

**METHOD AND SYSTEM FOR ACQUIRING  
A THREE-DIMENSIONAL SHAPE DESCRIPTION**

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The use of three-dimensional images or shapes is becoming increasingly important, also for new applications, such as showing objects on the Internet, virtual reality, the film industry and so on.

Three-dimensional shape descriptions are usually acquired with two or more cameras or using laser systems. Existing systems may have a high cost price, may require a time-consuming calibration procedure and be difficult to transport, while in some cases the scene must be static, the working memory volume for the scene is determined or insufficient information concerning the topology of the shape is obtained.

An example of related research is an article by A. Blake et al., "Trinocular active range-sensing", IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 15, No. 5, pp. 477-483, 1993. According to this method two series of parallel lines are projected sequentially. The lines in the image can be identified by ensuring that the projected lines and epipolar lines intersect laterally. The lines may not therefore be too close together.

Another example is an article by Vuori and Smith, "Three dimensional imaging system with structured lighting and practical constraints", Journal of Electronic Imaging 6(1), pp. 140-144, 1997. According to this method a single pattern is projected but limitations are imposed on the dimensions of the scene for recording and on the relative distances between the pattern elements. This makes it possible to predict in which part of the image plane each individual pattern element is projected.

In addition, known systems and methods always start from absolute measurements and dimensions, which is not always required, particularly not when the application is aimed at showing and not at measuring the objects.

The present invention provides a method for acquiring a three-dimensional shape or image of a scene, wherein a predetermined pattern is projected onto the scene and the shape is acquired on the basis of the relative deformations of the pattern as detected in one or more images.

The invention further provides a system for acquiring a three-dimensional shape or image of a scene, comprising:

- at least one pattern generator for projecting a pattern on the scene;
- at least one camera for making an image or images of the scene;
- computing means for determining the shape of the scene.

The required hardware is simple and the system according to the present invention is therefore not very expensive.

According to the present invention it is no longer required to individually identify components of the projected pattern, such as lines or dots, either via a code in the pattern itself or via limitations imposed by the scene and/or the arrangement or a priori knowledge in respect thereof. In the method according to the present invention the shape can be acquired via the relative positions of the components in the pattern, for instance by determining the relative sequence of pattern lines.

According to the present invention a single image will suffice to acquire a three-dimensional image or a three-dimensional shape description and an acquisition time is required which is no longer than that for making a single image.

Because the recording time of a single image can remain limited and since reconstructions can be performed for a quick succession of different images, moving objects and their three-dimensional movements and changes of shape can be reconstructed.

According to the present invention the calibration procedure can be kept simple and few limitations need be imposed on the relative position of the pattern generator(s) and camera(s).

10 According to the present invention the projected pattern can be kept very simple and strongly interlinked, such as for instance a grid of lines. Owing to the simplicity the resolution of the pattern and thereby of the three-dimensional reconstruction can be kept high. Due to the strong interlinking of the pattern it becomes possible to determine the correct surface topology explicitly as a component of the output.

According to the present invention the absolute position of components of the pattern within the entirety of the pattern is of secondary importance. Three-dimensional shape descriptions can be generated without such information, except for a scale factor, by assuming a (pseudo-)orthographic model for the geometry of pattern projection and image formation. Perspective effects in this geometry are preferably kept limited.

According to the present invention both the three-dimensional shape and the surface texture of scenes can be determined. It is herein possible to eliminate problems of alignment of shape and texture since shape and texture are determined using the same camera(s). The final output, which can be a three-dimensional shape description with or without texture, can of course be made in any desired format, including formats which are for instance suitable for graphic work-stations or Internet.

According to a preferred embodiment the surface texture can moreover be acquired from the same image that is used to determine the three-dimensional shape. A

similar method can also be extended to cases where a pattern is employed with absolute definition of the components. It will be apparent that the procedure for acquiring coloured or multi-spectral surface texture, i.e. built up of different spectral base images, does not differ essentially from the procedures for one base image.

According to a preferred embodiment the projected pattern is regular and composed of similar basic shapes, such as rectangles or squares, formed by the composition of two mutually perpendicular series of parallel equidistant lines.

According to a preferred embodiment calibration takes place by showing the system two planes between which the angle is known, for instance a right angle. The parameters required for the shape definition can be determined herefrom, such as the angle of reflection of the projected rays relative to the image plane and, if necessary, the height/width ratio of the pixels.

