LASER PATTERN BASED 3D OBJECT MEASUREMENT SYSTEM FOR MEDICAL APPLICATIONS

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Abstract: This paper describes a mobile 3D object measurement system based on active triangulation. By using laser pattern projection the system is less dependent on ambient light than incoherent solutions. To guarantee cost effectiveness and short time to market it was assembled with off-the-shelf components. Besides its application area at nursing services and hospitals it was particularly developed to extend a telemedical ward round system for traumatology patients with the feature of fully automatic 3D wound capturing and wound measurement.

Introduction

Object measurement is an important task in many medical fields. Dentures, protheses or their casts need to be measured at the beginning of a computer aided design and manufacturing process. In traumatology woundsize can be used as an indicator for the process of wound healing. While many different methods of wound measurement [2] exist, none fulfills all requirements of high mobility, user friendliness and cost effectiveness combined with high accuracy to facilitate a high penetration in hospitals, surgeries, nursing services and even among telemedically attended patients themselves.

This paper describes a system developed to match these needs. The system provides an automatic creation of a true colour 3D model in which lengths, areas and volumes can be measured easily.

The system was developed to work as a standalone measurement tool [4,5] or as an extension for an existing telemedicine system [6] which replaces the ward round of the doctor by an asynchronous exchange of digital audio, image and health state data over mobile communication channels. Besides the visual interpretation of the wound image by the attending doctor, an objective documentation of the healing process based on measurements becomes possible now.

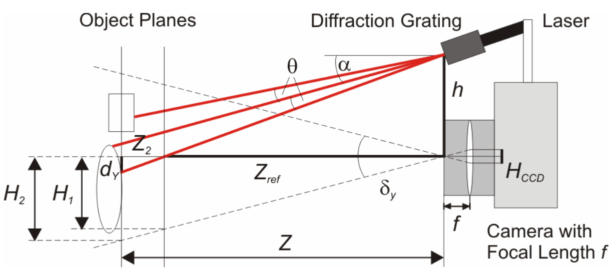

Figure 1: System draft

Developed System

Different methods of depth measurement were analysed according to their applicability and accuracy. The system described below emerged as the favorite.

To minimize total cost and to allow a short time to market, the system is based on of-the-shelf omponents. A digital still camera (Canon PowerShot G5) with a flash mount assembled miniature laser projector (see Figure 1) is used for 3D capturing. In contrast to other projection based systems which need high light outputs [3] this one uses a low power miniature laser module (6.9 mW). A diffraction grating transforms the single beam into a divergent 21 x 21 matrix of beams with a constant interbeam angle of 0.72°. The whole system is laser class 2M eye safe according to DIN-EN 60825-1 11/2001.

Camera Calibration

Since wound images are taken at macro distances, small focal lengths are most common. At these wide angles zoom lenses have their peak in radial abberation. The camera used has a 3 % abberation for pixel placement at the borders and up to 0.65 % vertical displacement in the center regions causing a much higher distance measurement error. Under a typical setup with a measurement distance of 40 cm, a focal length of 7 mm (35 mm equivalent focal length) and the laser mounted in 8 cm height under an angle of 10° the distance error reaches 2.49 % in distorted image considering 0.65 % pixel abberation. This results in an even higher area and volume measurement error considering their quadratic and cubic properties.

As a solution the camera calibration method suggested by [7,8] was used to calculate the intrinsic camera parameters focal length, principal point, skew coefficient, radial and tangential distortion. While these parameters have to be determined only once they can be used to correct every picture taken. An example is given in Figure 2.

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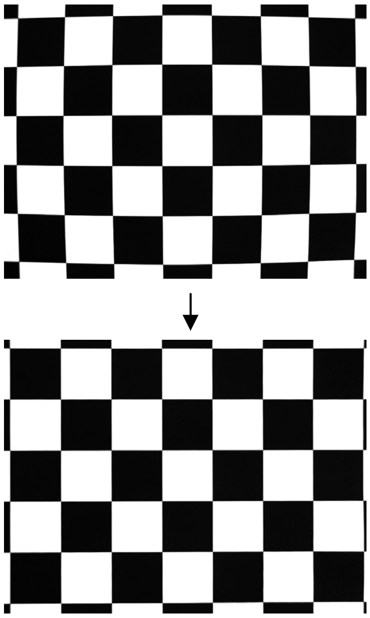

Figure 2: Distorted (top) and corrected image (bottom) taken with a Canon G5 (f=7 mm)

