Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [WNG Brain-Machine Interface based on Electrocorticography using high speed UWB wireless body area network]

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Re: []

Abstract: [A important use case of dependable body area network(WBAN) for implanted devices is introduced to perform reliable and massive data for ECoG-based Brain machine interface to require amendment for IEEE802.15.6 wireless medical body area network.]

Purpose: [information]

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Brain-Machine Interface based on Electrocorticography using high speed UWB wireless body area network

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Outline

- ECoG-BMI system
  - 1st Generation 128ch system: Clinical ECoG-BMI system
  - Clinical test in 2020
  - 2nd Generation 4096ch system
    - Next generation system
    - Flexible electrode technology
    - UWB wireless technology

- BMI (system evaluation)
  - Real-time decoding
  - Robotic arm control and cortical adaptation
BMI Project (Osaka U & NICT)

Real time control of external devices just by thinking
A promising therapy for severely disabled patients

ALS, spinal cord injury, amputated limb, stroke, ……

communication

robot control
Recording methods for clinical BMI

**ECoG**: Electrocorticogram
Good balance (Information rate, invasiveness, long-term stability)

- **fMRI, MEG**: No invasive
  - Info: high
  - Huge system
- **EEG**: No invasive
  - Info: low
  - On/Off (1bit selection slowly)
  - Long-term
- **ECoG**: Non invasive
  - EEG
  - MEG
  - Invasive
  - ECoG
  - SEEG
  - Intracortical implant
  - Low invasive
  - Info: middle
  - Robotic hand control in RT
  - Long-term
- **Spike or LFP**: High Invasive
  - Info: high
  - Short-term
ECoG signal

SUA: Single Unit Activity
MUA: Multi Unit Activity

ECoG(50〜180Hz) sync with motion = informative

Clinical Research (using wired ECoG-BMI system) (by Osaka Univ.)

Implantable system is necessary for daily life support by BMI system  “Wireless” is the key
1st generation ECoG BMI system

- 128ch (# of electrodes)
- ISM band (2.4GHz)
- Clinical test in 2020
- Communication device for ALS
- Robot arm control for Paralysis
A fully implantable wireless BMI system

Pre-clinical test in 2017-

Clinical test in 2020

Prototype 64/128ch system
six months in a monkey (2013)
1st Generation 128ch system (Improvement for clinical use)

- Abdomen unit
  → Integrated into head unit
Smaller system can decrease various risks.

LSI improvement
→ Lower noise, safety, etc.

Current version: Casing, non-touch energy supply

Prototype 64/128ch system
six months in a monkey (2013)
1st Generation 128ch system (Improvement for clinical use)

- Receiver Coil for energy supply
- Surface electrode array with bio-compatible silicone
- TSMC CMOS 0.25μm (7.1mm □ 7.3mm)
- 32ch x 4chips
- Noise (input) 3μVpp
- Capable of High-γ band recording
- GLP test (bio-compatibility)
- Implant test (animal)

Wireless transmitter (2.4 GHz ISM Band) ~ 1.9Mbps

Surgical opening

Sensory area
Motor area

Surgical opening

Electrocorticography
2nd generation ECoG BMI system

- 4096ch (~ # of electrodes)
- UWB band (7.9GHz)
- Clinical test in 2030?
- Robot arm control
  for Paralysis
  with individual finger control
Next generation multi-channel BMI system more than 4,000 channels

For more accurate estimation of movement intentions

- a large number of recording channels
- recording at several regions simultaneously

Our target

implantable, distributed, and wireless

Issue of multi-channel system: volume of data
ex. ECoG, 1kS/s, 12bit-ADC

- \(~1Mbps@100ch\), \(~100Mbps@10,000ch\)
Improvement for next generation (128ch-> 4096ch)

Issues to be solved

(1): High density electrode array
   Silicone + Pt array
   \[\rightarrow\] Parylene-C + Pt (or Au)

(2): LSI (amplifier + ADC)
   32ch x 4 chips
   \[\rightarrow\] 64ch x 64 chips

(3): Wireless transmitting
   ISM (1.9Mbps)
   \[\rightarrow\] UWB(128Mbps)
2nd Generation
(4096ch ECoG-BMI system)

Flexible electrode technology
Electrode Array

(Safety, High density, Stability)

