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Noncontact Measurement of Cardiac Beat by Using Active Stereo with Waved-grid Pattern Projection

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Abstract— **We propose a method to observe cardiac beat from 3D shape information of body surface by using the active stereo with waved-grid pattern projection, and report preliminary experiments to evaluate validities of the proposed method. By comparing results of our method with those of electrocardiogram (ECG), we confirmed sufficient correspondences between peak intervals of depth changes between contiguous frames measured by the active stereo and R-R intervals measured by ECG. We proposed the visualization of the spatial distribution of depth change plotted on the 3D shape of chest surface. We confirm that the spatial phase difference, which is caused by heart pump ability, appears in the 3-D shape change of chest surface.**

I. Introduction

Some researchers proposed noncontact measurement of cardiac beat by applying the thermal imaging [1] and the microwave reflectometry [2] in order to decrease the discomfort of examinees by attaching sensing devices on their body. These methods need expensive measurement devices. Novel measurement method by using webcam was proposed as feasible solution with low-cost devices [3]. However, this method detects cardiac beat by using color information of face, and doesn't make measurement of cardiac mechanical movement directly and quantitatively.

We previously reported the non-contact measurement of cardiac beat by applying a 3-D measurement method based on the grid-based active stereo [4]. The grid-based active stereo is the 3-D shape reconstruction by using a measurement system, which consists of a projector and a camera. The image of pattern light is projected on the target object, and the image of pattern light is captured by the camera. 3-D shape of the target object is computed by analyzing the spatial distribution of the pattern light in the image. We realize noncontact measurement of cardiac beat by computing 3-D shape change of chest surface caused by cardiac pulsation. We had reported that, by simultaneous measurement with our proposed method and the ECG, there are sufficient correspondences between peak interval of 3-D shape change measured by our method and R-R interval measured by ECG.

In this study, we apply a new 3-D shape reconstruction proposed by us [5] for noncontact measurement of cardiac beat. The new method uses a grid-based active stereo with a waved-grid pattern that consists of vertical and horizontal sinusoidal lines. The new method is optimized for the monochromic camera as high speed camera, and the image analysis for 3-D shape reconstruction is based on continuity of the pattern. Thus, 3-D shape measurement with higher precision and stability than our previous method is promising. We made preliminary experiments about the proposed cardiac measurement and evaluated the validity

II. System configuration

The 3-D measurement system used in the present work consists of a camera and a projector as shown in 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 static pattern emitted from the projector, and no synchronization is required between the camera and the projector.

The projector casts a static pattern on the target surface. The pattern is configured with vertical and horizontal sinusoidal curves to create a grid pattern (details are described in next section). And, the target surface 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. Since the projected pattern is static with single color, no synchronization is required, high frame rate scanning is possible.

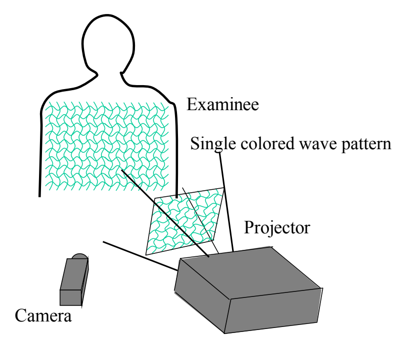

Figure 1. System configuration.

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

III. Method

A. 3-D shape reconstruction of chest wall

In the 3-D reconstruction method, by using a wave-shaped grid pattern as shown in Figure 2, the intersection points can be used as features for matching. Instead of explicitly encoding the positional information of a structured light, the proposed pattern implicitly gives information which can make the order on the candidates of corresponding points.

To obtain unique correspondences between the camera and projector images by spatial encoding, a complicated pattern of large window size have been required in previous methods [6]-[8]. Moreover, while the wider baseline is desirable to improve accuracy, the observed pattern will be more distorted, which makes it difficult to decode the pattern in practical cases. Therefore, we use a simple but informative pattern that is easy to detect and decode.

