IMAGE SEQUENCE ANALYSIS OF SURF ZONES: METHODOLOGY AND FIRST RESULTS

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ABSTRACT
Numerical modelling of highly complex processes in the surf and swash zone is an important task in coastal zone management. As input and reference for these numerical models three-dimensional information about the water surface is required. In this paper a method for reconstructing a dynamic digital surface model of a surf zone based on stereo image sequences is presented. The surface model is obtained by digital image matching using a variation of the well-known vertical line locus method. Processing principles for image sequence analysis and first promising results are described, based on image data from a groyne field on a North Sea Island in Germany.

1. INTRODUCTION

In coastal zone management the optimisation of constructions like dykes or groynes is of high interest. The design of their shape and surface properties requires detailed information about the waves attacking them. In this context monitoring and prediction of the sea state in the surf zone is very important. The processes in the surf zone, like wave breaking, wave runup and wave overtopping can be described by numerical modelling, (e.g. Strybny, Zielke, 2000). However, currently only point-wise gauge and buoy measurements are available to control such models. The geometric shape of the water surface is an important input for the numerical models.

In principle the water surface can be provided with the required temporal and spatial resolution for the calibration and validation of the numerical model using digital photogrammetry (Strybny et al., 2001). Digital image matching was already employed successfully for the determination of wave parameters from stereo images in the past (e.g. Redweik, 1993). Further examples for the determination of sea surfaces using stereo images are given in (Taguchi, Tsuru, 1998), (Yamazaki et al., 1998) and (Holland et al., 1997).

The goal of our work is the area-wide, three-dimensional and temporally quasi-continuous determination of the water surface in the surf zone using an automatic photogrammetric approach. The approach is based on stereoscopic image sequences and image matching.

2. IMAGE MATCHING

The computation of a digital water surface model from images requires the interior and exterior orientation of the images and homologous points. Assuming the orientation to be given, the identification and the image coordinate measurement of homologous points in two or more overlapping images via image matching over time remains the major task to be solved.

2.1 Point-wise Correlation

The three-dimensional determination of the water surface is accomplished by digital image matching using photogrammetric stereo images as implemented in the software package LISA (Linder, 2003). By successively continuing point-wise matching based on cross correlation over the model area through a sophisticated region growing starting from given seed points, a 3D point cloud is generated, subsequently a digital surface model (DSM) is obtained by interpolation.

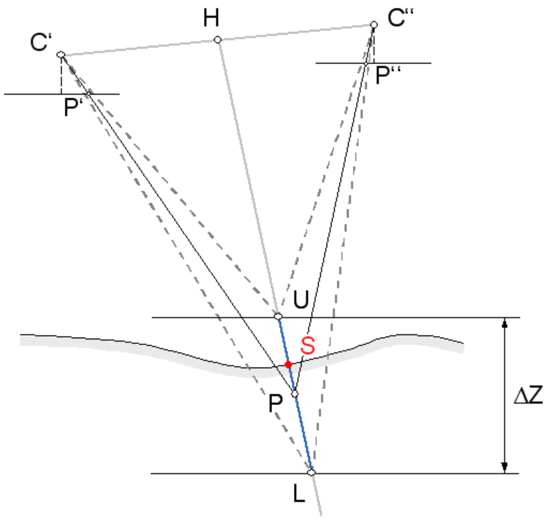

Figure 1. Point-wise matching algorithm

The point-wise matching algorithm runs as follows: Approximate 3D coordinates for the seed point, the maximum height variation ΔZ in object space and orientations of the images are needed as input data. A straight line is then defined through the centre H of the camera basis C'C'' and the seed point P (see Figure 1). Also the uppermost point U and the lowermost point L lie on this line. Between U and L several points are defined in a way that their distance in image space amounts to approximately one pixel.

Using the collinearity equations all these points are then projected into image space yielding several point pairs (P', P''). Square windows of a predefined size are set-up around each position, and for each pair of windows the cross correlation coefficient ρ is computed. The point pair with the maximum coefficient ρ_{max} is considered to be the pair of conjugate points corresponding to the point S in object space (see again Figure 1), provided that ρ_{max} lies above a pre-specified threshold value. Otherwise the point is rejected.

In order to exclude incorrect correlations due to small contrast for example, ρ_{max} is also checked for uniqueness: From the neighbouring five correlation coefficients on either side, the minimum value ρ_{min} is selected. The maximum and minimum correlation coefficients are identified. If the difference between ρ_{max} and ρ_{min} is smaller than a value of 0.5, the object point is rejected.

The described principle of point-wise correlation can be considered as a variety of the method of vertical line locus (Bethel, 1986). The difference is that points are selected on the line $\overline{HP}$ rather than a vertical line through P.

