Telemetric Artificial Skin for Soft Robot

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ABSTRACT

Robots of new generation to coexist with human harmoniously will require the sensor skin that is soft to cover the whole body. But it would be very difficult to fabricate such a skin with existing technology, because it is laborious to place and wire vast amount of sensor elements on the 3-dimensionally configured robot surface. In this paper we propose a novel method to fabricate such a sensor skin. The skin contains sensor chips which receive the electrical power and transmit the tactile signal without wires. The skin is configured in an arbitrary shape easily, and it is elastic and tough because each sensing element does not need any fragile wires. The fabrication of the prototype telemetry tactile chip and experimental results of multiple chip signal detection are shown.

INTRODUCTION

The robot working closely with human will require the sensor skin that is soft to cover the whole body [1] . But it would be very difficult to fabricate such a skin with existing technology[2,3,4], because it's laborious to place and wire vast amount of sensor elements on the 3-dimensionally configured robot surface.

In this paper we propose a novel method to fabricate such a tactile sensor skin based on telemetry. The skin can be configured in an arbitrary shape easily. It is elastic [5], and tough because each sensing element does not need any fragile long wires to transmit the sensing signal. The principle and the experimental results are shown.

TELEMETRY CHIP FOR ARTIFICIAL SKIN

The goal of the research is to establish a method to fabricate a sensor skin through the following process. (See. **Fig. 1**)

<1> Preparation of molding material containing sensor chips which receive the electrical power and transmit the tactile signal without wires, and

<2> learning the sensor chip position after molding.

In this paper, we design the sensor chip to realize such a process. **Fig. 2** shows the structure of the sensor chip. Each chip is composed of three parts, a coil for both sensing and signal transmission, an electrical circuit and a power receiving coil. The operation of simple structure is as follows.

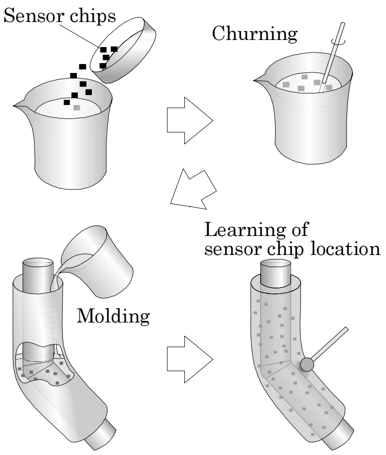

Fig. 1: The process of sensor skin fabrication.

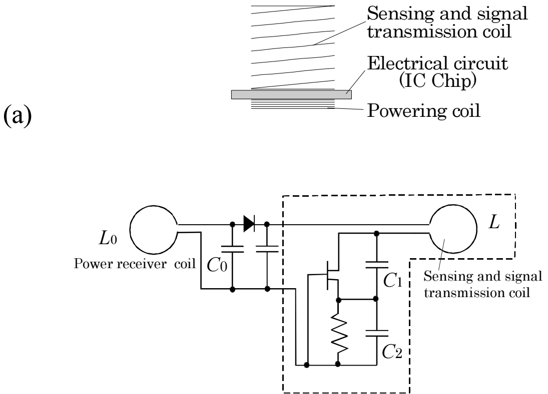

Fig. 2: Structure of the sensor chip. The sensing coil L and capacitance C_1 and C_2 form a colpitts oscillator.

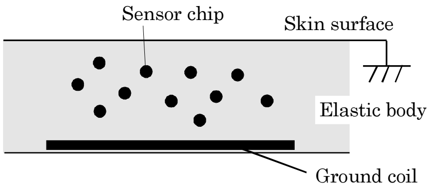

Fig. 3: Powering and signal transmission are done through inductive coupling between the sensor chip and a ground coil. Each chip is identified by both the powering frequency and the signal frequency.

