A novel bio-machine interface for the behavior modulation of living organism

생물 행동 조절을 위한 새로운
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Outline

• Proposal feedback
• Background
• Concept idea
• Experiments
• Conclusion
• Future works
Proposal feedback

• Reorganize the main topic theory that can integrate the sub research ideas to one story

• Turtle study and mouse study should have different concept

• What is the ultimate goal of this research? surviving? navigation?

• Future work and application
Background
Needs & Limitations of “Biomimetic robots”

Limited condition

Real nature environment
Needs & Limitations of “Biomimetic robots”

**Needs**
- Development of robotics technology
- Exploration
- Operation in extreme environment
- Dangerous mission

**Limitation**
- Battery capability / charging
- Capacity for locomotion
- Size and weight
- Range of operation
- Communication

Gecko robot, MIT

ACM-R5, TITECH

Moon Monkey, DFKI
Brief history

Mimetic Robot

Control Organism

Living Organism

Robo-rat, NYU
Robo-roach, NCSU
Cyborg Beetle, Berkeley
Canine, Auburn Univ
# Brief history

<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Target</th>
<th>Stimulus</th>
<th>Method</th>
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<tbody>
<tr>
<td>Rat navigation guided by remote control</td>
<td>2002</td>
<td>Rat</td>
<td>Innervation (Brain)</td>
<td>Training</td>
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<tr>
<td>Cockroach Controlled Mobile Robot:</td>
<td>2004</td>
<td>Roach</td>
<td>External stimulus (Light)</td>
<td>Instinct</td>
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<tr>
<td>Virtual Fences for Controlling Cattle</td>
<td>2006</td>
<td>Cow</td>
<td>External stimulus (Electric shock)</td>
<td>Instinct</td>
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<td>Darpa's cyborg shark</td>
<td>2006</td>
<td>Shark</td>
<td>External stimulus (Chemical Plume)</td>
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<tr>
<td>Japans' RoboRoach</td>
<td>2006</td>
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<td>Innervation (Feelers)</td>
<td>Instinct</td>
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<tr>
<td>China's RC Pigeon</td>
<td>2007</td>
<td>Pigeon</td>
<td>Innervation (Brain)</td>
<td>Training</td>
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<tr>
<td>Darpa's RoboMoth.</td>
<td>2007</td>
<td>Moth</td>
<td>Innervation (Muscle)</td>
<td>Direct</td>
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<tr>
<td>RF control of beetle</td>
<td>2008</td>
<td>Beetle</td>
<td>Innervation (Muscle)</td>
<td>Direct</td>
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<tr>
<td>Remote command of a trained canine</td>
<td>2011</td>
<td>Dog</td>
<td>External stimulus (Sound)</td>
<td>Training</td>
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<tr>
<td>Line Following Terrestrial Insect Biobots</td>
<td>2012</td>
<td>Roach</td>
<td>External stimulus (Feelers)</td>
<td>Instinct</td>
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![Chart showing the use of different stimuli and methods](chart.png)
Concept idea
Limitations of conventional research

- Not safety stimulation (Electirc)
- No selective stimulation

- Simple stimulation
- Can not complex behavior control

- Lack of reliability
- Instinct behavior problem

- Energy supply problems
- Communication problem

Control Organism
Requirements of this research

Safety

Ability

Reliability

Duration

Novel Bio-machine Interface

(Animal-robot interaction)
Key idea

Stimulation controller

Investigator

command

Device

Stimulation

Organism

Result of movement

One-way Control

Stimulation controller

Investigator

command

Device

Stimulation

Organism

Result of movement
Key idea

Bio-machine Interaction

Machine
Think & Decision

Stimulation

Safety

Locomotion Feedback

Reliability Duration

Artificial Interaction

Organism
Motivation increase
Ability

Bi-directional Control

Navigation

Specific interface design

Motivation increase

Ability
Research theory

Conventional stimulator

Novel Bio-machine Interface
(main task: navigation)

Parasitic Robot

MIDAS system

Safety
Ability
Reliability
Duration
Experiments 1

Parasitic Robot System for Waypoint Navigation of Turtle
Introduction

Yellow Sharksucker - Remora

- Transportation
- Supply food
Overview the parasitic robot for turtle

Animal-robot Interaction

- Locomotion Feedback
- Light stimulation
- Feed the Snack

Turtle
- Hunger Motivation

Machine
- Think & Decision

Navigation
Construction of the parasitic robot

- Stimulation module
- Control module
- Reward module

(Carbone Frame, 9V battery, Regulator, Weight of 97g)
Waterproofed by Heat-shrink Tube
Construction of the parasitic robot

Ground Control System
- XBee pro chip
- Computer
- Monitor
- Position, Waypoint, Head-angle, State
- Camera
- Calibration
- Image capture

