RatBot: A Rat "Understanding" What A Human Sees

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Abstract
Rat robot has weak vision and cannot understand objects in human style which limits its applications. This extended abstract presents a Ratbot capable of understanding some of what the rat sees like human beings. The developed Ratbot accepts electrical stimuli to take expected actions. By incorporated with the computer vision techniques, its vision ability is improved. The interesting objects captured by a compact camera on the rat back can be detected and the finding is tied with the stimulus for a special action. Our Ratbot can accomplish tasks of walking through a path guided by an interesting object by itself.

Author Keywords
Rat robot, Computation of visual cognition, Navigation

ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces- Prototyping, Evaluation/methodology.

Introduction
An animal robot is an animal mounted with a stimulator (a circuit), which generates electrical stimuli to specific brain areas, in order to drive the animal to take actions that humans expect. The stimuli are delivered to the specific brain areas via electrodes implanted there. Thus,

animal robots can be controlled by humans to navigate through an environment, following a designated path. Because of their special motion and perception abilities, animal robots have great potential in rescue and military applications.

Rat robot (Ratbot), is a typical animal Robot studied [15]. One drawback of Ratbot exists that the vision ability of a rat is weak and it can find only some special objects with a biologically significant visual stimulus [10]. Further, it does not know the meaning of objects from the viewpoint of human beings. For example, even it knows "where an object is", it does not know "what it is". This leads to the situation that humans are required to identify the objects arrangements in an environment and then give appropriate instructions to them for roaming. This limits the possible application environments where humans' sights are not capable of reaching.

Thus, it is important to enhance the vision system for Ratbots in order for them to understand some of what they sees like human beings. This work is a preliminary study to deal with the problem. An Ratbot is developed in which the rat accepts stimuli to take expected actions, such as turning left, turning right, and walking forward. A compact camera is assembled at the back of the rat and the computer vision techniques are incorporated to the Ratbot to improve its vision ability. The interesting objects captured by the camera can be detected and the detection results are transferred to a stimulation controller to determine the actions of the rat. The object finding ability can be seen as the embedded ability of the Ratbot because we tie the detection with a stimulus for a special action. The experimental results demonstrate that the Ratbot can accomplish tasks of walking through a path guided by an interesting object by itself.

Related Work in Animal Robot

Existing animal robots can be categorized to three classes: aerial, aquatic and terrestrial animal robots.

There are remarkable studies in aerial animal robots. The first animal robot appeared in 1997. The locomotory reaction of a *Periplaneta Americana* to various electrical stimuli was analyzed. By using two photosensors as inputs, the electronic backpack could drive the insect to walk along a black line [6]. The success of *Periplaneta Americana* robot greatly inspired the research of animal robot based on insects. Microprobes in the *Manduca sexta* were implanted during early metamorphosis to directly control its wing motion [3], which were able to affect the flight direction of *Manduca sexta*. In [14], stimuli were delivered to the brain of Beetles to elicit, suppress, or modulate wing oscillation, which accomplished the control of flight initiation, cessation, and elevation. Turns were triggered by direct muscular stimuli. In [1], the flight control of honeybees has been studied.

The second category of animal robots are based on aquatic animals. In [8], the locomotion control of goldfish in the horizontal plane was accomplished by stimulating the Nflm region in the midbrain. In [11], Peng et al. showed that the adult carps' behavior of turning left, turning right, moving forward, and moving backward could be induced by electric stimulation in the cerebellum.

Terrestrial animal robots such as *Gekko gecko* [18] and rat [15, 4, 7, 9, 16] were also investigated. Rat robot was first developed in [15]. The electrical stimuli to the somatosensory cortices (SI) and medial forebrain bundle (MFB) were used as cues and rewards, respectively. The rat can be easily guided through pipes and across elevated runways, and even be instructed to climb or jump from trees. A new method was proposed for rat robot navigation which was based on virtual punishment [7]. Electrical stimuli were delivered to the *thalamic ventral posterolateral nucleus* (VPL) and *amygdala nucleus* (AMY) of the rat brain. Because of the virtual harm feeling, rats would change directions and escape actively. In [9], the immobile behavior triggered by the *dorsolateral Periaqueductal gray* (dlPAG) stimulation was investigated. By stimulating MFB or dlPAG during navigation, the state of rat could be switched between motion and motionless. The freezing time could be controlled in certain extent. In [16], a new locomotion control scheme was developed in rat navigation.

In spite of extensive researches on animal ratbots, few efforts have been made to improve the cognitive ability by incorporating the recent work in computational intelligence to animal ratbots, such as computer vision. This work focuses on the enhancement of vision system for a ratbot by integrating the computer vision techniques to it.

