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Skin Surface Shock Wave

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***Abstract*— This paper discusses the Skin Surface Shock Wave which is generated after we impart an impulsive force to human skin. The force is given by an air jet during 200[ms]. The basic behavior of shock wave is measured by a high speed camera with the frame rate of 2000[Hz]. Through the experiment, we found an interesting behavior where there exists a remarkable difference between young and elder subjects especially during the recovery phase. while there is nearly no difference between two during the force imparting phase.**

***Key Words*: Skin Shock Wave, Air Jet, High Speed Camera, Aging**

I. Introduction

There have been a number of works discussing human skin characteristics concerning with medical examination, welfare application, and cosmetic application. There are two approaches for measuring dynamics of human skin as shown in Fig.1, where a force is given at a point and we observe the displacement at the same point as shown in Fig.1(a), while we observe the displacement at the neighbor as well as the force applying point, as shown in Fig.1(b). Since human skin deforms not only at the force applying point but also around the neighbor, we take the approach where the area instead of the point information is measured. By supposing the axi-symmetry, we finally focus on the line passing through the center of the force applying point as shown in Fig.1(b). For measuring the skin characteristics, we are particularly interested in observing the dynamic behavior, such as how quickly human skin deforms and recovers after a force impartment. We prepare both a high speed force applying unit and a deformation capturing unit, so that we can evaluate the dynamic characteristics appropriately. As for the force applying unit, we prepare an air jet system capable of controlling the operating time as well as the duty ratio. The deformation capturing unit is composed of a laser projector for making a line mark over human skin and a high speed camera with the frame rate of 2000 [Hz]. By using the system, we can measure human skin characteristics for 22 subjects with 10 young (20s) and 12 elder (70s).

Through the experiments, we found a skin surface shock wave where it progresses toward the outer direction just like a shock wave when we apply an impulsive force to the surface of human skin. The traveling speed of skin surface shock wave has nearly no correlation with age. On the other hand, we found that the recovery speed of human skin has a strong correlation with age. Without such a high speed sensing system, we could not observe the skin surface shock wave. This paper is organized as follows. After briefly introducing the related works, we describe the measurement system precisely. Then, we show the experimental results with the comparison between young and elder subjects, and give some discussions before concluding remarks.

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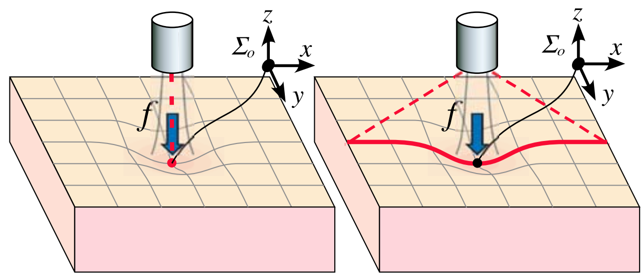


(a) Point measurement (b) 2D measurement

Fig. 1. Two approaches for measuring surface deformation

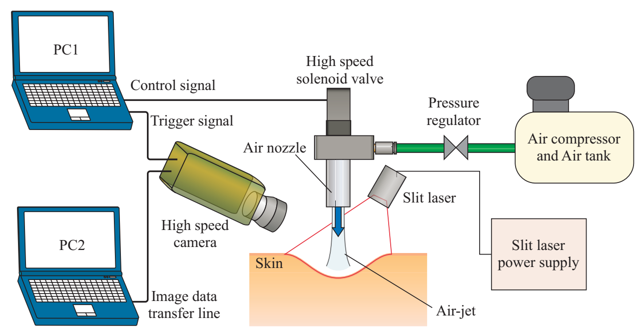
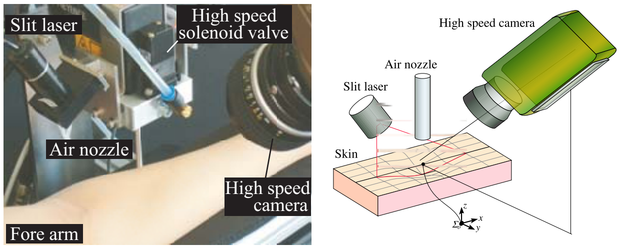


