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A Sensitive Skin Using Wireless Tactile Sensing Elements

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Abstract

In this paper, we propose a method to realize a flexible robot skin that covers wide robot surfaces. We attach a film type of a 1-D coil array that transmits electrical power to wireless tactile sensing elements and obtains sensor signals from them. Then we cover the robot bone with an elastic sensor skin containing wireless sensing chips. Since the skin can move on the bone freely, the skin does not prevent large motions of robot body. The tactile elements without wires bring a tough and elastic sensor skin. The concept of wireless tactile sensing, the design of the film coil array, and a new design of a wireless tactile sensing chip are shown.

Key words: *tactile sensor, robot skin, haptic interface, sensitive skin, telemetry, wireless sensor*

1 INTRODUCTION

In order to realize a wide area of a soft sensor skin covering the entire body of robots, several ideas of wireless tactile elements have been presented[1][2]. But those papers described only the sensing chip designs, and no methods of their equipment on a real robot had been shown. In this paper we propose a 1-D film coil array to power wireless tactile sensor chips and obtain sensing signals from them. The film is attached on a robot bone first, and we cover it with a sensor skin containing wireless sensing elements. Since the skin can move on the bone freely, the skin does not prevent large motions of robot body. The tactile elements without wires bring a tough and elastic sensor skin.
The design of the film coil array and results of wireless signal transmission using a new type of wireless sensing element are shown.

2 WIRELESS SENSITIVE SKIN

Fig. 1 shows the fabrication process of our sensitive skin. A 1-D film coil array is attached on a robot bone rigidly. The film powers wireless sensing elements contained in a skin and exchanges signals with them through inductive coupling. Each site on the 1-D film is driven independently then overlapping of the films is allowed. Therefore such a 1-D film can fit various shapes of robot surfaces. After that we equip elastic body on it. Each site on the 1-D film coil array has a powering coil, a signal receiver coil, a driving coil, a signal amplifier, and an interface circuit for random access from a processor. See **Fig. 2.** A computer connected to this film access each site randomly, and read sensor signals existing around the accessed site.

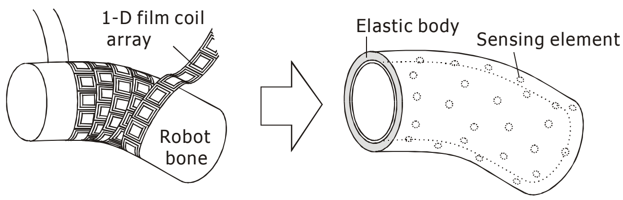


Fig. 1: Equipment of our sensitive skin.

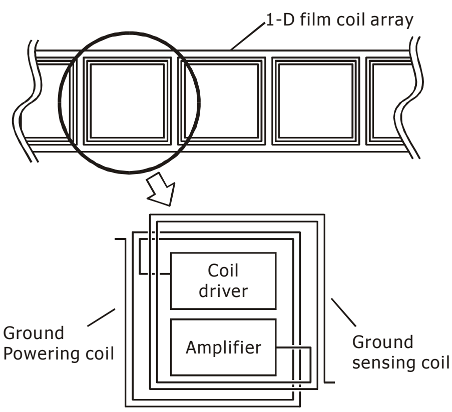


Fig. 2: Structure of the 1-D film coil array. Each site has a coil driver, a signal amplifier, and an interface circuit.

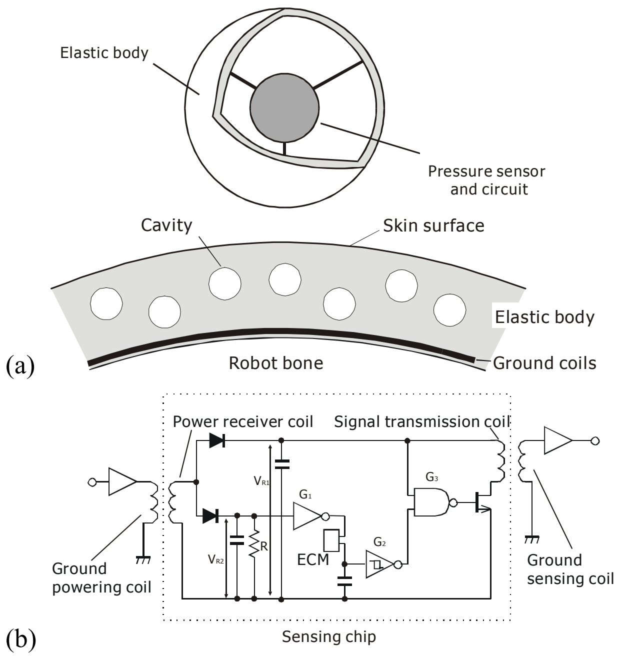


Fig. 3: (a): Structure of the sensing element. The element measures the air pressure of the cavity in a sensor skin. (b): electrical circuit of the sensing chip.