Surface Acquisition

The projection of the 21 x 21 divergent laser beams allows the triangulation of 441 distance values on an area of e.g. 100 cm² at a distance of 40 cm. Since pattern area and density are proportional to the distance, different woundsizes can be captured at full resolution. The distance of the projection of every single laser spot can be calculated by evaluating the vertical skew d_Y (see Figure 1) which corresponds to its projection d_v on the image plane. With the laserspot location (i, j) in image coordinates, d_v is defined as distance in the (u, v) coordinate space on the image plane

$$\begin{aligned} u &= i \cdot D_u \\ v &= j \cdot D_v \end{aligned} \tag{1}$$

with pixelsizes D_u and D_v leading to

$$Z = \frac{h \cdot f}{-d_v + f \cdot \dfrac{\tan(\alpha + n_y \cdot \theta)}{\cos(n_x \cdot \theta)}} \tag{2}$$

with n_x and n_y specifying the beam number from the center to the outside and θ as the interbeam angle. The cosine term is necessary for trapezoidal correction of the outer beams. Laser height h and angle α are the only missing parameters for distance calculations since the CCD's geometry data and the diffraction patterns interbeam angle is given. They are calculated from laser projections in images of a calibration plate at different distances g_1 and g_2 with structures of known size and therefore known reproduction scale β_1 and β_2.

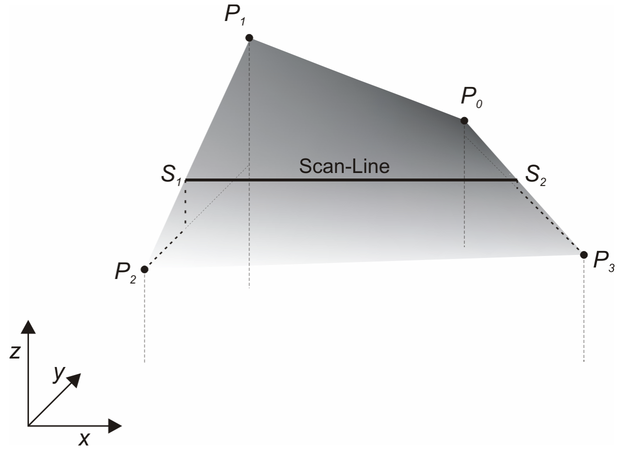

Figure 3: Linear surface interpolation

$$\alpha = \tan^{-1}\left(\left(\frac{d_{v2}}{\beta_2} - \frac{d_{v1}}{\beta_1}\right)\left(g_2 - g_1\right)^{-1}\right) \tag{3}$$

$$h = g_i\left(\tan(\alpha + n\theta) - \frac{d_{vi}}{\beta_i}\right), \quad i \in \{1, 2\} \tag{4}$$

In order to aquire a complete discrete distance map the distance for all pixels of an image is calculated out of the neighbouring measurement spots. A linear approach (see Figure 3) which ressembles gouraud shading is applied. The application of nonlinear NURBS (Non Uniform Rational B-Spline) interpolation featuring local interpolation and global approximation [1] is currently under evaluation.

Automation

Laser Spot Locating and Concealment

Different methods of image processing have been implemented for an automatic recognition of the laser spots. Since the CCD sensor has to be able to capture the true colour texture of the measurement object a bandpassfilter for the laser's wavelength of 635 nm could not be used to reduce the image complexity.

To assign the correct ordinal number within the 21 x 21 matrix to all recognized laser spots, different estimation algorithms are applied which take the occurrence of occlusions and reflections into consideration.

The process of triangulation and depth map creation requires only one image containing the laser projection. When mapping the texture onto the reconstructed surface with this image containing laser spots, the natural impression of the imaged object is altered. To conceal the laser spots within the image different error concealment algorithms could be applied. Simple median filtering can not be used because the laser spots cover areas of several pixels in diameter. Since the position of the spots is known, algorithms like [9] could be applied but would not be able to correct the

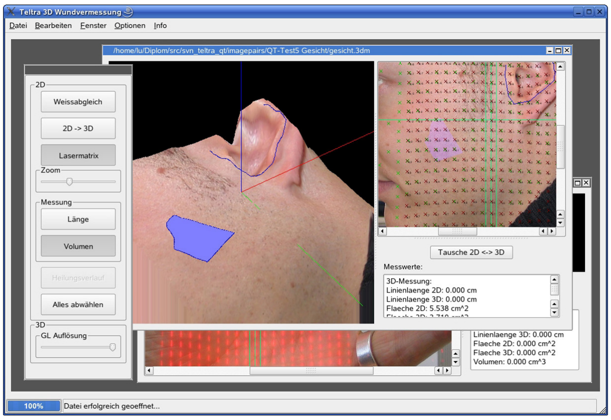

Figure 4: Screenshot of the wound measurement software

additional illumination from the laser spots on the surface.

