Extraction and Visualization of Cardiac Beat by Grid-based Active Stereo

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Abstract. We propose a method to observe cardiac beat from 3D shape information of body surface by using grid-based active stereo, and report preliminary experiments to evaluate validities of the proposed method. By comparing results of our proposed with those of electrocardiogram (ECG), we confirmed sufficient correspondences between peak intervals of inter-frame depth changes measured by the active stereo and R-R intervals measured by ECG. We tried the visualization of the spatial distribution of inter-frame depth change plotted on the 3D shape of thoracoabdominal region. And, the shape change by cardiac beat is mainly found on the left side of the chest region.

Keywords:: Active stereo, Cardiac beat measurement, Non-contact physiological measurement

1 Introduction

Some researchers proposed cardiac beat measurement without contact by applying the thermal imaging [1] and the microwave reflectometry [2] in order to decrease the discomfort of examinees by attaching sensing devices on the body. These methods need expensive measurement devices. Novel measurement method by using webcam was proposed as feasible solution with low-cost devices [3]. However, in this mehotd, it is considered that the cardiac rate can be measured, but the waveform of cardiac beat cannot be measured accurately.

Hence, we propose a non-contact measurement method of cardiac beat by applying a 3D measurement method based on active stereo. We consider that non-contact cardiac beat measurement by 3D sensor has one advantage of obtaining spatial distribution of cardiac beat. We expect that the spatial distribution of cardiac beat change enable us to assess the cardiac function.

The active stereo systems that consist of cameras and video projectors have been widely used for 3D measurements. However, determining correspondences between the 2D pattern and the captured image is a difficult problem. A stable solution that

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produces precise results is projecting multiple patterns (e.g., Gray code patterns[8], or phase shift methods[9]). However, using multiple patterns mean taking a long time for capturing and is not suitable for dynamic scenes.

Active stereo using a static pattern is more suitable for dynamic scenes, but, determining correspondences from a single pattern is a difficult problem. Some works use color-coded lines[10] or small patterns that can be classified uniquely[13]. Others use pattern intensity itself as positional information. However, most of them have problems such as coarse resolutions or instability.

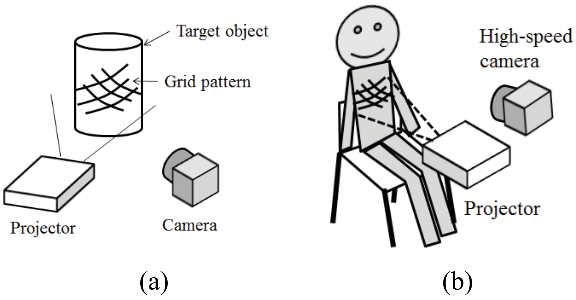
The present work uses an active stereo with a static grid pattern that consists of vertical and horizontal lines. From each image captured by a high-frame-rate camera, 3D shape is reconstructed using multiple epipolar constraints of a connected grid pattern [4]-[7]. By using multiple epipolar constraints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

We also conducted preliminary experiments and evaluated the validity of proposed method.

2 System configuration

The 3D measurement system used in the present work consists of a camera and a projector (Fig. 1(a)). 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(Fig. 1(b)).



(a) (b)

Fig. 1. System configuration: (a) the projector, the camera, and the grid pattern, (b) the experimental system for measuring cardiac beat.

3 Method

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 2). 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.

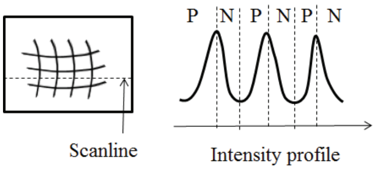


Fig. 2. Line detection.

The idea of simultaneously using multiple epipolar constraints for each region connected by the grid pattern has been proposed in several recent works [4]-[7]. 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 3 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.

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.

Cardiac beat is extracted from time-series change of the point cloud 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, Delaunay triangulation with linear interpolation was used to get the interpolated vertices[12].

Then, the FFT band-pass filter which passes 0.4-5 Hz is applied to the time-series data set of the inter-frame change of depth in each re-sample vertices, and the cardiac beat component is extracted. Here, the inter-frame depth change means the difference of depth between current frame (t) and previous frame (t-1).