3 STRUCTURE OF THE WIRELESS TACTILE SENSING ELEMENT

The sensing element is illustrated in **Fig. 3**. A sensor chip transmits the air pressure of the cavity in a sensor skin wirelessly. Power supply and signal transmission is done through inductive coupling between the coils on the sensor chip and a powering coil on the 1-D film coil array. The principle of tactile sensing is shown in **Fig. 4** and **Fig. 5**. First a computer designates one site on the 1-D film array and starts powering the chips existing around the site by activating the film coil driver. When it finishes charging the condenser on the sensing chip, it stops the powering. Then the sensor chip generates an impulse with a certain time delay from the cutoff moment. Since the time delay reflects the air pressure of the cavity as is shown in **Fig. 4**, we obtain the pressure of the cavity air from this delay.

The mechanism of the impulse generation is as follows. After stopping the powering, the G1 output in **Fig. 3** rise up with a delay t_R. The current through the ECM (electret condenser microphone) in which the current is controlled by the air pressure with a JFET, changes the delay time Δt of G3 rising. When G3 stops the MOS current, an impulse generates. As shown in **Fig. 4**, voltage at A2 is written as

$$V = \frac{I_M}{C} t = \frac{\alpha}{C} Pt \tag{1}$$

where α is a constant of EMC and P is the air pressure. Therefore the delay time Δt is written as

$$\Delta t = \frac{CV_{Th}}{\alpha P} \tag{2}$$

neglecting the impulse width, where V_{Th} is positive threshold voltage of the Schmitt trigger inverter .

The impulse is detected by a sensing coil of the accessed site and amplified in the site. Then the delay is measured.

The variation of t_R is used for multiple chip identification.

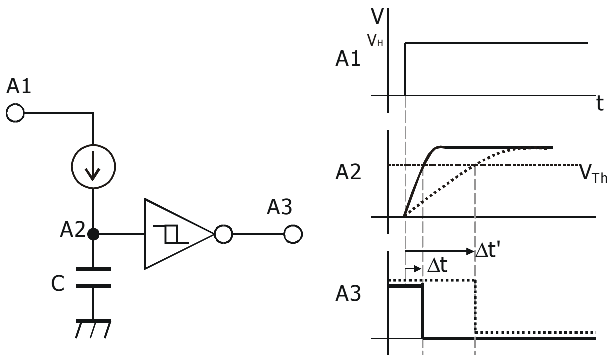
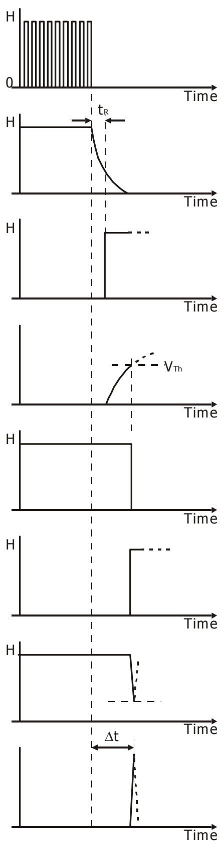


Fig. 4: Time delay Δt is determined by the capacitance C and the ECM current reflecting the air pressure.



(1) Stop the powering signal.

(2) The resistance R lowers the voltage V_{R2}.

(3) Time t_R later, output of G_1 rises up.

(4) G_2 input rises to G_2 threshold V_{Th}.

(5) G_2 falls.

(6) G_3 rises up. Then MOSFET turns on.

(7) MOSFET drain current decreases V_{R1}.

(8) When the coil current is stopped by MOSFET, an impulse is observed by the ground sensing coil.

Fig. 5: The operation of the circuit.

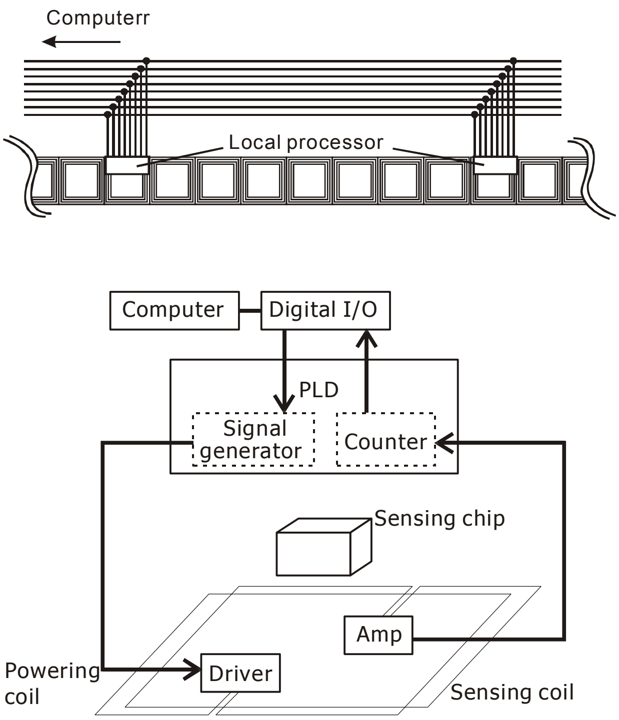


Fig. 6: Architecture of the 1-D film coil.