Moreover concealment is not desired because the natural impression is of utmost importance in medical imaging. Therefore a second image has to be captured with deactivated miniature laser projector for a colour correct texture. Congruent mapping of reconstructed surface texture is achieved by blockmatching in order to compensate translation or slight rotation of the camera between the two expositions.

White Balancing

In addition to the automatic white balancing of the camera a white chart which can be placed in the background of the captured scene is automatically detected and used as a white reference for improved

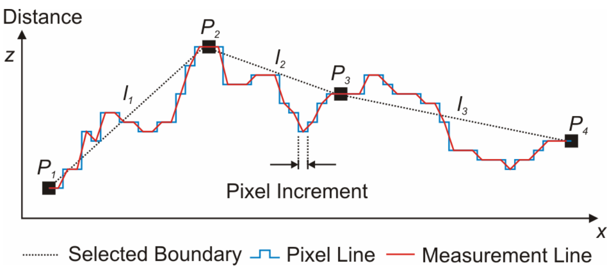

Figure 5: Measurement of contour lines

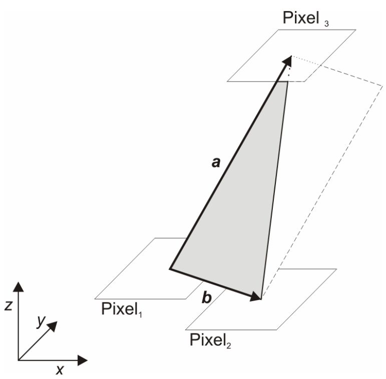

Figure 6: 3D triangle area

white balancing. The white chart is detected within the scene using circle markers on its corners which can be found automatically in three steps: Edges are detected within one colour channel or a greyscale representation by convolving the image with the sobel operator. The circle radii and centers are acquired by hough transforming the edge image until the global maximum is reached. At last a least squares approach is used to fit the edge pixels in the circles' surroundings to ellipses. These ellipses are an acceptable shape representation approximation for the circles which are distorted by perspective projection.

USB Control

The whole capturing process including camera parameter and laser setup is remotely controlled by a tablet PC or notebook via USB in order to qualify the whole system for telemedical applications. Even a patient should be able to capture a 3D image by just pressing one special button on the control unit under the camera or on the touchscreen of the tablet PC.

Measurement

Lengths, areas and volumes can easily be measured by the attending doctor using the object measurement software. A screenshot of its user interface is shown in Figure 4. The software is based on the well known QT framework [10] and is therefore platform independent.

All measurements are automatically calculated on basis of the interpolated surface map. In Figure 5 a user selected boundary which was drawn on a 2D image is shown in the depth profile represented by the pixel line. The 3D length of this polygon line P_1-P_4 is calculated on basis of the measurement line which uses linear interpolation between two adjacent pixels in order to achieve subpixel accuracy.

Area calculations operate on triangle surfaces between three pixels as illustrated in Figure 6.

Volume measurement was implemented using a covering surface approach: The wound surrounding line works as the boundary where a virtual cover surface is adhered like transparent film (see Figure 7). Volumes

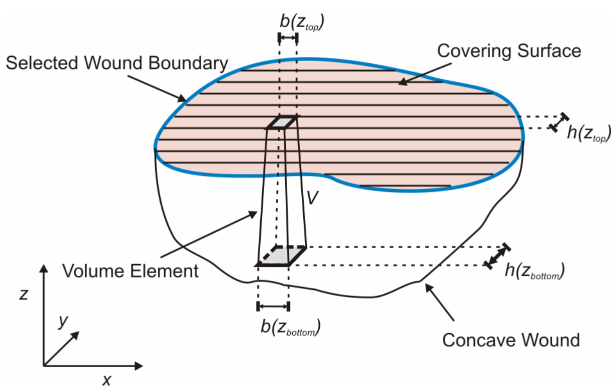

Figure 7: Volume measurement based on volume elements

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Figure 8: 3D camera

below this surface are integrated over volume elements with dynamic base and top areas depending on their distance. The algorithm is applicable for concave and convex forms so that holes as well as bulge volumes can be measured.

Conclusion and Outlook

A laser pattern based system for 3D object measurement was introduced. Due to its laser projection it is less dependent on ambient light than ordinary pattern projection systems while nevertheless providing a true colour texture map on the OpenGL visualization of the measurement object.

Figure 8 shows the 3D camera of the portable system which is qualified for mobile application. Its accuracy, ease of use and cost qualify it for use in hospitals, surgeries, nursing services or among telemedically attended traumatology patients as in our project.

To confirm the system's practical capability a field study will take place within the scope of the Televisite project of the Teltra Research Group [11] at the Bergmannsheil University Hospital in Bochum.

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