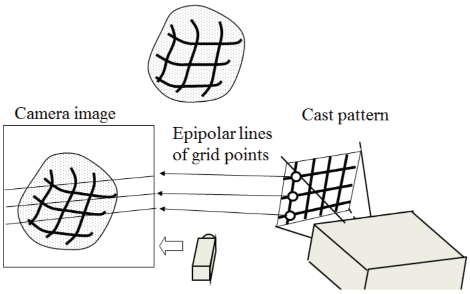


Fig. 3. Epipolar constraints of grid points.

4 Experiment & results

Actual measurement 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 examinee A is shown below. Fig. 4 shows point cloud reconstructed from projected pattern image and re-sampled point cloud. Fig. 5 shows a contour map computed by the re-sampled point cloud.

We examine the relationship between the periodicity of the filtered waveform by simultaneous measurement with ECG. The compact-type wireless ECG logger manufactured by LOGICAL PRODUCT CORPORATION is conducted in the simultane-

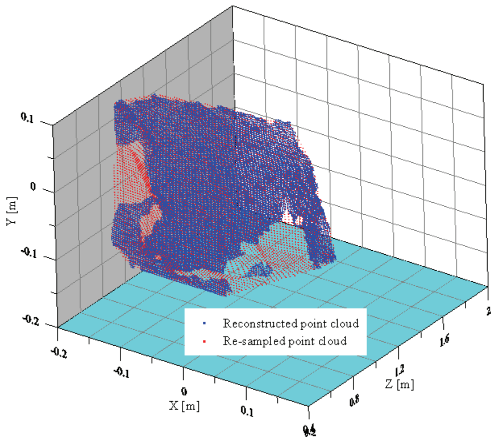


Fig. 4. Reconstructed point cloud and re-sampled point cloud.

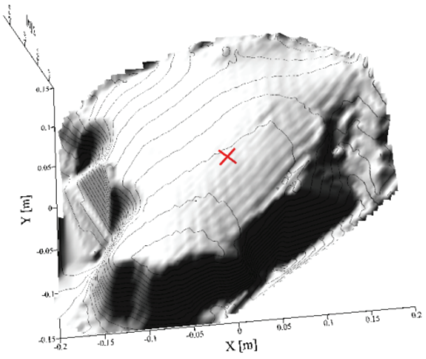


Fig. 5. Reconstructed 3D body shape

ous measurement. The electrodes of ECG are set on left breast region of the examinee. The sampling rate of ECG is set as 1000Hz.

The graph shown in Fig.6 is the raw waveform and the bandpass-filtered waveform at point which are shown as x-mark in Fig. 5. The raw waveform includes much noise component. However, the filtered waveform periodically changes. The blue line shows the cardiac-beat waveform. And the red one shows the respiratory waveform obtained by applying low-pass filter which passes under 0.4Hz. The amplitude of filtered waveform is very small of an order of sub-millimeter per one cardiac-beat.

We examine the relationship between the periodicity of the filtered waveform 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 Fig. 7, 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 Fig. 8. Here, the R-R interval means the peak interval between continuing two R-peaks. The 95% coefficient interval (95%CI) in normal breathing is 0.001236+/-0.03830. And, 95%CI in breath holding is -0.005383+/-0.02561. This plot suggest that there is sufficient correspondence between both peak intervals, and is not severe systematic error. The value of difference in breath holding is smaller than in normal breathing. Therefore, we think that respiratory body movement influences the calculation of the depth change waveform. The reduction of influence by respiratory movement is one of future subjects.

Fig. 9 shows the spatial distribution of inter-frame depth change plotted on the 3D shape of thoracoabdominal region. The time-series change of the spatial distribution

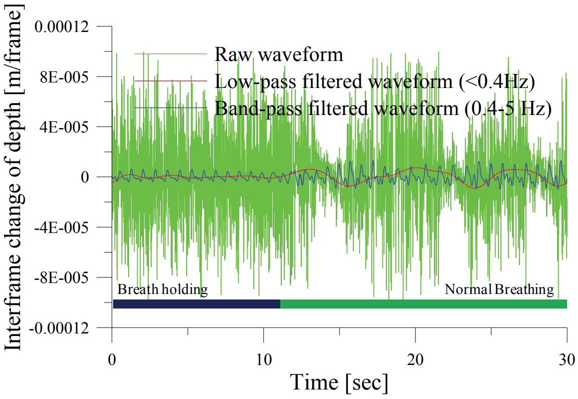


Fig. 6. Raw waveform and the bandpass-filtered waveform.

