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Factors Affecting the Accuracy of Volume-Oscillometric Blood Pressure Measurement during Partial Pressurization of the Wrist

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Abstract— **We compared the volume-oscillometric responses of the airbag pressure sensor and the contact force sensor across and along the radial artery on the wrist during partial pressurization by an airbag. Because of the anatomic structure and non-uniform pressurization pressure distribution, elongated and shifted oscillometric pressure waveform envelope variations are observed. For the contact force sensors directly above the radial artery, S-shaped pressurization curves can be seen possibly due to temporal softening of the radial artery stiffness at near zero transmural pressure. These differences in the shape of oscillometric envelope as well as pressurization curve may be the leading factors for inaccuracies of volume-oscillometric blood pressure measurement by partial pressurization method using an airbag.**

I. INTRODUCTION

Worldwide prevalence of hypertension is estimated to be as many as one billion individuals. Approximately 7.1 million deaths are attributed to hypertension annually [1]. In addition, hypertension has been shown to have a strong correlation with increased risks of strokes, heart attacks, chronic renal failure, and retinopathy. For prevention and early diagnosis of complications related to hypertension, it is necessary to evaluate and monitor the blood pressure accurately and frequently [2]-[3].

To improve the user convenience and comfort level, the feasibility of measuring blood pressure by volume-oscillometric method during partial pressurization of the wrist using an airbag has been evaluated. Wu *et al.* simulated the pressure transmission ratios of square air bladders during partial compression of the wrist, and proposed that the square air bladder size should be greater than 0.25 times the diameter of the wrist for effective pressurization of the radial artery [4]. The authors constructed a 3-D finite element model by simply extending a 2-D finite element model and applied a uniform pressure load on the skin. For more accurate and realistic simulation of the wrist and the radial artery during local compression by an air bag, however, the 3-D anatomic effects and non-uniform pressurization of the compression surface need to be carefully considered.

In this paper, we investigate factors that affect the accuracy of the volume-oscillometric method during partial pressurization of the wrist using an airbag. To determine the systolic and diastolic blood pressures in this measurement method, characteristic ratios are applied to the pressure waveform envelops in a similar manner to the conventional volume-oscillometric method, as shown in Fig. 1. We then compared the characteristics of the volume-oscillometric response of the radial artery and of the pressurization curve between the whole regional signal measured by the airbag pressure sensor and the local regional signal measured by the contact force sensor.

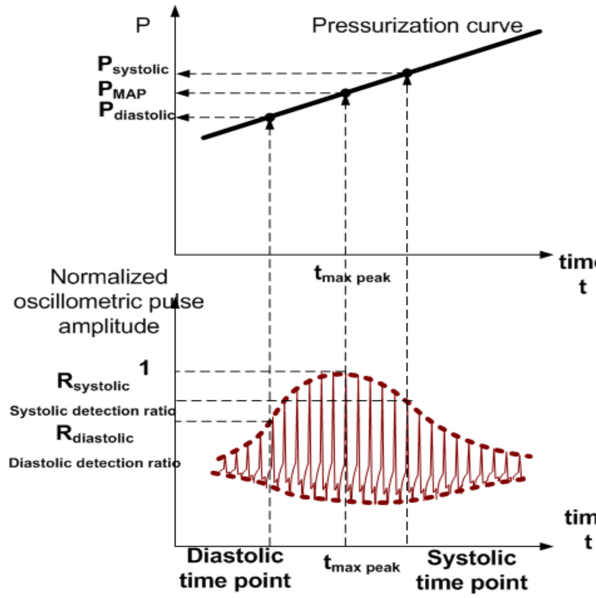

Fig. 1. Volume-oscillometric method

II. MEASUREMENTS AND RESULTS

To partially pressurize a region of the radial artery, an expandable silicone airbag with a folding sidewall is used. The bottom surface of the airbag, which contacts and compresses the skin, is a square of 2.5 cm x 2.5 cm. Pressure inside the airbag is measured by the MSI1620 pressure sensor connected to the upper part of the airbag through a silicon air tubing.

