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Food Simulator

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Abstract

The Food Simulator is a haptic interface that presents biting force. A taste of food arises from mixture of chemical, auditory, olfactory and haptic sensation. Haptic sensation while eating is a remained problem in taste display. The Food Simulator generates force to the user's teeth to display food texture. The device is composed of four linkages. The mechanical configuration of the device is designed to fit to the mouth. A force sensor is attached to the end effecter. The Food Simulator generates force according to the force profile captured from a real food. The device is integrated with auditory and chemical display for multi-modal sensation in taste.

Key Words: haptic, food texture, taste

1. Introduction

Taste is the last frontier of virtual reality. Taste is very difficult to display because it is multi-modal sensation composed of chemical substance, sound, smell and haptics. Taste perceived by the tongue can be synthesized from five basic taste. Sound is also easy to synthesize. Smell display is not popular but smell can be easily displayed using vaporizer. Remained problem in taste display is haptics.

The project has two goals. The first is development of haptic interface for biting. It should have a suitable shape for putting into the mouth. The device should be effectively controlled to simulate food texture. The second goal is to present multi-modal sensation. Biting sound and chemical taste should be integrated with the haptic interface.

In order to achieve these goals, we developed a haptic interface that presents biting force. The device is composed of a 1DOF (degree-of-freedom) mechanism that is designed to fit to the user's mouth. The Food Simulator generates force according to the captured force of real food. A film-like force sensor is used to measure biting force of real food. A force sensor is installed in the Food Simulator and the device is actuated using force control method.

The Food Simulator is integrated with auditory and chemical sensation of taste. Sound of biting is captured by a bone vibration microphone. The sound is displayed using a bone vibration speaker. It is synchronized with biting action. Chemical sensation of taste is displayed using an injection pump and a tube installed at the end effecter.

2. Related work

There have been numerous work on visual and auditory displays. Haptic interface for hand or finger is one of the major research field in virtual reality. Smell display is not popular but smell can be easily displayed using vaporizer. There are some work on smell displays [Nakamoto,T, et.al., 1994] [Davide,F. et.al. 2001].

Taste is very difficult to display because it is a mixture of multi-modal sensation. Taste perceived by the tongue can be measured using a biological membrane sensor [Toko, K,. et al.,1994,1998]. The sensor measures chemical substance of five basic taste; sweet, sour, bitter, salty and “Umami.” Umami is the fifth basic taste created by glutamate [Kawamura,Y., Kare,M.R., 1987]. Based on the data from the sensor, arbitrary taste can be easily synthesized from the five elements of basic taste.

There are some work in measuring biting force. A multi-point force sensor is used to measure force distribution on the teeth [Khoyama,K. et al., 2001,2002]. Sensory property of texture of real food is also studied [Szczesniak,AS. 1963, 2002]. However, research on haptic display for biting is very rare.

Dental schools have been working on training of chewing. A master-slave manipulator for mastication was developed [Takanobu,H. et.al. 2002]. The robot applies force to the patient's teeth according with manipulation of the doctor.

3. System Configuration of the Food Simulator

We developed a haptic devise that simulates biting force. The shape of the device is designed to fit to the user's mouth. Configuration of the mechanical linkage is determined considering structure of the jaw. The shape of the linkage enables force application to the back teeth. Considering sanitary issues, the end effecter is covered with cloth and rubber. The cover is disposable. Figure 1 shows overall view of the apparatus.

The haptic device is composed of a 1DOF mechanism The device employs four linkages. Figure 2 illustrates its mechanical configuration. The linkages are driven by a DC servo motor (MAXON Motor, RE25). The user bites the end effecter of the device. Working angle of the end effecter is 35 degrees. The maximum generated force to the teeth is 135N. A force sensor is attached at the end effecter. The sensor detects force applied by the user's teeth.

The device is controlled by a PC (Pentium 4, 2GHz). Update rate of force control is 1700Hz.

