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Basic Study on Non-contact Measurement of Cardiac Beat by Using Grid-based Active Stereo

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Abstract— **We propose a new non-contact measurement of cardiac beat from 3D shape information of body surface by using grid-based active stereo, and basically examine the validity of the proposed method. By simultaneous measurement with our proposed method and ECG, there are sufficient correspondences between peak intervals of inter-frame depth changes measured by our method and R-R intervals measured by ECG.**

I. INTRODUCTION

Recently, the Heart Rate Variability (HRV) is widely used for evaluating the effects of mental stress to automatic nerves. HRV is commonly measured by the electrocardiogram (ECG). Long term measurement with ECG makes examinees feel uncomfortable by attaching electrodes and measurement devices on the body.

Some researchers proposed non-contact HRV measurement by applying the thermal imaging [1] and the microwave reflectometry [2] in order to decrease the discomfort of examinees. These methods need expensive measurement devices. Novel measurement method by using webcam was proposed as feasible solution with low-cost devices [3]. However, it is considered that the color-image analysis is not robust for variation of the lighting environments and the skin colors of examinees.

The 3D image measurement known as active stereo is considered as the robust method against variations of illuminations and object colors. Recently, many application researches of 3D measurement systems have been conducted using active stereo. For instance, Kinect distributed by Microsoft Corporation draws much attention from various researchers and developers. We think that 3D image sensors like Kinect will be brought into our daily life in near future.

Hence, we propose a non-contact measurement method of cardiac beat by applying a 3D measurement method based on active stereo. Physiological measurement by 3D measurement is robust against variation of lighting environments, and applicable even in dark condition by using a near-infrared light source for the pattern projector.

The present work utilizes a 3D measurement system that can capture high-speed motions of dynamic scenes. The system is based on grid-based active stereo methods that have been studied by us and several researchers [4]-[7]. Those methods uses static pattern projection for active stereo, 3D shapes is captured with high frame rate by using high-speed camera as the imaging device. Moreover, since the system is based on active stereo system, high-precision measurement can be possible by using a wide-baseline configuration (i.e. the camera and the projector are arranged with a long distance between them). Since the body motion caused by cardiac beat is small and fast, high frame-rate and high precision measurement is important.

In this research, we propose a novel non-contacat measurement of cardiac beat from 3D shape information of body surface by using grid-based active stereo, and basically examine the validity of proposed method.

II. RELATED WORKS OF ACTIVE STEREO SYSTEM

Active stereo systems that consist of cameras and pattern projectors have been widely used for 3D measurements. Some of those systems use point or line lasers with scanning mechanism. However, those are not suitable for high frame-rate capturing, because they require a certain period of time for scanning a scene. Some other systems use 2D patterns, projected by devices such as video projectors. While those systems can capture wide surface of the scene without scanning mechanism, determining correspondences between the pattern and the captured image becomes a difficult problem. One typical solution is projecting multiple patterns (e.g., Gray code patterns[8], or phase shift methods[9]). However, since multiple imaging with synchronization is needed, it takes time for capturing a scene and it is not suitable for capturing highly dynamic scenes.

Active stereo using a static pattern is most suitable for capturing dynamic scenes. However, determining correspondences from only a single image is a difficult problem. Some works use color-coded lines[10] or small patterns that can be classified uniquely[11]. Others use pattern intensity itself as positional information. However, most of them have problems such as coarse resolutions or instability.

The present work uses an active stereo with a static grid pattern that consists of vertical and horizontal lines. From each image captured by a high-frame-rate camera, 3D shape is reconstructed using multiple epipolar constraints of a connected grid pattern [4]-[7].By using multiple epipolar constraints and continuity of a grid patterns, these types of

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methods have sufficient stability and density of measurement points.

III. SYSTEM CONFIGURATION

The 3D measurement system used in the present work consists of a camera and a projector (Figure 1). Parameters of the camera and the projector such as the focal length, aspect ratio, or angle of view are assumed to be known by calibration. The system uses a fixed pattern emitted from the projector, and no synchronization is required between the camera and the projector. The projector casts a grid pattern on the target surface, and it is captured as a series of images by the camera. By processing the images frame by frame, the dynamic shape of the target surface is reconstructed.

