DEVELOPMENT OF A ELECTRIC FIELD DISTORTION TACTILE SENSOR
S. Suzuki*, Y. Saegusa and T. Takahashi
Seikei University, JAPAN

ABSTRACT
A tactile sensor system, based upon the electric field distortion, is proposed. Tactile sensors, detecting electric resistance or capacitance, have two opposing electrodes in general. Such structure have difficulty to make flexible sensor sheet, which is needed for robotic manipulator or other skin like sensing purpose. In this study, a sensing system with one electrode, embedded in conducting gel was developed inspired by the electric proximity sensor of animals such as sharks or catfish. Sensing electrode array was microfabricated and object detection by field distortion was demonstrated.

KEYWORDS: Tactile Sensor, Electric Field, Distortion, Gel, Flexible

INTRODUCTION
Developing a robotic hand with capability of human hand is a milestone in bioengineering. Mimicking skin sensation by tactile sensor is a part of such researches and various kinds of tactile sensors have been developed for use of manipulator control or sensing device[1,2]. However, some have solid silicon structure and another have two electrodes for capacitance or resistance measurement. Such structures are not suitable for a soft material sensor, replacing skin sensation. For developing flexible tactile sensor that can be fitted on the mechanical manipulator requires simple structure. A sensing system consists of micro fabricated single electrode and soft material is suitable for such purpose.

THEORY
Some kinds of sharks are known to have Ampullae of Lorenzini, which respond to electric potential in water[3]. Elephantnose fish, lives in Africa, generate weak pulse of electric field, and detect the distortion of field with sensors on the skin[4]. These skin sensation, is extraordinary for human, but is well established and indispensable sensing system for some animals. It works almost like radar in water, even though the electric field of the sensor is almost dc, while that of radar wave is radio frequency. We investigated to develop a object detection system, mimicking elephantnose fish’s electro sensory organ. Basic principle of the system is almost like a radar, which emits electric signals to the space and detects the reflected signals. If some objects, with different electric permittivity, exist around the electrode, it will deflect the electric field. However, time delay of reflected signal is so small because the objects is in vicinity, in this case within some 10 cm, and reflection time is within time resolution of detector. For evaluation of field distortion, difference of the wave form from that of vacant space.

EXPERIMENTAL
Sensing electrodes were fabricated on a 1mm thick glass substrate. Schematic view of electrode arrangement is shown in Figure 1(a). Four round electrodes, 2mm in diameter, were placed 10 mm apart in square. Each electrode is lead to contact pad. A sensing electrode is surrounded by ground plane, which serves as counter electrode of a sensing electrode and grid electrode for connecting wire. Inner diameter of counter electrode is 4mm. The electric field produced between the sensing electrode and the counter electrode is well approximated by that of a dipole. The center of sensing electrode is the center of dipole, and the axis of dipole moment is perpendicular to the substrate plane. Field intensity decreases inversely proportional to the cube of distance in far field. This speculation tells that the sensing zone of this sensor is restricted almost within the radius of counter electrode. If the counter electrode is infinity, or placed beyond the size of device in practice, detection range of the sensor is not restricted by geometry of the electrode, but rather by the resolution of electric instruments. Vapor evaporated aluminum layer, c.a. 5 µm thick, was patterned by photolithography. After patterning of the electrodes, the aluminum layer was chemically modified to make better adhesion with acrylamide gel, by dipping in 1 % aminopropyltriethoxy-silan(APTES) solution. After 1 hour immersion, the substrate was heated in 80 deg. C in dry oven. Lead wires were fixed on the contact pads and ground plane by silver paste and mechanically reinforced by epoxy cement.

Sensing region of aluminum electrode was covered with 3mm thick acrylamide gel. Composition of acrylamide gel is shown in Table 1. 2.7 %C acrylamide/N,N'-Methylene-bisacrylamide mixture was dissolved in deionized water by 10 %T concentration. 4.0 mL acrylamide solution, 2.5 mL 1.5M Tris-HCl pH8.8 and 3.35 mL deionized water were mixed and 5 µL of N,N,N',N'-Tetramethylethylenediamine (TEMED) was added. After degasification in a vacuum chamber, 50 µL 10% ammonium persulfate (APS) was added to the acrylamide solution to initialize the polymerization[5]. The acrylamide solution was, then, casted into the planer chamber, formed on the electrode substrate by silicone resin frame. The frame was covered
with grass plate to prevent the contact with oxygen molecule in the air. After polymerization of acrylamide gel, cover plate and silicone resin frame can be removed easily for shrinkage of the gel.

