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Telemetric Robot Skin

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Abstract

Human-friendly robots of new generation will require the sensor skin that is soft and covering the whole body. But it would be very difficult to fabricate it with the traditional technology, because placement and wiring of vast amount of sensor elements on the 3-dimensionally configured robot surface is laborious. 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 principle and the experimental results are described.

Key words: *tactile sensor , telemetry, artificial skin, soft mechanics*

1 Introduction

Human-friendly robots of new generation will require the sensor skin that is soft and covering the whole body [1]. But it would be very difficult to fabricate such a skin with the traditional technology[2,3,4], because placement and wiring of vast amount of sensor elements on the 3-dimensionally configured robot surface is laborious.

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, and

<1> it is elastic [5], and

<2> 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.

2 Telemetric 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.

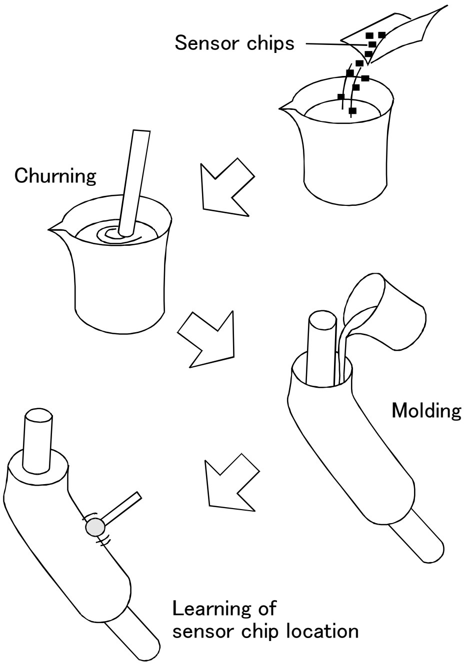

Fig. 1: The process of sensor skin fabrication.

3 Structure of the sensor chip and signal transmission

Fig. 2 shows the structure of the sensor chip. Each chip is composed of the three parts, a coil for both sensing and signal transmission, an electrical circuit and a power receiving coil. The simple structure operates as follows.

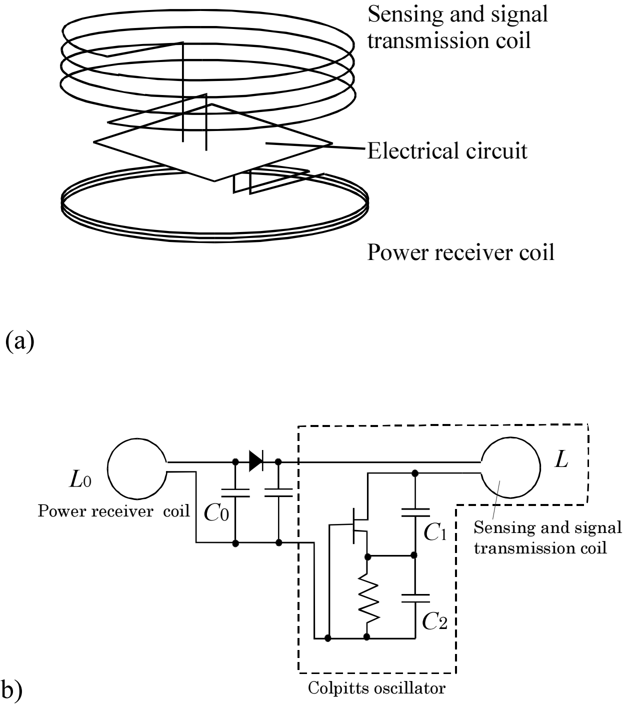

Fig. 2: Structure of the sensor chip. The sensing coil L and capacitance C_1 and C_2 form a Colpitts oscillator.

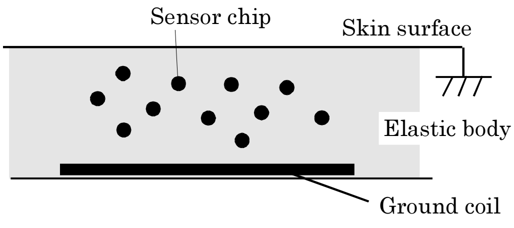

Fig. 3: Powering and signal transmission are done through inductive coupling between the sensor chip and a ground coil. Each chip is identified by both the powering frequency and the signal frequency.