4 ARCHITECTURE OF 1-D FILM COIL

The architecture of the 1-D film coil array is shown in **Fig. 6**. One PLD local processor is located in eight sites. The processor sends excitation signal to the site that the computer designates and sends to the computer the delay time Δt that is also measured by the local processor. Since the clock of the PLD is 40 MHz, the Δt is measured with resolution 25 ns.

5 EXPERIMENTS

A photograph of a 1-D film coil is shown in **Fig. 7**. The right hand square print pattern is a sensing site has a powering coil, a coil driver, a sensing coil and an amplifier. The powering coil and the sensing coil are 10 turns and 40 x 40mm in outer size. The powering voltage is 5 V at 1.5 MHz. The sensing coils voltage is amplified by 50 times and sent to the local processor.

A photograph of the sensor chip is shown in **Fig. 8**. The diameter, height and turn of the power receiver coil were 22mm, 1mm and 50 turns, respectively. And these parameters of the signal transmission coil were 12mm, 1mm and 30 turns, respectively. The electrical circuit of the sensing chip is shown in **Fig. 9**.

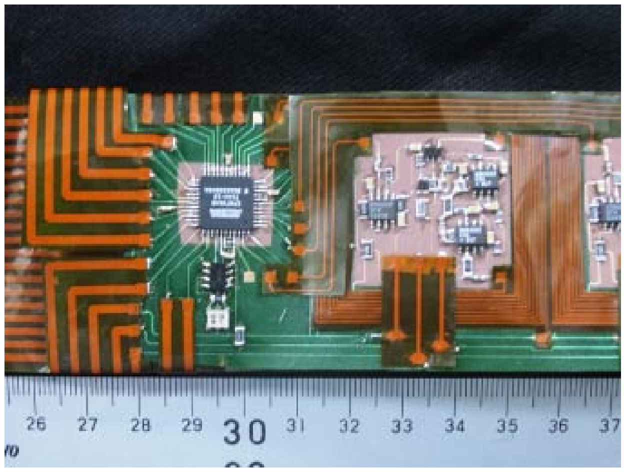


Fig. 7: A photograph of a 1-D film coil. Right: a site of coils. Left: a local processor.

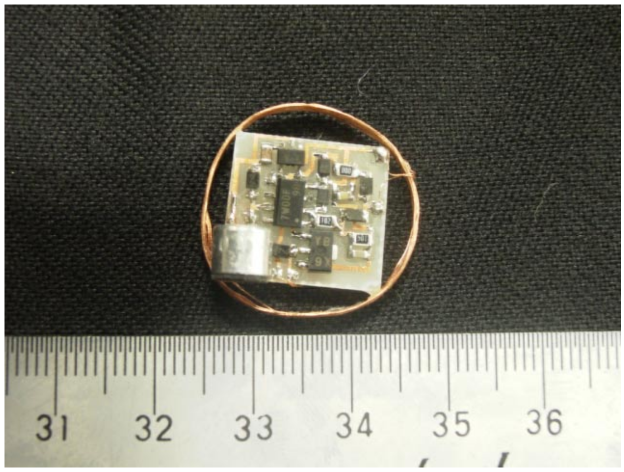


Fig. 8: A power receiver coil (50 turns, 22mm in diameter, and 1mm high) and a signal transmission coil and an ECM are connected to a circuit.

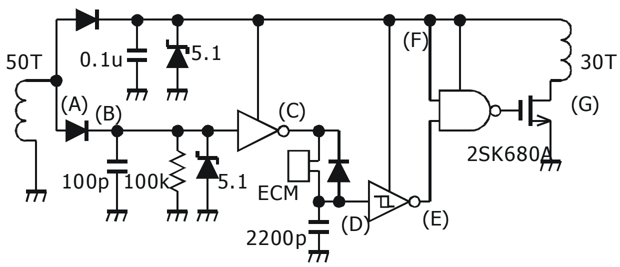


Fig. 9: Electrical circuit on the sensing chip.