Figure1. overall view of the apparatus

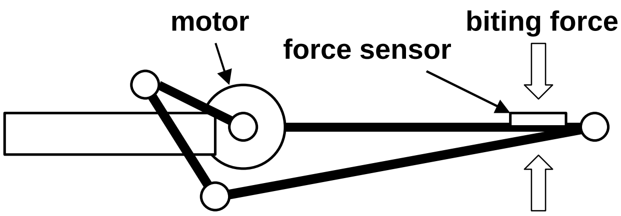

Figure2. mechanical configuration of the haptic device

Servo controller of the device is implemented using following equation:

$$Power = K_p(\theta_d - \theta)(1.0 + K_f Force) - K_v\dot{\theta}$$

where:
Kp: position feedback gain
Kv: velocity feedback gain
Kf: force feedback gain
Force: measured force by the FlexiForce sensor

The Kf is added for presentation of hard surface of a virtual food. The motor generates force according with applied force by the user. The method eliminates displacement of the virtual surface. Figure 5 and 6 shows effect of the method. Position of the teeth is maintained while the user bits the device strongly (over 70N).

4. Measurement of Biting Force of Real Food

The Food Simulator generates force according to the captured force of real food. A film-like force sensor (Kamata Industries, FlexiForce) is used to measure biting force of real foods. Thickness of the sensor is 0.1mm. Sensing area is a circle whose diameter is 9.5mm. Sensing range is 0 to 110N. The maximum sampling rate is 5760Hz. Figure 3 shows overall view of the sensor.

Biting force is measured by putting this sensor into the mouth with a real food. Figure 4 shows the scene of the participant of the experiment, who is biting a cracker and the FlexiForce sensor.

Figure3. force sensor

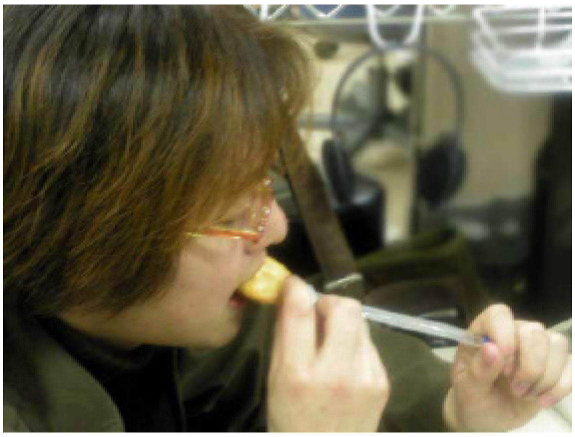

Figure4. force sensor and real food

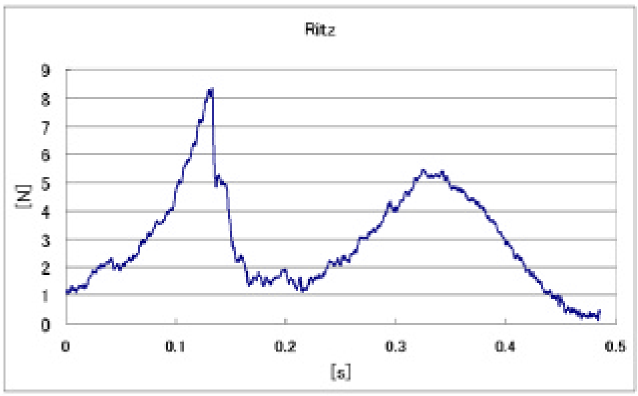

Figure 5. measured force of a cracker

Figure 5 shows measured biting force of a real cracker. Two peaks are appeared in the profile of the measured force. The first peak represents destruction of the hard surface of the cracker. The second peak represents destruction of its internal structure. Figure 6 shows measured biting force of a real cheese. The slope appeared in the figure represents elastic deformation of the cheese.

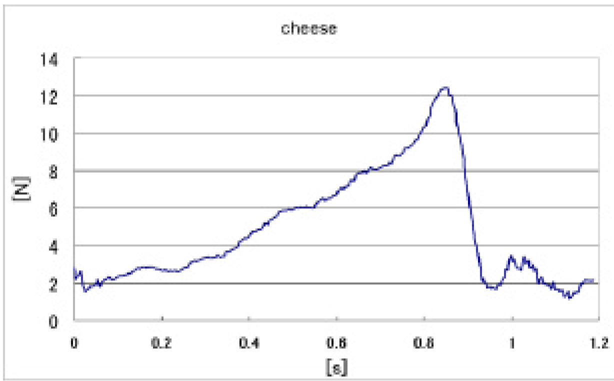

Figure 6. measured force of a cheese

5. Method of Generation of Biting Force

The Food Simulator generates force according to the captured force of real food. The FlexiForce sensor is installed in the Food Simulator and the device is actuated using force control method. The profile of the biting force of the real food is realized by force control of the device.