2.2 Region Growing

A three-dimensional point cloud is generated continuing the point-wise correlation over the entire model area by region growing. Region growing is divided into two parts.

First, the original images are down-sampled. Then, rays in the XY-plane are defined starting from each seed point into the eight main directions. Using a constant step size in X and Y direction, points on these rays are then selected. The step size is taken to be equivalent to the grid size of the DSM to be eventually generated. Starting from the results of the seed point, point-wise correlation on the reduced image resolution is then carried out for each new point, always using the Z value of the previous point as initial height value. Region growing in each direction and for each seed point continues until the correlation fails.

In the next step a regular DSM is interpolated from the resulting 3D points, and point-wise correlation is repeated for each grid node using the original images. Finally, the results are low-pass filtered to eliminate gross errors.

3. IMAGE SEQUENCE ANALYSIS

The analysis of image sequences is a challenging problem and has been an important research topic in the areas of photogrammetry and computer vision for some time. Horn (1986) for example uses optical flow to determine the motion of a camera from an image sequence. An algorithm obtaining a 3D model from image sequences is presented by Pollefeys et al. (2000). The system is able to extract automatically a textured 3D surface from an image sequence without prior knowledge about the scene or the camera. In our case image sequence analysis is instead used for the surface determination of a dynamic process, i.e. the tracking of a moving surface with static cameras.

The basic idea of processing image sequences in our approach is that the change in height of the DSM from one image to the next in the area of non-breaking waves is very small. This value obviously depends on the recording frequency and must be chosen accordingly. It is possible to start the process of image matching using only a few manually measured seed points (Santel et al., 2002). Our method is then able to find the needed seed points of the following stereo pairs automatically.

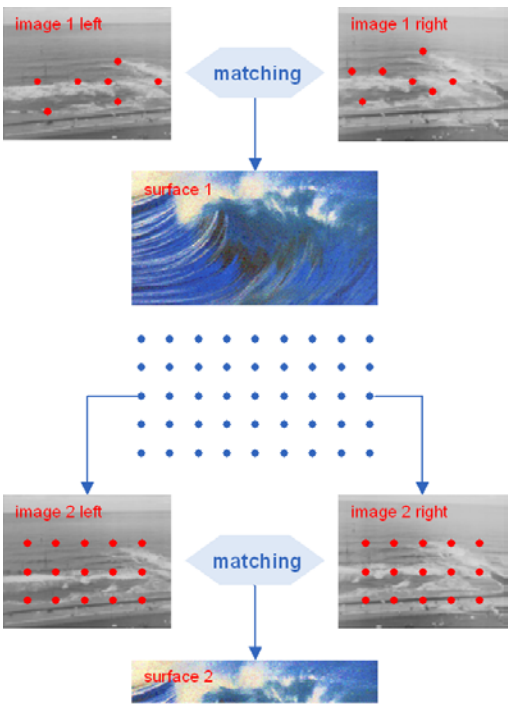

Figure 2. Determination of wave surfaces from image sequences

In the following the analysis of image sequences is described more in detail (see Figure 2). The matching procedure is executed for the first stereo pair at time step [i]. This leads to a large number of object points. Because of the small wave motion, the object points of the time step [i] can be utilized as seed points for the following time step [i+1]. In order to reduce the matching effort only a pre-specified amount of regularly spaced points generated at step [i] is used as seed points at [i+1]. Matching of the stereo images [i+1] is carried out, then the results are used in the same way for the stereo images [i+2] and so on.

4. IMAGING SYSTEM, TEST AREA AND IMAGE ACQUISITION

For the image acquisition four digital video cameras with a 2/3 inch interline progressive scan CCD were used. The CCD-sensor has a radiometric resolution of 10 bit and a geometrical resolution of 6.7 x 6.7 µm² per pixel. The frame sensor size is 1296 x 1031 pixel, the maximum frame frequency is 12 frames per second. The system allows for a maximum observation period of 20 minutes. For synchronisation of the cameras the exposure time is controlled by an external trigger signal.

