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Digital Non-Contact Surface Reconstruction Scanner

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***Abstract*—Most anthropometrical measurements today are based on using such standard tools as anthropometers, calipers and tape measures. Automatization of measurement process with high speed and accuracy using non-contact scanners can give significant benefit for industry and for customers. The problem of digital surface reconstruction and surface measurement is especially important in medicine: for facial surgery simulation, diagnosis of craniofacial anomalies, trauma to the head, and for reconstructive surgery.**

Different approaches and equipment have been developed for the solution of this problem; for example, the photogrammetric method based on the principle of rasterstereography [1], a moiré - based light projection system [2], and the 3D reconstruction system [3]. All these methods are based on non-contact measurement principles. The surface digitization system based on a contact method is presented in [4]. The systems described above have many unresolved problems, (such, for example, as a time consuming analysis of the pattern of the object in order to obtain its digital image [1]; a lengthy calibration procedure and intensive computation (off-line processing of data) [2]; huge size and weight, high cost of the system [3]; slow data acquisition and restricted accuracy due to friction of a probe with a surface [4]).

Thus the need of a simple, cheap and fast 3D digital surface reconstruction system still exists today. The system presented in this paper allows one to solve these problems.

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***Index Terms*—Computer Vision, Medical Imaging, Image Representation, Medical Application.**

I. INTRODUCTION

The task of three - dimensional human body reconstruction arose due to evaluation of new academic and practical results in medicine, in particular, for facial surgery simulation and diagnosis of craniofacial anomalies. Two principles were considered during the development of the system presented in this paper: rasterstereography [2] and the triangulation principle (which is based on continuous scanning of a body surface by a laser beam). Although both methods are three dimensional surface reconstruction methods, rasterstereography allows scanning only one side of an object, whereas the triangulation principle gives the digital image of a whole body. The triangulation principle was therefore chosen as more appropriate for the solution of this task.

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Different measurement equipment and instruments were considered for the practical realization of the 3D scanning system. The idea of scanning of an object by a laser beam can be implemented by using standard displacement sensors and non-contact measurement probes. However, for digitisation of an object by such devises the object needs to be rotated many times. The number of turns of the object depends on the resolution required. Therefore, this method can be useful for digitisation of static objects, but not practically applicable for scanning of a real person due to the body sway during rotation. The method based on scanning of an object by a laser line was chosen in order to digitise the whole surface during only one turn of the object.

II. EQUIPMENT USED FOR 3D DIGITAL SURFACE RECONSTRACTION

The system has been developed and built using different measurement devices, which were not originally constructed for the realization of the relevant problem. The laser scanning system is presented in Figure 1. The system works as follows: The laser projects a narrow line onto a surface of an object. The object is rotated on the rotary table. Two CCD cameras record position of the line according to the angle of rotation of the object. The frame grabber and the PC computer process under software control images from the cameras and record co-ordinates of points where the light falls on the surface of the object. Data obtained are stored on the hard disk of the computer and then the digital image is reconstructed by the program.

In order to find the appropriate frame grabber the following requirements were taken into consideration:

- digitization of an image should be done on-line during scanning of an object;
- simultaneous image acquisition from all cameras;
- the price of the system should be kept to minimum.

For practical realization of the task the following were considered: frame grabbers (FG) which use a processor of a host computer for acquisition and analysis of images; frame grabbers with own digital signal processor (DSP) on the board; FG which use electronic memory of a host computer; FG with memory on the board. Taking into account all requirements for the task with analysis of different types of image processing equipment, it was decided that a FG with own DSP and memory on the board is a more appropriate frame grabber for this project.

Two types of cameras were considered for implementation: tube cameras and CCD cameras. Tube cameras were designed before CCD cameras, but they are still in the use in many technical areas. One of advantages of a tube camera, which can be useful in this application, is its flexibility to alter electronically separate arias of an image on the image plane. It can be seen that width of a laser line is not equal on the image plan: it is wider in the centre and slimmer on the ends. Disadvantages of tube cameras are: parameters are not stable during a time, relationship between input-output signals are highly non-linear. Due to these problems a tube camera requires often calibration. Lifetime of tube cameras is significantly less than CCD cameras. CCD cameras have been constructed on another principle – using electronic cells, each of which generates electrical current from photons. It gives linear relationship between input-output signals of the camera. Compact size, simple control from a computer and high resolution are other advantages of CCD cameras, which made the cameras more appropriate in machine vision and image processing applications than tube cameras. The problem of extracting a correct profile of a laser line can be easily solved by software programming. Thus, the CCD type of cameras was chosen as a more appropriate type for realization of the 3D surface reconstruction task.