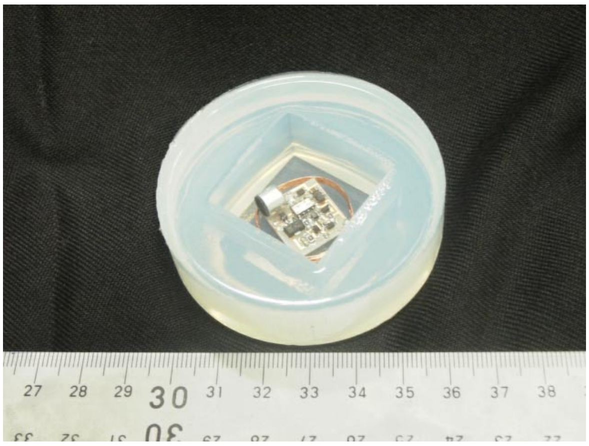


Fig. 10: A Photograph of a test skin. A sensing chip is placed in a cavity (30 x 30 x 15mm) of silicone rubber.

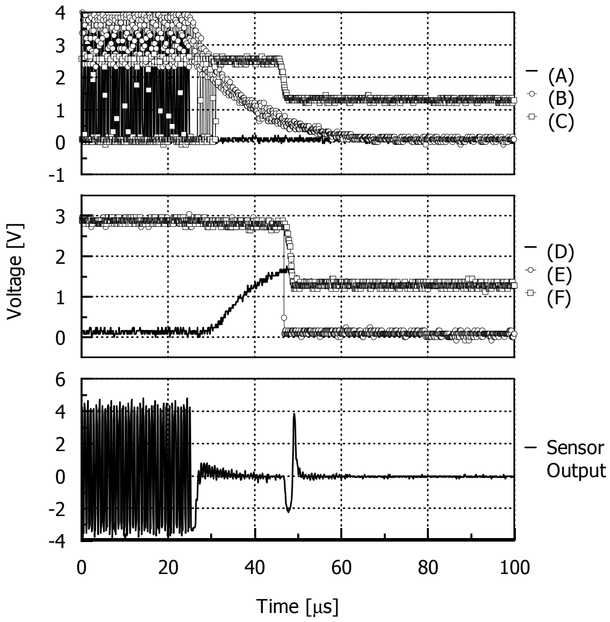


Fig. 11: Sensor chip operation and a detected signal by a sensing coil. The top and the second figures show the voltages at (A), (B), (C), (D), and (E) in **Fig. 9**, respectively. The bottom figure shows the voltage observed at a sensing coil under the test skin.

We show basic experimental data using a test skin containing one sensing cavity. See **Fig. 10**. In a 30 x 30 x 15 mm cavity of a silicone rubber, a sensing chip is located. When we put the rubber on the 1-D film coil array, a sensing coil on it detected the sensor signal as shown in **Fig. 11**. The time delay moved when we touch the skin as shown in **Fig. 12**. **Fig. 13** shows a dynamic signal of the pressure sensing. We plotted the impulse delay Δt sampled at 500 Hz when we tapped the test skin four times. These results show the sensing system of 1-D film coil array successfully detected the tactile signal from the test skin.

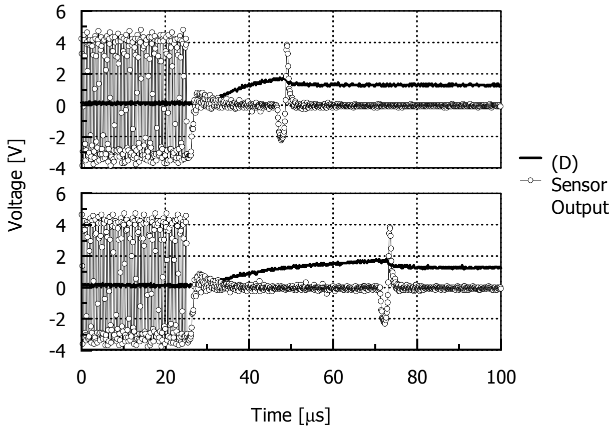


Fig. 12: Output of a ground sensing coil under the test skin. When we touch the test skin, the impulse moved.

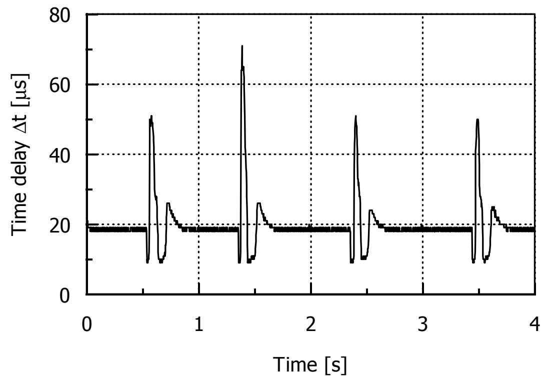


Fig. 13: A dynamic signal of the pressure sensing. Plots of the impulse delay Δt sampled at 500 Hz when we tapped the test skin four times.

Acknowledgment

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