1] Electric power supply

The power supply is done through inductive coupling [6] between chip coil L_0 and the ground coil under the skin. (See **Fig. 3**.) It is powered only at a resonant frequency

$$\omega_0 = \sqrt{L_0 C_0} \tag{1}$$

which is determined by the L_0 and C_0 in **Fig. 2**(b).

2] Sensing and signal transmission

The sensing coil L and capacitance C_1 and C_2 form a Colpitts oscillator with the oscillation frequency

$$\omega = \frac{1}{\sqrt{LC}} \quad \left(\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} \right) . \tag{2}$$

The oscillation is detected by the ground coil also through inductive coupling. Because the inductance L has the relation with the length of the coil as

$$L = K\mu\pi a^2 \frac{N^2}{l} \quad , \tag{3}$$

the normal strain around the coil is detected from the frequency modulation as

$$\frac{d\omega}{\omega} = \frac{dl}{2l} \quad . \tag{4}$$

See **Fig. 3**. (Nagaoka's coefficient K is assumed to be constant. Generally the sensitivity is better than Eq. (4) when the change of Nagaoka's coefficient is considered.)

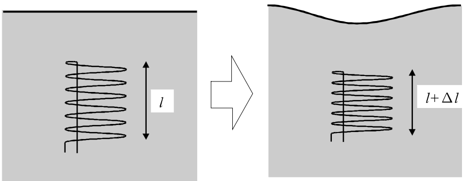

Fig. 4: The principle of tactile sensing. The change of the sensing coil length induces the frequency change of the Colpitts oscillation.

3] Identification of sensing chip

We identify each sensing chip by two kinds of resonant frequencies, the powering frequency ω_0 and the Colpitts oscillation frequency ω. Therefore if we assign N_p and N_S channels to the powering frequency and oscillation frequency, respectively, we can identify elements of

$$N_{\text{total}} = N_p \cdot N_S \quad . \tag{5}$$

PROTOTYPE OF TELEMETRY CHIP

We fabricated a hybrid large model of the sensing chip as shown in **Fig. 5**. Each chip has different oscillation frequency by tuning the sensing coil's turn from 20 to 40. A sensing coil L, an IC chip, a powering coil L_0 and capacitance C_0 were bonded manually. The IC chip was produced in the project MCS01 supported by the Japanese MMCS committee. A bi-polar transistor circuit as shown in **Fig. 6** was mounted on a monolithic IC chip, although capacitance of 0.1 μF and 2200 pF were attached outside it. The powering coil was 40 turns.

Four chips were placed in a silicone rubber. (See **Fig. 7**, **Fig. 8**.) We supplied the ground coil (50 mm in diameter both) with 12 V amplitude of 1.3 MHz through impedance matching capacitor.

The ground sensing loop observed a signal as shown in Fig. 9. This signal is mixture of the four kinds of chip signals of 20, 25, 30, and 35 MHz.

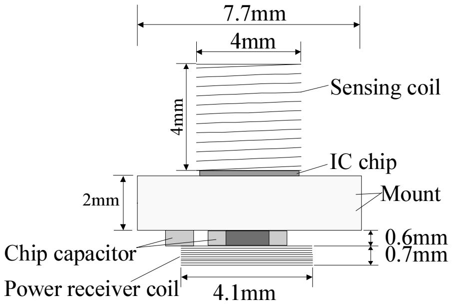

Fig. 5: A hybrid model of the sensing chip.

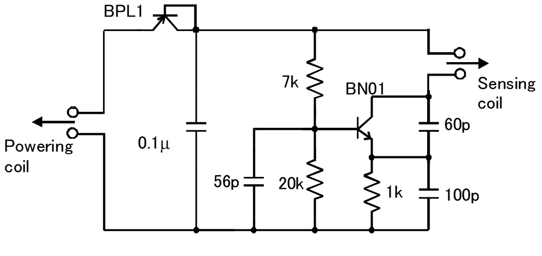

Fig. 6: An oscillator IC produced by Japanese chip service association.