As it was discussed above, a surface of an object should be illuminated in order to reconstruct its 3D image on a computer. It is clear, that the bigger the difference between brightness of the line projected on the surface and the illumination of the object is, the more accurate a model of the object can be obtained. It was decided to use a low power laser as a more appropriate source of light. A laser produces a highly collimated beam with minimal spread, which can be directed from long distances into small, confined areas. A spectrally pure laser light is very useful for illumination of small areas in the presence of large amounts of ambient light noise.

Two types of lasers were considered for this project: gas lasers and solid-state lasers (laser-diodes). It is well known that a gas laser produces a smaller beam diameter than a solid-state laser. However, a solid-state laser has several distinct advantages, including small size, low power consumption, minimal heat production, long lifetime, high reliability, low-voltage operation, and low cost. The laser can be modulated or continuous wave, infrared or visible laser light, with remote operation and adjustable output power. For a special application a laser can be supplied with a line-generating lens. The safety requirements were taken into consideration before choosing a particular type of a laser for this project. It should be mentioned that a line-generating lens splits a laser beam into a wide line that significantly reduces a collimated output of a laser beam. Thus, taking into account the requirements for the task, a laser diode was chosen for this project due to its parameters, high reliability, small power consumption and low cost.

Three approaches were considered in order to collect data points from the whole surface of an object:

- to project on an object a grid of laser lines from both sides;
- to project a single laser line on an object, and to rotate the laser-cameras system around the static object;
- to project a single laser line on an object, and to rotate the object on the rotary table whereas the laser-camera system remains static.

The first approach requires special optics and high precision mechanics in order to move a laser-cameras system around an object. The second approach requires a simple line-generating lens, but the mechanical part of the system remains very complicated to build. The third approach has been considered as more appropriate for the solution of the task due to its simplicity and relevant inexpensive equipment.

The electromechanical part of the system includes the rotary table, the synchronous motor, the general purpose inverter, the electromagnetic sensor, the 72 metal marks, attached on the disk of rotary table, and the analog-digital / digital-analog converter, which is connected to the PC computer (Fig. 2).

III. DESCRIPTION OF THE APPROACH OF 3D DIGITAL SURFACE RECONSTRACTION

The idea of extracting co-ordinates of surface points by a laser line is presented in Fig.3. It can be seen from the figure, that distance from the point O to the point A represents the radius R of the surface at this point for one diagonal slice in the cylindrical co-ordinates. The angle of rotation is obtained by the magnetic sensor attached to the rotary table. Radii of other surface points in vertical direction are obtained in the similar way by processing next diagonal slice. In practice a radius is obtained by calculating the position of the line on the computer screen using information from the memory of the frame grabber. The relationship between the screen co-ordinates and the object co-ordinates is obtained from the calibration table. (The description of the calibration procedure is omitted in this paper).

The number of frames to grab and process can be altered by the software according to the accuracy required. The digital / analogue converter is used in order to control the rotary table. Impulses from the magnetic sensor are converted by the A/D converter to the level, which is recognised by the converter as the signal of a new position of the disk. The computer program is constructed in such a way that it works in the similar manner as a trigger with feedback signals from the rotary table. The first camera begins to grab an image after receiving a command impulse from the A/D converter. The process will automatically be stopped if any problems with the camera or the frame grabber arise.

It can be seen on the screen that the width of a laser line is not equal on the ends and in the middle. The algorithm of aligning a laser line is implemented. Thresholding of a pixels level allows the extraction of the position of the laser line in screen co-ordinates. For the second camera the algorithm works in the similar way. The algorithm allows processing data even the information about the laser line disappears from one of the cameras. The rotary table stops after receiving the signal from the program, which counts the number of frames to grab during one revolution. The program makes transformation from the screen co-ordinates to the real space co-ordinates for every frame. Transformation from the cylindrical co-ordinates to the Cartesian co-ordinates needs to be done for visualization of the wire-frame of the image on the display.

Radii of points on a surface of an object can be obtained from trigonometric relationship between such parameters as the camera angle, distance from the camera to the center of rotation and location of image points in the focal plan (Fig. 4). The solution is as follows:

According to the law of sines from the triangle ABC the following can be obtained:

$$\frac{sin\theta}{d} = \frac{\sin\alpha}{b}, \tag{1}$$

where

$$\theta = \frac{\pi}{2} - \alpha + \beta,$$

then

$$BC = \frac{AC \times \sin\alpha}{\sin\theta} = \frac{AC \times \sin\alpha}{\sin(\frac{\pi}{2} - \alpha + \beta)} = \frac{AC \times \sin\alpha}{\cos(\beta - \alpha)}. \tag{2}$$

