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Development of an Implantable Wireless ECoG 128ch Recording Device for Clinical Brain Machine Interface

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Abstract— **Brain Machine Interface (BMI) is a system that assumes user's intention by analyzing user's brain activities and control devices with the assumed intention. It is considered as one of prospective tools to enhance paralyzed patients' quality of life. In our group, we especially focus on ECoG (electro-corti-gram)-BMI, which requires surgery to place electrodes on the cortex. We try to implant all the devices within the patient's head and abdomen and to transmit the data and power wirelessly. Our device consists of 5 parts: (1) High-density multi-electrodes with a 3D shaped sheet fitting to the individual brain surface to effectively record the ECoG signals; (2) A small circuit board with two integrated circuit chips functioning 128 [ch] analogue amplifiers and A/D converters for ECoG signals; (3) A Wifi data communication & control circuit with the target PC; (4) A non-contact power supply transmitting electrical power minimum 400[mW] to the device 20[mm] away. We developed those devices, integrated them, and, investigated the performance.**

I. Introduction

Electrocorticogram (ECoG) indicates a biological electrical activity, which is recorded with the electrodes directly placed on brain surface. It characterizes higher spatial resolution (better signal-to-noise ratio) compared to electroencephalograms (EEG) [1], and provide lower risk due to a less-invasive method and more stable measurement compared to needle electrode arrays [2]. Thus, ECoGs have been used to identify epileptic foci for clinical purpose, and have been known as a promising tool for controlling a brain machine interface (BMI) / brain computer interface (BCI) for medical and welfare applications [3]. However, the electrodes on the brain surface are directly wired to a recording PC outside of body, and the recording is limited generally within 2 weeks due to its infection risk. So, for further improvement of ECoG-based BMI, it is indispensable to implant all the devices within the patient's head and abdomen. Therefore, we are developing a fully-implantable wireless system to record ECoGs for clinical BMI.

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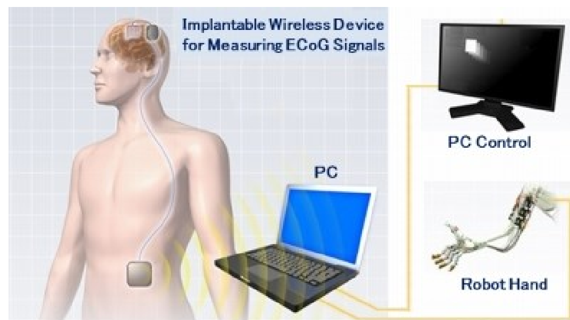

Figure 1. Conceptual Diagram of Clincal BMI

II. 2ND PROTO-TYPE

This is our second proto-type. The device is placed into head, abdomen, and out of body, as shown in Fig.2 and Table 1. The reason that the wireless controller is located in abdominal part is to prevent the user's brain from wireless effects. The head part and the abdominal part are connected with 10 fine cables under the skin. The data communication and power supply are wirelessly conducted so that the in-body devices are fully implanted. The 2nd proto-type is shown in Fig.3 and Fig.4.

The device consists of 5 components: the head part contains 3D highly dense multiple-electrodes, ECoG measuring circuits, and a titanium skull case; the abdominal part contains a Wifi controller and the receiver of a wireless power supply; the out-of-body parts contains the transmitter of a wireless power supply. Table 2 lists those developers.

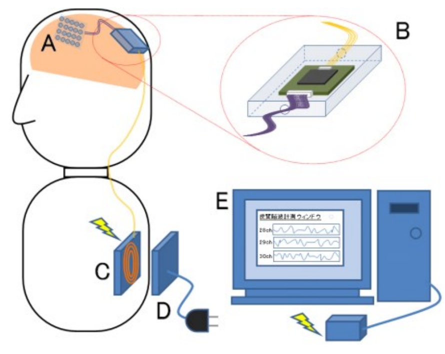

Figure 2. Conceptual Diagram of the Proposed Device

TABLE I. LOCATIONS OF DEVEICE PARTS

	Name	Location
A	High-Density Multiple-Electrode Sheet	Head
B	ECoG Measuring Circuit in a Titanium Case	
C	Wireless Controller with Wireless Power Supply (Receiver)	Abdomen
D	Wireless Power Supply (Transmitter)	Out of the Body
E	PC with a Wifi Access Point	

