Sensors and Materials, Vol. 13, No. 2 (2001) 107–117
MYU Tokyo

S & M 0434

Development of High-Speed Pressure Distribution Measurement System and Its Application to Food Texture Characterization

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(Received November 1, 2000; accepted March 5, 2001)

Key words: tactile sensor, texture, pressure distribution, sampling speed, measurement

I-scan, the pressure distribution measurement system developed by Tekscan Inc., has the capacity for many applications in various fields because of its unique properties. Its basic system is described in this paper, and a modified system which is supplied for measuring in tests in higher sampling rates with food texture characterization is also explained in detail in terms of its improvements and effects.

1. Introduction

The uniqueness of the pressure distribution measurement system, I-Scan, by Tekscan Inc., is that it is easy to measure surface/planar distribution of force on a material with its one sensor-sheet and quick to display measured results on a desktop image by operating its software: the principle, structure and many applications of this system are described in ref. 1. The applicable area of the pressure distribution measurement system (PDMS) is so extensive that it is used in not only technological/scientific but also dental, medical and auto (car)-industrial fields: these examples are given in refs. 2 and 3.

Many applications of PDMS developed thus far have been provided for analysis of static or semi-static phenomena. Those measurements can be carried out with a sampling rate below 100 Hz, because the standard sampling rate of the system is set at 100 Hz. However, there are some requests for applications that can be used in dynamical phenomena: for instance, PDMS is used in the auto-industry for applications such as vibration tests of parts, analysis of movements of passengers in a car and measurement of sealing pressure distribution in engine gaskets. (ref. 4) The supplied applications for these cases function well in analyzing variable pressure distributions because such variations can be captured sufficiently well at a sampling rate of 100 Hz.

Currently, the auto-industry requires a faster sampling rate for PDMS to analyze tests on the safety of drivers/passengers in car accidents. Some say that the sampling rate should be up to 5,000 Hz for satisfying such needs. The sensor system can be customized to achieve a sampling rate of 1,000 Hz in Tekscan, and thus far 1,000 Hz is the maximum for the current system. In the next section we present a sensor system which has been developed to measure high-speed events and describe how it has been realized; in the third section we introduce an application of this system: analyzing the pressure distribution between food and the tongue in human mastication of several types of foods. We also refer to the requirements that still remain for our new system.

2. Pressure Distribution Measuring System

2.1 *Block Diagram*

We initially provide a block diagram on pressure distribution measurement with the I-Scan system. The diagram is composed of four parts: 1) sensor sheet, 2) connector, 3) interface card and 4) software, and these parts are respectively joined with arrows indicating outputs/signals as shown in Fig. 1.

2.2 *PCI bus*

Since the Industry Standard Architecture bus (ISA-bus) has been expanded into interface card systems in direct memory access (DMA), many PDMSs have introduced

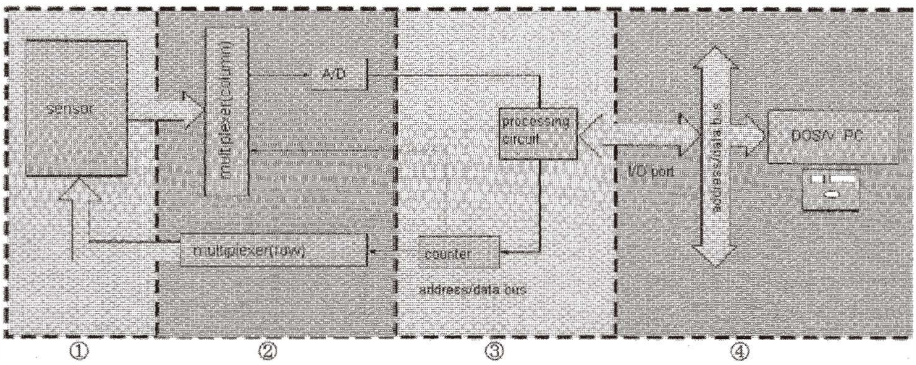
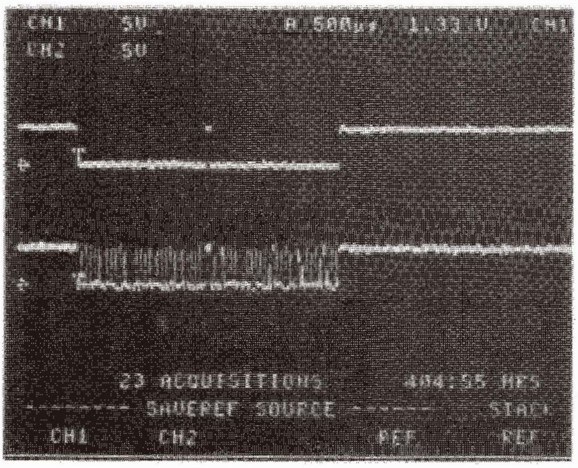