To measure cardiac beat of a subject, the subject sits still on a chair and the pattern is cast to the breast surface from the front of the subject. The camera is also set in front of the subject, but the distance between the camera and the projector (the baseline) is set to be long enough so that the precision of the 3D measurement can be sufficiently high(Figure 2).

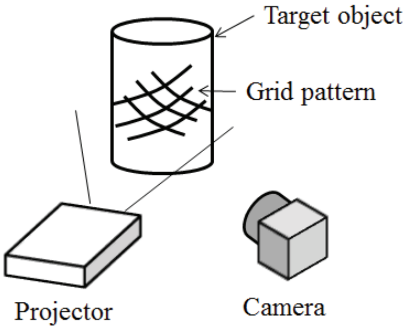

Figure 1. Pattern projection and the projector-camera system.

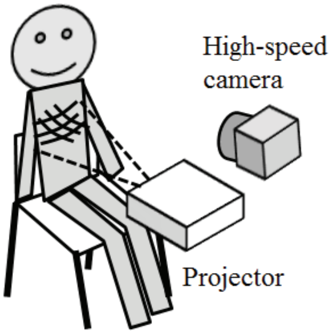

Figure 2. Configuration of the experiment for measuring cardiac beat.

IV. METHODOLOGY

The shape reconstruction method is similar to the work of Sagawa et.al. [6]. However, while color-coding is used in [6], we use only gray-scale images to utilize inexpensive high-speed cameras. Therefore, we extended the method of [6] to make it applicable to gray-scale images. The detailed method is yet to be published.

Here, we briefly explain the method of [10]. In the method, we the projected pattern is a grid-lines whose directions are vertical and horizontal. From the captured camera images, curves that form the grid lines are extracted. The curve detection is based on labeling. For example, detection of 'vertical' curve is based on labeling each pixel into positive (P) or negative (N), each of which means that the derivative of the intensity profile along the horizontal scan-line is positive or negative(Figure 3). By using the segmentation framework, continuity of the curves and directional information is taken into account. Then, the continuity of the captured grid pattern is estimated by using interpolations between the grid lines. Finally, the correspondences between the camera images and the projected pattern are determined, taking account of all the epipolar constraints in the continuous regions connected by the grid patterns.

The idea of simultaneously using multiple epipolar constraints for each region connected by the grid pattern has been proposed in several recent works [1] -[4]. This is because, by using multiple epipolar constraints, it is possible to decide unique correspondences for a connected region, and reconstruct the absolute 3D positions for the grid pattern. Figure 4 shows epipolar lines of three of the grid points. If a connected grid is observed from the camera image, all the grid points conform to the epipolar constraints. This is a strong constraint and is generally sufficient to decide unique correspondences between the grid pattern and the camera image.

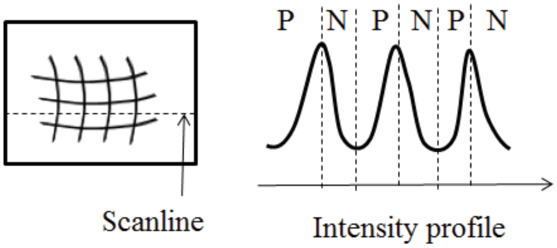

Figure 3. Labeling and segmentation for line detection

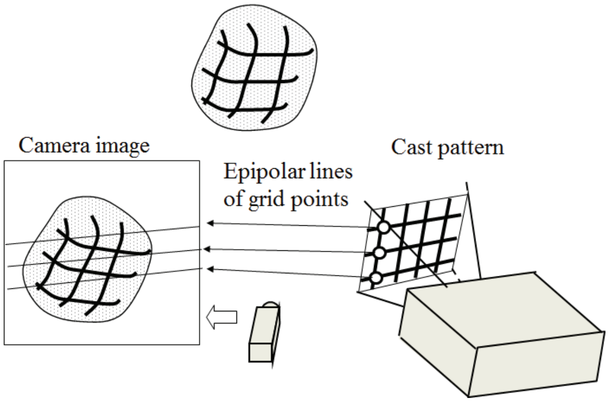

Figure 4. Epipolar constraints of grid points

Using the correspondences between the camera image and the pattern image, 3D points of the grid lines can be reconstructed using triangulation. Also, by using interpolation between the grid lines, pixel-wise depth estimation for the camera image is conducted [6]. Thus, dense point cloud data for the dynamic scene for each frame can be obtained.