Fig. 2. A schematic diagram of experimental system

II. Related Works

There have been a number of works discussing human skin characteristics. Gierke et. al. have investigated the dynamic behavior of human tissue while imparting sinusoidal disturbance to human tissue[1]. Yoshitoshi et. al. have measured the skin characteristics through a contact probe and clarified the difference between normal and edematous parts[2]. Omata et. al. have developed a vibration type tactile sensor and measured the mechanical impedance of human skin through frequency field[3]. O'Donnell et. al. have measured the internal behavior of human skin by using the technique of ultrasonic speckle tracking[4]. Irie et. al. applied the impact force, so that they can obtain the characteristics of human skin with viscoelasticity[5]. The common point in these works is that they utilize a contact probe for obtaining



(a) Overview of system (b)Coordinate system

Fig. 3. Experimental system

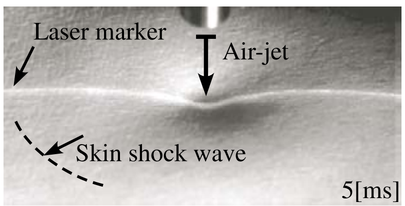


Fig. 4. Deformation of human skin by air-jet

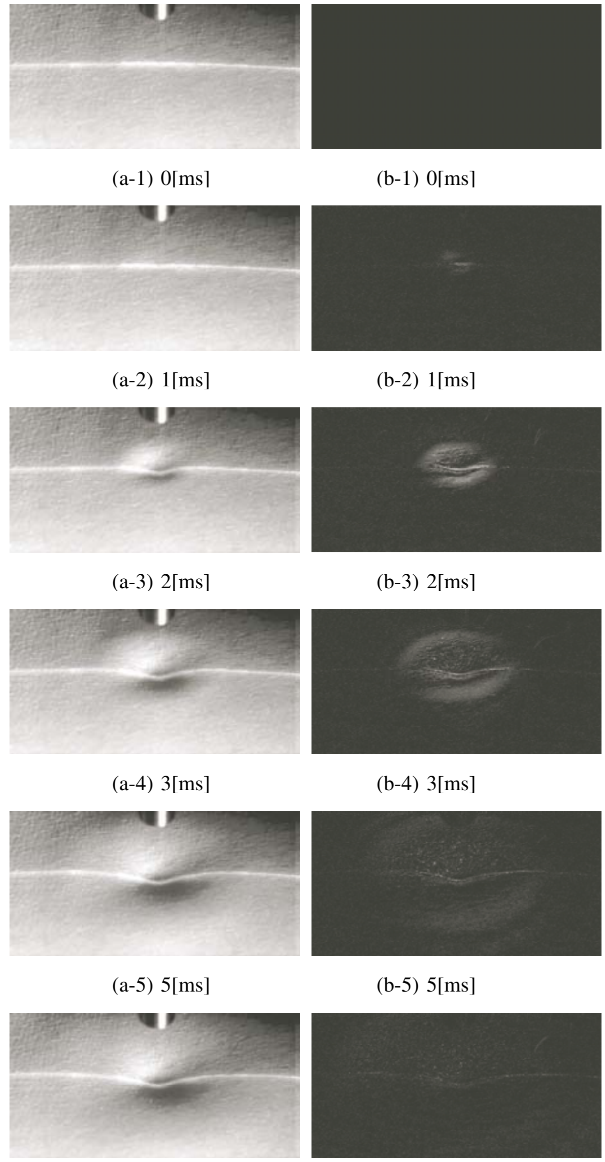
the skin characteristics. A big issue for such a contact approach is that the human skin has a possibility for getting a damage through direct contact between the probe and the skin surface.

