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HARDWARE AND SOFTWARE HUMAN BACK THREE-DIMENSIONAL RELIEF RECONSTRUCTION

The improved method of human back three-dimensional relief reconstruction is offered in the work. The mathematical model and 2D to depth coordinate transformation equation are developed. It is shown that pattern usage and its image subpixel processing provide high precision reconstruction. The results of theoretical researches are confirmed experimentally. The developed software enables the automated three-dimensional relief reconstruction.

Keywords: *reconstruction, pattern, pixel, relief, projecting system.*

Introduction

Today the non-invasive measurement methods more frequently use images to represent and process measurement information in many technical fields. Any image can be considered as a two-dimensional signal carrying more informational than an ordinary one-dimensional one. Such images are the images of musculoskeletal system parts captured by musculoskeletal diagnostic system. Thanks to hardware and software human back three-dimensional relief reconstruction one can evaluate not only numerical and spatial asymmetry under non-optimal statics and dynamics but also receive positional relationship and geometrical dimensions of musculoskeletal system parts.

Problem Definition

Rapid evolution of computer technologies has created necessary conditions for development of three-dimensional reconstruction methods using simpler technical means. These means use stripes projection, which are formed in coherent or non-coherent light with the predefined spatial intensity distribution. Such a reconstruction is based on the triangulation method when object is illuminated by the pattern set. If the angular disposition of the light source (projector) and camera axes is known, then the unique correspondence of intensity distribution elements (pattern) and camera image elements is provided. The picture of parallel stripes projection depends on the shape of the illuminated surface. Decoding provides the distance coordinate that is the depth coordinate for each point of the object surface [1 – 3].

Such a three-dimensional shape reconstruction method has a number of limitations because of image distortion and pattern borders blurring caused by non-ideal linearity of optical system. The surface of the research object (human skin) brings ambiguity due to its heterogeneous and considerable light absorption and dispersion [4]. All these reasons complicate pattern edge detection. In addition, the quantization of the pattern image increases the error of depth coordinate evaluation.

So, to eliminate the described limitations it is necessary to solve the next problems:

- develop a mathematical model of the depth coordinate of the object subject to scaling and non-linearity of the optical system;
- perform image preprocessing to provide high-precision detection of the solid pattern edge with one pixel in depth;
- detect nodal pattern points which has random disposition and order them;
- use interpolation to reconstruct the surface of the object.

Main Part

The improved 3D shape reconstruction method based on detection of the nodal points coordinates is offered. These points enable to estimate the third coordinate.

First of all, the point coordinates of the surface image must be detected in two-dimension space to get depth points coordinates. In general the precision of such a system depends on the camera parameters and its position as well as lighted line edge or point detection on the shape image.

Suppose that the camera parameters are known then the main problem is the precise detection of the line edges and nodal points.

Let us consider beams passing through some optical system as shown in Figure 1.

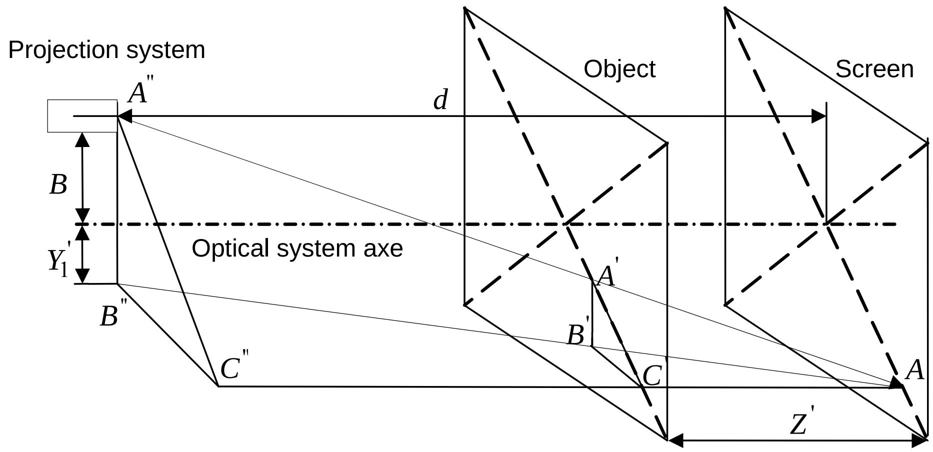


Figure 1. Light beams passing in the projection system.

Projection system is installed at the distance d from the screen plane and the distance B from the optical axe of the registering device. The projection system projects the point A to the screen with X_1', Y_1' coordinates. The point A is transformed to the point A' with X_2', Y_2' coordinates after placing the object at the distance Z' from the screen. The position of the illuminated point A' on the registering device depends on the object distance from the screen.

