New Optical Equipment in 3D Surface Measuring

Klara Wenzel, Ákos Antal, József Molnar, Bertalan Tóth, Péter Tamas

Abstract:

Referring to a Hungarian Government supported healthcare project „Intelligent tool and methodology to monitor and safeguard childhood spine deformities" (SPINE GUARD) the Department of Mechatronics, Optics and Information Engineering at Budapest University of Technology and Economics developed a new complex optical measuring equipment built up a projector and a digital camera.

If the computer controlled projector projects an equidistant grid of lines then the camera takes a picture from a different position about the object to be measured and with a special software removing the grid lighted background there will be a virtual Moiré effect. After some picture processing the 3D (2,5D) reconstruction is finished.

In an other working way the projector lights a rainbow on the object. The edges of the rainbow lines cut the cross-section of objects. An other special software reconstructs the 3D (2,5D) objects from the camera captured cross-section curves.

Presentation is about the principle of measuring and evaluation of results and precision.

Keywords: *3D measuring, Moiré method, 3D reconstruction of human body.*

1. Introduction

Surface reconstruction is one of the most important topics in computer vision due to its wide field of application. Some examples of applications are range sensoring, industrial inspection of manufactured parts, object recognition and 3D map building. There are several different techniques that can be used for optical three-dimensional measurements on object surfaces, such as interferometric, stereovision, coded structured light and moiré methods. These are based on both contact and non-contact procedures and present different sensitivities.

Interferometry is an old technique to measure the deviation between two wave fields with a sensitivity of a fraction of the wavelength of the illumination source. Holography is an interference-based technique that represents a wave front reconstruction a process by which the amplitude and phase variation across a wave front may be recorded and subsequently reproduced. Stereovision is based on imaging the scene from two or more points of view, and then finding correspondences between the different images in order to triangulate the 3D position. Coded structured light consists of replacing one of the two cameras by a device that projects a light pattern onto the measuring surface [1]. Moiré methods are based on Moiré effect that occurs wherever a repetitive structure is overlaid with another structure and the line elements are nearly superimposed.

Stereo vision is similar the human vision, taking pictures from different position upon the same picture points the 3D position of points are countable. If we use another aspect of stereo vision, where a projector lights of the body taking a picture the 3D reconstruction is possible by Moiré method as well as by scanner techniques.

2. Measuring Equipment

We have built an equipment capable of measurement using Moiré method and scanning method. The equipment is a computer controlled projector connected with a camera (Figure 1).

Fig. 1. Measuring equipment.

3. Moiré Theory

The Moiré phenomenon can be readily observed when superimpose two periodic or quasiperiodic structures. When the two structures have the same or slightly different line spacing and their lines are set approximately parallel, a new coarse pattern appears. This pattern is known as a Moiré Fringe pattern. The spacing and orientation of the Moiré fringes depend on the spacing and orientation of the structures being overlapped whereas the visibility of fringes is related to the width of transparent or black lines with respect to the line spacing of the structures [2]. In Figure 2, Moiré pattern caused by two straight-line gratings with different frequencies tilted with respect to one another is shown.

3.1. Moiré phenomenon appearance

Superposition of periodic and/or quasiperiodic patterns in optics frequently results in striking spatial configurations commonly called Moiré patterns. The spatial frequency of these new periodicities may be considerably lower than the original ones. Therefore, they become pronounced at low contrasts. Composite patterns can be formed in different ways. For example, addition, subtraction, and multiplication (three of the four basic rules of arithmetic) are easy to display by optical means. Pattern combinations according to any of these can be made, with corresponding composite configurations having different appearances [3]. Multiplicative superimposition of two structures is the most common method for generating moiré patterns.

3.2. Moiré topographical methods

Moiré topographical methods can be distinguished as: the basic grating-shadow, the grating-projection, the grating-TV and the synthetic grating methods. Shadow Moiré - contour mapping technique that involves positioning a grating close to an object and observing its shadow on the object through the grating. Thus, the basic grating-shadow method offers the best accuracy and the simplest arrangement because the projected grating and the master grating are identical: they have the highest degree of binding. Shadow Moiré technique presents the disadvantage that the master grating has a similar size to the measured object. Projection Moiré is a contour mapping technique that involves projection of a grating onto an object to produce a shadow grating that is observed through another grating. The projection-type methods offer a lower degree of binding between the phenomenon and the observing grating, larger object size, and more flexibility in adjusting the sensitivity, but there are very rigid demands for the performance of the projection and the master grating. All methods were the master grating is generated by an electronic time varying signal or by a computational process offer the lowest degree of binding. This means complete independence of both gratings in amplitude and phase. The advantages are additional operations like detection, different types of superposition, and elevation detection. Their disadvantage is the limited accuracy of all optoelectronic devices [4], [5]. To cope with the above requirements, projection moiré has been chosen as the measuring method to be enhanced.

