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전기화학 체외 탄소 나노튜브 문신 센싱을 이용한 통증 진단 분석

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Diagnostic Neuro Nerve Pain Analyzing with Electrochemical Extra corporeal Carbon Nanotube Tattoo Sensing

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초 록

인간의 통증 조절은 뇌 신경 전류에 따라 달라진다, 이들 분석 진단은 우울증, 자살 충동, 암 통증, 질병 통증, 치매, 간질 통증 등과 같은 신경 신호 감지와 관련된다. 이같은 통증진단을 위해 생체 내 0.1 mm 마이크로 와이어 프로브를 사용하여 전기화학적 3전극 시스템으로 뇌 전류를 분석했으며, 이 프로브는 탄소 나노튜브 페이스트 코팅 바늘 타입을 사용하였다. 이때 작업 전극은 직경 0.3 mm 바늘 타입 Ag/AgCl 코팅 Ag 와이어 기준으로 쥐 뇌의 근육 중심에 삽입되었고, 기준전극은 직경 0.1 mm Pt 마이크로 바늘을 생체 내 근육 피부 깊숙이 5 mm 깊이 삽입하여 2.0~–2.0 V 전위 창, 50 mv/s 주기 스캔 및 신체 시스템의 1.0×10^{-5} A 민감도로 마취상태에서 진단하였다.

Abstract : As the human pain controls depend on the brain neuro current, here assay is related to specific nerve potential detection, nerve pain induced amplification current detection, such as Depression, suicidal impulse, cancer pain, disease pain, dementia, epileptic pain signals, etc. For this purpose, the brain current was analyzed by electrochemical three-electrode systems using 0.1-mm micro wire in vivo probe, which probe was made by using carbon nano tube paste coated needle type. Here working electrode was inserted in the rat brain's muscle core with a 0.3-mm-diameter needle type Ag/AgCl Cl-coated Ag wire reference, and counter electrode of 0.1-mm-diameter Pt micro needle was inserted 5 mm deep into the in vivo muscle skin, under anesthesia with 2.0~–2.0 V potential windows, 50 mv/s cyclic scan and 1.0×10^{-5} A chrono amperometric sensitivity on the body systems. Under the optimum conditions, diagnostic application was performed to such as smell signal, muscular strength, five/sense assay and thinking neuro current. These neuro diagnostic technologies can include auditory sonar recognition, odor diagnosis, texture recognition, emotion recognition, visible color change recognition, etc. It can also amplify emotional recognition such as joy, hate, love, sadness, etc. And it can extend the pain of the skin or *in-vivo* whole body.

Keywords : Voltammetry, bio current, feeling sense, in vivo, brain pain wave

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1. Introduction

In vivo brains, the neuro nerve pain signals depend on the molecular transmitters in the nerve systems. Human disease pain is concentrated in the cranial nerves. Nerve control is linked to disease control. Here detection of the extra cellular nerve current is related to the evaluation of sophisticated *in-vivo* electro physiologic methods such as electro encephalogram[1], magneto encephalography[2], neurological disease[3], brain computer interfacing[4] and other analogous methods. The signal detection of these methods, however, requires complicated magnetic amplification[5], spectrometric separation[6], nuclear magnetic resonance[7,8], and photometric scanning. Moreover, these methods can be used only under laboratory conditions, are not applicable in *in-vivo* direct implantation, and demand expensive instrumental systems. The electrochemical voltammetric method, however, is usable for *in-vivo* implementable micro or macro probe techniques such as *in-vivo* bladder assay[9], live-brain application[10], skin cell detection[11], and *in-vivo* vascular assay.[12] Furthermore, electrochemical circuit systems have long been recognized as simple[13], fast response, and powerful tools for signal amplification[14], and accumulated stripping voltammetric methods are very sensitive[15] for nano- or pico-range detection.[16,17] As such, in this study, highly sensitive[18,19] neuro detection was optimized by a handheld voltammetric circuit. Added to this, diagnostic application was performed to feeling-sense assay[20] for human psychological neuro signals and *animum* brain activity. Thus, the system may be applicable to *in-vivo*[21] plasma assays and in vitro.[22–24]

2. Experimental Neuro diagnostic Systems Design

a micro-voltage current measurement circuit as a wearable.It is manufactured in the size of a wearable portable. The neuro diagnostic sensor was manufactured with an artificial skin tattoo sensor, a micro needle sensor, and a painting sensor. Therefore, it could be inserted into the in vitro muscle. The measurement control program can perform time-difference operation control on X, Y, 2D, cyclic voltammetry, stripping voltammetry, and the like. Neuro current amplification was extended in the range of 1.0×10^{-3} A to 1.0×10^{-9} A. Ion voltage measurement was able to measure the redox reversible potential in the range of 1 V to 3 V. These experimental results are designed to be applicable to the field of biological EEG neurological diagnosis control.

3. Experimental conditions

Fish: carp 15–25 C m long, mass 10–150 g, Three were tested repeatedly.

Experimental temperature: Experiment was conducted at an indoor temperature of 25ºC in the water tank.

Skin sensor: researcher's back of hand, forehead skin, the 3 electrode potential was based on the hydrogen reference electrode.