We simulated two food:

(1) cracker

The force control of the device has two stages (Figure 7). First, the device apply force to maintain its position. This process presents hard surface of the virtual cracker. When the biting force exceeds the first peak the force control turns into the second stage. The device generates the same force as measured from the real cracker. This stage is controlled by open loop. Destruction of internal structure of the virtual cracker is simulated by the second stage.

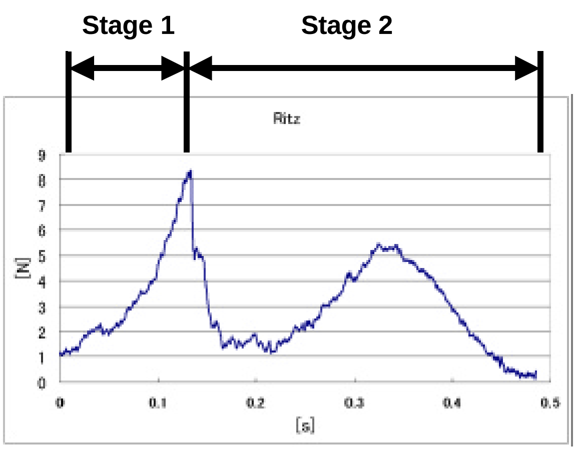

Figure 7. Method of simulation of cracker

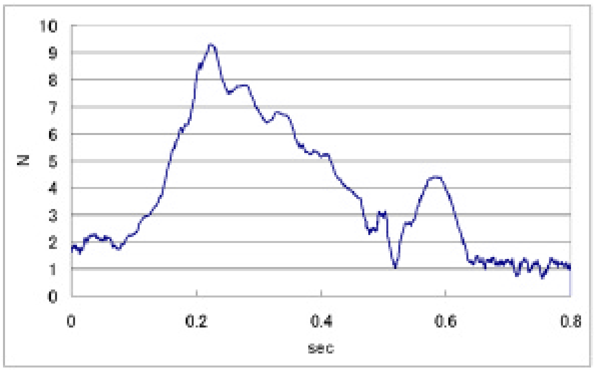

Figure 8. Measured force of virtual cracker

Figure 8 shows measured force of virtual cracker displayed by the Food Simulator. The profile of the measured force has two peaks, which is as same as the real cracker. The shape of the profile is different from the real cracker. The difference seems to be caused by the open loop control.

(2) cheese

Figure 9 shows two stages of force control for a cheese. In order to simulate elastic deformation of the cheese, we estimated the spring constant of the cheese form the data. The device generates force according to the spring constant to display elasticity of the virtual cheese. When the biting force exceeds the peak the force control turns into the second stage. The device generates the same force as measured from the real cheese. This stage is controlled by open loop. Destruction of the virtual cheese is simulated by the second stage.

Figure 10 shows measured force of a virtual cheese displayed by the Food Simulator. The profile of the measured force is similar to the real one.