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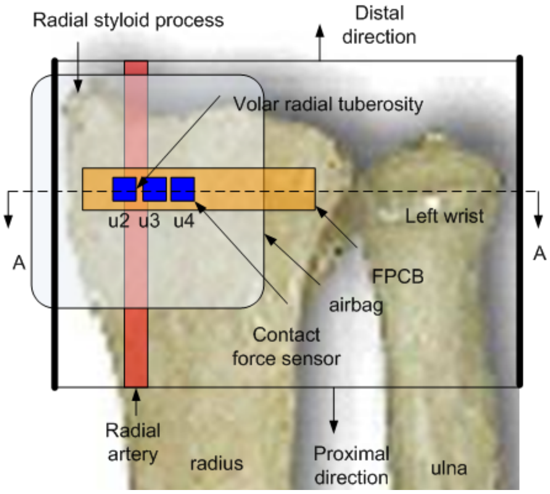
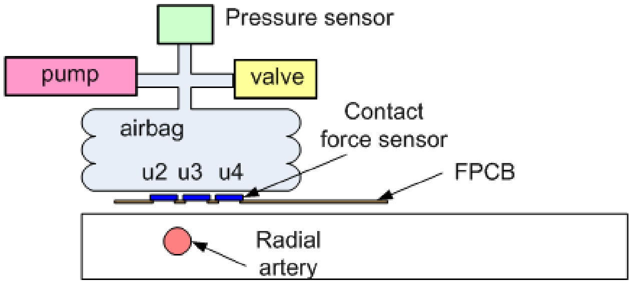
Fig. 2. Arrayed contact force sensor on flexible PCB



(a) Top-down view

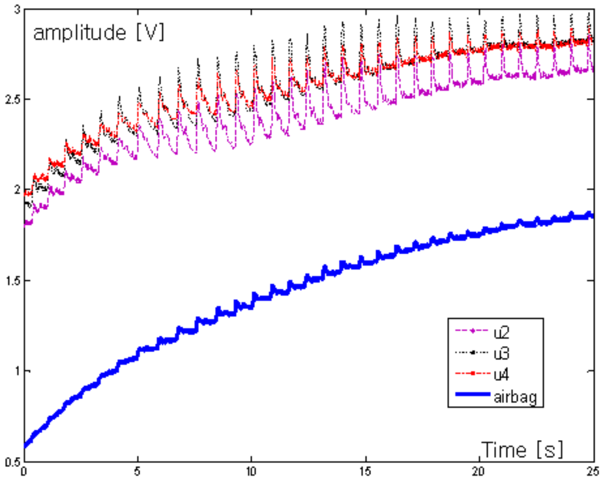


(b) Cross-sectional view along the AA line

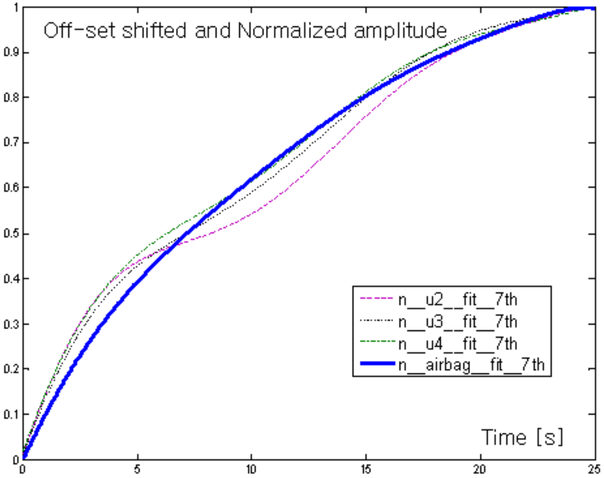
Fig. 3. Setup for acquiring the volume oscillometric responses of the radial artery by the airbag pressure sensor and the arrayed contact force sensors across the artery direction