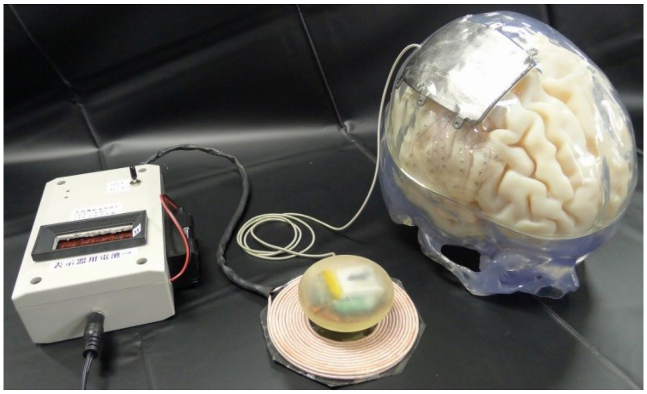

Figure 3. Appearance of the 2nd Proto-type

TABLE II. LIST OF DEVELOPERS

Parts	Developers
3D Highly Dense Multiple Electrodes	Unique Medical Corporation & Shyne Moriss (Osaka Univ.)
ECoG Measuring Circuit	A-R-Tec Corporation & Takeshi Yoshida (Hiroshima Univ.) & Hiroshi Ando (NICT)
Titanium Skull Case	Asuka Denki Seisakujo Corporation & Masayuki Hirata (Osaka Univ.)
Wifi Controller	Hitachi Corporation
Wireless Power Supply	Yuki Ota, Fumihiro Sato, Hidetoshi Matsuki (Tohoku University)
Assembling & Performance Investigation	Takafumi Suzuki (NICT) & Kojiro Matsushita (Osaka Univ.)

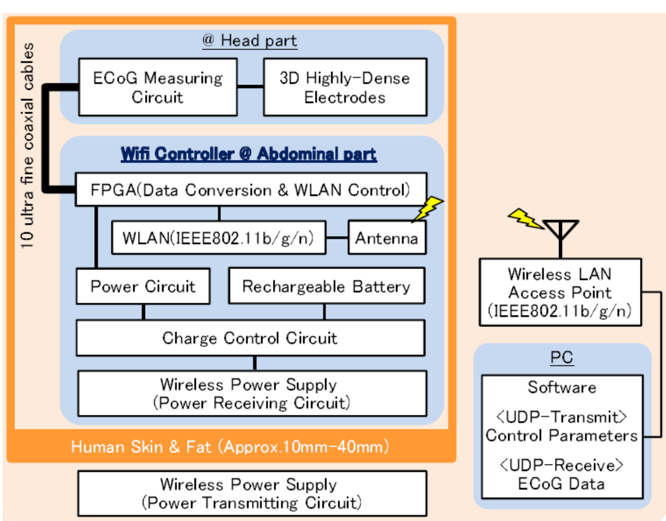

Figure 4. System Architecture of the 2nd Proto-type

III. DETAIL OF DEVICE PARTS

A. 3D Highly-Dense Multiple Electrodes

The proposed electrodes are designed for higher spatial resolution and better signal-to-noise ratio compared to the conventional electrodes (i.e., the conventional electrode is 3.0 [mm] in diameter, and the array is made of the electrodes at 10 [mm] intervals as shown in Fig.5 (left). Therefore, we made a grid electrode of 1.0 [mm] in diameter, and the array contains approx. 100 electrodes at 2.5[mm] intervals. We confirmed that it fits to human brain surface as shown in Fig.5 (right).