Fig. 1. Block diagram of Tekscan system: ① the sensor sheet is made of polyester film of 0.1 mm thickness and printed electrodes of pressure-sensitive ink on its surface; ② the connector is composed of two multiplexers for measuring and an A/D converter; in addition, it functions to fasten the sensor sheet; ③ the interface card is formed by memory and interface circuits to control scanning of the row and column electrodes; ④ the software analyzes data from the sensor.

interface card systems with ISA-bus for DMA, but the transfer rate in DMA through ISA-bus is a bottleneck for data transfer which determines the sampling rates in a system.

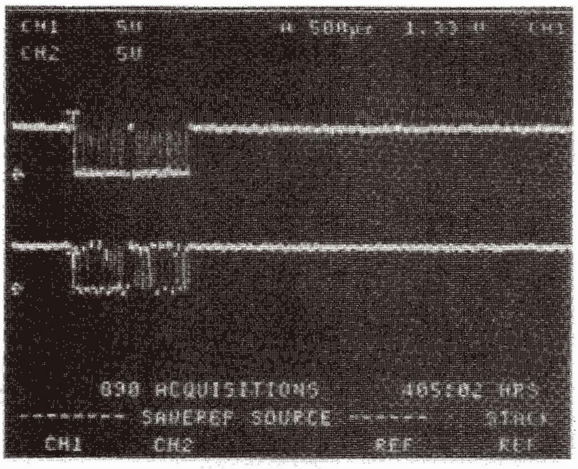
Our PDMS introduces a different type of interface card system that works on Peripheral Component Interconnect bus (PCI-bus) for DMA to obtain faster transfer of sampling data than the other PDMs that have introduced the usual interface card systems working on ISA-bus for DMA. The PDMS with PCI-bus performs more than twice as fast as the system with ISA-bus. (Fig. 2)

(a)



ISA (2.4 msec.)

(b)



PCI (1.[illegible] msec.)

Fig. 2. Two oscilloscope displays of signals: on (a) ISA-bus and on (b) PCI-bus.

2.3 *Speeding up scanning*

Let us show how the scanning is carried out in the PDMS.

Figure 3 shows the chart of a single PDMS. The left rectangular area seen as a mesh is a sensing unit composed of pressure-sensing electrodes (the scanning points/cells consist of 2288 (i.e., 44 rows by 52 columns) electrodes); the right diagram indicates the handling system and processing flows in relation to the respective units. Figure 4 shows circuits at the terminal of a sensor-sheet. In a scanning period, 44 passive (rows) electrodes are held at a constant current/voltage, while 52 active (columns) electrodes are varied for current/voltage under the control of the processing unit to measure resistance values at each scanning cell, where active and passive electrodes meet at right angles to each other.

The driving circuit and multiplexer unit run for each scan to successively select active electrodes which turn on/cut off electric currents by programmed procedure, and compute the force on the respective contact cell based on its obtained value of resistance.

We describe our method for the modification of speeding up scanning in the above-mentioned system: It is clear that the acceptable way to achieve a high scanning rate without remaking the main hardware is to modify our processing circuit to increase the number of times of scanning with one sensor sheet. Therefore, we have attempted to improve circuits in the driving module to establish a ten times shorter total period required for each scan by selecting fewer sensing cells which are sufficient to maintain a permissible level of accuracy. The results are given in the following.