Considering the coordinates of the points A and A', the distance d and light beams passing geometry, the depth coordinate Z' evaluates as

$$Z' = d\sqrt{\frac{\left(X_1' - X_2'\right)^2 + \left(Y_1' - Y_2'\right)^2}{X_1'^2 + \left(Y_1' - B\right)^2}} . \tag{1}$$

To determine the true coordinates of A and A' points it is necessary to consider the scaling coefficients of optical system k and k_1, as the captured image is scaled. So, the expression (1) can be represented as

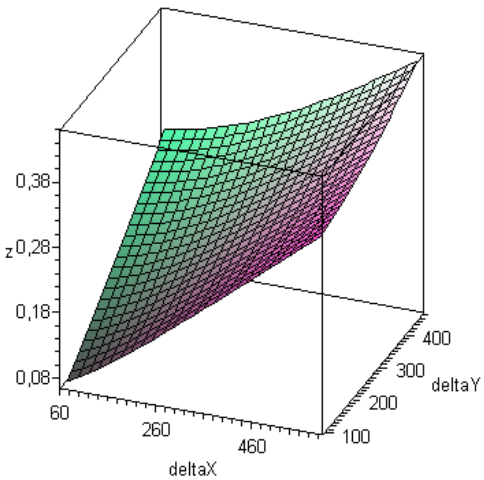
$$Z' = d\sqrt{\frac{(X_1'k - X_2'k_1)^2 + (Y_1'k - Y_2'k_1)^2}{(X_1'k)^2 + (Y_1' - B)^2}} . \tag{2}$$

The expression (2) is the transformation equation of the 2D coordinates to the depth coordinate. The static characteristic is shown in Figure 2a with such example values of X'1 = 0, Y'1 = 0, d = 1.8 m, B = 0.9 m, k = $30 \cdot 10^{-5}$, k1 = $40 \cdot 10^{-5}$.

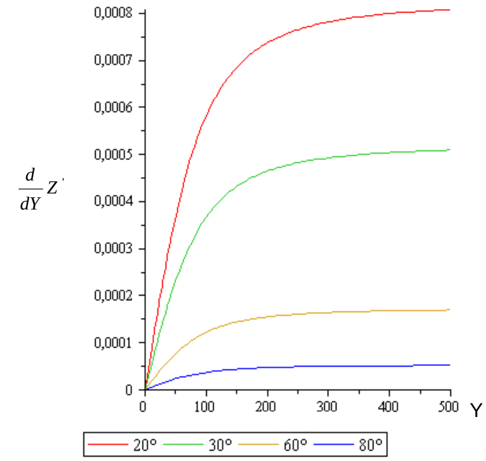
To evaluate the sensitivity of the mathematical model the expression (2) is transformed to

$$\frac{dZ'}{dY} = \frac{Yk^2}{\sqrt{\dfrac{X^2k^2 + Y^2k^2}{\dfrac{X_1'^2k^2}{d^2} + tg^2(\alpha)}}\left(\dfrac{X_1'^2k^2}{d^2} + tg^2(\alpha)\right)} , \tag{3}$$

where X, Y – horizontal and vertical difference of points coordinates before and after object placing, α – angle between the optical axe of the camera and the projection device beam.



a)



b)

Figure 2. Graphical characteristics of transformation function:
a) static characteristic;
b) sensitivity depending on different values of angle α

The sensitivity plot depending on different values of angle α is given in Fig. 2b. Analyzing the Figure 2b one can conclude that the higher sensitivity is provided by the smaller values of the angle α. The divergence angle of the light beams of projection device should be also considered when selecting the optimal value of the angle α.

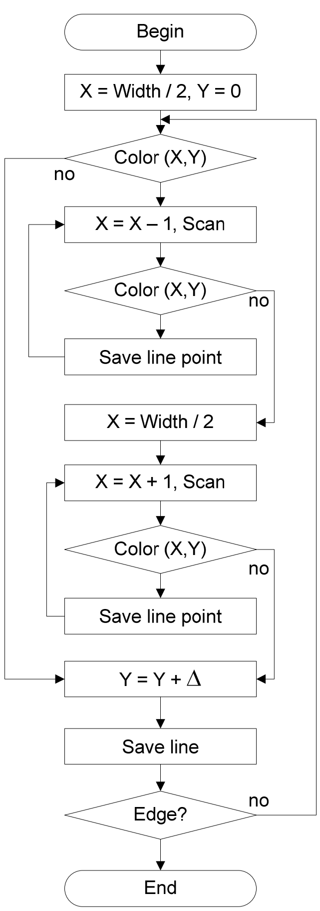


Figure 3. Line detection algorithm

A hardware and software system for three-dimensional human back relief reconstruction is proposed on the basis of stated theoretical researches. The system includes a projection system and an image capturing and processing system. The system operates as described below. The horizontal and vertical patterns are projected one after another by the projection system to the screen, the distance to which is *d*. The images of the patterns are captured by the registration system. The pattern images are captured again after bringing the object into the system. Basing on the captured images the coordinates of the nodal points are detected and the depth coordinate of each point is calculated using expression (2). The common points of the vertical and horizontal lines received as the result of pattern images processing are the required node points. Simple software identifies common pattern points, their layout and determines their subpixel coordinates as described in [5 – 7].