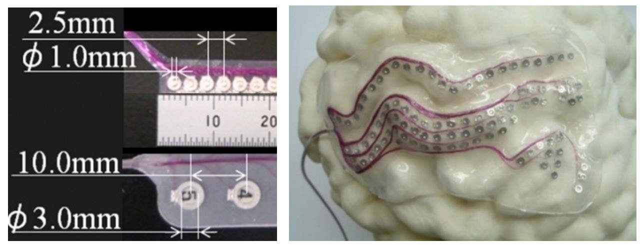

Figure 5. Appearance of the 3D Highly Dense Multiple Electrodes

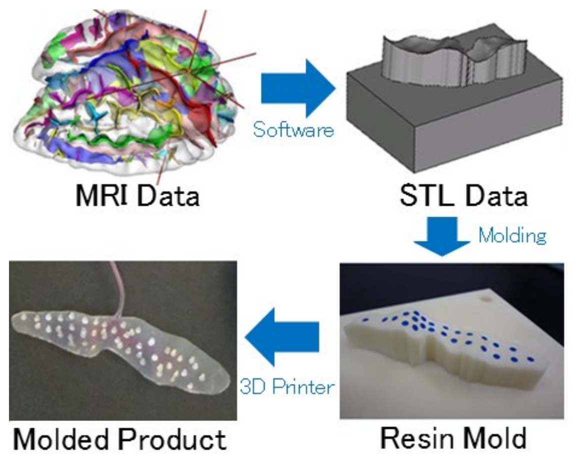

Figure 6. Fabric Process of the 3D Highly Dense Multiple Electrodes

B. ECoG Measuring Circuit

The ECoG measuring circuits are shown in Fig.7. One circuit functions 64 [ch] analog amplifiers and 12 [bit] A/D converters at the maximum sampling rate of 1 [kHz]. Then, we use two circuits at once, in order to deal with 128 [ch] ECoG signals. The specification of the ECoG measuring circuit is listed in Fig.8 and Table 3.

Figure 7. Appearance of the ECoG Meauring Circuits. The right figure shows the location of the circuits inside of the skull case.

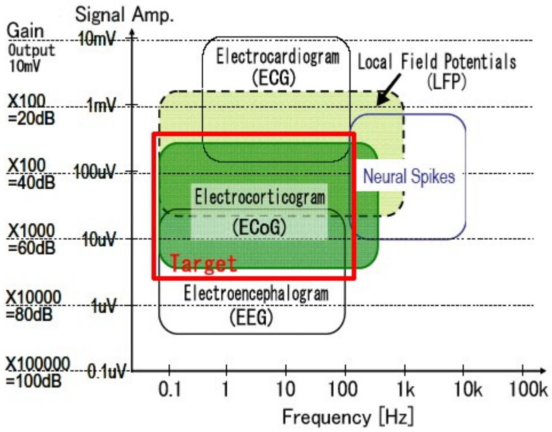

Figure 8. Target Range of the ECoG Measuring Circuit

TABLE III. SPECIFICATION OF ECOG RECORDING CIRCUITS

Name	Specifications
Number of Input Channel	128[ch] (64 [ch] / 1 chip)
Low Pass Filter	0.1 / 1 / 10 [Hz]
High Pass Filter	240 / 500 / 1000 [Hz]
Amplifier Gain	40 / 50 / 60 / 70 / 80 [dB]
Input Voltage Range	1[uV] to 1 [mV]
Sampling Rate	200 / 500 / 1000 [Hz]
Power Consumption	10 [uW/ch]
Circuit Size	28.5mm*19.4mm*5mm

C. Titanium Skull Case

We developed a titanium skull case, which contained a 128ch-ECoG measuring circuits. This case functioned as both protecting the circuits and substituting an artificial skull bone. The case is fabricated as follows: (1) We acquire the target patient's head MRI data; (2) We convert MRI data (DICOM data) to 3D model data, extract one part of the skull, design a circuit location; (3) Finally, the skull case is cut out from a titanium block with the CAD data.