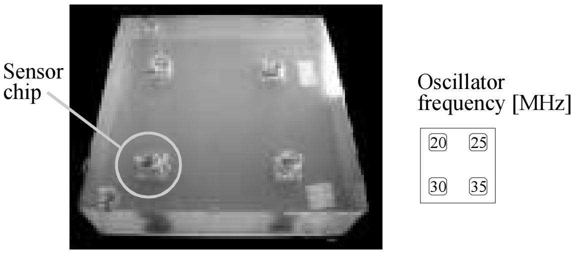

Fig. 7: Photograph of four sensor chips molded in silicone rubber.

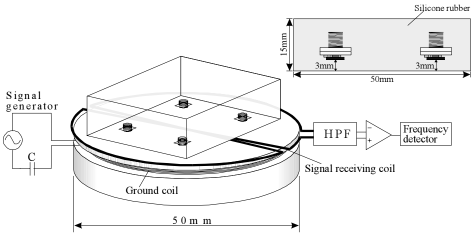

Fig. 8: Experimental setup of telemetric tactile sensing. The ground sensing loop is twisted to remove the induction of powering.

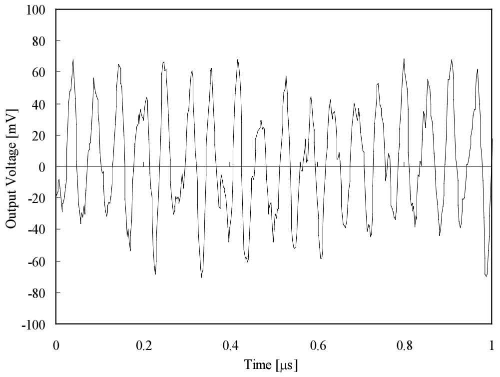

Fig. 9: Output voltage of the ground sensing loop in Fig. 8. Mixture of the four chip signals.

CHIP SIGNAL SELECTION

Fig.10 shows the block diagram of the signal detection. We obtain a certain chip's frequency by counting the alternation of the signal coming through a fixed band-pass-filter after a proper frequency shift.

The waveform in **Fig. 11** is the frequency-shifted sensing loop signal filtered with center frequency 10.7 MHz. In this experiment, we obtain the modulation of the 20 MHz chip by counting the alternation. **Fig. 12** shows the detected oscillation frequency obtained when we pressed an object (an acrylic cylinder 2mm in diameter) against the sensor surface just above the 20 MHz chip.

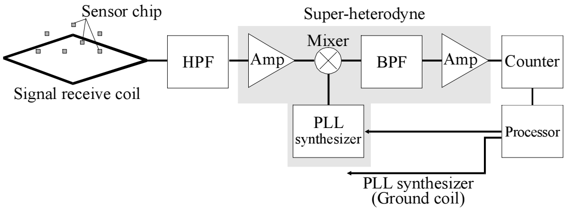

Fig.10: Block diagram of heterodyne signal demod-ulation.

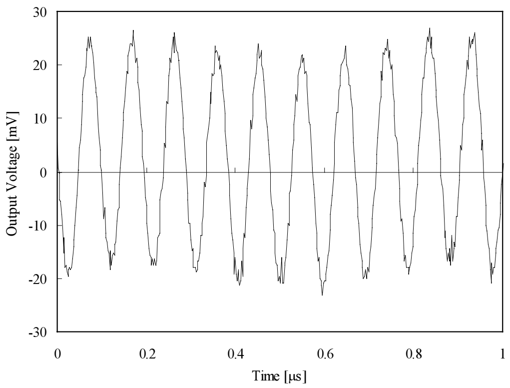

Fig. 11: Selected signal waveform.