Mice: 7.5–10 C m body length, 5–10 C m tail length, 11–30 g body weight was used. Three experimental fish and mice were used for repeated measurements. For statistical errors, the median value of repeated measurements 3, 5, and 15 was used.

4. Carbon Nano Tube (CNT) Paste Probe, Sensor Preparation

A micro-carbon working electrode[25–27] was developed by mixing 0.5 mL standard liquid metal mercury and 0.5 g carbon nanotube paste (Nano structured & Amorphous Materials, Inc.). This was prepared overnight via catalyzed chemical vapor deposition (catalytic CVD) prior to use, magnetic stirring in a 2M nitric-acid solution[28,29], and cleansing with triple purified water. The resulting material was then mixed with reagent-grade mineral oil (New Jersey USA, 1-800-01, Acro) and water in a 40:40:20 percent ratio, relatively. The resulting modified-paste was inserted into a 1-mm-diameter, 10 mm long needle-type plastic syringe with copper wire connecting the electrode to the voltammetric workstation. Counter and reference graphite pencil electrodes were prepared using 0.5 mm diameter Hipolymer HB pencil leads; the frontal part of the lead was connected with copper wire using para film (I Nexus, South Korea, Inc.)

5. Features of carbon nanotubes:

The reasons for using carbon nanotube neural

sensors are as follows.[30)]

Strength: It is more than 100 times stronger than steel, and has excellent elastic modulus, so it bends well.

Electrical conductivity: It has a high level of electrical conductivity similar to that of copper, and it is also possible to have semiconductor properties.

Thermal conductivity: It has a high thermal conductivity similar to diamond, which is effective for heat dissipation or absorption.

Light weight: Very light because it's hollow.

Excellent surface area: It has a very large surface area compared to its small size, so it can be used in various fields such as catalysts and sensors.

Human Affinity: Stable in redox reactions, therefore stable in human muscles, blood vessels, gastrointestinal digestive fluids, biochemical, medical, and acid-base neutralization reactions

6. Preparation of electrode and detection systems

The three-electrode sensors[31–34)] of the counter, reference, and working probe prepared using 0.2-mm-thick copper paper with a 5-mm-diameter-circle electrode (CUE) were connected to voltammetric systems using a 0.3-mm Cu wire. (Fig. 1(A) insert photo

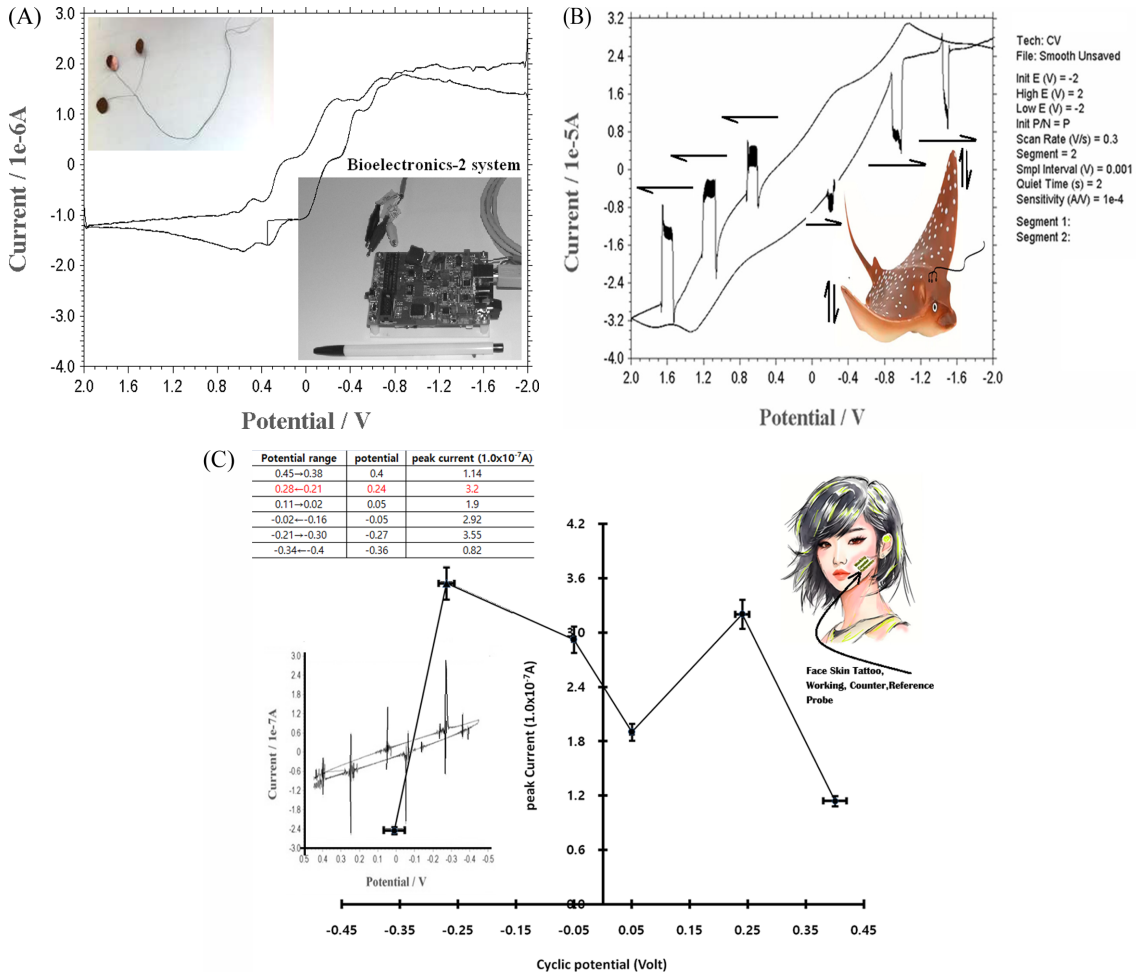
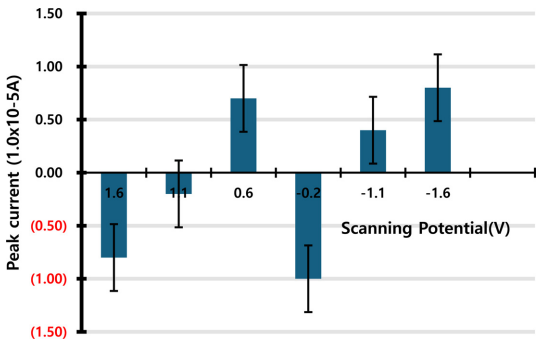