On the other hand, there have been several works addressing the measurement of human organs through non contact approach where a force is given to skin by an air jet. Kaneko and Kawahara have developed the co-axis type non-contact impedance sensor where both the air nozzle and the distance sensor are so arranged that they can keep the common axis for ensuring high sensing accuracy[6]. Kawahara and Kaneko have proposed the non-contact stiffness imager capable of displaying the stiffness distribution around the point where the force is imparted[7]. They have also developed the non-contact imager with phase differentiator that can detect a tumor existing in human lung[9]. It has been also reported that the non-contact sensor is applied for measuring human eye stiffness for diagnosing Glaucoma[8]. These non-contact sensors have great advantages in term with avoiding damage to the target and with keeping sanitation. As far as we know, this paper is the first challenge for measuring human skin characteristics by combining both a high speed camera and an air jet.

III. Experiments

A. Experimental System

Fig.2 shows a schematic diagram of experimental system where it is composed of an air jet supply unit and a skin deformation capturing unit. The air jet supply unit is further composed of an air compressor, an air tank, a pressure regulator, a high speed solenoid valve (Satake Co. Ltd.), and an air nozzle for supplying air for skin surface. We would note that the valve can operate with the frequency of 1000[Hz] according to the command signal. As far as we know, this is the valve with the highest response in the world. The deformation capturing unit is composed of a high speed camera (Phantom V7.1, Vision Research Co. Ltd.) with the frame rate of 2000[Hz] and a slit line laser projector (LD-10RCS, Sakai-Galasu Eng. Co. Ltd.) for making a line mark over skin surface. We prepare two computers where PC1 and PC2 are used for controlling the solenoid valve and for capturing the image data during operation, respectively. Fig.3 shows the bird view of the experimental system, where all components are so arranged that they may not interfere with each other. This system configuration allows us to capture the deformation of human skin with each 0.5[ms].



(a-1) 0[ms] (b-1) 0[ms]
(a-2) 1[ms] (b-2) 1[ms]
(a-3) 2[ms] (b-3) 2[ms]
(a-4) 3[ms] (b-4) 3[ms]
(a-5) 5[ms] (b-5) 5[ms]
(a-6) 7[ms] (b-6) 7[ms]
(a) Original image (b) Skin shock wave

Fig. 5. An example high speed camera image

B. Experiments

We executed experiments for 24 subjects with 10 young (20s) and 12 elder (70s). As for the force applying point, we choose a part of forearm with the distance of 5 [cm] from the elbow. The experiments are done with the applying force of 0.18[N], the force applying time of 200[ms], and the data capturing time of 500[ms], respectively. Fig.4 shows a photo during a force impartment where we can observe a skin shock wave which is defined by the traveling wave caused by the impact force. The traveling velocity of the shock wave is approximately 3[m/s], which nicely coincides with that of former works[5]. We would note that such a shock wave disappears when we utilize the solenoid valve whose response is not quick enough. Fig.5 shows the propagation of skin shock wave where (a) and (b) are the original image and the shock wave image, respectively. From Fig.5(b), we can clearly recognize the existence of skin shock wave. Fig.6 shows the skin deformation with respect to time, where blue and red lines are typical responses of 20s and 70s, respectively. An interesting observation from Fig.6 is that there exists a remarkable difference between young and elder subjects especially during the recovery phase, while both are almost same during the force imparting phase. As a general tendency, the skin of young subject can recover even quicker than that of elder one.

IV. Discussion

Experimental results tell us that there exists a remarkable difference between young and senior subjects in recovery phase. In this chapter, we further consider this point by defining a couple of new parameters, d and $b_{\frac{1}{2}}$, where d and $b_{\frac{1}{2}}$ are the displacement at the force applying point and the width at $d/2$, respectively, as shown in Fig.6(b-1). We also introduce the normalized half width with $\hat{b} = b_{\frac{1}{2}}/d$. $\hat{b}$ denotes the relative half width with respect to the displacement and, therefore, we can evaluate the change of the half width irrespective with the absolute value of the vertical deformation. Fig.7 shows the time histories of d, $b_{\frac{1}{2}}$, and $\hat{b}$ during both the force applying and the recovery phases, where red and blue lines correspond to young and elder subjects, respectively. We would note that we handle the data only in the time interval under $d > 0.5$[mm], so that we can avoid the influence of noise. From Fig.7, we can again see much difference between two, especially during recovery phase. Fig.8 shows the correlation between the velocity of skin surface shock wave and age in force applying phase. From this figure, we can recognize that the speed of skin surface shock wave is not much difference with respect to age. Now, we define the recovering velocity by α, where