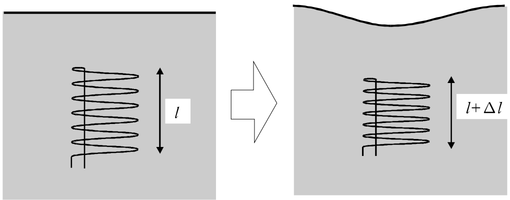

Fig. 4: The principle of tactile sensing. The change of the sensing coil length induces the frequency change of the Colpitts oscillation.

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 resonant 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. 4**. (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.)

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

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

4 Design of inductive powering

In this section, we examine the conditions of the coil turn and the frequency for effective powering.

[1] The needs from the circuit chip

Let I be the current of the signal transmission coil L needed in a certain noise environment. Then the minimum current which must be supplied by a transistor of the oscillation circuit is given as I/Q where Q is the quality factor of the resonance of C_1, C_2 and L. The coil must have an ability to supply voltage $V \geq 1$ [V] to a load resistance

$$R = QV/I. \tag{6}$$

In this research we assume that $Q \approx 20$, $I \approx 10$ [mA] and $R \approx 1$[kΩ].

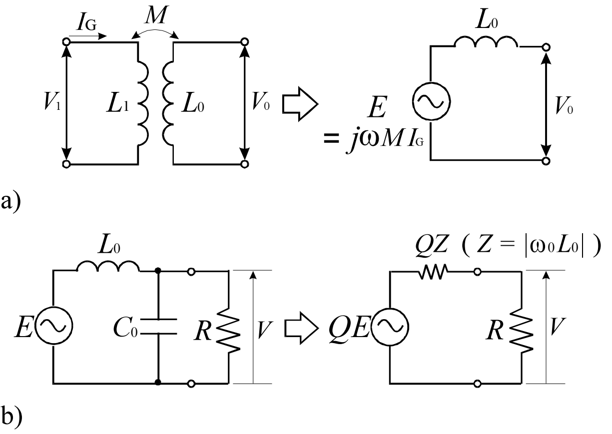

Fig. 5: (a):Equivalent circuit of power receiving coil. (b): Equivalent circuit of power receiving coil with resonant capacitor (at the resonant frequency).

[2] Optimum frequency and turn of the coil

The power receiving coil is equivalent to the circuit on the right hand of **Fig. 5** (a). Next the power receiver with capacitor C_0 and load resistance R is equivalent to the right hand circuit in **Fig. 5** (b), at the resonant frequency $\omega_0 = \sqrt{L_0 C_0}$. Then the voltage V at the load R is written as

$$V = \frac{R}{QZ + R} QZ \frac{E}{Z} \tag{7}$$

where Q is the quality factor of the resonance and $Z = |\omega_0 L_0|$. Here QZ is written as

$$QZ = \frac{A\omega^2 n^4}{\rho n + Bn^2\omega^2} \tag{8}$$

where A, B and ρ are constants, and n is the turn of the receiver coil. The numerator is square of reactance ωL_0, and the ρn and $Bn^2\omega^2$ are the terms of energy loss by resistance and harmful resonance arising from floating capacitance, respectively. The loss at the condenser is neglected. The QZ is monotonically increasing with respect to frequency ω, and the maximum is

$$(QZ)_{\max} = \frac{A}{B} n^2 \cdot \tag{8}$$

The plots in **Fig. 6** are our experimental results of QZ vs. frequency ω, of small coils with radius a = 1 [mm]. The diameter of the used wire was 0.05 [mm]. You will see that the QZ is saturated over several MHz.

On the other hand, the ratio E/Z in Eq. (7) is written as

$$\frac{E}{Z} = \frac{I_G n_G}{r_G} \frac{l}{n} \tag{9}$$

independently to ω, where l is the height of the receiver coil, and n_G, r_G and I_G are respectively the turn of the ground coil, the radius of the ground coil and the ground coil current.