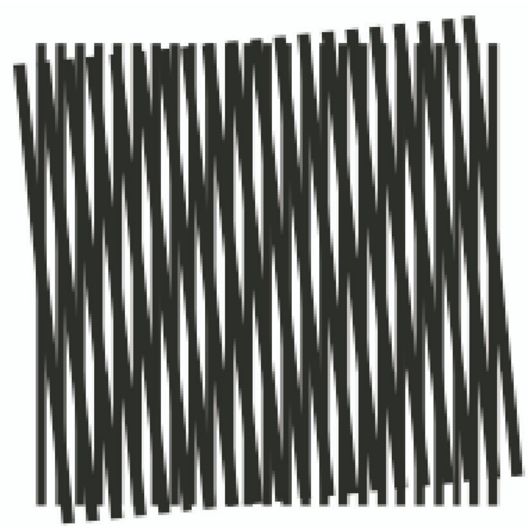

Fig. 2. Moiré pattern caused by two straight-line gratings with different frequencies tilted with respect to one another.

Figure 3 shows the Moiré picture of a body.

Fig. 3. Processed Moiré picture.

4. Rainbow Measuring by the Equipment

Projector lights the body with differently colored light-beams. Colored beams draw the surface curves onto human body. Picture taken from a different position (Figure 4) is proper to reconstruct geometry the back surface of body.

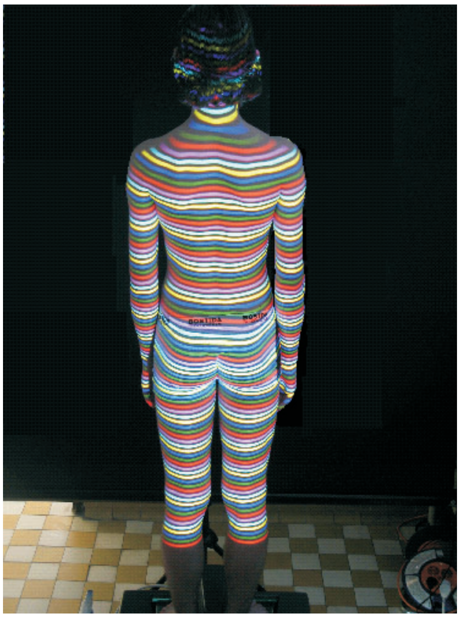

Fig. 4. Rainbow lighted person.

If we want to reconstruct the surface we have to calibrate the picture in 3D and calculate 3D coordinates the indentified surface points.

4.1. Calibration Process

As we want to achieve necessary accuracy, we have to to calibrate the cross-sections in the photo, in order to develop measuring methods, as well as to analyze errors.

Colored light-beams light a planar curve in every position of the frame. Points of curve are defined by processing of pictures. For 3D scanning the plane to plane perspective transformation is bijection. Perspective transformation by homogenous coordinates is a linear transformation [8] projects quadrangle to quadrangle. The matrix of transformation (1) has eight independent coordinates.

$$\underline{\underline{P}} = \begin{bmatrix} p_0 & p_1 & p_2 \\ p_3 & p_4 & p_5 \\ p_6 & p_7 & 1 \end{bmatrix} \qquad (1)$$

Corners of a rectangular calibration element are appropriate to define of matrix coordinates (Figure 5).

Corners of calibration equipment are (t_x^i, t_y^i), and corners of its picture are (v_x^i, v_y^i) $(i=0, 1, 2, 3)$ then the transformation is shown in (2)

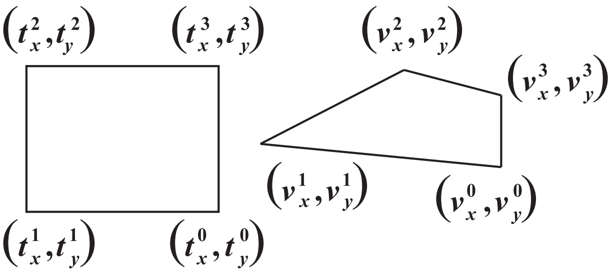

Fig. 5. Planar perspective projection.

$$\begin{bmatrix} v_x^i \\ v_y^i \\ 1 \end{bmatrix} = \begin{bmatrix} p_0 & p_1 & p_2 \\ p_3 & p_4 & p_5 \\ p_6 & p_7 & 1 \end{bmatrix} \cdot \begin{bmatrix} t_x^i \\ t_y^i \\ 1 \end{bmatrix} \qquad (2)$$

There are eight unknown coordinates and eight equations (3) there [6].

$$v_x^i = \frac{p_0 \cdot t_x^i + p_1 \cdot t_y^i + p_2}{p_6 \cdot t_x^i + p_7 \cdot t_y^i + 1}$$

$$v_y^i = \frac{p_3 \cdot t_x^i + p_4 \cdot t_y^i + p_5}{p_6 \cdot t_x^i + p_7 \cdot t_y^i + 1} \qquad i=0,1,2,3 \qquad (3)$$

Determination of corner coordinates can be defined from calibration photo (Figure 6).