It can be seen from the triangle BDC that

$$BD = BC \times \sin\beta, \tag{3}$$

thus, from the triangle BDO the following can be obtained:

$$BO = \frac{BC \times \sin\beta}{\sin\gamma} = \frac{AC \times \sin\alpha}{\cos(\beta - \alpha)} \times \frac{\sin\beta}{\sin\gamma} =$$

$$= \frac{AC \times \sin\alpha \times \sin\beta}{\cos(\beta - \alpha) \times \sin\gamma} =$$

$$= \frac{AC \times \sin\alpha \times \sin\beta}{\cos(\beta - \alpha) \times \sin(\frac{\pi}{2} - \alpha)} =$$

$$= \frac{AC \times \sin\beta \times tg\alpha}{\cos(\beta - \alpha)}, \tag{4}$$

where

$$\gamma = \frac{\pi}{2} - \alpha,$$

$$\beta = arctg\,\frac{EF}{f}.$$

Thus, the radius R (which is the distance OB from the center of rotation of the disk of the rotary table to the point being recorded) is:

$$R = OB = \frac{AC \times \sin\beta \times tg\alpha}{\cos(\beta - \alpha)}.$$

IV. PRACTICAL REALIZATION OF A TRIANGULATION PRINCIPLE USING TWO CCD CAMERAS, WORKING SIMILTANEOUSLY

The present approach of the digital image reconstruction is based on the triangulation principle. In this case shadowing of some parts of the image may appear and the problem of missing data will arise. This problem was solved using a dual point of view with two cameras.

Figure 5 was created using rectangular polygons.

V. CONCLUSIONS

The idea of extracting co-ordinates of surface points by a laser line is given in this paper together with the algorithm of 3D digital surface reconstruction. It should be emphasized that the representation of an object by bi-parametric cubic surfaces (B-splines) gives big reduction of data points [5]. Smooth curves also give considerable advantages in visual representation of such complicated surfaces as a human face.

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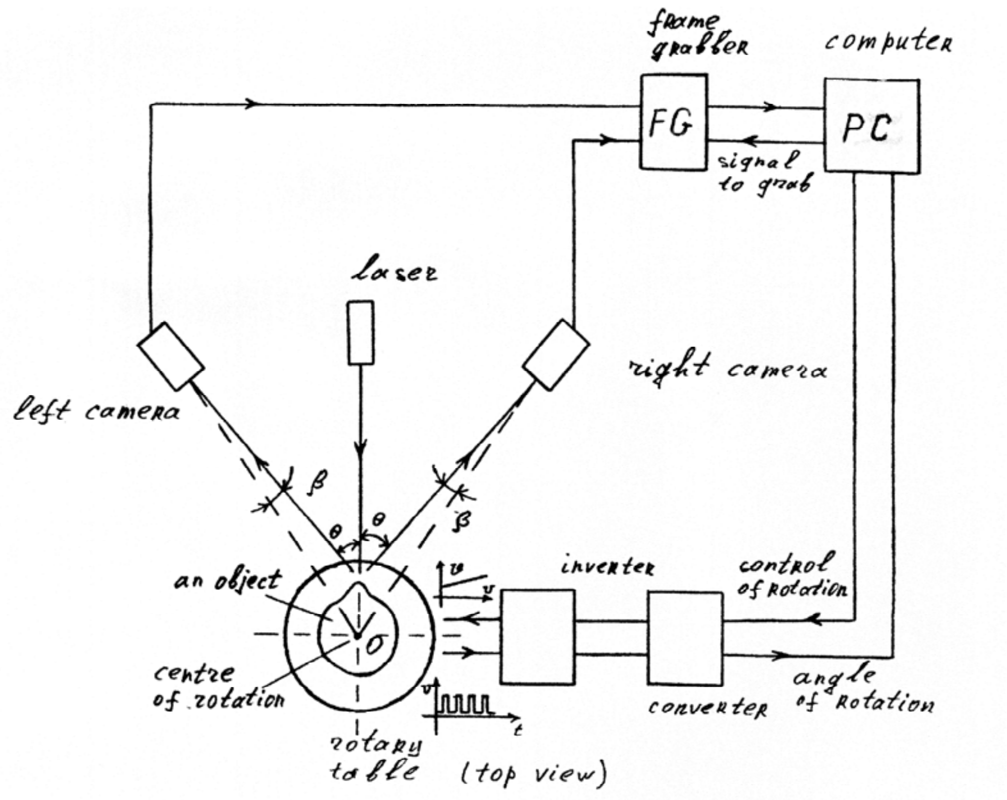


Fig.1, The laser scanning system.