Therefore the V becomes the maximum for the n which maximize following quantity

$$\frac{R}{\frac{A}{B}n^2 + R}\left(\frac{A}{B}n^2\right)\frac{1}{n} \quad , \tag{10}$$

that is,

$$n = n_{\text{opt}} = \sqrt{\frac{B}{A}R} \quad \cdot \tag{11}$$

To find out the n_{opt}, we should note that the QZ becomes equal to R at the turn n_{opt}. The plots in **Fig. 7** are experimental results of QZ vs. turn n, for the same coils as previous ones with radius a = 1 [mm]. The 5 MHz line shows that $n \approx 80$ would be the best for a load resistance R = 1 [kΩ], for example.

We summarize above discussions. The optimum frequency and turn were determined as follows, for the 2mm diameter coil and constant amplitude of ground coil current.

- A high frequency is preferable, however a higher frequency than several MHz brings us no merits.
- The optimum turn of the coil is 80 for a load resistance of 1 [kΩ].

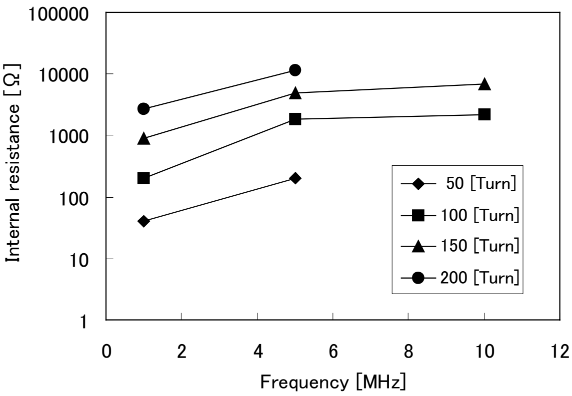

Fig. 6: Equivalent internal resistance vs. frequency. The radius of the coil was 1 [mm].

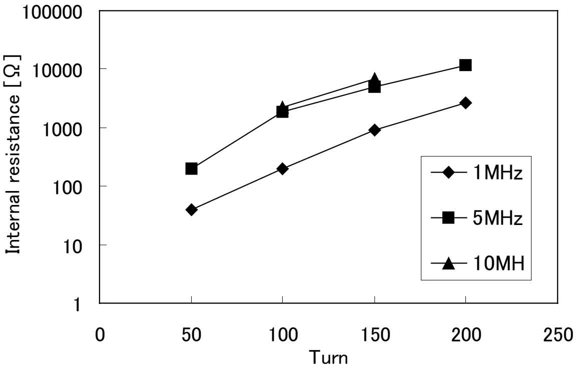

Fig. 7: Experimental results. Equivalent internal resistance vs. the turn of coil.

5 Prototype of telemetry chip

We fabricated a hybrid large model of the sensing chip as shown in **Fig. 8**. 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. 9** was mounted on a monolithic IC chip, although only the capacitance of 0.1 μF was attached outside it. The sensing and the powering coil were 30 and 40 turns respectively.

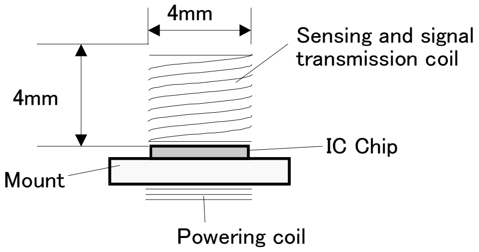

Fig. 8: A hybrid model of the sensing chip.

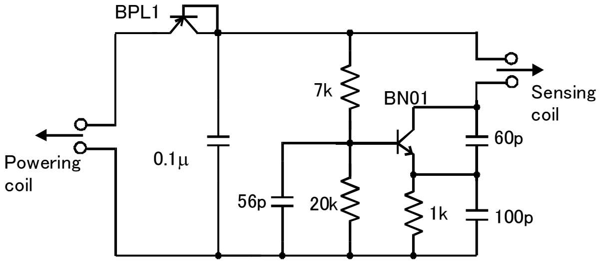

Fig. 9: An oscillator IC produced by Japanese chip service association.