Figure 3. Test area
Source: NLWK – Norden

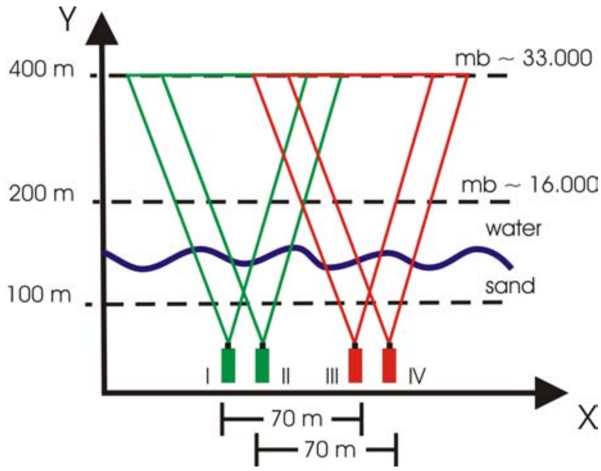

Figure 4. Camera constellation in planimetry

The selected area is a groyne field seawards Norderney Island in the coastal waters of the German North Sea (see Figure 3). The size is approximately 200 by 200 m². A measurement campaign took place in August 2002. The measurements were carried out from the top of two high buildings close to the groyne field (white dots in Figure 3). On each building two cameras were set up. Due to the altitude of the camera positions of about 40 m and a maximum imaging distance of 400 m at the outer boundary of the area under investigation, the cameras point downwards with an angle of approximately 10 degrees. This camera constellation results in two overlapping stereo models (see Figure 4). The orientation of the images was established manually after image acquisition. The orientation parameters are assumed to be constant for the acquisition of an image sequence.

5. RESULTS

For the generation of the dynamic DSM well distributed seed points were measured manually in the first stereo pair of the image sequence. Using these seed points approximately 20 000 conjugate object points were determined automatically. Subsequently, matching of a 30 s image sequence acquired with a frequency of 8 Hz has been carried out successfully as described in section 2 and 3.

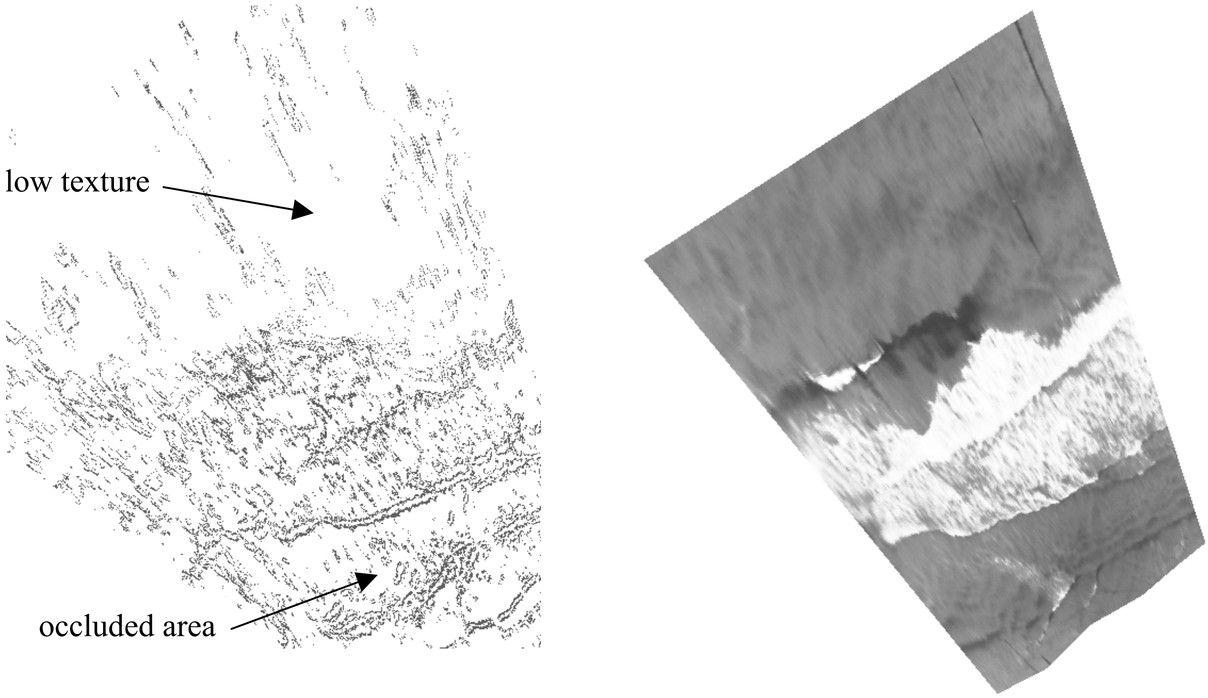

Figure 5. Correlated points and associated orthophoto

Figure 5 shows the correlated points derived for a particular instance in time. Areas without points are located on the backward slopes of the wave peaks and arise due to occlusions in the surf zone or due to the low texture further away from the beach.