The cardiac beat is extracted from time-series change of the 3D body shape reconstructed by above mentioned method. Since the reconstructed shapes are consist of unorganized vertices, it is not a simple process to compute the inter-frame correspondences for obtaining the time sequence of shapes. To obtain inter-frame correspondences, the point cloud is re-sampled at fixed 2D grid points arranged in xy-coordinates, where the z-coordinate of the re-sampled points are the depth values from the camera (here, it is assumed that the front direction from the camera is the z-axis). Then, the vertices sampled at the same xy-coordinate is set to be a set of corresponding points. In the algorithm for re-sampling the point cloud, 3D shape interpolation at the fixed xy-coordinates are required. In this work, the Delaunay triangulation with linear interpolation was used to get the interpolated vertices[12].

Then, the band-pass filter which passes 0.4-5 Hz is applied to the time-series data set of the depth value in each re-sample vertices, and the cardiac beat component is extracted.

V. EXPERIMENT & RESULTS

Actual measurements by experimental system is executed to examine the validity of our proposed method. In experimental system, the SILICON VIDEO® monochrome 643M, manufactured by EPIX inc., is used as the high speed camera. The 643M provide a maximum of 211 FPS at 640 by 480 resolution. In this experiment, the frame rate is set at 100 FPS. The focal length of camera lens is 8mm. The EB-1750, which is manufactured by EPSON Corporation, is used as the pattern projector. The distance between the camera lens and the projector lens is set at 600mm.

Examinees are two health male (examinee A: age: 41 years old, body height: 171 cm, body weight: 62 kg/ examinee B: age: 39 years old, body height: 173 cm, body weight: 69 kg). Prior to the measurement, we obtained the consent document on the measurement execution from the examinees. In the measurement, the examinees wear a white T shirt. The measurement time is set at 30 seconds. In the measurement, at first, examinees stop breathing during about 10 seconds, and take breathing during last seconds.

Here, the experimental results about the examinee A is shown below. Figure 5 shows point cloud reconstructed from projected pattern image and re-sampled point cloud. Figure 6 shows the 3D contour map computed by the re-sampled point cloud. The graph shown in Figure 7 is the raw waveform and the bandpass-filtered waveform at point which are shown as x-mark in Figure 6. The raw waveform includes much noise component. However, the filtered waveform periodically changes. The amplitude of filtered waveform is very small of an order of sub-millimeter.

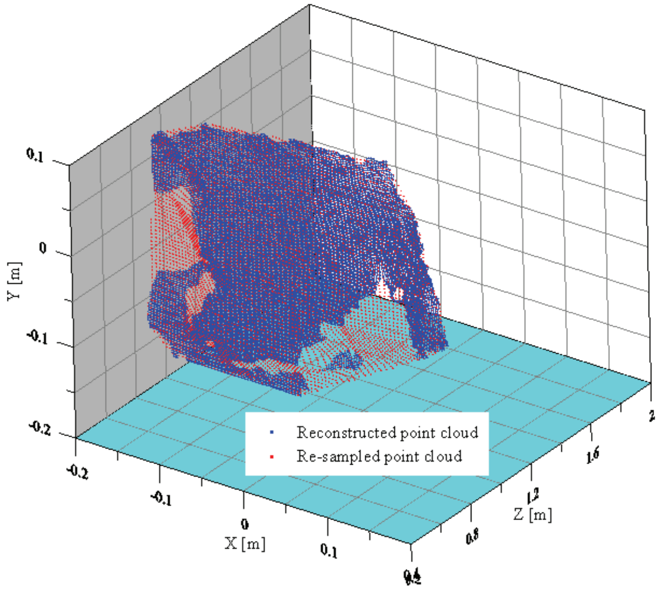

Figure 5. Reconstructed point cloud and re-sampled point cloud.

