Strojniški vestnik - Journal of Mechanical Engineering 54(2008)7-8, 503-506
UDC 681.786

Paper received: 02.06.2008
Paper accepted: 07.07.2008

Laser Multiple Line Triangulation System for Real-time 3-D Monitoring of Chest Wall During Breathing

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An optical system for 3-D chest wall measuring during breathing is described. The system is based on a laser multiple-line triangulation technique. It uses a CCD camera and a laser that simultaneously projects thirty-three light planes on the measured surface. The accuracy is ±0.5 mm, the measuring range is 400x600x500 mm and the frequency is 80 Hz. The system efficiency was tested by an adult volunteer, who was breathing in two regimes: rib-cage-dominant and abdomen-dominant. The results show the breathing pattern in a graphical and numerical way.

Keywords: breathing measurement, chest wall, laser triangulation, 3-D measurement

0 INTRODUCTION

The measurements of respiratory mechanics during tidal breathing are limited due to the invasiveness of devices used to measure flow of pressures at mouth. Since human breathing is involuntary, all devices which interfere with nasal or oral airway change the pattern of breathing and make tidal volume measurement inaccurate. Currently available devices, such as respiratory inductive plethysmographs, magnetometers, and stretching belts [1-2], are not accurate and produce a lot of artifacts when they are compared to mouth breathing recorded by flow meters. Approximately 10% of adult patients and all children below the age of 5 do not cooperate well with the standard lung function measurements in order to get true respiratory system performance.

The optical methods do not disturb the breathing pattern due to a noninvasive principle of measurement. All known optical methods are limited to measure the chest wall displacement at certain number of predefined points. They are mainly based on laser triangulation [3-4] or stereophotogrametry [5]. Their common drawback is the need to determine the measuring points before signal acquisition. This is done by positioning the measuring sensors or by sticking the photogrametrical markers on the patient's torso.

To avoid the above mentioned problems, we introduced a 3-D laser multiple-line triangulation method. Its novelty is in the measurement of the entire three-dimensional shape of the chest wall at the frequency which is in general limited with the camera frame rate (80 Hz in our case).

Non-invasive methods, such as laser multiple-line triangulation method, will contribute to regular medical work to obtain the lung volumes and changes in lung volumes in real-time without the need of invasive monitoring.

1 MEASURING PRINCIPLE

The main elements of the measurement setup are shown in Fig. 1. The system is based on the multiple-line laser triangulation principle [6]. It consists of a laser projector and a camera. The diode-type laser projector (Lasiris SNF-533L, 20 mW, 670 nm) generates a light pattern of 33 equally inclined light planes directed toward the measured surface, i.e. human chest. The camera records the illuminated surface from a different viewpoint, and consequently, the light pattern is distorted by the shape of the surface (Fig. 2). An ambient light is filtered by a narrow-band interference filter (10 nm FWHM, centered at 670 nm) which is placed between the lens and the camera's CCD sensor. The image contrast is improved consequently.

The measuring apparatus is designed to operate in two modes: high-speed and real-time. In the high-speed mode, the image sequence is acquired first, and the processing is done later. The maximum acquisition frequency is limited to 80 Hz by the camera. In the real-time measuring mode all the processing is done in between two consecutive measurements.

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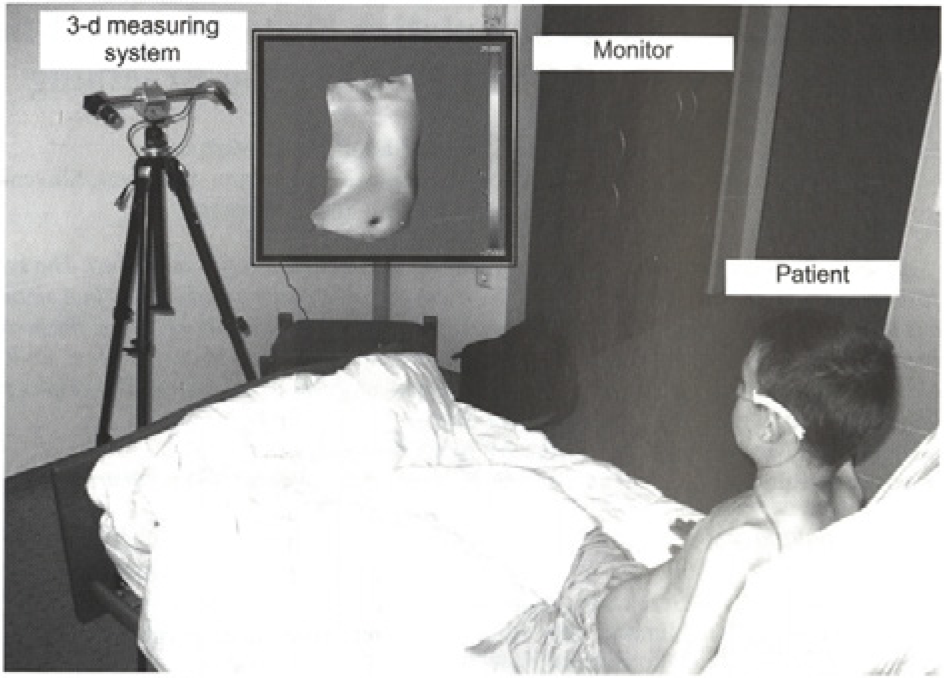