Parasitic Robot
- Stimulation Module
  - LED Display
    - Carbon frame
  - LED Unit 5 ea
  - Power
    - Battery
  - Regulator

Control Module
- Micro Controller
  - Atemega8
- Register
- Memory
- PID controller
- LOS guidance
- Communication
  - XBee pro chip
  - zigbee

Reward Module
- Linear Actuator
  - Serial Port
  - Motor Driver
  - 2 Pole Ferrite Motor

XBee pro chip
zigbee
Atemega8
Register
Memory
PID controller
LOS guidance
XBee pro chip
zigbee
Position, Waypoint, Head-angle, State
XBee pro chip
zigbee
Waypoint Guidance A desired path for the vehicle to follow are defined by a set of waypoints and connecting line segments.

Line of Sight Guidance In order to guide the ship sailing to commanded waypoints, a simple line-of-sight (LOS) guidance technique (McGookin et al., 2000) is introduced.

Navigation Algorithm

1. $n \leftarrow 1$
2. while navigating do
3. Get the waypoint $w_n(x_n, y_n)$ and robot pose $p(x, y), \theta$
4. $\varphi_{los} \leftarrow \tan^{-1}\left(\frac{y_n - y}{x_n - x}\right)$
5. $\delta_{control} \leftarrow \theta - \varphi_{los}$
6. Turn on the LED which is the closest to $\delta_{control}$
7. if $L \leq R$ then
8. Activate the feeder and give the reward
9. $n \leftarrow n + 1$
10. end if
11. end while
Experiment setting

• Water Tank
  - 10T PVC Frame
  - Length 4m, Width 1.5m, Depth 1m
  - White Background
Position Awareness (Image Processing)

- **CMOS Camera Specifications**
  - 1328 X 1048
  - Rolling shutter
  - Sony IMX035LQR-C
  - 480Mb/s
  - Free-running acquisition: 1328x1048 at 23FPS

- **OpenCV**
  - Marker Detection
Wireless communication (Zigbee)

• Xbee Specification
  ▪ Indoor/Urban: up to 100’ (30 m)
  ▪ Outdoor line-of-sight: up to 300’ (100 m)
  ▪ Transmit Power: 1 mW (0 dBm)
  ▪ Receiver Sensitivity: -92 dBm
  ▪ TX Current: 45 mA (@3.3 V)
  ▪ RX Current: 50 mA (@3.3 V)
  ▪ Power-down Current: < 10 μA

• Communication Protocol

<table>
<thead>
<tr>
<th>STX (1)</th>
<th>NUM (1)</th>
<th>CMD (1)</th>
<th>LRC (2)</th>
<th>ETX (1)</th>
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<tr>
<td>02H</td>
<td>‘9’</td>
<td>‘R’</td>
<td>“##”</td>
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<th>STX (1)</th>
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Training session for Parasitic robot and Turtle
Results

Fig. Controlled path of turtle by Parasite robot

Fig. Learning curves for attraction force
Parasitic robot for Turtle
Evaluation of results

- **Safety** → Non-invasive stimulation (visual, food)  
  2month experiment days

- **Ability** → Motivation induce method (training),  
  Derive the maximum swimming speed of turtles

- **Reliability** → Increased some of accuracy in the training progresses, but affected by target’s condition (hunger, fatigue)

- **Duration** → An energy harvesting system could not be implemented
• The result shows that the proposed concept of parasitic robot interacts well with the target animal (turtle) and moves it for the purpose of the robot.

• Limitations of training interaction method, such as lack of reliability in the case of sleeping or fullness

• Journal of bionic engineering in Elsevier [published]
Experiments 2

Medial preoptic circuit motivates object exploration and acquisition.

(Cooperated with Prof. D S Kim laboratory)
Photostimulation of MPA-vPAG circuits triggers object-craving responses (Prof. D S Kim laboratory)

Virally mediated expression of ChR2 driven by the CaMKIIα promoter in MPA neurons. Scale bar, 200 μm.
Viral expression of ChR2 driven by the CaMKIIα promoter in axon terminals in the vPAG. Scale bar, 200 μm.