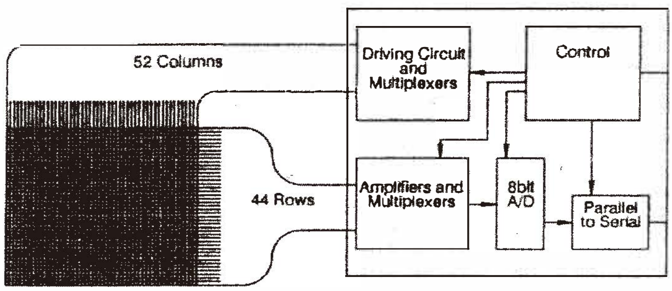


Fig. 3. Block diagram of the handle system.

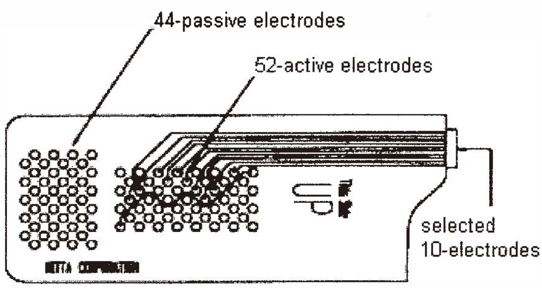


Fig. 4. Circuit of the TAB-area at the terminal of a sensor-sheet.

2.4 *32-bit Driver, Windows software*

We must refer to which software is in use during scanning with the system: we provide a PCI interface card for operating with application software. The current software runs on Windows, and it has many functions for analyzing the data from the sensor.

2.5 *Newly designed sensor system*

Our modified PDMS is set to be capable of having 200 sensing points at 1,200 Hz of its sampling rate. In a comparative inspection of this system and another, we adopt a load cell, Nitta 6 axes force sensor system, as that one; its capability of scanning at the maximum 8,000 Hz satisfies our demands of sensor response in high-speed tests.

The fixture shown in Fig. 5 is conformed by the equipment for free fall of an object (rubber ball) from a height of several inches to the embedded load cell. In this inspection, the modified PDMS performs very well at scanning: its responses coincide exactly with those of the comparative sensor, as seen in Fig. 6 (as output values vs time in a graph). Figure 7 displays the correspondence between the successive desktop pictures of pressure distribution responses (above) and the graph of force vs time (below); both are scanned and calculated by the new system. Figure 8 shows the two graphs of force vs time obtained in the same condition for an event: the analog output from one cell sensor vs time is given below, and that from the load cell vs time is given above.

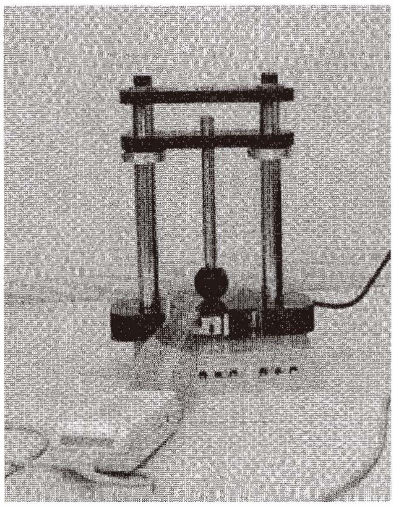


Fig. 5. New system and comparative force sensor in our tests.

Note that there is a relation between the sampling rate and the number of sensor cells for one sensor sheet as follows:

The total scanning time on a sensor sheet = #{scanning cells in use} * {scanning time for one cell}, where #{_} denotes "the number of {_}."

Note that #{scanning cells/sec.} = 1/{scanning time, at one cell}, we have:

The sampling rate of a system (Hz) = #{scanning cells /sec.} / #{scanning cells on a sensor-sheet in use}
=1 / (#{scanning cells on a sensor-sheet in use} * {scanning time for one cell}).