Schematic diagram of electric field distortion measurement system is shown in Figure 1(b). Round electrode is energized by short impulse from a pulse generator. Half maximum pulse width was 20 ns, which is smaller than the delay of reflected pulse. Pulse generator, oscilloscope and electrode are connected by coaxial cable, in which excitation pulse and reflection pulse going through. Superimpose of forward and backward pulse waves is observed by the storage oscilloscope. The amplitude of reflected pulse before and after application of mechanical load on the gel were compared by subtracting the waveform data with same time course. Acrylamide gel surface was depressed and deformed by a round tip acryl rod. The radius of

Figure 1: Top view of electrodes (a) and schematics of field distortion measurement system (b). 2mm φ aluminum electrodes were micro fabricated by photolithography. Each electrode was surrounded by ground plane, and connected to the contact pad. 10 ns width impulse from the pulse generator energizes the sensor electrode and emits wave of electric field. The pulse wave was reflected by the impedance steps in the surrounding space. The apparent terminal impedance at the sensing electrode is defined by the distribution of the electric field and complex electric permittivity around the sensing electrode.

Figure 2: Differential signal wave forms for mechanical loads, 0 to 7g, on the acrylamide gel surface (a) and average amplitude of differential signals (b). Thick line in (a) is the excitation pulse signal. Thin lines show the difference of the signal for each load value, subtracted by the original signal. The negative peaks at 20 ns shows the difference induced by pressing the gel. The average height of differential signal peak is proportionally increased with the load until 7 g, and attain plateau for higher mechanical load on the gel.

608
the tip is 10 mm. The push rod is connected with sheath tube with two coils. One coil suspend the rod for small load, and another pushes the rod for large load. The sheath tube is mounted on a micro positioning stage. Mechanical load of the rod was controlled by the spring constant of the pushing coil and position of micro stage. Sensor substrate was placed on a precision electric balance and calibrated. Mechanical load exerted upon the acrylamide gel was measured by the balance.

RESULTS AND DISCUSSION

Reflection signal of sensing electrode was measured for evaluation of the system. Figure 2(a) shows the differential signals, calculated by subtracting unloaded signal from the loaded signals, with 0 – 7 g weight force on the gel, by thin lines. Original pulse signal, reduced by the factor of 0.2 is also shown by thick line. After the largest peak of excitation pulse, a small peak of reflection, at 15 ns, follows with delay of 12 ns. This delay correspond to the length of the coaxial cable, 1 m, connecting the oscilloscope and the electrode, providing the speed of light in the cable is 1.8 x 10^8 [m/s]. The peaks of differential signals appear around the 15 – 25 [ns]. The modulation by the field distortion is seen to appear specifically in the reflection pulse. It is persuading because modulation by the field distortion occurs only when the electric field pulse propagate the free space, on the way it emitted from the sensor electrode, reflected by impedance boundary, and return to sensor electrode. Precise contribution of reflections at every impedance step is difficult to analyze for its complexity and the time resolution of the instruments. However, wave form of the specific peak at 20 - 25 ns, in the differential signal, increases with magnitude of the load. It suggest the relation between the distortion of gel and electric field, and the form of reflection wave. The averaged peak amplitude over 20 – 25 ns, is plotted against the magnitude of the mechanical load on the gel, in Figure 2 (b). The averaged peak amplitude rises until 7g weight force and attained the plateau of 0.12 mV. This non-linearity may come from the limit of gel deformation or geometric pattern of the field.

To investigate the sensing range around the sensing electrode, sensitivity of the sensor was measured at the distances of 0 – 10 mm from the electrode. The slant of regression line for the differential signal amplitude and mechanical load, within the range of 0 - 10 g weight force range, are plotted in Figure 3. Sensitivity is highest on the sensing electrode and decreases with the distance from the electrode. The sensitivity may converges to almost zero beyond 8 mm. The data points are not on the fitting line for large fluctuation of signals. It will be reduced by time averaging of the signal. The detection range of 5 mm is due to the dipole arrangement of electrode. The electric field decays steeply with distance and confine within the dimension of the electrode. It is suitable for high resolution detection by multiple electrode array. On the contrary, mono polar arrangement in which counter ground is arranged far enough from the sensing electrode, will increase the sensing range.

CONCLUSION

Feasibility of tactile sensing by electric field distortion was investigated. The sensor has sensitivity to the mechanical load on the gel. Sensing range of the sensor is almost comparable the size of the electrode. High resolution detection is expected by the electrode array of larger numbers.

REFERENCES


CONTACT
*S. Suzuki, tel: +81-422-37-3733; seiichi@st.seikie.ac.jp