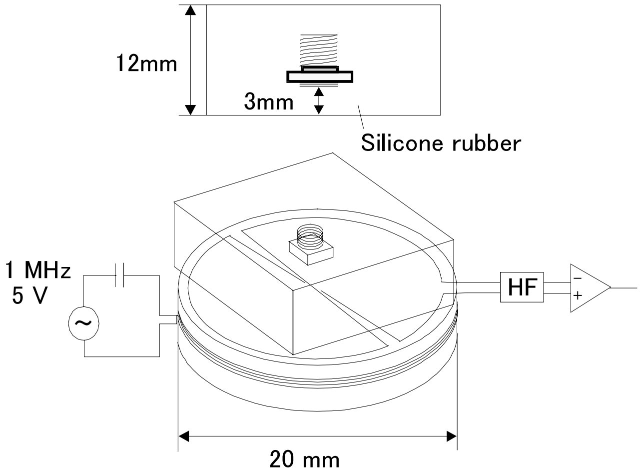

Fig. 10: Experimental setup of telemetric tactile sensing. The ground sensing loop is twisted to remove the induction of powering.

A single chip was placed in a silicone rubber. (See **Fig. 10**.) We supplied the ground coil (20 mm in diameter and 50 turns) with 5 [V] amplitude of 1 [MHz] through impedance matching capacitor. The ground sensing loop observed 10 [MHz] oscillation as shown in **Fig. 12**. The frequency was shifted as shown in **Fig. 13** while we pressed an object (an acrylic cylinder 8mm in diameter) against the rubber surface.

6 Summary

We proposed a novel method to fabricate a sensor skin on a robot. Using telemetry chips enables us to fabricate elastic and tough skin on a 3-dimentionally configured robot surface. The structure and operation of the sensing chip was proposed. A hybrid chip was fabricated and tested successfully.

Acknowledgment

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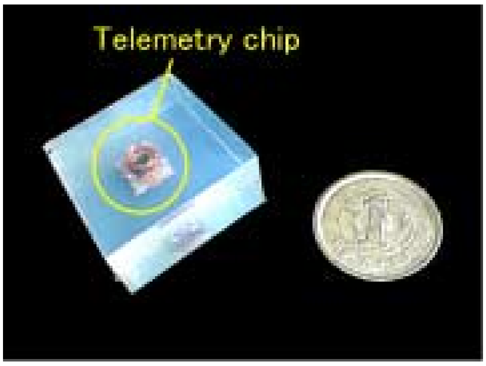

Fig. 11: A photograph of the prototype sensor.

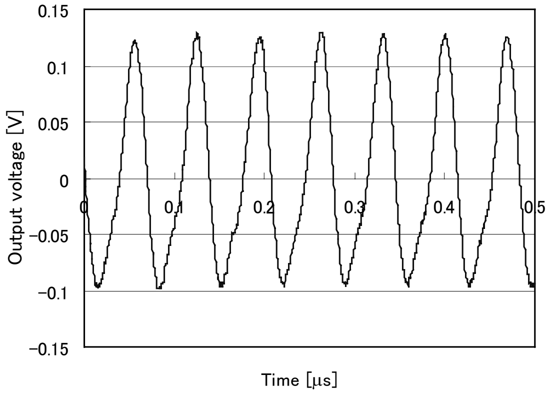

Fig. 12: Output voltage of the twisted ground loop in Fig. 10.

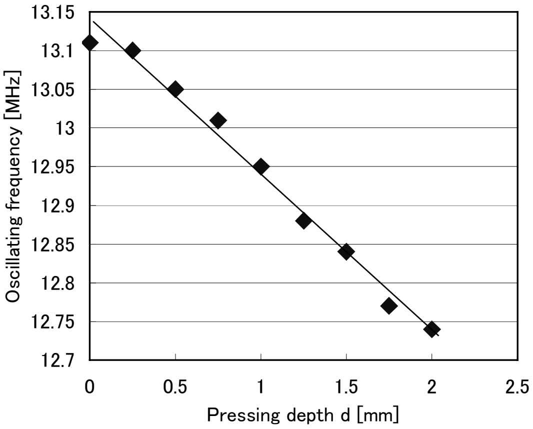

Fig. 13: Plots of oscillating frequency when we press an object against the sensor surface.

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