Fig. 1. Cyclic-voltammetric-potential variation from -2.0 to 2.0 V, with a 50 mv/sec scan rate, in the forehead cutis, under three-electrode conditions. (A): No-sensing condition for the steady state. (B): -1.6, -1.1, and -0.3 V cyclic anodic action scan, and 1.6, 1.1, and 0.6 V cathodic action, fish fin up and down movement. (C): Cyclic redox peak current of left face skin sensor, redox 1 round trip scan, mouth exercise 3 times repeated.

shown), The voltammetric workstation was made in these authors' institution. A method employing electrochemical neuro detection was employed using cyclic voltammetry[35–37] and chrono amperometric circuits. It was carried out using the new bioelectronics-2 system, which was pioneered by these authors' institution. The computer-controlled voltammetric system[38–40] was developed with a +–2.0 V potential range, a 2 mA current range, a 10 pA measuring current, and a compact 3"×2"×1" size. The power input and data interface were connected by the USB port of a PC. The instrument is compact, as big as the usual cellular phone (Fig. 1(A) insert photo shown), and it can be used for biological, microorganism, and environmental trace assay. *In-vivo* detection was performed using a 0.5-mm-diameter × 10-mm copper-wire-type implantable probe. The redox voltage current control conditions are as follows, initial potential: –2 V, final potential: +2 V, scanning rate: (V/s): 0.1 to 10, sweep segments: 1 to infinity, sample interval (V); 10^{-4} to 10^{+2}, delay time: 1 to 120 sec, sensitivity (A/V): 1.0×10^{-3}A to 1.0×10^{-10}A, multi-tasking, multi-user, 12 people at the same time can be operated under measurement conditions.

Table 1. Fish stingray nerve response value, muscle exercise, redox amplification signal, and current size in Fig. 1(B).

Potential	Current (1.0×10^{-5} A)
1.6	-0.8
1.1	-0.2
0.6	0.7
-0.2	-1
-1.1	0.4
-1.6	0.8



7. Results and Discussion

7.1 Optimization of the cyclic voltammetric potential

As *in-vivo* currents depend on the applied input potentials and sensing probe amplifications, working probe was attached to the forehead cutis, under stable conditions, and CV scan was performed from –2.0 to 2.0 V under optimum conditions. The redox voltammogram shown in Fig. 1(A) is simple, and no signal was obtained from it. Thus Fig. 1(B), fish fin up and down movement muscular-action signal was conducted, and under optimum conditions, cyclic-potential variation was performed with 50 mV/sec movement, with three-time muscle strength, from positive to negative scan, which is related to the chrono potential windows. The results are shown in Table 1. at the start, no action or peak current was not obtained. Under these conditions, muscle actions were performed and were continued during the positive scan. In the –1.6, –1.0, and –0.3 negative direction, muscular actions were performed, then at 1.6, 1.1, and 0.6 V, same-strength muscular actions were performed. The calculated peak results are shown in Fig. 1(B). These results can be used for neuro sensing detection and *in-vivo* electrophysiological methods, such as electro encephalogram. Thus, more specific application was carried out.

Table 1 shows the voltage-current response of a sensor inserted into both wings of a fish stingray in Fig. 1(B). They responded sensitively to small vision light intensity response, pain response, ambient environment change response movement, temperature change, sound wave pressure change, etc. The redox current was released. Current intensity was emitted in the range of 1.0×10^{-2} A to 1.0×10^{-5} A. The voltage was emitted symmetrically at a median value of 0 V in the range of +2.0 V to –2.0 V. Therefore, it is possible to decompose the nerve current corresponding to the complex attention environment. Fig. 1(C) is a human skin experiment. A definite muscle exercise peak can be seen with a left facial skin sensor, one redox round trip scan, and three repetitions of mouth exercise.