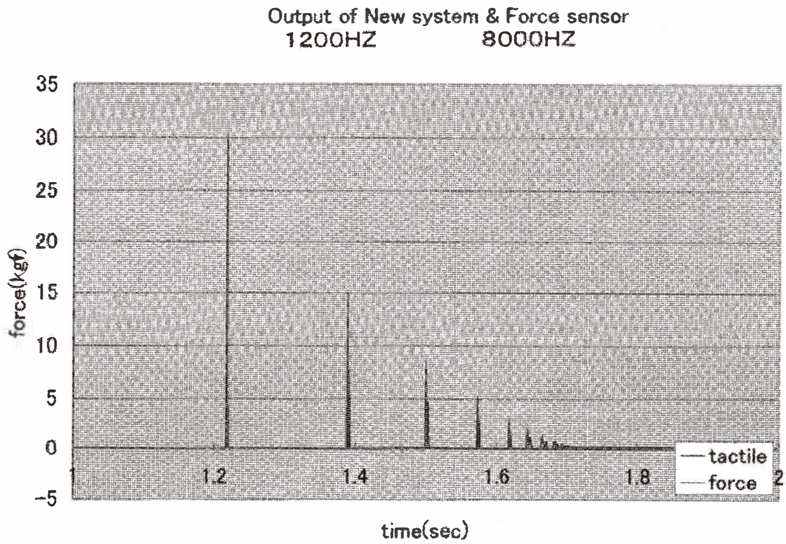


Fig. 6. Output vs time of new system and force sensor in comparison.

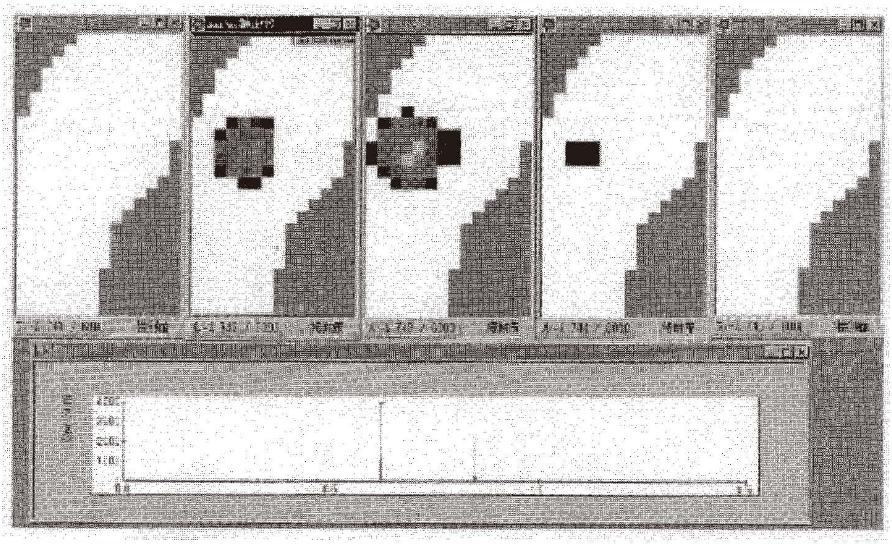


Fig. 7. PC displays of new sensor system.

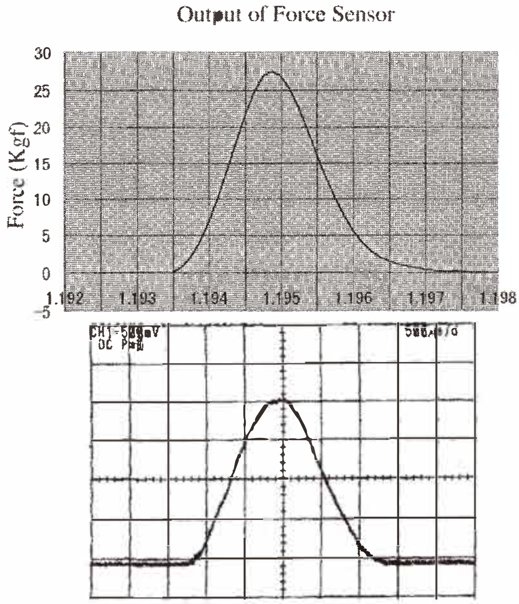


Fig. 8. Output vs time for force sensor and new system restricted to one cell sensor in comparison.