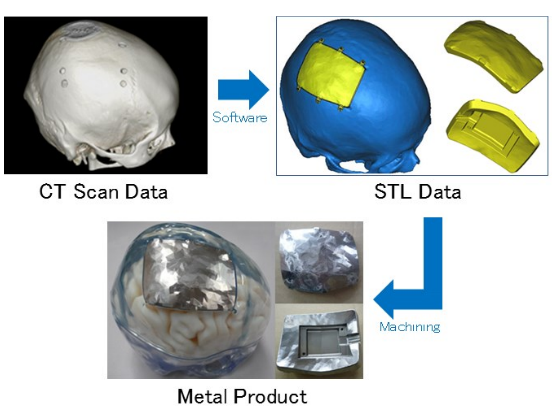

Figure 9. Fabric Process of the Titanium Skull Case

D. Wireless Controller

We adapted the Wifi for the second prototype. Our Wifi chip achieves 16Mbps as the maximum data transmission rate, which allowed the transfer of 128-ch * 12-bit ECoG data * 1kHz in real time. Max power consumption was approximately 200 mW, which meant that most of the system power was consumed by the wireless data transfer. The size was 40 mm * 40 mm * 5 mm, as shown in Fig.10.

The abdominal device is based on the wireless controller as shown in Fig.11.

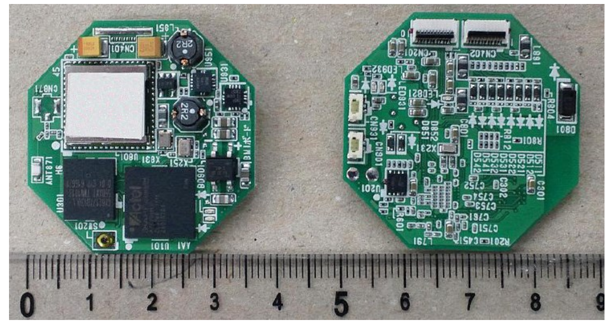

Figure 10. Appearance of the Wireless Controller

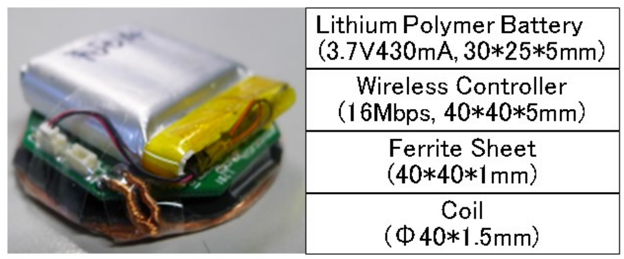

Figure 11. Abdomenal Device, which consists of a wireless controller, a lithium polymer battery, a fferrite sheet, a coil.

E. Wireless Power Supply

The wireless power supply consists of two parts. One is a transmitter positioned outside of the human body (Fig.12 left), and the other is a receiver located inside the human body (Fig.12 right). The specification is listed in Table 4. We achieved a wireless power supply of 400 [mW] at a distance of 20 [mm], which was sufficient to run the entire implantable device.

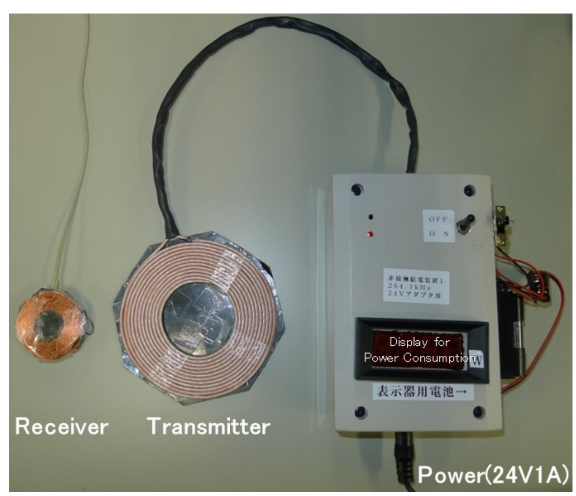

Figure 12. Table 4 Specification of a Wireless Power Supply.