An overview of our algorithm is shown in Figure 3. First, we detect curves from the image. For the curve detection, we use a method based on belief propagation (BP) [9], where the image is segmented so that parallel line structures with a certain range of directions are emphasized by BP, and the parallel lines can be detected as borders of the segmented regions. With the method, vertical and horizontal lines of a single color are separated and robustly detected. From the detected curves, intersection points are calculated, and a graph structure of the grid is constructed from the connection of the points.

For each intersection point, candidates of the corresponding grid point are selected by using epipolar constraints and matching scores that compare an image patch around the intersection point and the grid points on the pattern image. For the epipolar constraints, the lens distortion of the projector is accounted for. Since multiple candidates of correspondences are usually found, one solution is determined by another BP algorithm.

Finally, the depth information for all the pixels are interpolated by matching between the pattern and the captured image and 3-D shapes are densely reconstructed.

B. Extraction of vital sign

Cardiac beat is extracted from time-series changes of the depth data calculated by the above mentioned method. Since the reconstructed point cloud consists of unorganized vertices, it is not a simple process to compute the correspondences between frames for obtaining the time sequence of shapes. To obtain correspondences between frames, the 3-D shape data is re-sampled at fixed 2-D 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

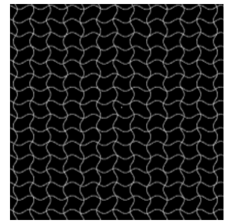


Figure 2. Wave-shaped grid pattern.

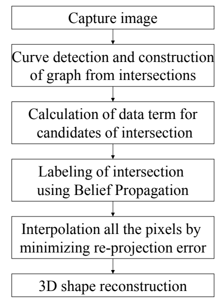


Figure 3. Algorithm of 3-D shape recontruction.

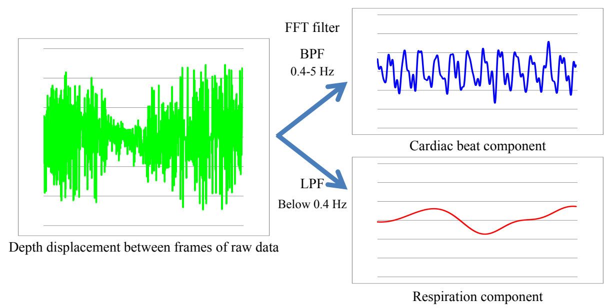


Figure 4. Extraction of vital sign: Cardiac beat component and respiration component is extracted by FFT filter.

direction from the camera is the z-axis). The vertices sampled at the same xy-coordinate are assumed to be a set of corresponding points. In the algorithm for re-sampling the 3-D shape data, 3-D interpolation at the fixed xy-coordinates is required. In this work, Delaunay triangulation with linear interpolation was used to get the interpolated vertices [10].

Then, the time-series dataset of the depth displacements between frames in each re-sample vertices is computed. Here, the depth displacement between frames means the difference of depth between the current frame (t) and the previous frame (t-1). As shown in Figure 4, the waveform of the time-series dataset is very noisy because of the camera image noise caused by image capturing with high frame rate. However, by applying a band-pass filter with Fast Fourier Transform (FFT) which passes 0.4-5 Hz to the waveform of depth displacement between frames, the cardiac beat component is extracted. In a similar way, by applying the FFT low-pass filter which passes below 0.4 Hz to the depth displacement between frames, respiration component is extracted.

IV. Experiments and Discussion

Actual measurements by an experimental system are executed to examine the validity of our proposed method. In the 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 capturing at VGA 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 health people. 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 15 seconds, and take breathing during last seconds.

Here, the experimental result about examinee A is shown below. Figure 5(a) shows the image of the chest on which the pattern is projected. And, Figure 5(b) shows a reconstructed 3-D shape of chest.