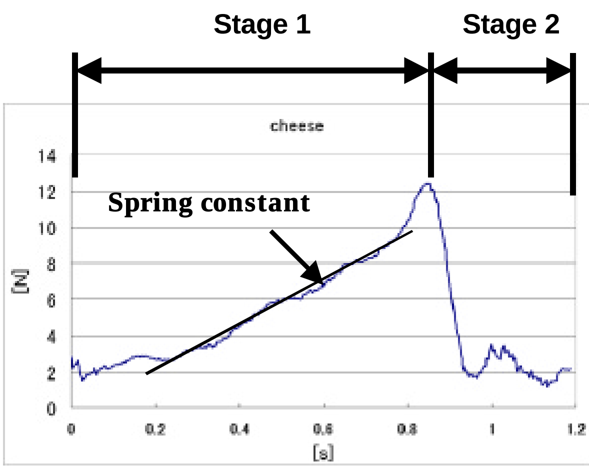

Figure 9. Method of simulation of cheese

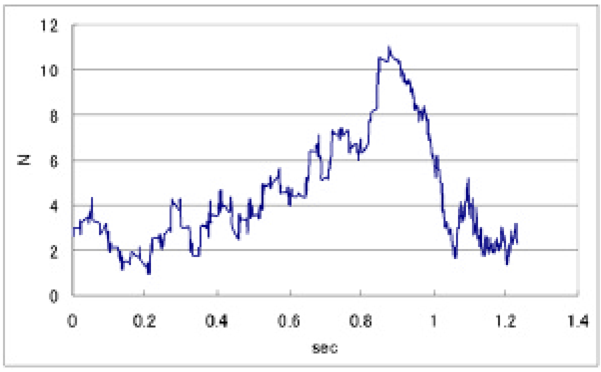

Figure 10. Measured force of virtual cheese

6. Enhancement of Crispness

We tried presentation of a crispy food. “Senbei” or rice cracker is a typical crispy food. Figure 11 shows biting force of a real rice cracker. Position of the teeth is also measured by biting the linkages described in the section 3. The linkage is applied at the other side of the back teeth. The result indicates several large peaks. These sharp peaks are closely related to the crispness of the rice cracker. The peaks are difficult to display by using the simple recording-playback method described in the section 5.

We therefore introduced position control in the second stage to display the peaks. Two points are set in the destruction process to apply force to the teeth. Figure 12 shows biting force displayed by the device. The result shows that two sharp peaks are created. This process enhances crispness of the rice cracker.

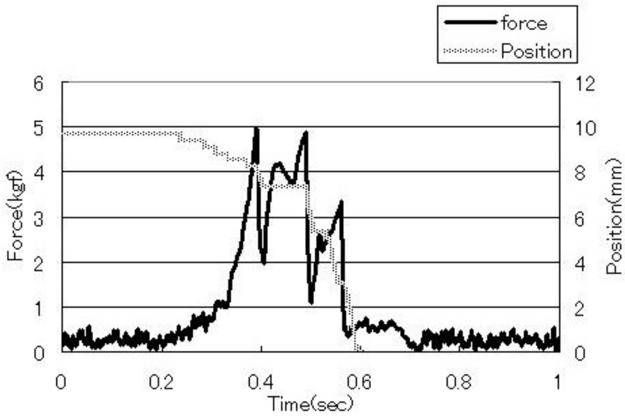

Figure 11. Measured force of a real rice cracker

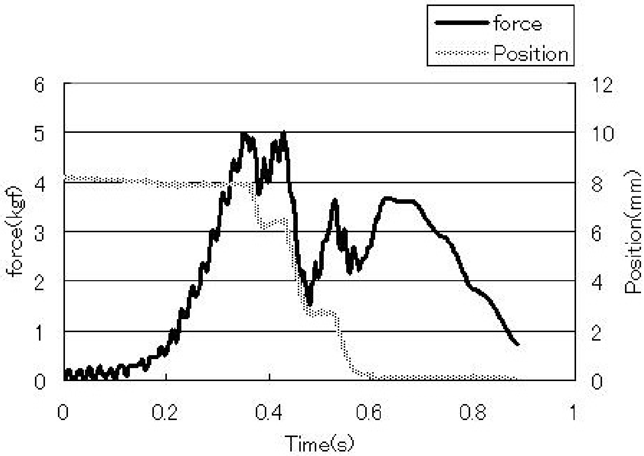

Figure 12. Measured force of a virtual rice cracker

7. Multi-sensory Display

The second goal of the Food Simulator project is to present multi-modal sensation. We tried integration of multi-modal display with the haptic interface.

(1)Sound

Sound is closely related to biting action. Destruction of a hard food generates sound. The sound is perceived by vibration of the bone. Bone of the jaw mostly contributes to the sound of biting. In order to display the sound we recorded sound of a real food by using a bone vibration microphone. Figure 13 shows a scene of recording. The bone vibration microphone is inserted into the ear. An accelerometer is installed in the microphone and picks up vibration of the bone of the jaw.