7.2 Chrono amperometry and current amplifi-cation

As neuro current detection depends on the applied redox potentials, amplitude current ranges, and detection skin surface, a three-electrode probe

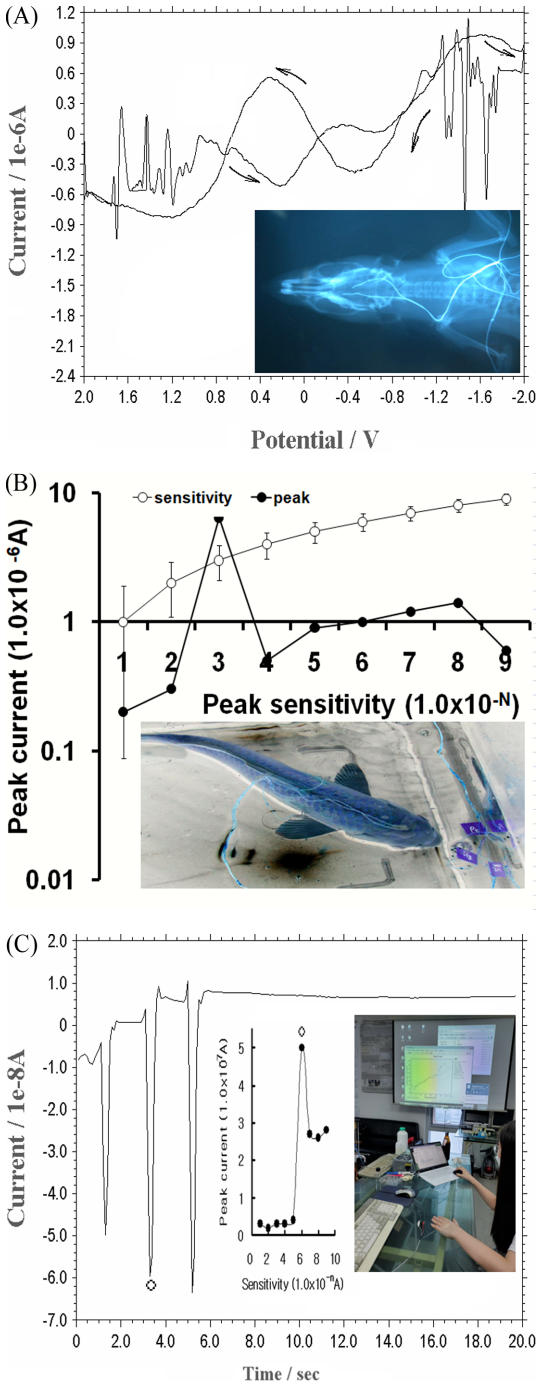


Fig. 2. (A) Cyclic neuro signals with a -2.0 V initial potential, a 2.0 V switching potential, and a 50 mv/sec scan rate. (B) Cyclic-voltammetric-amplitude variation from 1.0×10^{-1} to 1.0×10^{-9} A, under the same conditions as in (A). (C) Chrono amperometric-current variation from 1.0×10^{-1} to 1.0×10^{-9} A, using 0 V potential.

was attached to the back hand skins, and fish brain core, after which more specific cyclic-potential ranges were examined from –2.0 to 2.0 V.

Fig. 2(A) shows the results of the cyclic-voltammetric neuro current of redox scan. During oxidation scan, muscle tension was performed and was repeated at three points, from –2.0 to 2.0 V. Here, however, only negative potentials were obtained from –2.0 to –1.4 V scan, and only the 1.42×10^{-6}, 17.8×10^{-6}, and 0.98×10^{-6}A peak currents appeared. Thus, reduction scan was performed in the negative direction, but from 1.6 to 1.2 V, only the 0.92×10^{-6}, 0.78×10^{-6}, and 0.62×10^{-6} A peak currents appeared. Here, both signals can be used for neurodetection, but more sensitive amperometric-current ranges are required. Thus, more specific experiments were performed. Fig. 2(B) shows the results from the 1.0×10^{-1} to1.0×10^{-9} A exponential amplified variations, using a 50 mv/sec scan rate. Here, the linear curve represents the –1 to –9 amplifications, and the straight line is the sensing current for the backhand cutis through continuous muscular actions. A 1.0×10^{-3} A maximum peak current is shown, and the other ranges are linearly varied. Thus, 1.0×10^{-3} A was used for potentio metrics, and under this potential, the chrono amprometric-current sensitivity was examined, which can be applicable to direct neuro detection and sensing signals. Fig. 2(C) shows the results for the 10^{-1}–10^{-9} A variation at the backhand cutis with the action current, and the inset curve shows the exact points. The first five points have no signal and are simple, but the 6th point is very sensitive, and a 5.0×10^{-7} A peak current was obtained, later decreasing to 3.0×10^{-7} A. Thus, the 1.0×10^{-6} amplification was fixed. The real current shown at this curve was from 10 to 50 sec, where the current was varied from 4.8 to 6.8×10^{-8} A. These results are applicable to any sensing detection. Under these conditions, the advanced redox potential and brain signals were examined in humans and animals.