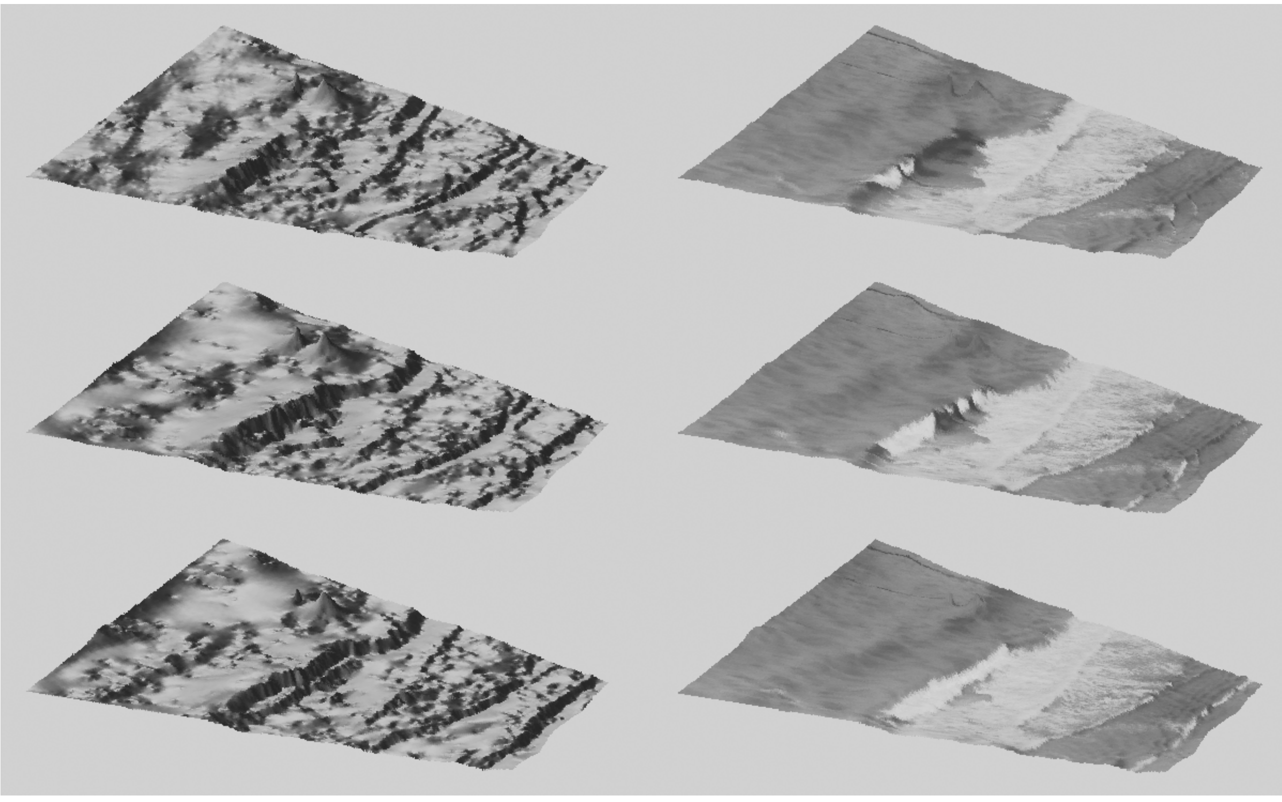

Figure 6. Sequence of water surfaces with $\Delta t = 1$ s
left: surface models; right: with overlayed orthophotos

In the left part of Figure 6 three derived water surfaces of an image sequence with a time difference of 1 s from epoch to epoch are illustrated. The position of the wave peaks can be well identified and tracked in the surface models. Additionally produced orthophotos overlaid to the corresponding surfaces are shown in Figure 6, right. In both illustrations the wave positions coincide. By overlaying the orthophotos the results of image matching are thus visually verified.

In subareas, like a pole in the groyne field problems arise. The pole for example is represented as a peak in the DSM. This problem can only be solved by the definition of a cut-out area. Further adjustments of the matching algorithm to the specific problems of water surface modelling and the optimisation of the parameter choice will be tackled as one of the next steps. Finally the analysis of the entire groyne field is achieved by combining the two overlapping stereo models.

6. CONCLUSIONS

Experiments of the developed procedure demonstrate the potential of our approach. Up to now only a qualitative analysis of the matching results is possible. The image matching is checked manually by overlaying orthophotos. In future the results will be spot-checked by manual stereo analysis.

During the measurement campaign at Norderney further measurements with conventional instruments, such as current meters, gauges and wave rider buoys have been carried out. From these point-wise measurements the altitude change of the sea surface can be derived. Using these data the developed procedure will also be checked.

The final DSM will then be used by the fluid dynamics group of our university as input and reference for the numerical models. The results of this step will finally show whether our approach of combining digital photogrammetry and fluid dynamics for surf zone modelling is useful for practical applications.

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