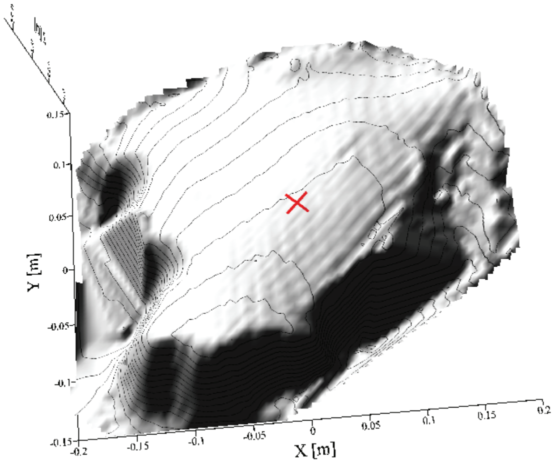

Figure 6. 3D contour map of body surface.

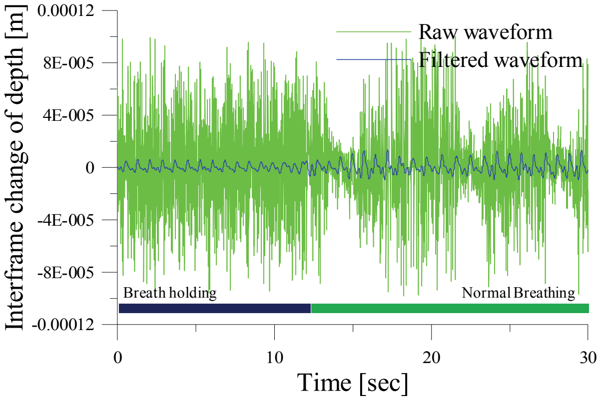

Figure 7. Raw waveform and the bandpass-filtered waveform.

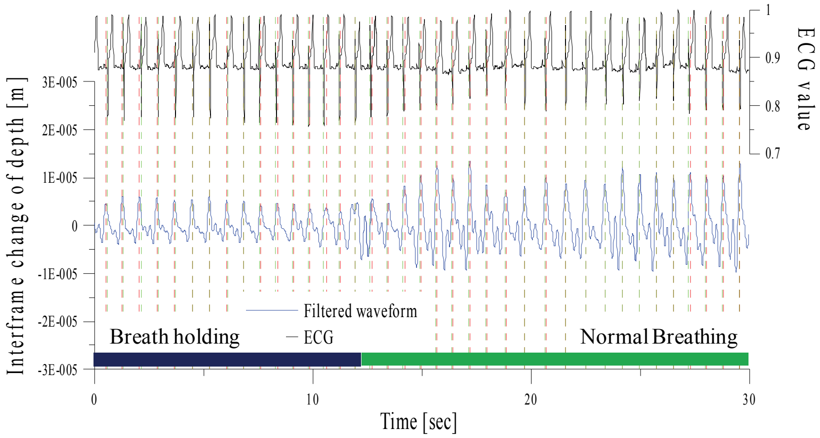

Figure 8. Raw waveform and the bandpass-filtered waveform.

The relationship between the periodicity of the filtered waveform is examined by simultaneous measurement with ECG. The compact-type wireless ECG logger manufactured by LOGICAL PRODUCT CORPORATION is conducted in the simultaneous measurement. The electrodes of ECG are set on left breast region of the examinee. As shown in Figure 8, the R peaks in the ECG waveform basically correspond the peaks of inter-frame depth change measured by our system. Especially, there is sufficient correspondence during breath holding. Both peaks correspond during a large part of normal breathing, although unstable waveform appears in the inter-frame depth change during the early part.