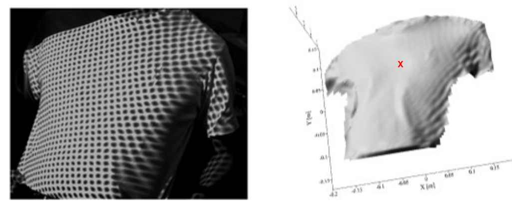
Figure 6 shows the extracted waveforms at a point which are shown as x-mark in Fig. 5(b). The filtered waveform periodically changes. The blue line shows the cardiac-beat waveform. And the red one shows the respiratory waveform obtained by applying a low-pass filter which passes under 0.4Hz. The amplitude of the 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 a 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. The sampling rate of ECG is set as 200Hz.

In Figure 6, the purple line shows the ECG waveform. The R peaks in the ECG waveform basically corresponds the peaks of the depth displacement between frames measured by the system. Especially, there are sufficient correspondences during breath holding. Both peaks correspond during a large part of normal breathing, although unstable waveform appears in the depth displacement between frames during the early part.

The relationship between R-R interval of ECG data and peak interval of depth displacement between frames is examined by 95% confidence interval (95%CI) of difference between the two values. Here, the R-R interval means the peak interval between continuing two R-peaks. 95%CI in normal breathing is calculated as 0.0012+/-0.038. And, 95%CI in breath holding is -0.0054+/-0.026. The results 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 works.

Figure 7 shows the spatial distribution of depth displacement between frames plotted on the 3D shape of the



(a) (b)

Figure 5. (a) input and (b) reconstructed 3-D shape of chest.

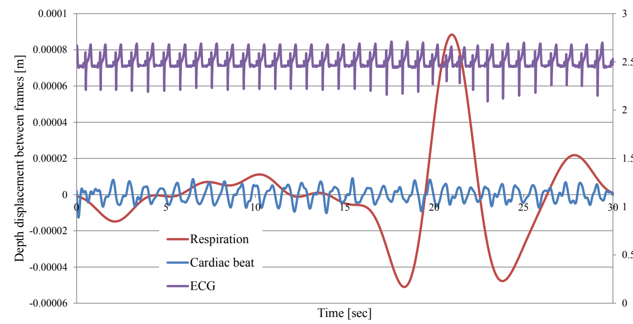


Figure 6. Measurement results of proposed method and ECG.

chest. The time-series variation corresponds to a single cardiac beat. The shape change by cardiac beat is mainly found on the left side of the chest. We expect that the visualization of minute shape change occurred by cardiac beat is realized by imaging the spatial distribution of depth displacement between frames with higher time resolution.

Here, 36 observation points (A1, A2, A3, …) are set on the reconstructed chest surface, as shown in figure 8. As one example, waveforms of cardiac beat in D1, D2, D3, D4, D5 and D6 are shown in figure 9. The phase difference between respective waveforms is observed. The phase of D1 is most advanced. In contrast, the phase of D6 is most delayed.

As the result of frequency analysis of all 36 points, 1.2 Hz is main component of cardiac beat in the data. The spatial distribution of phase at 1.2 Hz component at 36 points is shown as color contour map in Figure 10. Phase delay appears from the lower right side of chest toward upper left side. We consider that the phase delay is caused by heart dilatation and contraction.

V. 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 measurement.

By simultaneous measurement with our proposed measurement and ECG, there are sufficient correspondences between peak interval of the depth displacement between frames measured by the proposed method and R-R interval measured by ECG. This result suggests that non-contact measurement of cardiac beat is realized by the active stereo, though the depth displacement between frames includes large noise component caused by the camera noise with high-speed-rate capturing.

In addition, we proposed the visualization of the spatial distribution of depth displacement between frames plotted on the 3D shape of chest. And, the shape change by cardiac beat is mainly found on the left side of the chest. And, we confirm that the spatial phase difference, which is caused by heart pump ability, appears in the 3-D shape change of chest surface.