TABLE IV. SPECIFICATION OF THE WIRELESS POWER SUPPLY

Target Distance between coils	20mm
Transmitter Power	400mW
Receiver Coil Size	40mm*40mm*2mm
Transmitter Coil Size	100mm*100mm*5mm
Max. Temperature of Receiver	38 degree

E. Recharging Battery

At the second proto-type, we use the lithium polymer battery (3.7V430mA).We have proved that the battery lasts approx.6 hours to record ECoG signals. We also exchange to bigger battery if ignoring the size.

However, the lithium polymer battery is not proved as its bio-compatibility so that we need to look for implantable batteries and substitute for it.

TABLE V. SPECIFICATION OF THE RECHARGING BATTERY

Battery capacity	3.7V430mA
Estimated power consumption of the whole system	Average 80mW (Max. 200mW)
Estimated working time	Approx. 6 hours

IV. PERFORMANCE TEST

We are now conducting animal experiments with the device shown in Fig.13. It is designed for monkeys so that it functions only 64ch: in short, it consists of a 64ch flat highly-dence multiple electrodes, a titanium skull case, and one ECoG measuring circuit.

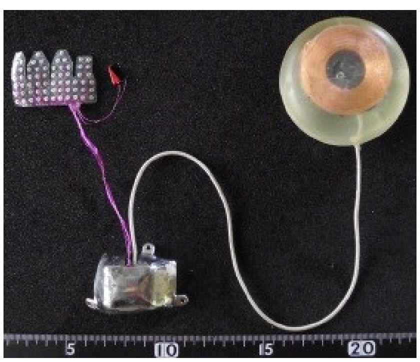

Figure 13. Appearance of the Implantable Device for a Monkey

Fig.14 shows the battery condition when we wirelessly supply power to the device. It takes approx.10 hours to the full condition. This is because that we temporally set the recharging current low due to keeping the device safe. Then, after recharging, it demonstrated that the device lasts approx. 6 hours.

Fig 15 illustrates one result of ECoG recordings with GAIN: 80db, Cut-off Freq.: 1-240Hz, Sampling:1kHz, and Num. of Ch.: 64ch , Distance between the implantable device and the recording PC: 3m.

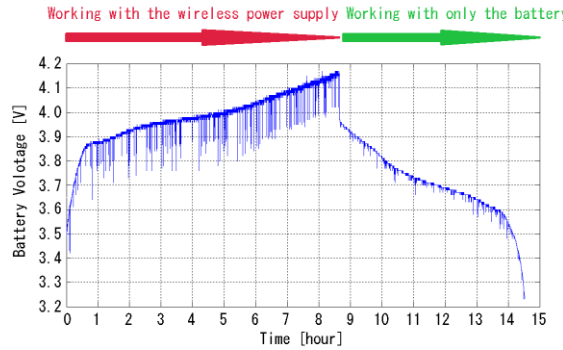

Figure 14. Investigation on the battery condition

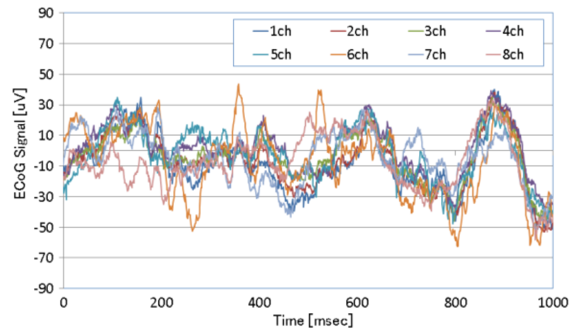

Figure 15. Example of ECoG recording data (displaying only 8ch)

V. CONCLUSION

Due to reducing the infection risk and achieving long-term ECoG measurement, we are developing a fully-implantable wireless ECoG recording device. In this paper, we introduced our 2nd proto-type: the 3D highly-dense multiple electrodes, the ECoG measuring circuits, the titanium skull case, the wireless controller, the wireless power supply. We have investigated those performances, and are trying animal experiments.

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