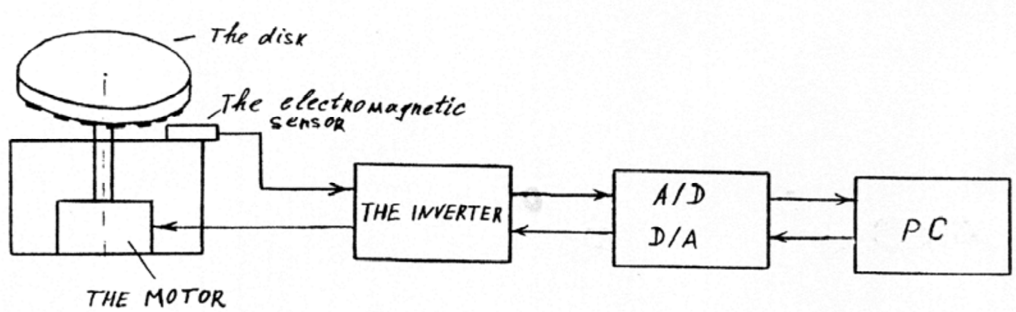
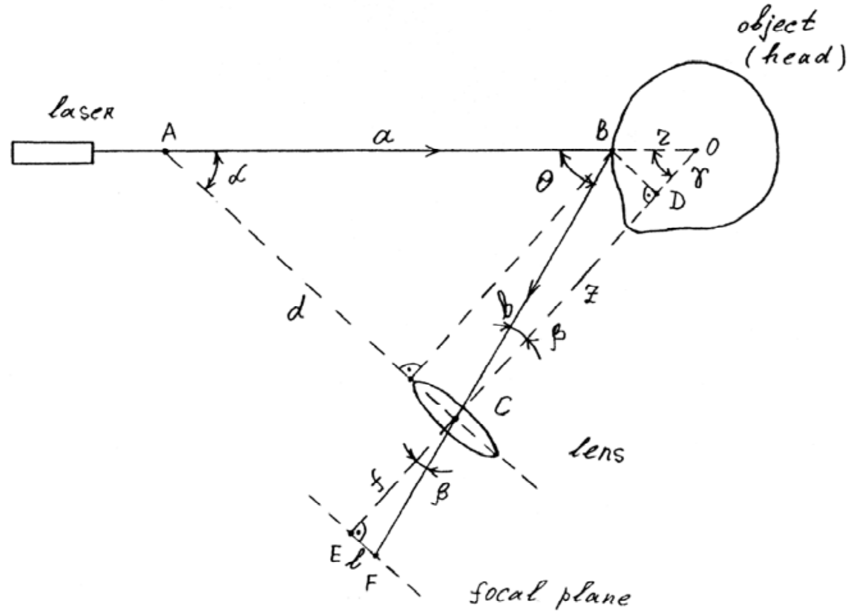


Fig.2, The electro-mechanical part of the system.



z - is the distance from the camera lens to the center of rotation O,
r - is the distance from the center of rotation to the point being recorded,
α – is the distance between the laser and camera,
l – is the distance on the image point in the focal plan,
f – is the distance from the camera lens to the focal plan,
O – is the axis of rotation of an object.

Fig.3 The idea of the extracting of co-ordinates of surface points by a laser line.

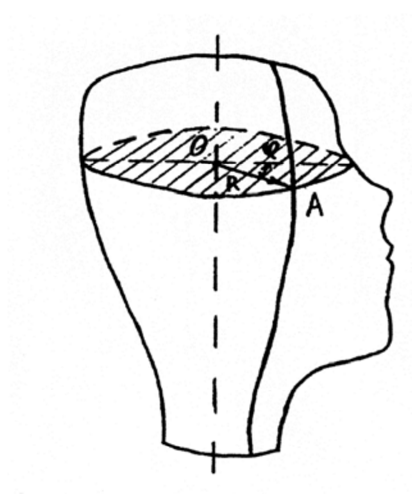


Fig.4, Radii of points on a surface of an object.

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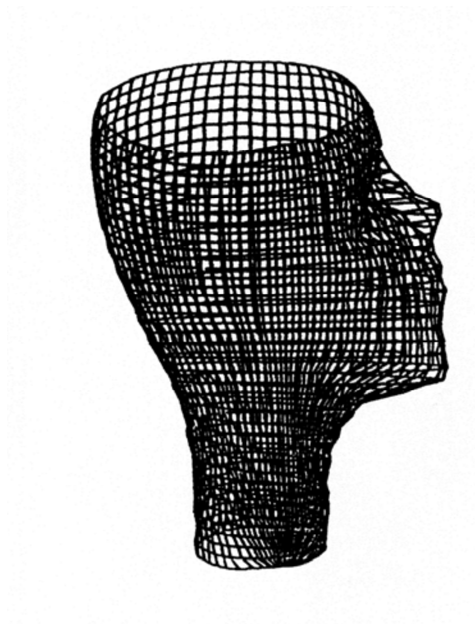

Fig.5, Digital image reconstruction using rectangular polygons.

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