The software algorithm of horizontal lines identification is shown in Fig.3. According to the algorithm the image is being scanned vertically starting from the highest central horizontal coordinate. If a point of a colour different from the background is found, not black in this instance, horizontal line scanning to both sides from the point is executed.

Scan operation checks if neighbour pixels in vertical direction belong to line. After line identification vertical scanning is continued having shifted scanning position to minimal step vertically, which is equal to step of Δ=2 – 3 pixels. The Δ shift is necessary for the guaranteed jump to the part of the image, where there are no points of the just identified line. In a similar way the algorithm is applied for vertical pattern line identification, but initial scanning direction is changed to horizontal and a middle left point is chosen as an initial scanning point.

The theoretical bases have been confirmed experimentally using a reference object – triangular pyramid. The geometrical dimensions of the pyramid faces were measured by standard digital slide gage of ШЦЦ-1-300-0,01-П3 with the absolute accuracy not exceeding ±0.04 mm in the measuring range of 0 – 300 mm. The height of the pyramid was measured with the standard height gage of ШР type with the absolute accuracy of ±0.01 mm in the measuring range of 0 – 630 mm. The patterns shown in Figure 4a were used in the experimental researches. The pattern width was selected experimentally to reduce the moire effect. Thus, the distance to the object was selected in the range of 0.5-1.2 m, the pattern width and period was 2 and 5 pixels respectively.

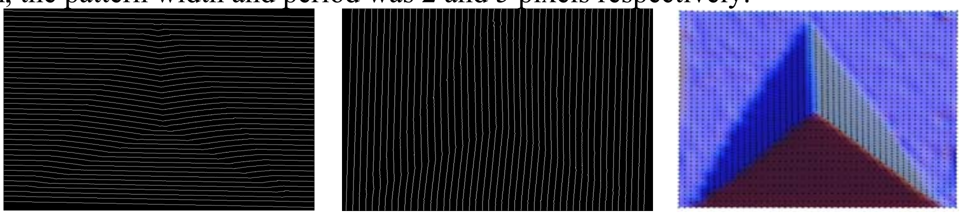
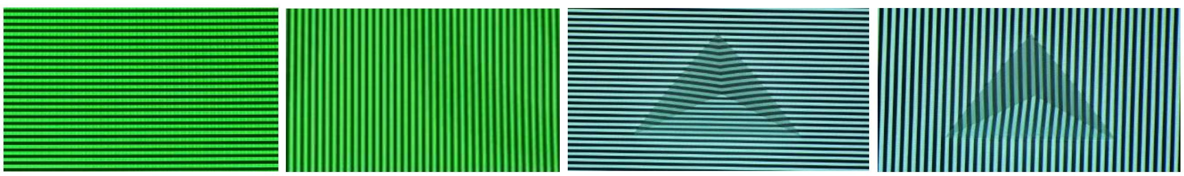


Figure 5. Patterns edge detection results and reference object relief reconstruction



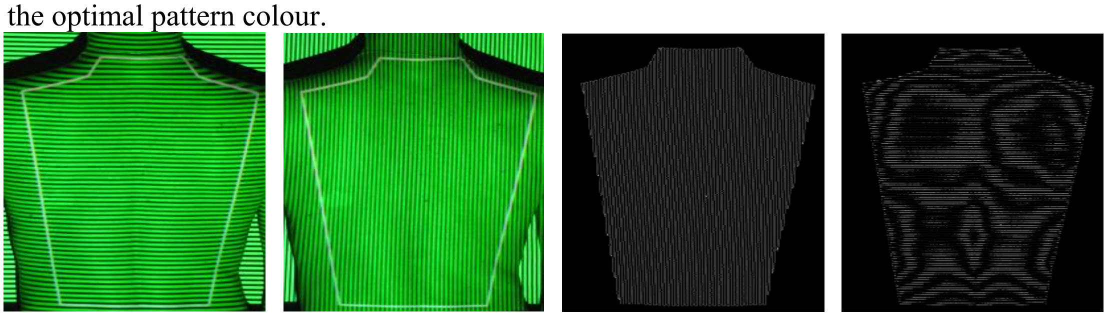
a) b)

Figure 4. Pattern images:
a) patterns with known intensity distribution;
b) patterns modified by object

As shown in Figure 4, the pattern images have changed after placing the object. The results of pattern edge detection and reference object reconstruction using the described method are shown in Figure 5. The method includes image preprocessing: low-frequency filtration, intensity distribution normalizing and subpixel edge detection.