Figure 1: *The graphical breathing assistance based on the laser multiple-line 3-D measuring system*

The processing involves: image processing [7], three-dimensional surface reconstruction [8], shape analysis, and displaying in shaded and color mode, where colors represent different amounts of depth changes at each measurement point. The maximum measuring frequency is lower in the case of the real-time measurement. However, it is still high enough, approximately 25 Hz, if the processing is done on a 3-GHz Pentium processor.

1.1. Calibration and accuracy

The calibration of the apparatus is based on a reference sample: a groove-shaped plate that is measured at various heights. The parameters related to the optical geometry of the apparatus are then numerically optimized until the minimum deviation (the sum of the squared errors) between the measured points and the reference surface is found. The major advantage of this procedure is that all the transformation parameters can be determined in a single measuring step, i.e., the camera's internal parameters (focal length, central point and distortion), the projector's distortion, and the projector's position regarding the camera (rotation and translation). The accuracy of the calibrated apparatus is ±0.5 mm, which is calculated as a standard deviation between points of the measured and nominal reference surface. The measuring range depends on the camera's and projector's lens focal lengths, CCD sensor dimensions, the triangulation angle, and the distance between the laser projector and the camera. In our case, the range is approximately 400×600 mm in width and height and approximately 500 mm in depth.

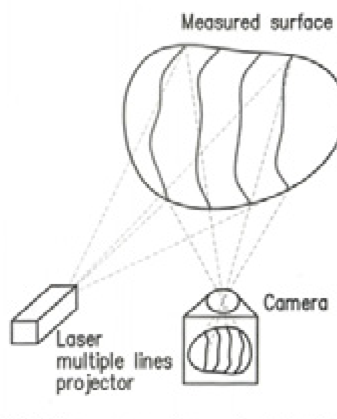

Figure 2: *The measuring principle is based on the laser triangulation with multiple-line illumination*

Figure 3: *The image of the volunteer's frontal torso illuminated by the laser multiple-line projector*

2 MEASUREMENT PROCEDURE

To test the monitoring efficiency of the breathing patterns, an adult male volunteer was studied. He was asked to take a normal breath out in the beginning of each measurement cycle. This pose was used as a reference shape for displacement calculation. After that, the rib-cage-dominant breathing and the abdomen-dominant breathing were performed several times.

The patient's chest must be located within the measuring range, which is in a distance between 1,200 mm and 1,700 mm from the apparatus. Its orientation is such that the laser light planes are directed vertically (see Fig. 3). Such orientation produces better visibility of the observed chest area. The adjustment of the right position of the apparatus according to the patient is divided into selecting of the proper distance and orientation. The position is adjusted when the laser lines lie in the central area of the image, and when the observed part of the body – chest – is in the central area of the image.

A custom developed measuring software was used to observe and analyze the three-dimensional chest shape in a real-time. The surface is displayed in the shaded mode and its displacements are shown numerically (waveform) and graphically (colors). In the waveform chart, the values of the selected points are plotted according to the acquisition time. The displacement at the certain point is calculated as a difference between point distances measured at the current and the reference time. It can also be calculated as a distance difference between two points at the same time.

3 RESULTS

The representative time series of images of two 3-D chest shape measurements are shown in Fig. 4. The red and blue colors clearly expose the most active regions. In the upper series the abdomen-dominant breathing was measured and the whole wall moves approximately uniformly outward.

