of an image sequence acquired during the first measurement campaign. In this case 30 well distributed seed points are sufficient.

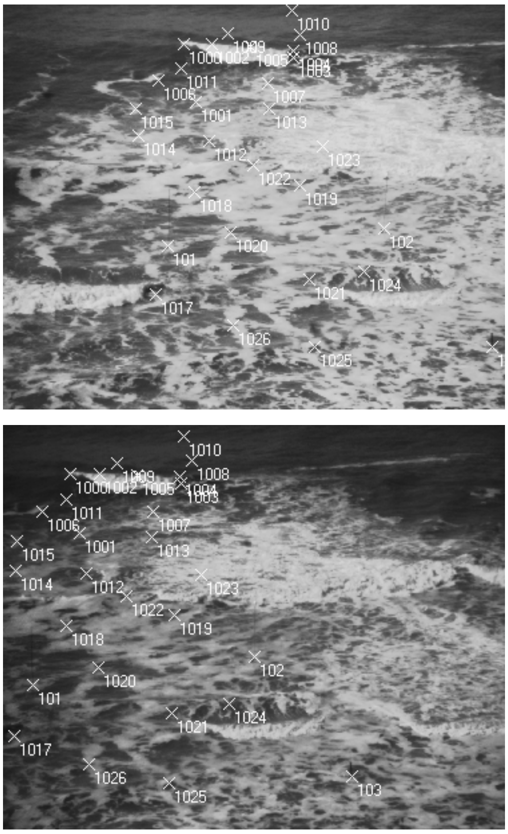

Figure 5. Measured seed points
(above: left image, below: right image)

Using these 30 seed points approximately 36 000 conjugate points are determined automatically. The conjugate points are superimposed in Figure 6 to the image in white. The visible small gaps are areas in which the matching software was unable to find conjugate points.

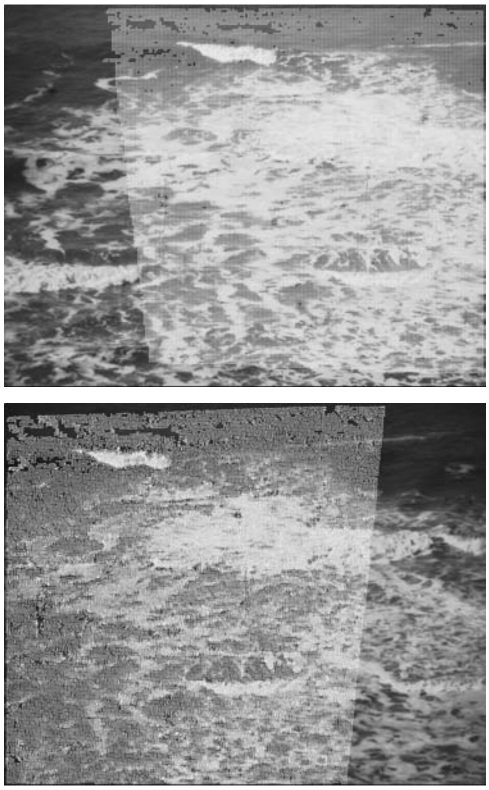

Figure 6. Matching of conjugated points
(above: left image, below: right image)

Experiments of processing of image sequences with the rigid transfer of seed points have demonstrated the potential of this procedure. The analysis of a 10 s image sequence acquired with a frequency of 5 Hz has been carried out successfully. Figure 7 shows a photogrammetrically measured surf zone in 3D at different time steps.

Figure 7. Sequence of wave surfaces ($\Delta t = 1.7$ s)

When applying the motion analysis procedure the vector field covers almost the whole image space except small borders and regions of low contrast and areas of highly irregular movement (e.g. breakers). Figure 8 represents a clipping of such a motion model with typical examples of matched and unmatched regions. The lines show the movement compared to the next image.

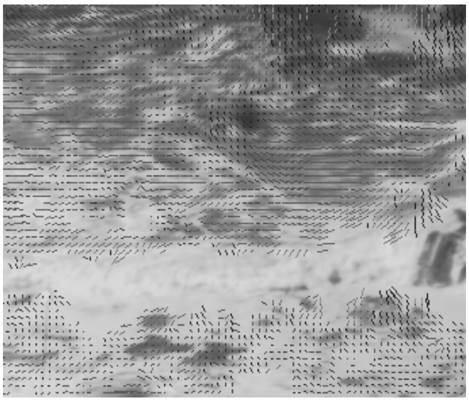

Figure 8. Matching result of a motion model (lines = movement compared to next image)

The calculations of the stereo models are still in progress.

7. CONCLUSIONS

Within the scope of the project WAVESCAN a groyne field at Norderney Island is recorded with four synchronised digital video cameras. For reconstruction of the sea surface a least squares matching algorithm is used. The obtained results show the high potential of the automatic measurement method. However, the approach has to be optimised in terms of level of automation, accuracy and speed.

The treatment of more than two images has to be integrated into the matching procedure also. For this purpose the acquired image coordinates are transformed into object space using the interior and exterior orientation. Subsequently, the calculated object coordinates are re-transformed in the convergent images. Thus sufficient seed points are available for a new matching between the convergent and one of the normal case images.

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