The experimental results processing shows that the error of the 3D object surface reconstruction doesn't exceed 0.1 mm. Therefore the method can be used for 3D relief reconstruction of various objects in medical and laboratory researches.

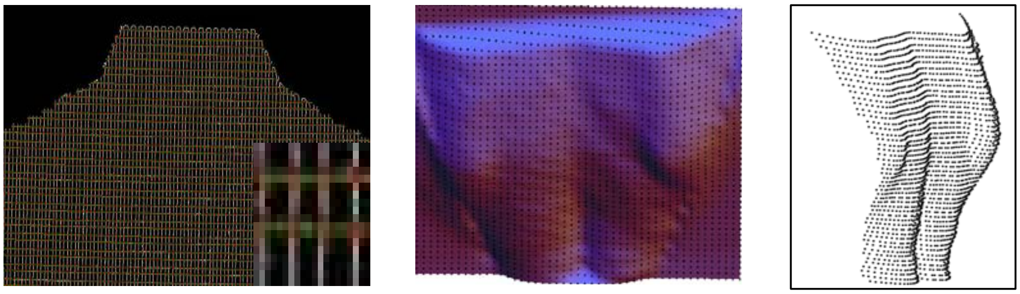
Particularly, the offered method was used for human back relief reconstruction. Because of light absorption and dispersion properties of human skin, there were experimental researches to determine the optimal pattern colour.



a) b)

Figure 6. Pattern images which are projected on the human back:
a) original image; b) preprocessed image

The most efficient patterns are determined to be of green and black colours. Projected pattern images and image preprocessing results are shown in Figure 6.



a) b) c)

Figure 7. Human body relief reconstruction results:
a) nodal points detection; b) reconstructed human back relief;
c) side slice of human back

The results of human back relief reconstruction based on nodal points identification and side slice of human back are shown in Figure 7.

The optical-electronic system of three-dimensional relief reconstruction is designed to implement the offered approach. The structure chart of the system is shown in Figure 8.

The system includes a projection device and a video camera connected to computer. The projection system enables a distance measuring channel using a laser to measure a distance to the screen and the object and two measuring channels of the pattern forming system. The work of the channels is separated in time to produce the images of horizontal and vertical pattern lines. The preprocessing unit (PPU) processes the images of the pattern lines and determines the disposition of the nodal points. The obtained information is transmitted to the high level software, which traces and represents the researched object on the PC.

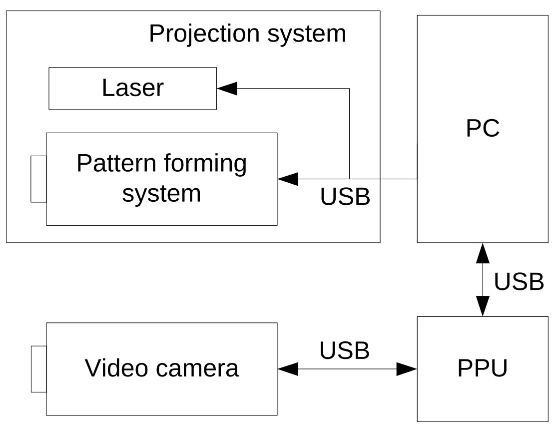


Figure 8. Optical-electronic system structure chart

The offered approach of hardware and software 3D relief reconstruction was compared with the well-known Moire lines method. It was determined that the offered method produces about 5 – 10 times more points to analyze than the Moire method increasing the reconstruction resolution. In addition, the obtained nodal points are ordered and have connectivity property (see Figure 7a) simplifying processing and increasing performance. In contrast, the nodal points of the Moire method have random disposition which sophisticates theirs coordinates detection.

Conclusions

The improved method of three-dimensional relief reconstruction based on triangulation is considered in the article. The method considers scaling and nonlinearity of the optical system and provides high-definition determining of the depth coordinates. The mathematical model and conversion equation of 2D coordinates into the depth coordinate are developed and simulated. The theoretical analysis of the conversion function enabled to determine the angle between camera optical axis and the direction of the light beams transmission from the projection device, which provides the highest sensitivity. It was discovered that the pattern system enables identification of the nodal points, and the developed software determines the coordinates of these points with subpixel accuracy. The practical realization of such a system and experimental researches have shown that the error of three-dimensional surface reconstruction does not exceed 0.1 mm, demonstrating high definition and high sensitivity of the method.

The proposed hardware and software reconstruction of the three-dimensional relief can be used not only in medical researches, but also in architecture, building, mechanical engineering, digital three-dimensional documenting of cultural values.

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