A Mobile True Color Topometric Sensor for Medical Tasks and Art Conservation Applications

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A mobile true color topometric sensor is implemented which uses a simplified photogrammetric camera calibration as well as colorimetric techniques for color reproduction.

1 Introduction

For many applications of 3-D measurement techniques the color of the surface under investigation is of similar importance as the geometry. This is especially the case in the field of art conservation and for medical tasks. A 3-D coordinate measuring system based on the fringe projection technique is presented which allows 3-D coordinate acquisition as well as a true color reproduction.

2 Topometric System

The topometric sensor head is based on two high-resolution color CCD cameras (1024 X 768 pixel) with digital interfaces (IEEE 1394) combined with a standard digital video projector for fringe projection and is controlled by a notebook. In this way a compact, mobile and all-purpose 3-D sensor is implemented (Fig. 1).

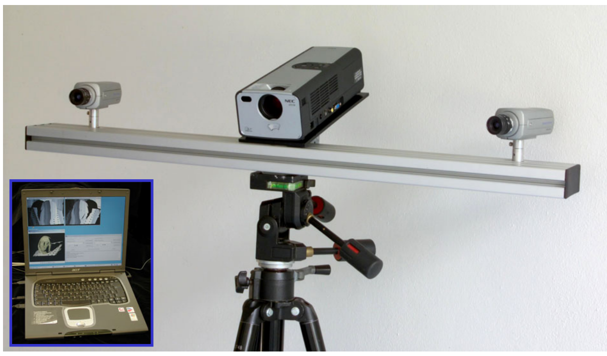

Fig. 1 *Setup of the topometric sensor: the 3-D coordinate measuring system uses a DLP video projector for fringe projection and high-resolution color CCD cameras for image capturing; the mobile system is controlled by a notebook.*

The measuring system allows to record up to 0.8 million 3-D coordinates with color information in approx. two seconds.

3 Stereo calibration and 3-D coordinate calculation

Based on the algorithm proposed by Zhang [1] a fast photogrammetric calibration is used which utilizes a plane dot pattern target which is printed with an inkjet printer and glued to a glass plate. The results of the photogrammetric calibration are the internal camera matrices K_{RL} which include as internal parameters the focal length and the principal point of each camera, the rotation matrices R_{RL} and the translation vectors t_{RL} for the left and the right camera.

For the calculation of the 3D-points with the collinearity equations [2] two corresponding image points are required. The locating of corresponding points can be reduced to a one-dimensional problem by taking into account the epipolar geometry. If the center of the left camera is defined as zero point of the global coordinate system the transformation from the left to the right camera is given by:

$$R_{RL} = R_R R_L^{-1}$$

$$t_{RL} = t_R - R_{RL} t_L$$

As a consequence of the epipolar geometry the corresponding point *m'* for an image point *m* can be located on an epipolar line $l_{m,m'}$. The fundamental matrix *F* describes the relation between image points in one image and corresponding points in the other image. This relation is called "epipolar constraint" and can be expressed as:

$$m^T \cdot l_{m'} = 0 \quad \text{or} \quad m'^T \cdot l'_m = 0$$

The epipolar lines $l_{m,m'}$ can be calculated by:

$$l_{m'} = F^T m' \quad \text{or} \quad l'_m = F^T m .$$

where *F* is the fundamental matrix given by

$$F = K_R^{-T} [t_{RL}]_X R_{RL} K^{-1}$$

Here $[t_{RL}]_X$ is the skew symmetric 3 x 3 matrix corresponding to t_{RL}:

$$[t_{RL}]_X = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}_X \equiv \begin{bmatrix} 0 & -x_3 & x_2 \\ x_3 & 0 & -x_1 \\ -x_2 & x_1 & 0 \end{bmatrix}.$$

If additionally a sequence of Gray coded binary and phase shifted sinusoidal fringe patterns is projected onto the object the horizontal location of an object point can be calculated from the stack of binary and phase values. Together with the epipolar constraint each corresponding point can be identified unambiguously.

4 Color Reproduction

To obtain an accurate color reproduction of the measured object it is important to assure color consistency throughout the system. This is achieved by calibrating the color peripherals. For this purpose images of a color chart (Fig. 2) with photospectrometric reference values are used. These reference values are given in the device independent CIE-Lab color space which is uniform with respect to the human eye`s sensitivity [3] while the camera data usually are provided in RGB color space. Using three independent linear regressions a set of correctional factors is determined which map the measured RGB values to the reference Lab values. The efficiency of color correction is quantified by the average color distance between the perceived colors and the reference colors of the chart. The color distance between two colors, $[L_1, a_1, b_1]$ and $[L_2, a_2, b_2]$, can be calculated by the Euclidean distance ΔE in the uniform CIE-Lab color space:

$$\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$$

5 Applications of the mobile true color topometric sensor

The true color topometric sensor is used as a tool for documentation of both shape and color. The measurement process is contact-free and non-destructive.

It is applied in medicine as well as in the field of cultural heritage protection. In oral and maxillofacial surgery it will substitute a slower monochromatic sensor for quantitative documentation and analysis of pre and post surgery facial structures. Fig. 3 demonstrate exemplarily the result of a calibrated color reproduction of a digitized facial surface. Under practical condition a color distance $\Delta E < 10$ has been obtained. In Fig. 4 the measurement of a statue is displayed. The 3-D data can be used for further investigations e. g. to support a following restoration process.

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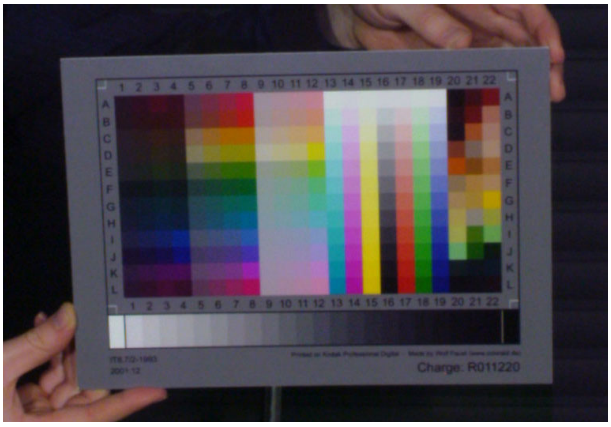

Fig. 2 *Kodak reference Color Chart (IT8-target). It contains 288 color patches (reference colors are given in a device independent color space). During the calibration process the colors that are perceived by the system will be matched to the reference colors.*

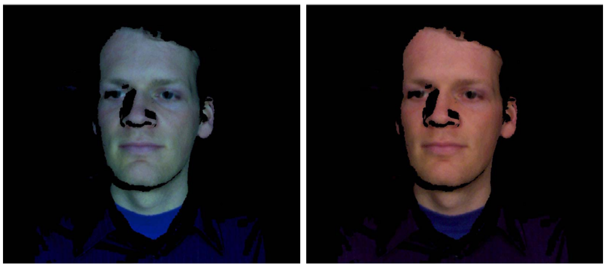

Fig. 3 *Image obtained with DLP video projector illumination before and after color correction.*

Fig. 4 *3-D measurement of a Madonna statue in the Lamberti Church in Münster with a mobile true color topometric sensor and the 3-D data with calibrated color information of the measurement (approx. 200.000 triangles with textures).*

References

[1] Z. Zhang, *A Flexible new Technique for Camera Calibration,* in Microsoft Technical Report MSR-TR-98-71 (1998)

[2] A.A.R. Cooper, S. Robinson, *Theory of close range photogrammetry*. In: K.B. Atkinson. *Close range photogrammetry*. Whittles publishing, 9-51 (1996)

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