Further advantages, features and details of the present invention will be elucidated on the basis of the following description of the preferred embodiment thereof with reference to the annexed figures, in which:

figure 1 shows a schematic view of a preferred embodiment of the method according to the present invention;

figure 2 shows an example of a detail of an image acquired with the arrangement of figure 1;

figures 3a-3d show a detail view with the results of line detectors and the combination thereof after a first correction step;

figure 4 shows an example of a discontinuity in the detected pattern;

figures 5a,b,c show a diagram elucidating the construction of the grid;

figure 6a-6b show a diagram elucidating the refining of the positions of the grid;

figure 7 shows a diagram elucidating the provision of the grid points with a label;

figures 8a-8b shows the result of the complete process of grid extraction for a detail image;

5 figures 9a-9b show two images elucidating the step for acquiring surface texture;

figures 10a-h show examples of obtained results.

In the arrangement of figure 1 a pattern is  
10 cast onto the scene by a projector and captured by a camera in an image plane. In this embodiment the projector and camera were placed at a distance of about 4 m from the scene. The angle between the projection direction and the viewing direction was approximately 7°.  
15 The projected pattern was a substantially square grid consisting of 600 horizontal and 600 vertical lines arranged on a slide using lithographic techniques, with a line thickness of 10  $\mu\text{m}$  and placed at mutual distances of 50  $\mu\text{m}$ . In this embodiment a 512x512 image was formed,  
20 taken up for the greater part by the part of the scene for reconstruction and typically 100 horizontal and 100 vertical projected lines were effectively visible in the image.

Figure 2 shows a detail of an image recorded  
25 under the above mentioned conditions.

Figure 3a shows such an image in more detail and the response of horizontal and vertical line detectors is shown in figures 3b and 3c. After determining the central line of these responses and a  
30 first filling of gaps, the central lines are combined in an initial reconstruction of the image pattern (d).

Due to for instance noise or other causes, discontinuities in the found pattern lines will be present in regions where the response of a line detector  
35 is relatively poor. Figure 4 shows an example of two lines which are interrupted, in this case in the vicinity of their intersection. As shown in figure 4, the immediate vicinity of the two end points of the segment

of a line are scanned in the present preferred embodiment of the invention over a region in the line of a width  $s$ . If points of other line segments are encountered in this process, a score is assigned thereto based on

5 characteristics such as the difference in the angle of inclination  $\epsilon$  of the line segments close to the discontinuity, the distance to the end points of those segments, the difference in intensity of the given end point and the end point of a candidate segment, as well

10 as the average intensity along the rectilinear link between the end points. Two segments are joined together if the sum of the scores is optimal. Such a result is already shown in figure 3d.

Figure 5 shows how the crossings or

15 intersections are constructed. Figure 5a shows the intersecting of two lines. Such intersections are brought together in a grid representation, wherein each grid point has a maximum of four neighbours (N, E, S and W), as shown in figure 5b. Grid points which are vertices of

20 a full quadrangle are of particular importance in subsequent correction steps. These are found as points of return by successive selection of the E neighbour, its S neighbour, its W neighbour, its N neighbour (c).

Figure 6 shows a refining step applied to the

25 grid. This step treats the grid as a system of linked lines, the position of which is refined by drawing out their continuity relative to their original discrete representation, shown in figure 6a, and by adding an attractive force which also gives the refined line

30 positions a preference for positions with image intensities of the same polarity as the lines in the pattern. The result of this improvement step is shown in figure 6b.

The grid points are provided with labels or

35 numbers as illustrated in figure 7. A random grid point in the image is chosen as reference point  $O(0,0)$ . The other grid points are given two labels, a "horizontal" label  $i$  and a "vertical" label  $j$ , which give the relative

position relative to the reference. The horizontal line labels  $i$  are incremented with each E step or decremented with each W step required to reach the grid point from the reference point. The vertical line labels  $j$  are  
5 incremented with each N step or decremented with each S step required to reach the grid point from the reference point. Defining of the labels amounts to defining the coherence of the grid.

Figure 7 likewise shows an example wherein  
10 different labels can result from choosing a different path, for instance for the point P. Herein the circumscribed path to the right is more reliable since this avoids the false parts of the grid designated with white. The reliability of a path is determined on the  
15 basis of the reliability of the individual grid points along the path and decreases the more links to adjacent grid points are missing and the more the individually found quadrangles in the observed pattern show less resemblance to squares as viewed from the projection  
20 direction. The labels are corrected iteratively/recursively where necessary. Older labels are herein overwritten by newer labels if the latter are more reliable.

Figure 8b shows the finally found grid for the  
25 detail image of figure 8a.

For further details in respect of defining the grid reference is made to the enclosure which includes the article "Active acquisition of 3D shape for moving objects" by the inventors.

