Biomechanical skin measurement system for analysis viscoelasticity

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Keywords: Linear motor, Actuator, Multi-component load cell, Viscoelasticity

ABSTRACT. We design the skin characteristic measurement system which is assembled with multi-component load cell and linear motor. The multi-component load cell simultaneously measures the normal load (Fz), and monitor (Fx, Fy) with strain gages. Capacity and accuracy of load cell are less than 5 N and 0.1. In this research, designed measurement system applies to determine in-vivo viscoelastic of human skin.

Keywords: Linear motor, Actuator, Multi-component load cell, friction coefficient

Introduction

Always human skin keep in contact with external surface, such as typing and grasping. When the skin come in contact with an object, physical interaction occurs between force and skin. Consequently predicting the physical responses of skin is important factor (i.e. friction coefficient, stiffness, elastic modulus and viscosity modulus) in the fields of medical science, cosmetics products, and robot. In this research, we designed a system which can measure force response of in-vivo human skin on real time. It consists of multi-components load-cell, actuator and fixator. In this research, we designed the in-vivo friction coefficients measurement system for human skin. A multi-component load cell especially was designed to precisely measure normal force in real time.

Measurements system

Fig. 1 shows the skin characteristic measurement system which is composed of actuator, forearm, multi-components load cell, linear motor, and jack. Actuator with 1 µm accuracy was used to apply the probe’s normal force to lower part of skin while maintaining a constant load. We designed the strain gage type multi-component of load cell with 0.1% accuracy and less than capacity of 5 N in order to measure forces in three axis simultaneously. The normal force is measured in z-direction and x, y-direction is used to monitor the probe if it is moving right direction. An arm fixator is possible to control vertical and lateral displacements, and horizontally to fix the arm. The contact-part with a arm is made of a silicon in order to removing unpleasantsness. We set up a guide device previously to mark the point on the forearm which is contacted to probe points. Moreover, Laser displacement sensor used to keep distance between finger-tip and probe and unified contact position. We used aluminum probe which are semi-sphere with radius of 2 cm. We have calibrated multi-component load cell in order to analyze accuracy. The calibration curves show in Fig. 2 As can be seen in Fig. 2, the cross effect errors x, y, z direction are calculated from the calibration curves: the error data are shown in Table 1. We set the equations to compensate cross effect errors and the parameters of inverse matrix in equations are shown in Table 2. We are confident that multi-component load cell is effective sensor in measuring in-vivo viscoelasticity properties of human skin with accuracy of 0.1%.
The arm is horizontally fixed on the arm-fixator and marked to contact parts with using a guide device then measuring viscoelastic properties of skin with a constant velocity and up to the given loads. Each hemisphere aluminum and silicon probe which has regular radius 10 mm is used, and viscoelasticity properties is measured according to probes and skin hydration at the same time. We use LabVIEW™ and Matlab™ to analyze received data with 200 Hz through a National instrument DAQ.

Results and discussion

Fig. 3 show compression and relaxation force, when give a pressure to fingertip with constant speed 1mm/s and 3.5mm of indentation displacement. The spectrum have some noise but this error is less than 0.05 N, hence this measurement was very precisely.
The model we propose to use to describe compression is General Solid Model and stress relaxation is Maxwell Model. General solid model is

\[
F(t) = \frac{k_1k_2}{k_1 + k_2} t - \left( \frac{k_1k_2}{k_1 + k_2} \right)^2 \mu + ce^{-\frac{k_1+k_2}{\mu}}
\]  

(1)

Fig. 4 shows model fit of general solid model and spring and damping coefficient shows Table 3. Maxwell model is

\[
F(t) = k(x_0 - x_1)e^{-\frac{t}{\lambda}} + F_1
\]

(2)

Fig. 5 shows model fit of maxwell model and spring and damping coefficient shows Table 4. We can find out that the forearm shows lowest spring and damping coefficient both of compression and relaxation. In this kind of result, because forearm is more distant with bone tissue.
**Table 3** Model Parameters of General Solid Model

<table>
<thead>
<tr>
<th>subject</th>
<th>$\mu$</th>
<th>$k_1$</th>
<th>$k_2$</th>
</tr>
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<tbody>
<tr>
<td>The index finger</td>
<td>11038</td>
<td>0.2824</td>
<td>39.6091</td>
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<tr>
<td>The middle finger</td>
<td>709</td>
<td>0.6107</td>
<td>14.6833</td>
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<tr>
<td>The ring finger</td>
<td>14662</td>
<td>0.3437</td>
<td>50.1421</td>
</tr>
<tr>
<td>The baby finger</td>
<td>14913</td>
<td>0.6747</td>
<td>70.6043</td>
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<tr>
<td>Forearm</td>
<td>320</td>
<td>0.2294</td>
<td>6.0179</td>
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</tbody>
</table>

**Table 4** Model Parameters of Maxwell Model

<table>
<thead>
<tr>
<th>subject</th>
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</tr>
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<tbody>
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<td>The middle finger</td>
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<td>The ring finger</td>
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<td>The baby finger</td>
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<tr>
<td>Forearm</td>
<td>0.0289</td>
<td>0.00935</td>
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</table>

**CONCLUSION**

In-vivo skin characteristic between probe and human skin are measured by multi-components load-cell. We measured dynamic mechanical interaction between skin and probe applied normal to the skin. We calculated damping coefficient, spring coefficient with General Solid Model and Maxwell Model. This measurement system can help us to appreciate the in-vivo skin which still remains very complex.

**References**