7.3 Application in the forehead cutis

For sensing detection, human skin and animal brain signals were analyzed. Under optimized conditions, a patch-type probe was attached to the forehead cutis and arms, after which the rat brain with action showed that the current in Fig. 3(A) is a real chrono amperometric peak. First, eye action

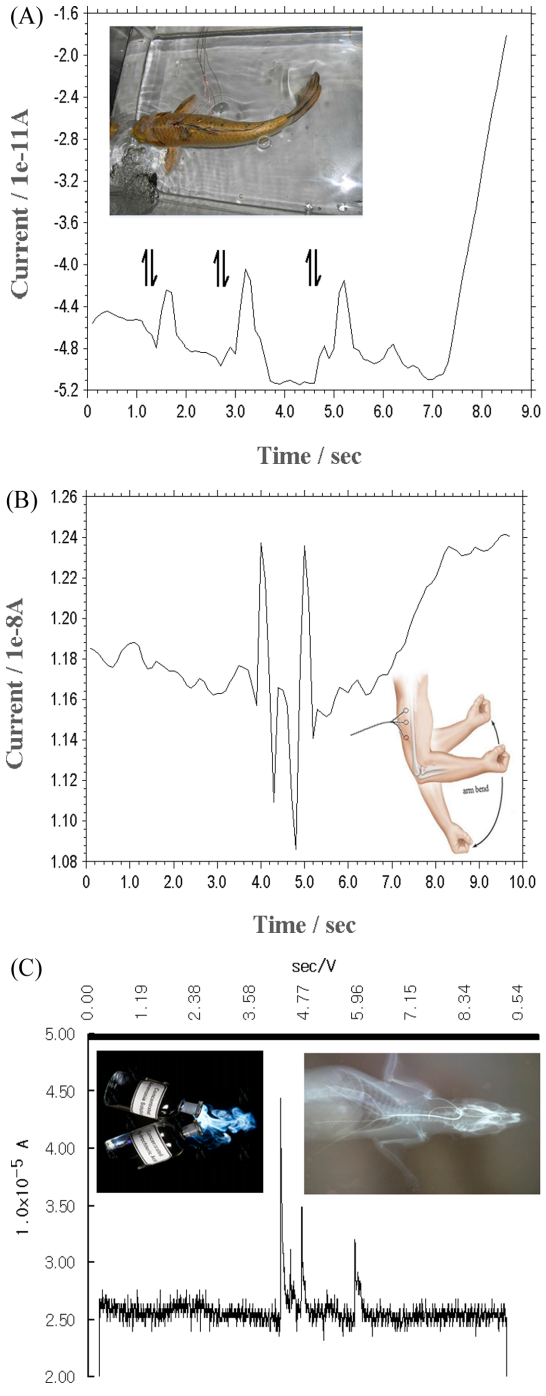


Fig. 3. (A) 1.0×10^{-5} A chrono amperometric sensitivity at the forehead cutis, with three-point muscular action. (B) 1.0×10^{-5} A chrono amperometric sensitivity at the arm elbow, with three-point muscular action. (C) *In-vivo* current in the mouse brain core, using a smell signal for an ammonium concentrate solution

was performed using the optimum parameters, and obtained with three points through three-time eye actions at 1.5, 3.5, and 5.5 sec/V were the 5.2×10^{-11}, 11.2×10^{-11}, and 7.5×10^{-11} A sensitive peak currents, which responded to the muscle currents. Under these conditions, arm action was conducted using the same method. Fig. 3(B) shows the results for the arm action for the chrono amperogram, for the three-point 4.0, 4.8, and 5.0 sec/V actions. Here, the peak currents were 0.09×10^{-8}, 0.12×10^{-8}, and 0.11×10^{-8} A. They can thus be assayed for neuro signals. Then more specific experiments were performed using a rat brain in *in-vivo* implantation, which indicated greater sensitivity when applied to living brain tissue. A working electrode was inserted in the rat brain's 0.5-mm core using a 0.3-mm-diameter needle-type micro hand drill, under anesthesia. A 10-mm-long, 0.1-mm-diameter Ag/AgCl Cl-coated Ag wire was used as the reference electrode. A counter electrode (0.1-mm-diameter Pt) was inserted 5 mm deep into the backbone tissue, and all the electrodes were cemented with a tooth binder and were connected to a 0.05-mm enamel-coated copper wire with a voltammetric system. Fig. 3(C) shows the chrono amperometric peak current results, under no-sensing conditions, with light, smell, noise, and any vibration. At the first peak, a simple, linear curve was obtained. Then a small test was performed three times, using ammonium solutions. Here, the chrono-range 24, 0.11, and 0.07×10^{-5} A peak currents were obtained at 3.58–5.98 sec/V. As satisfactory sensing-signal results were obtained. Therefore, the neurotransmitter current movement could be clearly distinguished, the proposed method can be used for extracellular, neuropsychiatric, and other types of neuro control.

7.4 Brainwave control application range

Fig. 4.

7.5 Brainwave control application range

A: Brainwave control Oculus glasses monitor: It is a system that is recently sold as a product, and brainwave control can be linked to these glasses monitors.