Active engagement of various 3D objects with different shapes, colors, and textures by ChR2<sup>MPA-vPAG</sup> mice.
Photostimulation of MPA-vPAG circuits triggers object-craving responses (Prof. D S Kim laboratory)
MIDAS System
(MPA-induced drive-assisted steering)
MIDAS System
(MPA-induced drive-assisted steering)

Reinforcement learning

Muscle control

Motivation

Control

Ability ↑ Reliability ↓

Reliability ↑ Ability ↓

Motivation Control

New type Animal Cyborg
Construction of the MIDAS

- **Stimulation Module**
  - LED + Fiber-optic Cannula
  - 3pin header
  - 150 mA blue LED (473nm)
  - Servo motor
  - Target object
  - Motor Driver

- **Power**
  - 3.7v Li-po
  - Regulator

- **Control Module**
  - Micro Controller
    - 16MHz ARM Cortex-M0
    - Register
    - Memory
  - LED frequency controller
  - Communication
    - BLE (Bluetooth Low Energy)

- **Ground Control System**
  - RFD22102
  - Computer
  - Monitor
    - Position, Waypoint, Head-angle, State
  - Camera
    - Calibration
    - Image capture

- **Construction of the MIDAS**
  - Prey-like-object
  - Blue LED + optic-fiber
  - Servo-motor
  - Battery
  - Communication & control chip
Maximum current (typical): 150 mA continuous; 300 mA pulsed (10 ms pulse, 10% duty cycle)

Output power: 8.0 mW @ 150 mA blue LED; 1.5 mW Amber LED

Dimensions: 6 x 6 x 6 mm

Mass: 200 mg

Electrical interface: 3 pins header, 1.27 mm

Pinout: Pin 1, Pin 3: Cathode (-); Pin 2 (center): Anode (+)
Control Algorithm of Optogenetics

- Light intensity: 1.5mW ~ 2.0mW
- Frequency: 0Hz~40Hz
- Duty Cycle: 20% (turns off for 40ms after 10ms flash)
Construction of each module
Remote control device and system

Control device

Integrated control device
Servo motor +
Communication and control chip +
Battery module included

Communication Protocol (BLE)

Bluetooth Low Energy Transmission

Than existing systems
Packet Size,
Channel number reduction
Simplified connections and Wait function optimization

Control monitoring system

Control monitoring system
BLE communication function +
Servo motor control and LED control +
With automatic control
Behavior after wearing remote control device (light stimulus ON)
Automatic navigation system
Test 1 - Velocity

- Target tracking speed change according to controlled remote light stimulus frequency

(a) Guiding angle = 0°

(b) 473nm pulse
0, 5, 10, 20, 40 Hz

Average velocity (cm/s)

Pulse frequency (Hz)
Test 2 - Angle Velocity

• Change of angular velocity according to controlled visual stimulus angle

\[
Chasing\ angle\ error\ (\%) = \left| \frac{\alpha}{90^\circ} \right| \times 100\ (\%)
\]
Navigation Algorithm

- **LED Control with the stimulus angles between -15 and +15 degrees**
  
- **Only control servomotor**

\[
\theta_w = \tan^{-1}\left(\frac{y_{los} - y}{x_{los} - x}\right)
\]
Test 3 - Navigation

- Control of mouse movement by optical stimulus and visual stimulus control (4way navigation)

![Diagram showing navigation process and visual and optical stimuli](image)

**Graphs:**
- Graph (d): Average velocity vs. stimulation frequency (Hz)
- Graph (e): Navigation accuracy vs. stimulation frequency (Hz)
4-Waypoint Navigation Test

Stimulation

Sham_stim.
Test 4 - Obstacle avoidance ability

- Obstacle avoidance and breakthrough ability when unexpected obstacle appeared during rat control
4-Waypoint Navigation Test

Stimulation

Sham_stim.
Application
Test 5 - 3D maze

Automated 3D-maze navigation by using object-chasing behavior in mice
Test 5 - 3D maze

3D maze navigation
without light stimulation
vs
with light stimulation
Test 5 - 3D maze result

- Heat-map traces for mice navigating in a complex 3D maze containing seven hurdles under OC-only, LC-only, and OC+LC conditions.
Test 5 - 3D maze result

- Time of stay heat-map traces for mice navigating in a complex 3D maze under OC+LC conditions.
Compare with Optimal Paths

Path length: 6M
CTE: 15cm
Test 6 - Overcome the extinction of fear
Test 6 - Overcome the extinction of fear

Before the shock
Test 7 - facilitate the extinction of fear

MIDAS accelerates fear memory extinction
Test 7 - facilitate the extinction of fear

- The MIDAS system can facilitate the extinction of fearful place memories.
Evaluation of results

- **Safety** → Optogenetic stimulation. Maximum 3 month experiment days

- **Ability** → Immediate motivation induce method (MIDAS), Derive the maximum speed of mouse, Ability to overcome various obstacles

- **Reliability** → Increased accuracy, Not affected by target’s condition or memory

- **Duration** → An energy harvesting system could not be implemented
Closure

• This study demonstrates a remarkable improvement in control performance compared to previous studies as an organism control system

• Structural limitations (external objects)

• Nature Neuroscience [Second review]
Conclusion
Conclusion

Conventional stimulator

Novel Bio-machine Interface

Parasitic Robot

MIDAS system

Safety

Ability

Reliability
Thank you!!