3. Application to Food Texture Characterization and Discussion

3.1 *Food texture characterization*

The modified PDMS has capabilities in various technological/scientific fields. Let us introduce an interesting application of our system in this section: measuring the pressure distribution in human mastication of food reported in a previous study.[5] The new system is suitable for this application because the required sampling rate of 100 Hz is acceptable and the number of sensing cells can be set at fewer than 2,000. A material is put on a sensor sheet and masticated at once by a person in each experiment. (See Fig. 9)

There are different characteristics of texture for five kinds of foods used as samples and there also exist differences in the times/intervals and the maximum pressure of each mastication among individual examinees. Figure 10 shows the findings that the characteristics of the foods appear in the first mastication. Figures 11 and 12 are sets of graphs of pressure vs time for the first mastication at sampling rates of 1,200, 600, 300 and 100 Hz of a rice cracker/cheese, respectively. The effect of the high sampling rate is very clear in comparison with the curves for smoothness and continuity.

However, the appropriate sampling rate may vary with the texture of the food: foods of hard texture such as rice crackers need rapid sampling whereas those of soft texture such as cheese do not require as much. (It can be seen in Figs. 11 and 12 whether the dots of the sampling data in each graph form a 'curve' or not.) The outcome of this study indicates that a sampling rate of 1,200 Hz is sufficiently high to analyze human mastication. (ref. 5)

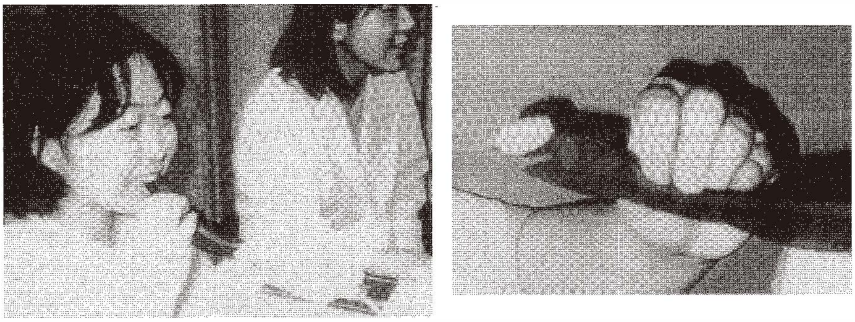


Fig. 9. Measuring mastication of food. (an experiment of masticating food: the sensor-sheet with food set on it to masticate together)

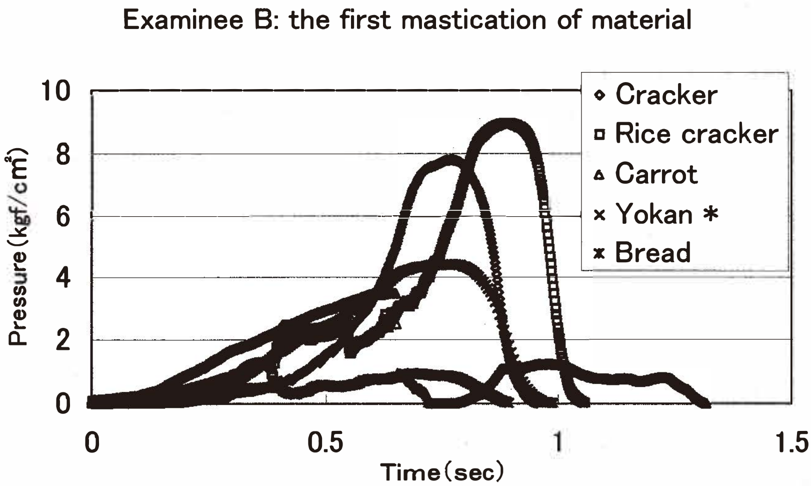


Fig. 10. Comparative graph of output vs time for the first mastication at five samplings of different foods. (Yokan: A Japanese sweet; a block of set red bean paste gel)

3.2 *Discussion*

However, there are still more requirements of the modified system to satisfy in future. We refer to the principal objects as follows:

1) higher sampling rate, 2) more 'scannable' sensing cells, 3) higher density of sensing cells and 4) more accuracy .