The relationship between R-R interval of ECG waveform and peak interval of inter-frame depth change waveform is examined by the Bland-Altman plot, as shown in Figure. 9. This plot suggests that there is sufficient correspondence between both peak intervals, and is not severe systematic error. The difference during breath holding is smaller than during normal breathing. Therefore, we think that respiratory body movement influences the calculation accuracy of the depth change waveform. The reduction of influence by respiratory movement is one of future subjects.

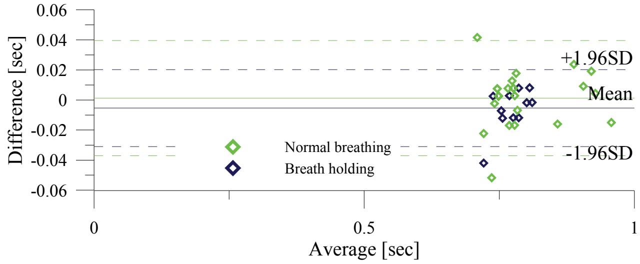

Figure 9. Bland-Altman plot between R-R interval and peak interval of depth-change waveform.

VI. CONCLUSION

We propose the novel non-contact measurement of cardiac beat from 3D shape information of body surface computed by using grid-based active stereo, and basically examine the validity of proposed method. By simultaneous measurement with our proposed method and the ECG, there is sufficient correspondence between peak interval of inter-frame depth change measured by our method and R-R interval measured by ECG. This result suggests that non-contact measurement of cardiac beat is realized by the active stereo.

REFERENCES

[1] Garbey, M.; Nanfei Sun; Merla, A.; Pavlidis, I.: "Contact-Free Measurement of Cardiac Pulse Based on the Analysis of Thermal Imagery," IEEE Transactions on Biomedical Engineering, Vol.54, No.8, pp.1418-1426 (2007)

[2] Nagae, D.; Mase, A.; , "Measurement of vital signal by microwave reflectometry and application to stress evaluation," Microwave Conference, 2009. APMC 2009. Asia Pacific, pp.477-480 (2009)

[3] Poh, M.; McDuff, D.J.; Picard, R.W.: "Advancements in Noncontact, Multiparameter Physiological Measurements Using a Webcam," IEEE Transactions on Biomedical Engineering, Vol.58, No.1, pp.7-11, (2011)

[4] Kawasaki, H., Furukawa, R., Sagawa, R. and Yagi, Y.: Dynamic scene shape reconstruction using a single structured light pattern, CVPR, pp. 1–8 (2008).

[5] Sagawa, R., Ota, Y., Yagi, Y., Furukawa, R., Asada, N. and Kawasaki, H.: Dense 3D reconstruction method using a single pattern for fast moving object, ICCV (2009).

[6] Sagawa, R., Kawasaki, H., Furukawa, R. and Kiyota, S.: Dense One-shot 3D Reconstruction by Detecting Continuous Regions with Parallel Line Projection, ICCV (2011).

[7] Ulusoy, A. O., Calakli, F. and Taubin, G.: One-Shot Scanning using De Bruijn Spaced Grids, The 7th IEEE Conf. 3DIM (2009).

[8] Sato, K. and Inokuchi, S.: Range-Imaging System Utilizing Nematic Liquid Crystal Mask, Proc. Int. Conf. on Computer Vision, pp. 657–661 (1987).

[9] Zhao, H., Chen, W. and Tan, Y.: Phase-unwrapping algorithm for the measurement of three-dimensional object shapes, Applied Optics, Vol. 33, No. 20, pp. 4497–4500 (1994).

[10] Zhang, L., Curless, B. and Seitz, S.: Rapid Shape Acquisition Using Color Structured Light and Multi-Pass Dynamic Programming, 3DPVT, pp. 24–36 (2002).

[11] Kimura, M., Mochimaru, M. and Kanade, T.: Measurement of 3D Foot Shape Deformation in Motion, 4th Digital Human Symposium (2009).

[12] Lee, D. T., and Schachter, B. J.: "Two Algorithms for Constructing a Delaunay Triangulation",, International Journal of Computer and Information Sciences, Vol. 9, No. 3, pp. 219-242 (1980)