B Voltage current amplification circuit: It can be connected to in vivo or in Vitro tattoo sensors in the human body, thus enabling human diseases,

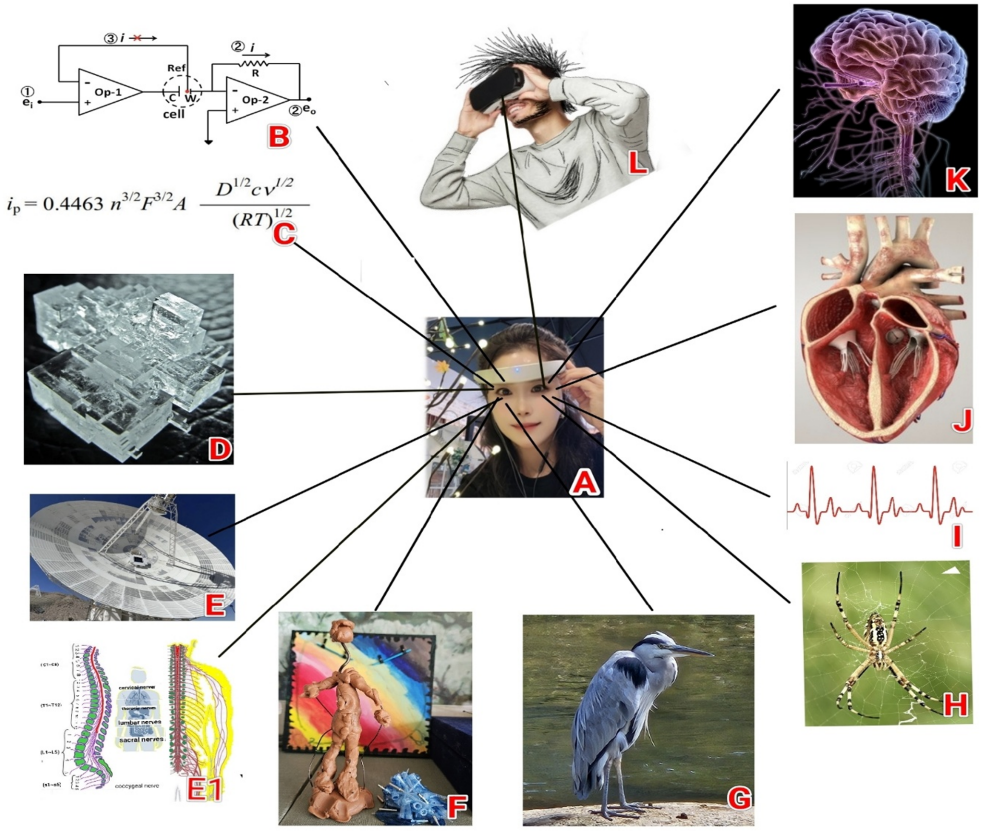


Fig. 4. The scope of application for cranial nerve wave diagnosis is divided into A to L and 12 fields.
A: Brainwave control Oculus glasses monitor, B Voltage current amplification circuit, C: Mathematical simulation, D: Synthesis of crystal molecules, E: Digital transformation of space communication, E1: The central nervous system, F: Creative arts science, G: Proliferation of plants and animals, H: Insect culture, I: biosignal diagnostic control, J: Artificial organs, K: Brain nerve control, L: Virtual reality control

virus diagnosis, and performance diagnosis control of internal organs.

C: Mathematical simulation: In vivo brainwave nerve signal amplification, high-dimensional operation, problem solving, future axis, statistics prediction, etc. are possible.

D: Crystal molecular synthesis: It can be calculated for organic and inorganic synthesis, functional material extraction and resynthesis, etc.

E: Space communication digital transformation: Natural emission signals, animal behavior noise, and space emission energy waves can be interpreted.

E1: Central nervous system: connected to nerves that are connected almost everywhere in the body through the spinal cord, centering on the brain. It sends signals throughout the body, processes and interprets information to produce results, stores and gives instructions.

F: Creative arts science: Human creative interpretation, imagination realization, art resynthesis, neural wave transmission, etc. can be used.

G: Proliferation of plants and animals: Unmanned aquaculture, drug production, cell embryos, etc.

H: Insect culture: DNA synthesis development, food production, therapeutic drug extraction, etc.

I Bio-signal Diagnostic Control: Unmanned Control, Remote Control, etc.

J: Artificial organs: Organ synthesis, mass production treatment, etc.

K: Brain nerve control: Neural network restoration, psychotherapy, etc

L: Virtual reality control: Virtual era restoration, etc.

These techniques described in A to L are already published papers. Therefore, these figures illustrate the amplified cranial nerve voltage current signal and the figures that can be linked A to L

8. Conclusions

Electrochemical neuro sensing was conducted using a voltammetric bio circuit, and a microprobe was directly implanted into the bran systems. The optimum diagnostic conditions were set at 30 s accumulation time, 2.0 V initial potential, –2.0 V switching potential on CV, and –0.3 or 0.3 V chrono amperometric potential, under the optimized potential can be attained to nano working current. Here, an eye action of muscular current was obtained, and the implanted *in-vivo* probe was activated to the five-sensing neuro assay. The results can be applied to brain sensing and to any other field requiring mammalian extracellular nerve analysis or real time *in-vivo* electro physiologic assay. Therefore, the results of the study can amplify brain cell ion currents emitted from brain nerves from 1.0×10^{-9} A to 1.0×10^{-3} A using artificial skin sensors. These voltage currents can measure trace currents that humans think of, and currents that humans dream of, emotional currents, pain and joy currents, excitation and imagination currents, microscopic natural state reactions, and light-sensitive currents. They are also expected to be able to perform sensitive sensory measurement controls

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Authors' contributions

This idea from **Suw Young Ly**, All authors read and approved the final manuscript.