The recorded sound is displayed using a bone vibration speaker. Figure 14 shows the bone vibration speaker. The speaker generates vibration in the bone of the jaw. The sound is synchronized with biting action. For example, sound of a virtual cracker is displayed at the beginning of the second stage of the force control shown in the Figure 7.

Figure 13. Measurement of sound of biting

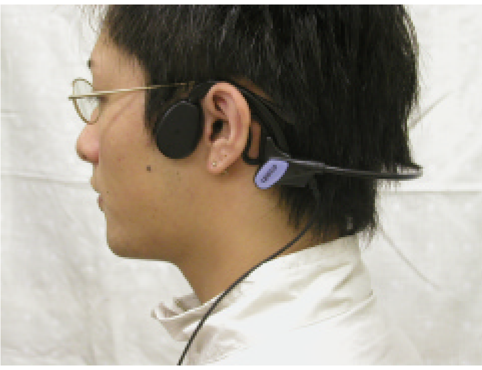

Figure 14. Bone vibration speaker

(2) Chemical taste

Chemical sensation perceived by the tongue greatly contributes to sense of taste. Arbitrary taste can be synthesized from five basic taste: sweet, sour, salty and Umami. Table 1 indicates typical chemical substance for each basic taste.

Chemical sensation of taste is presented by injecting a small amount of liquid into the mouth. A tube is attached to the end effecter of the haptic interface. Figure 15 shows the tube at the top end of the linkage. The liquid is transferred by using an injection pump (Nichiryo, DDU-5000). Figure 16 shows overall view of the injection pump. Injection of the liquid is synchronized with biting action. The pump provides 0.5ml for each bite.

Basic taste	Chemical substance
sweet	sucrose
sour	tartaric acid
salty	sodium chloride
bitter	quinine sulfate
Umami	sodium glutamate

Table 1. chemical substance for basic taste

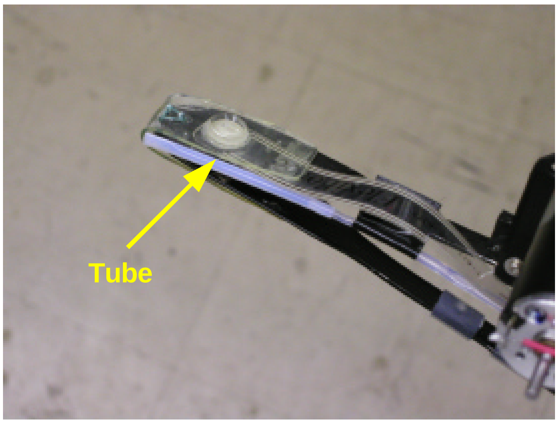

Figure 15. Tube for injection of chemical taste

Figure 16. Injection pump

(3) vision and smell

Visual and olfactory sensation of food occurs independently from biting action. Thus current prototype of the Food Simulator doesn’t support these sensations. However, HMD can provide visual of food. Also, smell can be displayed by a vaporizer.. These displays can be easily integrated with the haptic interface.

9. Applications for Food Simulator

Biting exercise contributes to human health. There are many application areas for the Food Simulator. For example;

(1) Training
The Food Simulator can be programmed to generate various forces other than that of real food. Elderly people can practice biting in reduced resistance to the teeth. On the other hand, increased resistance enables younger people to experience difficulty in biting of elderly people.

(2) Entertainment
The Food Simulator can change properties of food while chewing. A cracker can be suddenly changed into a gel. The user enjoys funny experience on chewing. This kind of entertainment contributes to chewing capability of children.

(3) Food design
Preferred resistance to the teeth can be found using the Food Simulator. The findings contribute to designing a new food.

10. Conclusions

This paper has shown a haptic device that simulates sense of biting. The device presents physical property of food. The Food Simulator is integrated with auditory and chemical sensation of taste.

The device can be utilized in experiments for human perception of taste. Taste is multi-modal sensation so that it is very difficult to control modality by using real food. The device displays food texture without chemical taste. This characteristics contributes to experiments for modality integration. Future work will include psychological study of sensory integration regarding taste.

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