1) and 2) mainly depend on improvements of hardware, especially the multiplexers and A/D-converter in the connector, to deal with control-signals/output-response in higher speed/frequency, while 3) and 4) essentially require a new sensor-sheet design such as smaller 'mesh' printed patterns of its pressure sensitive ink made of more sensitive materials to measure force.

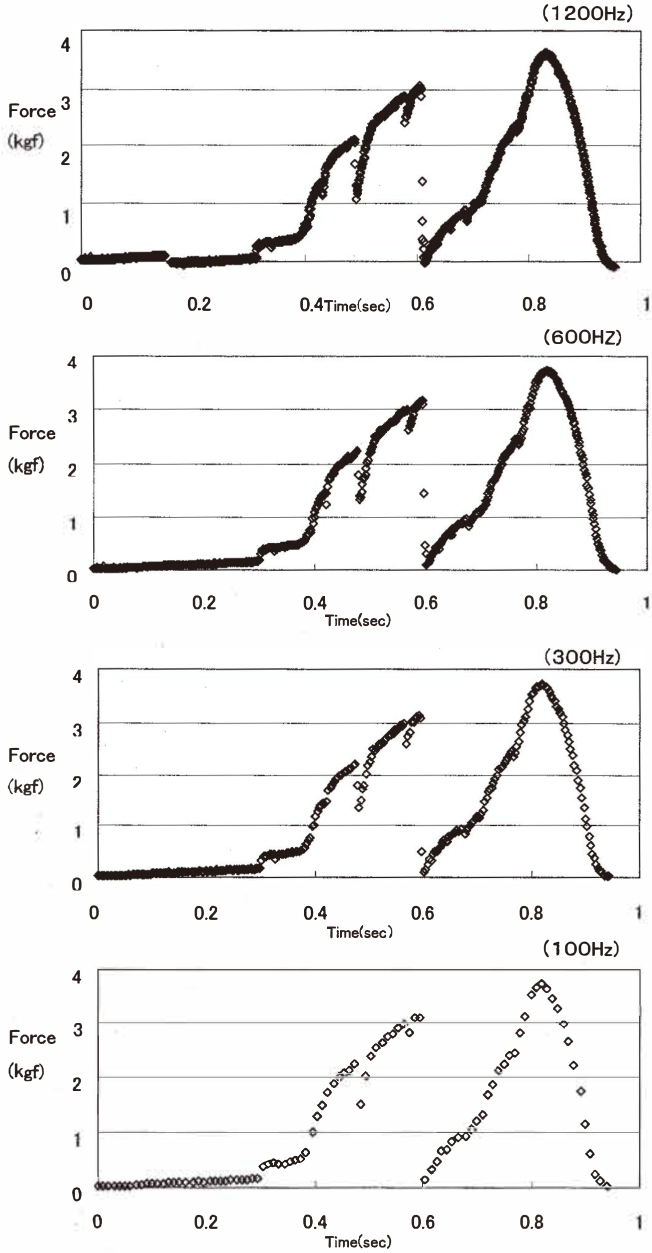


Fig. 11. Gaphs of output vs time for the first mastication at sampling rates of 1,200, 600, 300 and 100 Hz in a trial with a rice cracker.