$$\alpha = \frac{1}{N_r \Delta t} \sum_{i=1}^{N_r} \left| \hat{b}_i - \hat{b}_{i-1} \right| \tag{1}$$

where $\hat{b}_i$, N_r, and Δt are the normalized $\hat{b}$ at time i, the number of data, and the sampling interval, respectively. Fig.9 shows the correlation between α and age. It is interesting to say that there exists a pretty high correlation with $p < 0.01$.

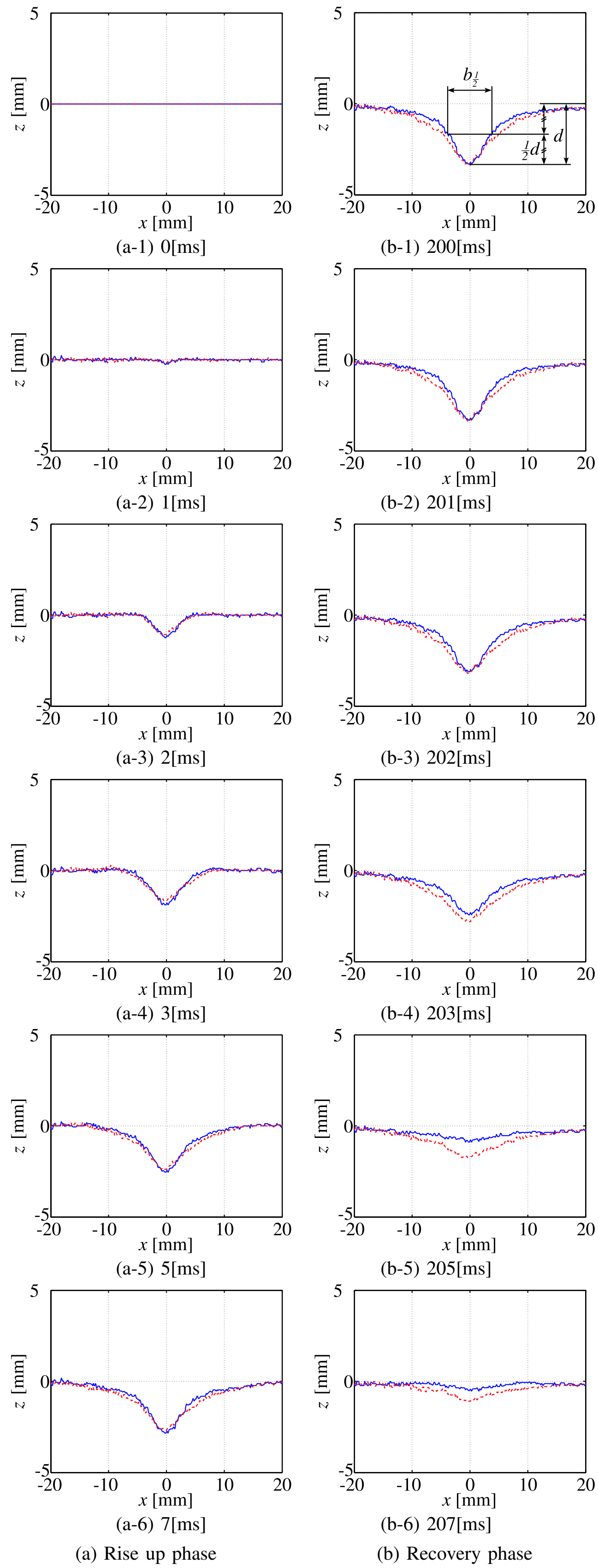
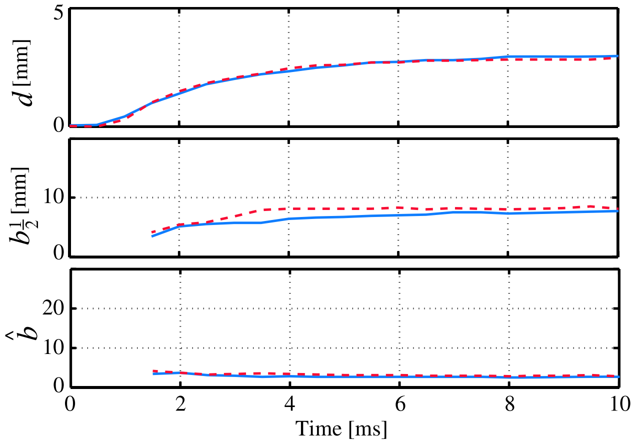
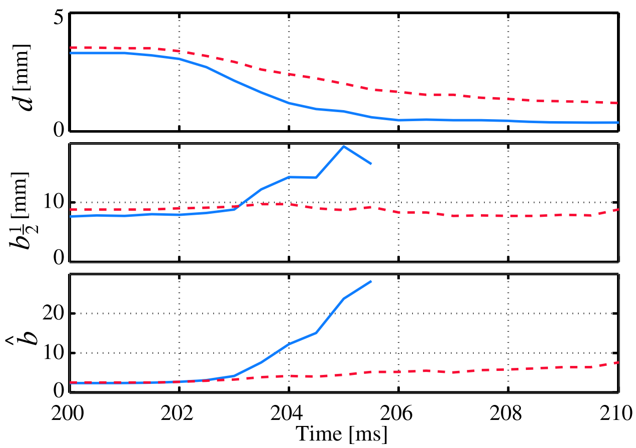