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Availability of data and materials

All materials are available by the corresponding author.

Declarations

Ethics approval and consent to participate

All experiments were performed according to established guidelines for the ethical use

Consent for publication

Not applicable.

Competing interests

declare no conflict of interest

References

1. R. R. Angevin and A. D. Estrella, Brain–computer interface: Changes in performance using virtual reality techniques, *Neurosci. Lett.*, **449(2)**, 123–127 (2009).
2. V. Logar, I. Škrjanc, A. Belic, S. Brezan, B. Koritnik, and J. Zidar, Identification of the phase code in an EEG during gripping force tasks: A possible alternative approach to the development of the brain computer interfaces, *Artif. Intell. Med.,* **44(1)**, 41–49 (2008).
3. A. Kubler and N. Birbaumer, Brain–computer interfaces and communication in paralysis: Extinction of goal directed thinking in completely paralysed patients?, *J. Clin. Neurophysiol.*, **119(11)**, 2658–2666 (2008).
4. V. Morash, O. Bai, S. Furlani, P. Lin, and M. Hallett, Classifying EEG signals preceding right hand, left hand, tongue, and right foot movements and motor imageries, *J. Clin. Neurophysiol.*, **119(11)**, 2570–2578 (2008).
5. L. Leocani, G. Magnani, T. Locatelli, V. Martinelli, M. Rovaris, M. Filippi, M. Falautano, G. Santuccio, F. Possa, and G. Comi, EEG correlates of cognitive impairment in MS, *Ita.l J. Neurol. Sci.*, **19,** 413–417 (1998).
6. I. Hollander, H. Petsche, L. I. Dimitrov, O. Filz, and E. Wenger, The reflection of cognitive tasks in EEG and MRI and a method of its visualization, *Brain Topogr.,* **3**, 177–179 (1997).
7. J. Sijbers, J. V. Audekerke, M. Verhoye, A. V. der Linden, and D. V. Dyck, Reduction of ECG and gradient related artifacts in simultaneously recorded human EEG/MRI data, *MRI*, **18(7)**, 881–886 (2000).
8. K. Roberts, A. Papadaki, C. Gonçalves, M. Tighe, D. Atherton, R. Shenoy, D. McRobbie, and P. Anand, Contact heat evoked potentials using simultaneous EEG and fMRI and their correlation with evoked pain, *BMC Anesthesiol.*, 1–12 (2008).
9. S. Y. Ly and J. H. Lee, Human urine diabetes assay and *in vivo* rat bladder assay using a fluorine-doped carbon nanotube catheter sensor, *Ann. Biomed. Eng.,* **37,** 2028–2033 (2009).