To measure the pressure within local contact regions between the airbag and the skin, an arrayed contact force sensor on a flexible PCB shown in Fig. 2 is used. To mount sensing chips (Intersema MS7801) on the flexible PCB, the sensing module is packaged by flip-chip bonding technique. The chip size and sensing element size of the unit contact force sensor are 2 mm x 2 mm and 1 mm x 1 mm, respectively. The gap between the unit contact force sensors is 0.3 mm. The resistance variation in the sensing chip due to externally applied pressure is detected using Wheatstone bridge detection circuit.

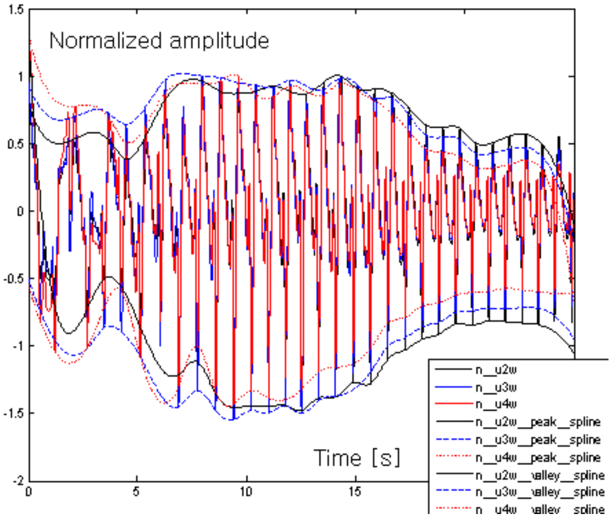
Before positioning the contact force sensor module or the airbag module, a reference point is marked on the volar radial tuberosity. It is a protruding region proximal to the radial styloid process that is easily palpable for the radial artery.



(a) Oscillometric responses from the sensors

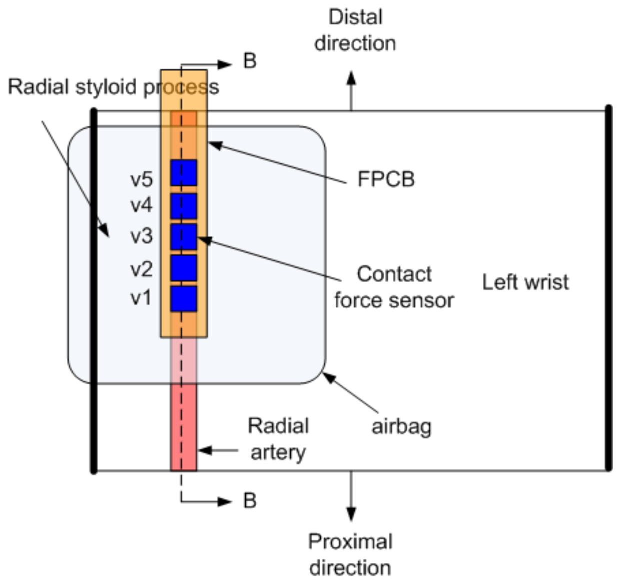


(b) Normalized and fitted curves for the valley points of the oscillometric response

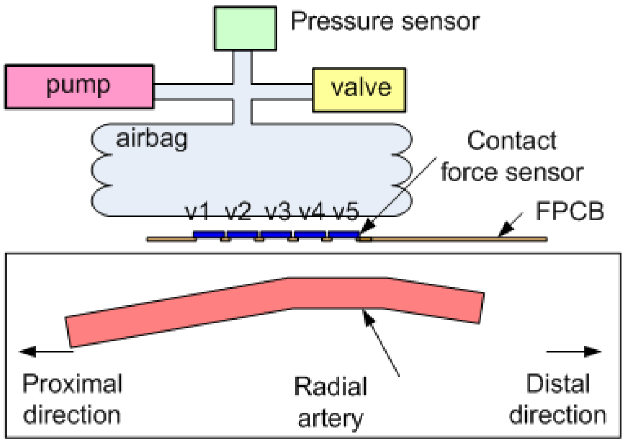


(c) Bandpass-filtered signals of the oscillometric response

Fig. 4. The oscillometric responses detected by the airbag pressure sensor and the arrayed contact force sensor across the artery direction