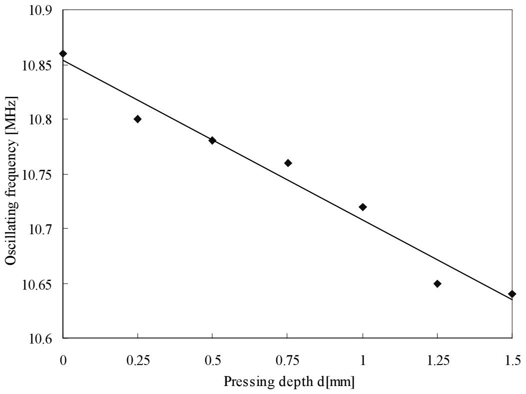

Fig. 12: Plots of oscillation frequency obtained when we press an object against the sensor surface.

DESIGN OF THE GROUND COIL

We designed a mesh type of ground coil easy to be mounted on an arbitrarily shaped surface. (See **Fig. 14**)

In order to localize the magnetic field near the net, we divided it into four regions to be driven successively. (See **Fig. 15**.)

A calculation of vertical magnetic field H_z by loop current J in **Fig. 13** (a) reveals that if the chip is located between z = 0.5 and 1, the minimum value of H_z (at the corner) is larger than 10 % of the maximum (at the center.)

In the experiment, the chips could work with 0.4 W total power consumption by a 10 cm ×10 cm net of 2.5 cm meshes if the chip coils were located in parallel to the net and within 1 cm from the net

Acknowledgment

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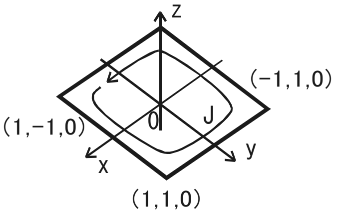
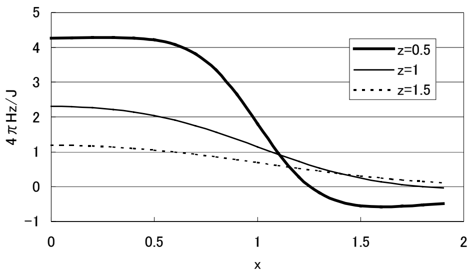
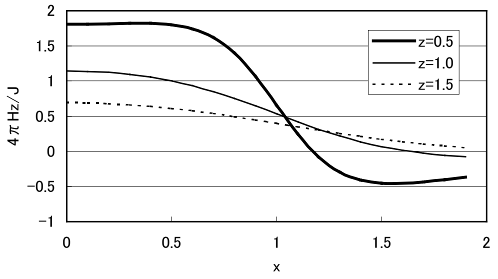


(a)



(b) y=0



(c) y=1

Fig. 13: The magnetic field induced by a loop current J illustrated in (a). The vertical component H_z at a point (x,y,z) is plotted in (b) and (c).

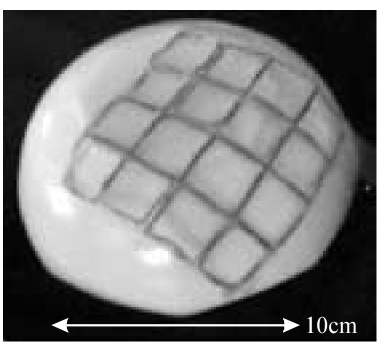


Fig. 14: A mesh type of ground coil.

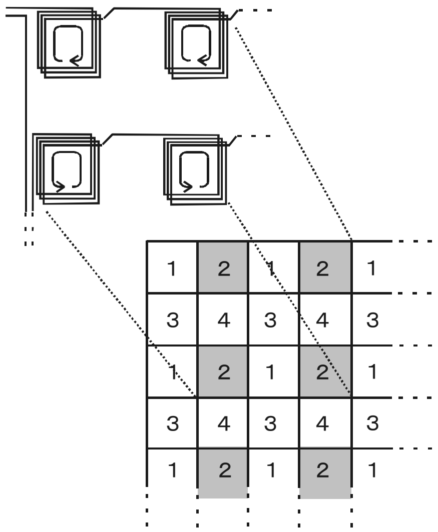


Fig. 15: The four regions 1, 2, 3 and 4 of the net are driven independently.

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