Fig. 6. 2D deformation



(a) Rise up phase



(b) Recovery phase

Fig. 7. Experimental results

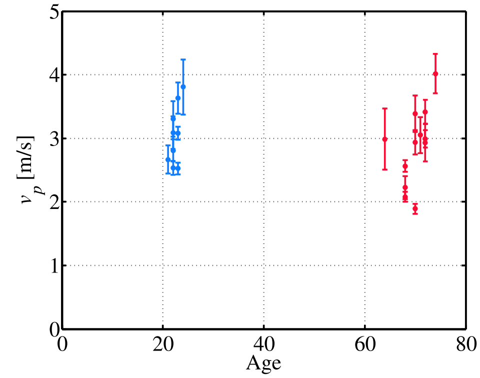


Fig. 8. Relationship between propagation velocity during rise-up phase and age

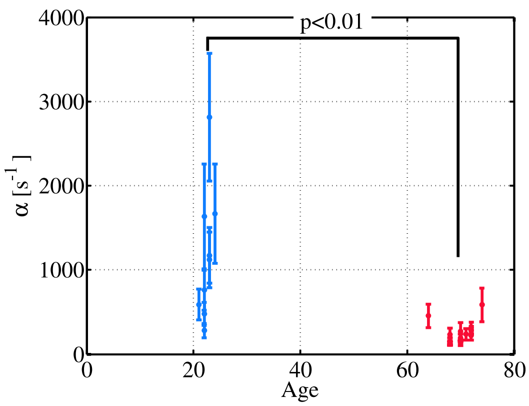


Fig. 9. Relationship between recovery velocity of normalized half band width and age

These discussions suggest that while the traveling velocity of skin surface shock wave does not change heavily with respect to age, the recovery velocity strongly depends on how much age you are. This probably comes from the age dependent damping effect of human skin.

V. Conclusions

By combining both an air jet unit with a high frequency and a high speed camera, we capture the dynamic characteristics of human skin. Through the experiments, we found a skin surface shock wave where it progresses toward the outer direction just like a shock wave when we apply an impulsive force to the surface of human skin. The traveling speed of skin surface shock wave has nearly no correlation with age. On the other hand, we found that the recovery speed of human skin has a strong correlation with age. In our future work, we will consider the relationship between the recovery speed and the local impedance parameters.

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