(a) Top-down view



(b) Cross-sectional view along the BB line

Fig. 5. Setup for acquiring the volume oscillometric responses of the radial artery by the airbag pressure sensor and the arrayed contact force sensors along artery direction

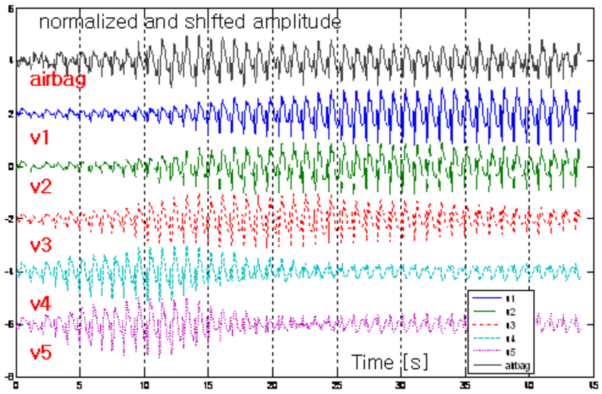


Fig. 6. Bandpass-filtered signals of the oscillometric responses detected by the airbag pressure sensor and the arrayed contact force sensor along the artery direction

A. Airbag pressure sensor vs. arrayed contact force sensor across the radial artery direction

Figure 3 shows the setup developed to acquire the volume-oscillometric responses of the radial artery detected by the airbag pressure sensor and the arrayed contact force sensor. The center point between the contact force sensors u2 and u3 is aligned on the volar radial tuberosity reference point found by palpation.

Pressure in the airbag is increased, and the resulting volume-oscillometric responses are captured by the airbag pressure sensor and the contact force sensors, as shown in Fig. 4(a). The valley points of the volume-oscillometric response signals are fitted by a 7th-order polynomial equation and normalized as in Fig. 4(b). Normalization is performed to correct for offset in the fitted curve and to allow comparison of pressure pulse responses among different measurements by scaling the fitted curve to its maximum pulse pressure.

For the airbag signal, this low-frequency component of the pressure signal represents pressurization pressure applied to the overall region under the compressing surface of the airbag on the skin. The pressurization curve obtained from the contact force sensor, on the contrary, represents local compression pressure that is applied directly under each unit contact force sensor. To analyze the magnitude variations of the pulse with respect to pressurization, the volume-oscillometric response signals are bandpass-filtered with low cutoff frequency of 0.5 Hz and high cutoff frequency of 10 Hz as in Fig. 4(c). The pressure responses are then fitted and normalized by the maximum peak value.

B. Airbag pressure sensor vs. arrayed contact force sensor along the radial artery direction

The setup used to measure the volume oscillometric responses detected by the airbag pressure sensor and the arrayed contact force sensor along the artery direction is shown in Figure 5. To see the magnitude variations of the pressure pulse as the sensing area is pressurized, the volume-oscillometric response signals are bandpass-filtered with low cutoff frequency of 0.5 Hz and high cutoff frequency of 10 Hz (Fig. 6). The pressure responses are then fitted and normalized by the maximum peak value.

III. DISCUSSION

A. Airbag pressure sensor vs. arrayed contact force sensor across the radial artery direction

Figure 4(c) shows almost identical oscillometric pressure waveform envelopes when the pressure pulse signals from the arrayed contact force sensors u2, u3, and u4 are bandpass-filtered and normalized. This indicates that the pressure pulse signal originated from the radial artery is transmitted through the tissue only with scaling effect to each contact force sensor. In this case, the systolic and diastolic pressure pointing times for the systolic and diastolic characteristic ratios could be similar in all cases of the contact force sensors u2, u3, and u4. When the pressure pulse sensing areas are on the same cross-sectional plane across the radial artery, therefore, the high frequency components of the pressure waveform do not affect the accuracy of the volume-oscillometric method by the airbag sensor or the arrayed contact force sensor.