Up: High Density (IED: 2.5mm)
Down: Clinical

1st Generation

3D-shape
Individual MRI Data

3D-double surface for intra-sulcus

2nd Generation

Flexible electrode array
- Parylene-C, High Density: IED 50μm
- Relationship between intracortical and ECOG signal

(Hirata M, IEICE Trans Commun, 2011)
Flexible Electrode array for ECoG

- Gold
- Parylene-C
- Silicon Wafer
- Aluminum Mask
- Parylene-C
- Oxygen plasma etching
- Platinum black

(a) (b) (c) (d)

- 50μm x 50μm
- Platinum black

Toda, Neuroimage(2011)

Monkey128ch
- > 2.5 years
- into sulcus
(Hasegawa Lab, Niigata Univ.)

September 2019

Submission

Slide 17

Takafumi Suzuki(NICT), Masayuki Hirata(University of Osaka)
2nd Generation
(4096ch ECoG-BMI system)

Wireless technology
- UWB(Ultra-Wide Band)
Super multi-channel system using UWB (4096ch)

1\textsuperscript{st} Generation (128ch)
- ISM band (2.4GHz) [1.9Mbps]
  12bit x 1kHz x 128ch
  = 1.5 Mbps

2\textsuperscript{nd} Generation (>4000ch)
  12bit x 1kHz x 4096ch
  = 49Mbps \rightarrow \text{UWB}
  (Ultra Wide Band)
  + Distributed system
UWB system (4096ch) -Prototype-

- Flexible ECoG electrode-mesh
- Neural recording LSI board (64ch-LNA, MUX, 12b-ADC)
- 8:1 Multiplexer and logic
- UWB detector
- Water proof package

Specifications:
- UWB@7.9 GHz ±0.625 GHz
- 6.4 Mbps (8 x 800 kbps)
- 512 ch base unit No.1
- Multi-channel recording and digital multiplexing block
- 51.2 Mbps (64 x 800 kbps)
- 128 Mbps (wireless)
- LED (time)
- ZigBee
- Battery
- Qi
- UWB receiver and PC connection block
- Wireless power supply

Dimensions:
- Inside body: 14 mm x 19 mm
- Outside body: 53 mm x 47 mm x 31 mm
- UWB transmitter: 15 mm x 15 mm
UWB transmitter and receiver

Including UWB transmitter, BPF, antenna, Zigbee, Li-ion polymer battery

- Including UWB receiver, antenna, Zigbee unit
- Connected to PC by USB2.0
- Real-time Graphical view
### UWB system (Specification)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of channels</td>
<td>64~4096 ch</td>
</tr>
<tr>
<td>Supply voltage</td>
<td>3.3 V</td>
</tr>
<tr>
<td>Total power of implant devices</td>
<td>2.03 W @4096ch (version 2014)</td>
</tr>
<tr>
<td>UWB bandwidth</td>
<td>7.275~8.525 GHz for internationally usage</td>
</tr>
<tr>
<td>UWB data rate</td>
<td>128 Mbps</td>
</tr>
<tr>
<td>MUX-A and MUX-B (common hardware)</td>
<td></td>
</tr>
<tr>
<td>Xilinx Spartan6 XC6SLX16, FPC connector (11pin)</td>
<td></td>
</tr>
<tr>
<td>UWB transmitter (water proof casing)</td>
<td></td>
</tr>
<tr>
<td>RF, BPF and ZigBee board</td>
<td></td>
</tr>
<tr>
<td>LVDS receiver (51.2Mbps), Magnetic Power SW (20mm range) and rechargeable Li polymer battery (400mAh)</td>
<td></td>
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<tr>
<td>UWB receiver</td>
<td></td>
</tr>
<tr>
<td>RF board, base board (Xilinx vertex4, USB2.0) and Zigbee board</td>
<td></td>
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<tr>
<td>PC</td>
<td></td>
</tr>
<tr>
<td>Core i7 3820 Win7 (USB2.0, GUI application)</td>
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</table>
Evaluation of UWB in human equivalent liquid phantom

(a) Diagram and (b) photograph of the measurement setup.

128 Mbps UWB wireless communication is available below 20 mm between inside to outside body.
Summary

Our collaborative project 1\textsuperscript{st} and 2\textsuperscript{nd} generation of ECoG BMI are introduced.

Medical applications will need high speed (100Mbps~) and secure wireless communication.
Thank you for your attention