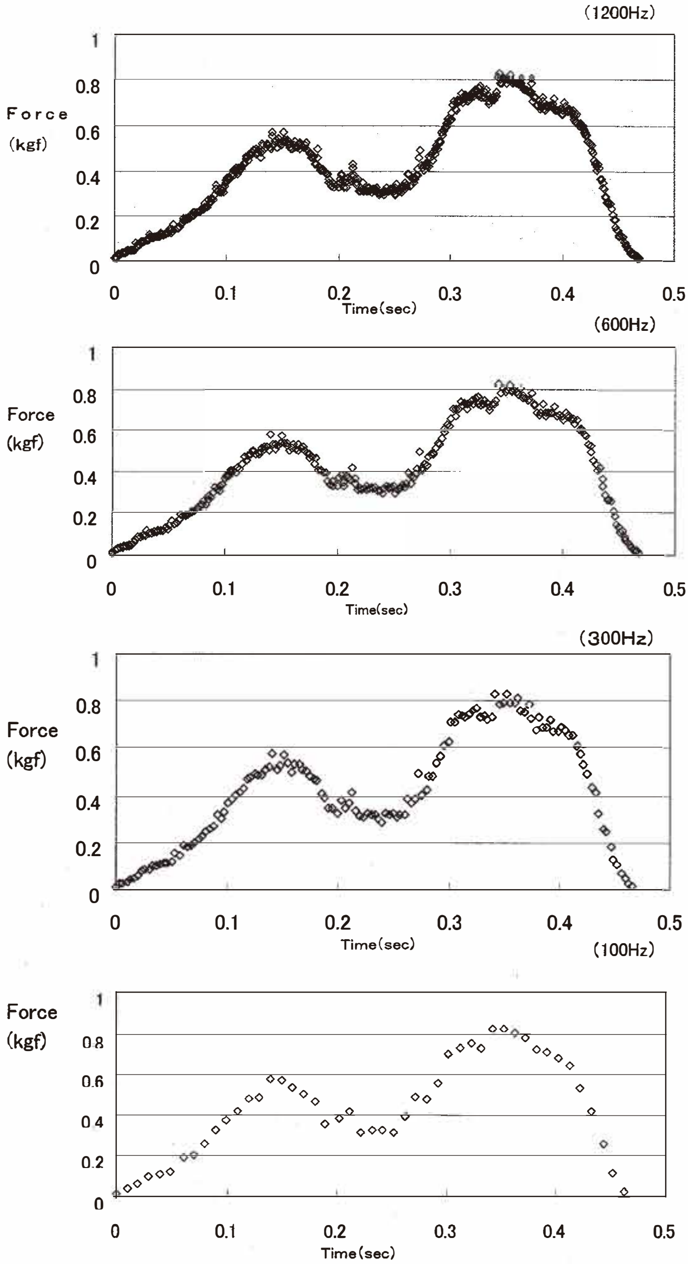


Fig. 12. Graphs of output vs time for the first mastication at sampling rates of 1,200, 600, 300 and 100 Hz in a trial with cheese.

4. Conclusions

A new pressure distribution measurement system has been developed and applied in a practical use as described: it is capable of scanning at a sampling rate 1,200 Hz, transferring data in high potential with a PCI-board and running on Windows application software through an optimized 32-bit driver. The capacities of this system can realize effective measurement in various fields as in the study of human mastication; we will address improvements such as faster sampling rate (in accuracy), higher scanning density of a sensor sheet and others.

Acknowledgements

We are particularly indebted to Dr. Kaoru Koyama at the National Food Research Institute of the Ministry of Agriculture, Forestry and Fisheries in Japan for her studies supported by the Society for Techno-innovation of Agriculture, Forestry and Fisheries with a food-developing project using high-performance biosensors. We thank her for her many suggestions and for providing the data obtained in the experiments.

References

1 C. Malacaria: Sensors Magazine (1998) 102.
2 K. Abe, et al.: PO Academy-Journal **7** (1999) 35.
3 T. Morita, et al.: Seikei-Kakou **8** (1996) 249 [in Japanese].
4 K. Yokoyama, et al.: JASE **49** (1995) 57.
5 K. Kohyama and M. Nishi: J. Texture Studies **28** (1997) 605.