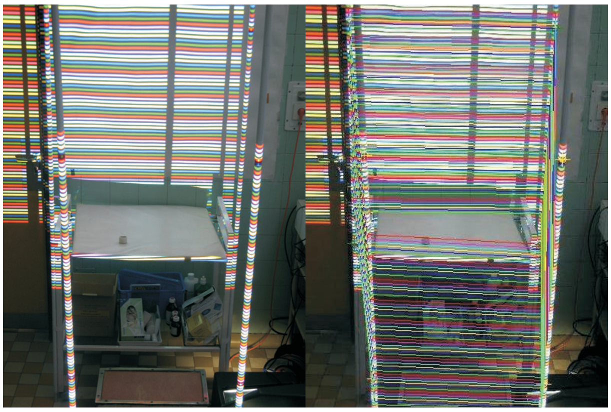

Fig. 6. Calibration.

We are able to filter different colors of the rainbow from the picture (Figure 7). Upon the filtered colors and calibrating rectangles 3D coordinates of the surface points are defined. The surface curves of the person are defined by polynomial regression. [7]

Surface curve interpolated by NURBS surface patches (Figure 7). [8]

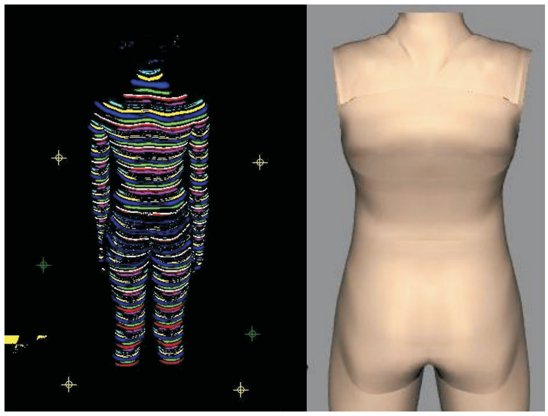

Fig. 7. Colored surface points and reconstructed surface.

5. Conclusion

Two methods and an integrated equipment has developed for optical measurement and reconstruction of 3D surfaces. The equipment and methods have been certified in practice, too.

ACKNOWLEDGMENTS

The authors would like to thank NKTH (Research and Technology Office of Hungarian Government) for the support since this study has been carried out as part of the project TECH_08-A1/2-2008-0121 (NKTH).

NKTH
Nemzeti Kutatási és Technológiai Hivatal

The research was also supported by HUNOROB project (HU-0045), a grant from Iceland, Liechtenstein and Norway through the EEA Financial Mechanism and the Hungarian National Development Agency.

AUTHORS

Klára Wenzel*, Péter Tamás, József Molnár, Ákos Antal - Department Mechatronics Optics and Information Engineering, Mechanical Engineering Faculty, Budapest University of Technology and Economics, Budapest 1111 Mûegyetem rkp. 3-9. Hungary.
E-mail: info@mogi.bme.hu.
Bertalan Tóth - Development Engineer Knorr-Bremse Fékrendszerek Kft., Budapest, 1119 Major u. 69. Hungary.
E-mail: Bertalan.Toth@Knorr-Bremse.com
* Corresponding author

References

[1] Salvi J., Pagès J., Batlle J., "Pattern codification strategies in structured light systems". *Pattern Recognition*, vol. 37, no . 4, 2004, pp. 827-849.

[2] Patorski K., Kujawinska M., "Handbook of the moiré fringe technique", Elsevier Science Publishers, New York, 1993.

[3] Bryngdahl O., "Characteristics of superposed patterns in optics", JOSA 66, 1976, pp. 87-94.

[4] Windischbauer G., "Survey on Applications of Moiré-Techniques in Medicine and Biology". In: *G. von Bally: Optics in Biomedical Sciences*, New York, Springer-Verlag, 1982, pp. 244-249.

[5] D'Acquisto L., Fratini L., Siddiolo A.M., "A modified moiré technique for three-dimensional surface topography". *Meas. Sci. Technol*, 2003, vol. 13, pp. 613-622.

[6] Kim D.K., Jang B.T., Hwang C.J., "A Palanar Perspective Image Matching using Point Correspondesand Rectangle-to-Quadrilateral Mapping". *Fifth IEE Southwest Symposium on Image Analysis and Interpretation*, 2002.

[7] Tamás, P., Halász, M., Gräff, J., "3D Dress Design". *AUTEX World Textile Conference*, Portorož, Slovenia, 2005, pp. 436-440.

[8] Szirmay-Kalos L., Antal G., Csonka F., "*Computer Graphics*". Computer Books Budapest, 2003.