It is however observed that the shape of the pressurization curve measured by the contact force sensor u2 is different from that measured by the airbag pressure sensor, as shown in Fig. 4(b). The pressurization curve of the airbag sensor increases monotonously whereas the pressurization curve of the contact force sensor u2 has a distinguishing feature of fast-slow-fast slope response. It is believed that this S-shaped pressurization curve may reflect temporal softening of the radial artery stiffness at near zero transmural pressure. The difference in the pressurization curve shapes results in different values for the systolic and diastolic pressures even when the same systolic and diastolic characteristic ratios are respectively used. Since the airbag pressurization curve includes pressurization signals from all local contact sites, therefore, the pressurization curve of the air bag sensor may not exactly represent the pressurization of the radial artery.

B. Airbag pressure sensor vs. arrayed contact force sensor along the radial artery direction

The oscillometric envelope shape in Fig. 6 is elongated and shifted along the y-axis to show clearly all oscillometric responses of the airbag sensor and the arrayed contact force sensors v1 through v5. The oscillometric signal from the airbag pressure sensor includes all signals from the sites v1 through v5 along the arterial direction.

This elongated and shifted oscillometric envelope may be caused by the anatomic structure around the radial artery. At unit sensors v5 and v4, the depth of the radial artery from the skin and the radius is smaller than that at unit sensors v3 through v1. At unit sensor v1, because the pressure from the airbag is transmitted relatively small on the arterial wall to flatten, the oscillometric response is sensed at late phase. On the other hand, at unit sensor v5 where the palpation is felt the strongest the pressurization pressure is efficiently transmitted to the radial artery. The radial artery is more easily compressed, and the oscillometric pulse response occurs at earlier time phase.

In addition, a non-uniform pressure distribution across the contact surface between the airbag and the skin may be another factor for the elongated and delayed oscillometric responses at v1, v2, and v3. When the pressure inside the airbag increases to 100 mmHg, for example, only the center portion of the compressed surface reaches equal or similar pressure while the actual pressurization pressure in the remaining portions are widely different.

Various deflection status of the arterial cross-section along the arterial direction under the airbag evidently and critically affects the determination of the systolic and diastolic characteristic ratios.

IV. CONCLUSION

We compared the volume-oscillometric responses of the airbag pressure sensor and the arrayed contact force sensor across and along the radial artery during partial pressurization of the wrist using an airbag. For the reasons of the anatomic structure and non-uniform pressurization, the local volume-oscillometric response measured by unit contact force sensors is different from the overall volume-oscillometric response of the airbag measured by the airbag pressure sensor. This difference leads to variations in the systolic and diastolic characteristic ratios that are needed for accurate measurement of the systolic and diastolic blood pressures, respectively. The pressurization curve also differs between the two cases, further affecting the accuracy of the volume-oscillometric method by partial pressurization using an airbag.

In order to ensure the accuracy of volume-oscillometric blood pressure measurement when a portion of the wrist on the radial artery is partially pressurized with an airbag, two approaches may be worth considering. One approach regards the sensing aspect, in which the contact force sensor is used for measuring the volume-oscillometric signal. By selectively acquiring and analyzing the pressure pulse response of the radial artery, the effect of signal deterioration by surrounding tissue may be minimized. Another approach takes into account the pressurization aspect, in which the length of the airbag along the radial is to cover only the region of the volar radial tuberosity while the width of the airbag across the radial direction is to pressurize the radial artery and its proximate region uniformly. This approach may facilitate more effective transmission of the pressurization pressure to the radial artery, thereby eliminating modulation of the oscillometric response envelop.

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