30 After the grid has thus been precisely defined, the three-dimensional shape thereof can be computed.

The three-dimensional shape of the visible surface illuminated with the pattern is reconstructed on the basis of the three-dimensional positions of the grid  
35 points. In the preferred embodiment the relative positions of these latter are obtained from the intersections of two parallel beams of rays, one of which represents the pattern projection rays and the other the image

projection rays and which are such that they form an angle as defined by calibration and that their intersections are consistent with the detected positions of the grid points in the image.

5               For further details relating to the definition of the three-dimensional shape description and the calibration used in the preferred embodiment reference is made to the enclosure which includes the article by the inventors "One-shot active 3D shape acquisition".

10              After the grid has thus been precisely defined, in a preferred embodiment the texture is also extracted from the same image which was used for the shape definition.

                In the image the cross section of an intensity  
15 profile of a pattern stripe will be Gaussian, approximated by the function:

$$w(x) = 1 - e^{-(x/\sigma)^n}$$

                In an experiment  $n = 2$  was chosen and the function was Gaussian. The intensity attenuation of the  
20 pattern stripes was subsequently modelled by superimposing this profile over the extracted grid lines. The result for the grid of figure 8b is shown in figure 9a. The greater the attenuation, the less representative for the real texture the image intensity is considered to  
25 be. In order to determine the texture an interpolation of intensities is taken as starting point, wherein account is taken of the relative attenuations and the distances to the point where the intensity is restored. The result serves only to initialize a non-linear diffusion process  
30 on the intensity, which eliminates the remaining traces of the pattern stripes. The result for the image of figure 8a is shown in figure 9b.

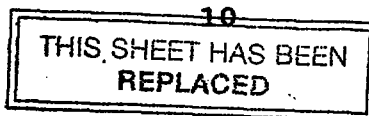
                Finally, the extracted texture is arranged ("mapped") on the surface.

35              For further details relating to the determining of the surface texture, reference is made to the enclosure, which includes the article by the inventors "A sensor that extracts both 3D shape and surface texture".

Figure 10 shows results obtained with this embodiment. Figures 10a and 10b show two input images for a hand and a face. Figures 10c and 10d show two views of the shape description obtained for the hand, figures 10e and 10f the shape description of the face. Figures 10g and 10h show two views of the texture coated ("texture mapped") shape description of the face.

Using additional steps perspective effect in the projection and viewing geometry can be taken into account in the above described preferred embodiment of the method and device. Using data additions absolute dimensions and distances can be obtained, so that the unknown scale factor of the shape description disappears. It of course remains possible to add codes to the projection pattern which facilitate the identification of pattern components. Different projections and/or images can be used simultaneously. The surface texture can also be obtained from images in which the pattern is not visible - for instance by using non-visible wavelengths or switching off the pattern - and/or the texture can be extracted by filtering out the pattern in other ways than described in this embodiment.

The present invention is not defined by the above described preferred embodiment, in which many modifications are conceivable; the rights applied for are defined by the scope of the following claims within which variations can be envisaged.



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**CLAIMS**

1. Method for acquiring a three-dimensional shape or image of a scene, wherein a predetermined pattern of lines is projected onto the scene and the shape is acquired on the basis of relative distances  
5 between the lines and/or intersections of the lines of the pattern.
2. Method as claimed in claim 1, wherein the pattern is a grid of mutually perpendicular lines.
3. Method as claimed in claim 1 or 2, wherein  
10 pattern lines are extracted from the projected image.
4. Method as claimed in claim 2 or 3, wherein intersections of the mutually perpendicular projected lines are extracted and provided with a label such as a number indication.
- 15 5. Method as claimed in any of the claims 2, 3 or 4, wherein the intersections are defined with an accuracy greater than the size of a pixel.
6. Method as claimed in any of the foregoing claims, wherein the surface texture of the scene is  
20 extracted.
7. System for acquiring a three-dimensional shape or image of a scene, comprising:
- a pattern generator for projecting a line pattern on the scene;
  - 25 - at least one camera for recording the scene; and
  - computing means for determining the shape of the scene.
8. System as claimed in claim 7, provided with an object of known shape for calibration thereof.
- 30 9. Image acquired according to a method as claimed in any of the claims 1-6 and/or a system as claimed in claim 7 or 8.
10. Method and/or system substantially in accordance with the description and/or figures.



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11. Method for acquiring a three-dimensional shape or image of a scene, wherein a pattern of lines is projected onto the scene, wherein the surface texture of the scene is extracted.

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