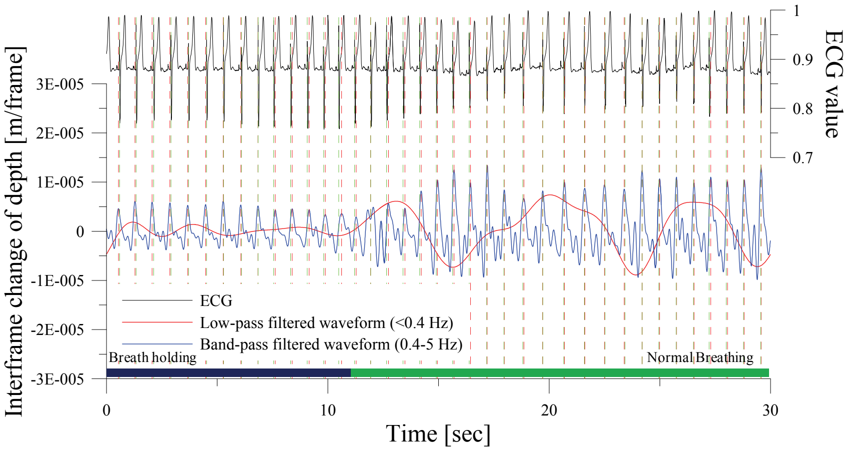


Fig. 7. .Simultaneous measurement by our proposed method and ECG.

in the figure corresponds single cardiac beat. The shape change by cardiac beat is mainly found on the left side of the chest region. We expect that the visualization of minute shape change occurred by cardiac beat is realized by imaging the spatial distribution of inter-frame depth change with higher time resolution.

5 Conclusion

We propose the extraction of cardiac beat from 3D shape information of body surface by using grid-based active stereo, and basically examine the validity of proposed method. By simultaneous measurement with our proposed method and ECG, there are 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. We tried the visualization of the spatial distribution of inter-frame depth change plotted on the 3D shape of thoracoabdominal region. And, the shape change by cardiac beat is mainly found on the left side of the chest region.

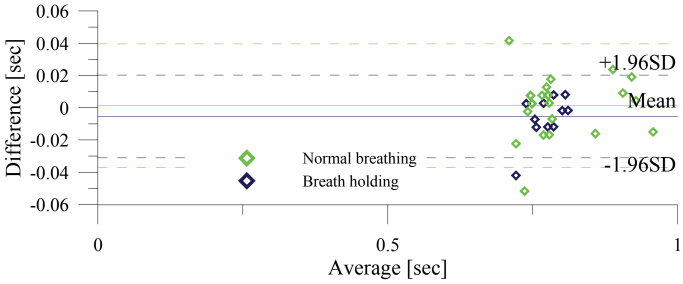


Fig. 8. Bland-Altman plot between R-R interval and peak interval of depth-change waveform.

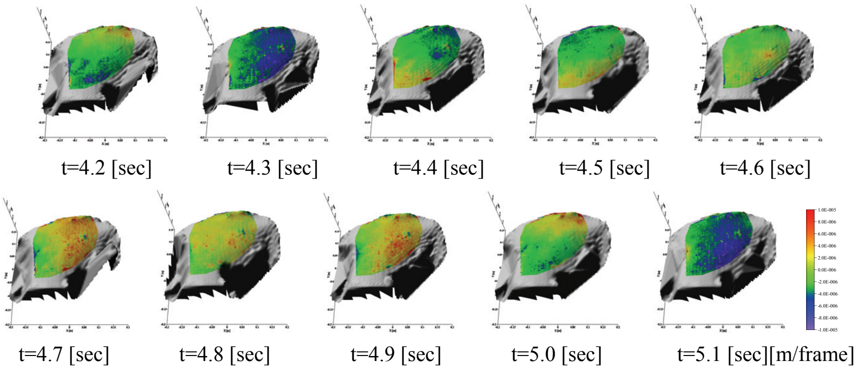


Fig. 9. Spatial distribution of interframe change of depth plotted on 3D shape of thoracoabdominal region.

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