Hereafter, we plan to examine the validity of the method by experiments for more examinees. And, we will conduct comparison experiments with a sphygmograph as well as the ECG.

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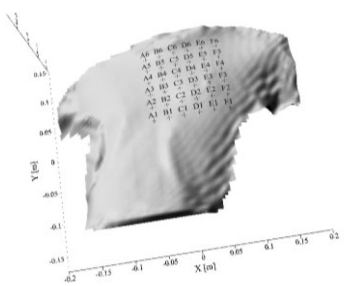

Figure 7. Observation points.

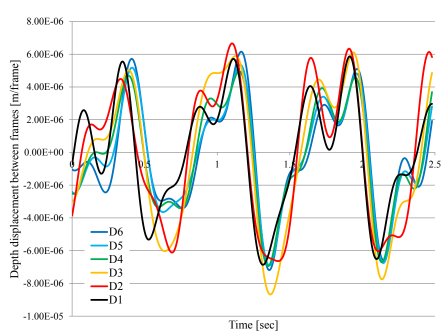

Figure 8. Phase difference of depth displacent at D1, D2, D3, D4, D5 and D6.

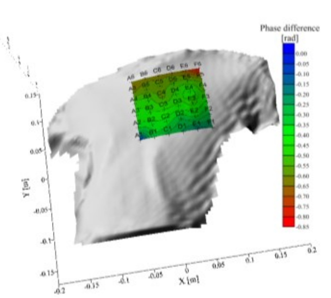

Figure 9. Spatial distribution of phase difference of depth displacent on chest surface.

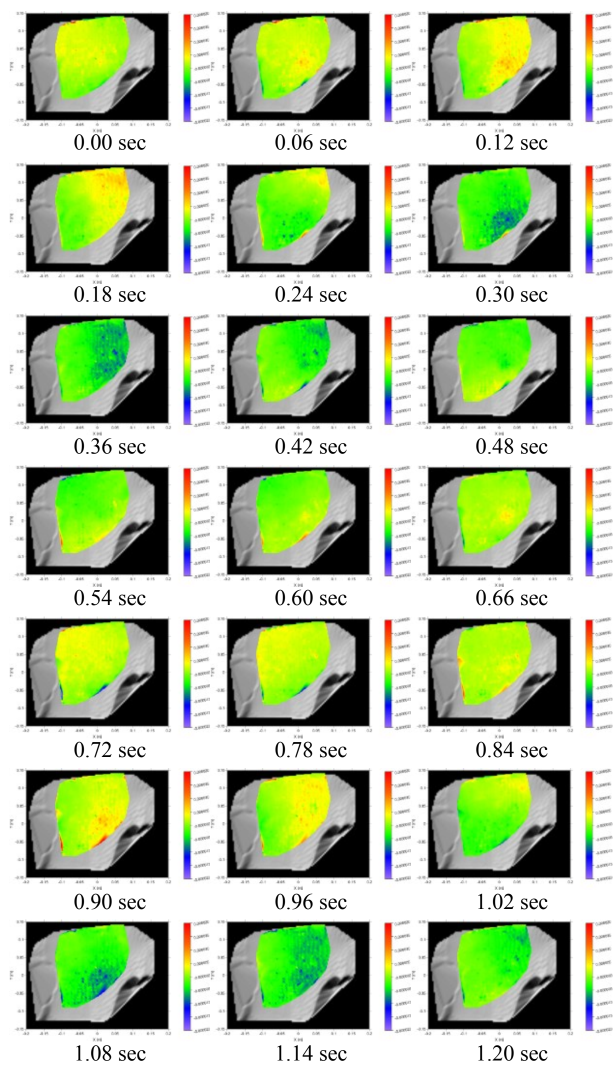

Figure 10. Spatial distribution of depth deplacement between frames plotted on 3D shape of chest.