Ratbot: Overview

Figure 1 shows an overview of our vision-enhanced Ratbot. The system contains two parts: the computation components and the rat-mounted pack.

The rat-mounted pack includes the following parts:

- A stimulation circuit, which generates electrical stimuli to the specific brain areas of the rat via implanted electrodes in the rat brain. Depending on the triggered stimulus to a specific brain region, the Ratbot would take one action of turning left, turning right, or moving forward.
- A compact camera, which captures the scene in front of the Ratbot.
- A wireless module, which receives stimulus instructions from the stimulation controller and sends videos from the compact camera to the computation component of visual cognition for searching of interesting objects. So it contains a stimulation receiver and a video transmitter.

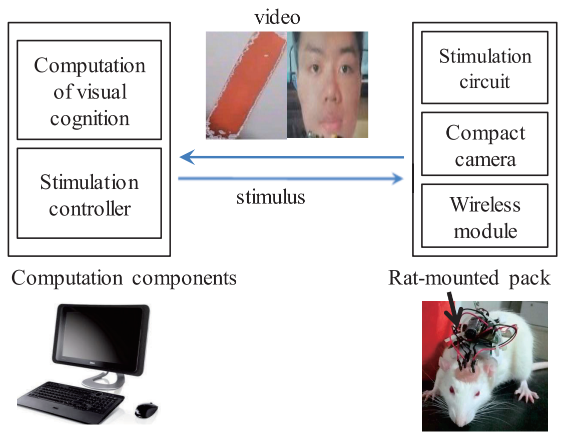

Figure 1: Overview of the system.

The computation components consist of a component for the computation of visual cognition and a stimulation controller. In the former part, computer-vision algorithms are implemented to search/find interesting objects from the video data transferred from the rat-mounted pack. Based on the searching results of the visual cognition component, the stimulation controller decides which stimulus should be delivered to the rat-mounted pack to trigger an action of the rat.

Rat-mounted Pack

The rat-mounted pack gathers the environment information and enables the communication between the computation components and the rat brain. It captures and transfers video data, receives stimuli, and generates stimulation pulses to the specific regions in brain. Figure 2 shows the three parts in the rat-mounted pack, a wireless module, the stimulator circuit, and the compact camera.

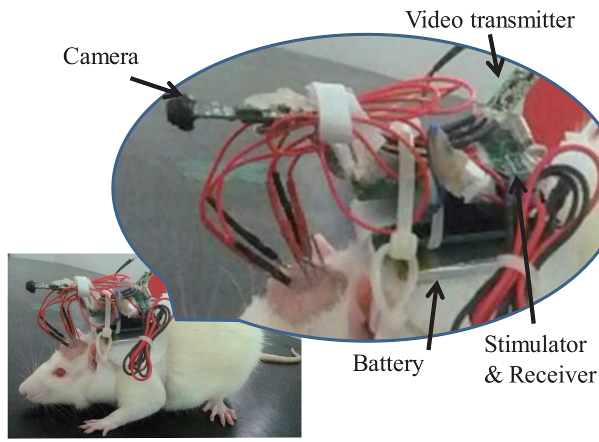

Figure 2: The rat-mounted pack, which includes a compact camera, a wireless module, and a stimulator.

The wireless module includes a stimulation receiver and a video transmitter which exchange information between the stimulation controller and the computation component of visual cognition.

The stimulator is made as small as possible by the use of surface mounted devices. The main processor of the stimulator is the Mixed-Signal ISP FLASH MCU (C8051F020). The processor has the characteristic that it is high speed, small size and low power consumption. These features make it suitable for the small rat-mounted pack. It has two 12-bit digit to analog converts (DACs), which produce output for jitter-free waveform generation.

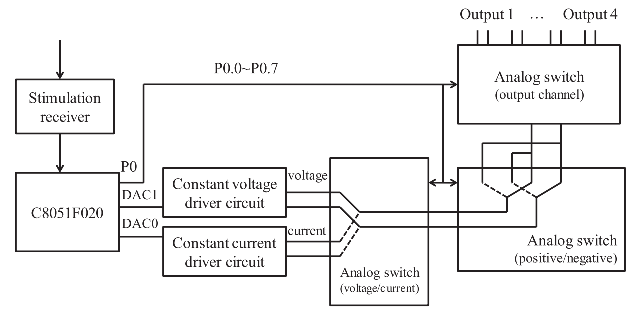

Figure 3: Circuit schematic diagram of the micro-stimulator. The stimulator gets input from the stimulation receiver and outputs to the implanted electrodes. It includes a C8051F020 MCU as main processor, constant voltage/current drive circuits and analog switch circuits.