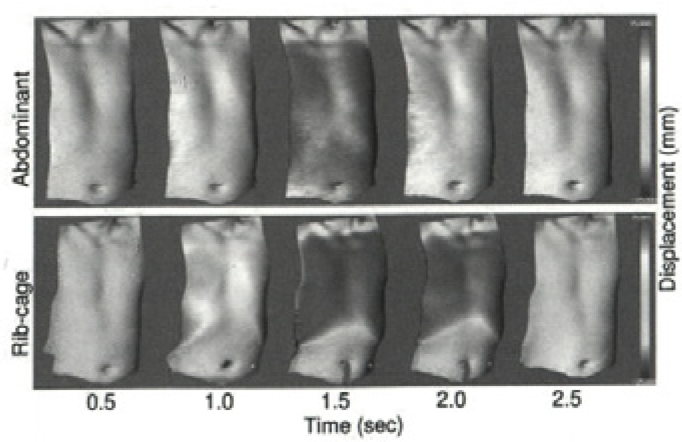

Figure 4: *3-D measurement of the chest wall during two breathing types. The displacements are presented with colors*

The rib-cage-dominant breathing is shown in the bottom series. It can be noticed that the upper chest part moves reasonably outward from the body, and that the bottom part stays in the same position or even goes a little inward.

The displacements of abdominal and rib-cage points were extracted from both measurement examples (see Fig. 5). A dissimilarity can be noticed between both types of breathing again. The tidal period is approx. 2.5 seconds in both examples. The rib-cage emphasized breathing is perhaps more interested due to significant displacements of the chest wall in both directions (Fig. 5b). The rib cage moves outward for ~30mm and the abdominal points move inward for ~15mm simultaneously. In the abdomen-dominant breathing, the maximal displacement is ~20mm for the rib-cage and the abdomen moves for half of that in the same direction.

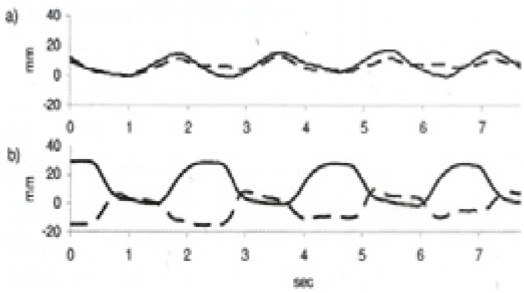

Figure 5: *The waveforms of the rib cage (—) and abdominal (---) displacement in case of: a) abdomen-dominant and b) rib-cage-dominant type of breathing*

4 CONCLUSION

The results of the presented 3-D measuring system demonstrate that it has sufficient accuracy (±0.5 mm), measuring range (400x600x500mm) and frequency (80Hz). The most important features are: the ability to measure the complete chest surface at the same time, the high measuring frequency and non-invasive measurement principle.

The presented technology shows the breathing pattern in a graphical and numerical way. In the future, it will help to train the patient how to breath by observing the image of his chest. We believe that the graphical communication with the patient is much more clear and easy to understand.

The system was developed at the University of Ljubljana, Faculty of Mechanical Engineering as a part of the applied research project L7-9391.

5 REFERENCES

[1] Gilbert, R., Auchinclus, J.H., Brodsky, J., Boden, W. *Changes in tidal volume, frequency, and ventilation induced by their measurement,* J Appl Physiol, 1972, vol.32, p.252-254.

[2] Binks, A. P., Banzett, R.B., Duvivier, C. *An inexpensive, MRI compatible device to measure tidal volume from chest-wall circumference*, Physiol. Meas. , 2007 vol. 28, p.149–159.

[3] Kondo, T., Inocchieri, S., Baldwin, D.N., Nelle, M., Frey, U. *Noninvasive monitoring of chest wall movement in infants using laser*, Pediatr Pulmonol, 2006.

[4] Drummond, G.B., Duffy, N.D., *A video-based optical system for rapid measurements of chest wall movement*, Physiol. Meas., 2001, vol.22, p.489-503.

[5] Groote, A.D., Wantier, M., Cheron, G., Estenne, M., Paiva, M. *Chest wall motion during tidal breathing*, J Appl Physiol, 1997 vol. 83, p. 1531-1537.

[6] Jezeršek, M., Gruden, V., Možina, J, *High-speed measurements of steel-plate deformations during laser surface processing*, Optics Express, 2004, vol.12, no.20, p.4905-4911.

[7] Jezeršek, M., Možina, J., *A Laser Anamorph Profilometer*, Journal of Mechanical Engineering, 2003, vol.49, no.2, p.76–89.

[8] Bračun, D., Jezeršek, M., Diaci, J. *Triangulation model taking into account light sheet curvature.* Meas. sci. technol. , 2006, vol.17, no.8, p.2191-2196.