10. S. Y. Ly and D. Y. Kim, Electrochemical assay of neurotransmitter glycine in brain cells, *Bull. Korean Chem. Soc.*, **28(4)**, 515–519 (2007).
11. S. Y. Ly, C. H. Lee, and Y. S. Jung, Voltammetric bioassay of caffeine using sensor implant, *Neuromol. Med.*, **11,** 20–27 (2009).
12. S. Y. Ly, Diagnosis of copper ions in vascular tracts using a fluorine doped carbon nanotube sensor, *Talanta*, **74(5)**, 1635–641(2008).
13. S. Y. Ly and D. W. Choi, Implementation of a biocircuit implants for neurotransmitter release during neuro-stimulation, *Curr Neurovasc Res.,* **10(3),** 238–246 (2013).
14. S. Y. Ly, S. H. Choa, M. H. Shin, S. R. Kim, H. S. Yoo, H. J. Shin, Y. S. Jung, and J. B. Choi, Trace uranium assay using infrared photo diode electrodes, *Anal. Lett.,* **43(9)**, 1471–1480 (2010).
15. S. Y. Ly and Y. K. Kim, Assay of glucose in urine and drinking water with voltammetric working sensors of infrared photo diode electrode, *Sensor. Actuat. A -Phys.,* **127(1)**, 41–48 (2006).
16. S. Y. Ly and C. H. Lee, Clinical *in vivo* bio assay of glucose in human skin by a tattoo film carbon nano tube sensor, *J. Oil & Appl. Sci.*, 34, 595–601 (2017).
17. S. Y. Ly, H. S. Yoo and S. K. Chun, Detection of trace metal in distilled alcoholic drinks, *Food Chem.*, **138**, 168–171 (2013).
18. Suw Young Ly, So Dam Yoo and Seung Kyu Chun, Detection of helicobacter pylori DNA in preliminary stage gastric cancer cells, *Pathology,* **44**, 251–2540 (2012).
19. S. Y. Ly, J. H. Lee, and D. H. Jung, Radioactive uranium measurement *in vivo* using a handheld interfaced analyzer, *ET&C,* **29**, 1025–1030 (2010).
20. S. Y. Ly, H. J. Heo, and M. J. Kim, Real time analysis of neurotransmitters in the brain using a micro-electrode system, *Curr. Neurovasc. Res.*, **7(1),** 32–38 (2010).
21. S. Y. Ly, Y. C. Kim, H. J. Hong, J. Kim, and K. Lee, Rapid voltammetric diagnosis of escherichia coli contamination in non-treated human blood plasma of healthy and sepsis-infected patients, *IEEE Sens. J.*, **18(6)**, 2200–2205 (2018).
22. S. Y. Ly, K. Lee, H. T. Kang, and H. S. Yoo, Investigation of trace cobalt in glass beads from an archaeological tomb, *IEEE Sens. J.*, **11(6)**, 1325–1328 (2011).
23. I. H. Cho, K. J. Choi, J. Choi, K. Lee, and S. Y. Ly, Trace assay of insulin in a pharmacy drug with a paste electrode, *Amino Acids,* **55,** 1279–1284 (2022).
24. S. Y. Ly, K. J. Choi, J. H. Kim, and K. Lee, *In vivo* diagnostic real-time wireless sensing of glucose in human urine and live fish deep brain cells, *Int. J. Sens.,* **12(7)**, 543–552 (2022).
25. S. Y. Ly, Diagnosis of copper ions in vascular tracts using a fluorine-doped carbon nanotube sensor, *Talanta,* **74(5)**, 1635–1641 (2008).
26. S. Y. Ly, K. Lee, Y. J. Choi, and B. S. Ra, Septicemia poisoning detection at vascular by copper immobilized macro probe, *Sens. Lett.*, **14(1),** 93–96 (2016).
27. S. Y. Ly, J. M. Bae, and J. Kim, Toxicological investigation of radioactive uranium in Seawater, *Toxicol. Res.,* **28,** 67–71 (2012).
28. S. Y. Ly, J. I. Chae, Y. S. Jung, W. W. Jung, H. J. Lee, and S. H. Lee, Electrochemical detection of ascorbic acid (vitamin C) using a glassy carbon electrode, *Nahrung,* **48(3),** 201–204 (2004).
29. S. Y. Ly, S. H. Choa, M. H. Shin, H. J. Shin, S.-R. Kim, H.-S. Yoo, and Y. S. Jung, Trace uranium assay using infrared photo diode electrodes, *Anal. Lett.,* **43(9)**, 1471–1480 (2010).
30. S. Vardharajula, S. Z. Ali, P. M. Tiwari, E. Eroğlu, K. Vig, V. A. Dennis, and S. R. Singh, Functionalized carbon nanotubes: biomedical applications**,** *Int. J. Nanomedicine,* **7**, 5361–5374 (2012).
31. S. Y. Ly, H. J. Heo, and M. J. Kim, Real time analysis of neurotransmitters in the brain using a micro-electrode system, *Curr. Neurovasc. Res.,* **7(1),** 32–38 (2010).
32. S. Y. Ly, Y. S. Jung, C. H. Lee, and B. W. Lee, Administering pesticide assays in *in vivo*-implanted biosensors, *Aust. J. Chem.,* **61(10)**, 826–832 (2008).
33. S. Y. Ly, J. E. Kim, and W. Y. Moon, Diagnostic assay of carcinoembryonic antigen tumor markers using a fluorine immobilized biosensor with handmade voltammetric circuit, *Eur. J. Cancer Prev.,* **20(1),** 58–62 (2011).
34. S. Y. Ly and M. J. Kim, Diagnostic assay of chromium (VI) in the ex vivo fluid of the urine of a smoker using a fluorine-doped handmade sensor, *J. Clin. Lab. Anal.,* **23(2)**, 82–87 (2009).
35. S. Y. Ly, C. H. Lee, and Y. S. Jung, Voltammetric bioassay of caffeine using sensor implant, *Neuromolecular Med.,* **11**, 20–27 (2009).
36. Y. Kim, Y. Lee, J. Yoo, K. S. Nam, W. Jeon, S. Lee, and S. Park, Multifunctional and flexible neural probe with thermally drawn fibers for bidirectional synaptic probing in the brain, *ACS Nano*, **18(20)**, 13277−13285 (2024).
37. X. Wen, B. Wang, S. Huang, T. L. Liu, M.-S. Lee, P.-S. Chung, Y. T. Chow, I-W. Huang, H. G. Monbouquette, N. T. Maidment, and P.-Y. Chiou, Flexible, multifunctional neural probe with liquid metal enabled, ultra-large tunable stiffness for deep-brain chemical sensing and agent delivery, *Biosens. Bioelectron.*, **131,** 37–45 (2019).
38. T. Wang, Y. Chen, Y. Wang, S.-H. Lee, Y.-S. Lee, and J. Dong, Advanced neural probe sensors toward multimodal sensing and modulation: design, integration, and applications, *Adv. Sensor Res.***, 4(2),** 22400142 (2025).
39. A. R. Harris, D. B. Grayden, and S. E. Joh, Electrochemistry in a two-or three-electrode configuration to understand monopolar or bipolar configurations of platinum bionic implants, *Micromachines*, **14**, 722 (2024).
40. V. Periasamy, P. N. N. Elumalai, S. Talebib, R. T. Subramaniamc, R. Kasi, M. Iwamotod, and G. G. Kumar, Novel same-metal three electrode system for cyclic voltammetry studies, *RSC Adv.,* **13(9)**, 5744–5752 (2023).