The electric stimulation pulses exported from the two DACs of the C8051 MCU are used to control a constant voltage driver circuit and a constant current driver circuit to produce mono-polar pulse. These pulses of constant voltage/current go through three analog switches and then are delivered into the implanted stimulation electrodes (see Figure 3).

The first analog switch is used to select between the input pulses, thus it outputs a mono-polar pulse of either constant voltage or constant current. The second analog switch converts the mono-polar input to a bipolar output. It reverses every half of the positive pulse to negative and the resulting bipolar pulse has the same duration and amplitude of the positive and negative phase. The third analog switch acts as a selector to choose among the four output channels which are connected to the implanted electrodes.

By using the three analog switch circuits, the stimulator works as pulse generator which outputs a voltage or current pulse. The amplitude of the output pulses are changeable. Thus the stimulator can produce signals of variance waveforms to meet different requirement in experiment.

The compact camera has the size of 20 $mm\times$ 8 $mm\times$ 1 mm and is light for the rat to carry on the back. The camera is placed such that its optical axis is in the same direction as the head of the Rat (see Figure 2). Therefore the camera can capture the scene in front of the rat. When the rat turns its head, the camera direction is changed accordingly. The video frames captured by the camera are transferred by the video transmitter to the computation components. Each frame has a resolution of 640×480 pixels.

Stimulation and Action

In this section, we describe the basic principles of the stimulation and the corresponding rat action, then present the training procedure of the Ratbot.

Stimulation Priciples

Electrical stimuli can be delivered into specific brain regions as rewards [12, 5] and steering cues [13] to control rat behavior. The medial forebrain bundle (MFB) in the rat's brain is known as a pleasure center, so electrical stimuli to the MFB can be used as rewards [5]. A reward stimulus in MFB will make the rat feel delighted, which motivates its motion and reinforces its behavior. Stimulations in the somatosensory cortices (SI) can be used as steering cues [15, 17]. Rats use their vibrissae to sense object surface when exploring the environment. The whisker barrel fields in SI receive projections from the contralateral facial vibrissae. When stimulated in one side of SI, the rat will feel a virtual touch on the contralateral vibrissae and make a turn.

Training

We adopt the rat behavior training method in [4] to build the correspondence between the stimuli and rat's behavior. The training process of the rat contains two parts, MFB reward training and SI steer training, given briefly as follows.

In MFB reward training, first the rat is trained to press a bar to obtain the MFB stimulus reward, until it would press the bar continuously to obtain the MFB stimuli once it is placed before the bar. Then it is placed on a narrow way to train the continuous movement behavior by deliver continuous MFB stimuli. Once the training is completed, when a MFB reward is sent to the rat, it will take an action of moving forward. In SI steer training, the rat is trained to make correct turns in a eight-arm maze. SI stimulations are delivered to drive the rat to make turns. After each correct turn, a MFB reward is given immediately to reinforce the correct behavior.

Due to subtle differences in brain structures, electrical stimuli may not be always effective for all rats. Some rats can't be trained to walk and turn correctly. In our experiments, about half of the rats can be trained to an eligible Ratbot.

Computation Components in Ratbot

The computation components in Ratbot include a component for computation of visual cognition and a stimulation controller. In the visual cognition part, two object detection algorithms are implemented for searching interesting objects, colored objects and faces. Based on the detection results transferred from the visual cognition part, the stimulation controller decides the stimulus for Ratbot to take corresponding action and delivers the stimulus to the rat-mounted pack.

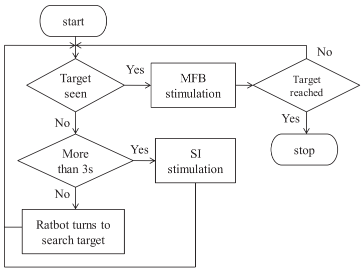

Figure 4: The stimulus controller.

Computation of Visual Cognition
In this study, we would like the visual cognition component to be able to find colored objects and human faces. So we develop colored object detection and face detection algorithms in this part.

For colored object detection, a specific color is treated as a random variable $\mathbf{c}$ conforming a single Gaussian distribution, $\mathbf{c} \sim N(\mu, \Sigma)$, where $\mathbf{c} = (R, G, B)$ is the color vector, μ and Σ is the mean vector and covariance matrix for the distribution. The parameters for the specific color are estimated from a group of natural training images by:

$$\mu = \frac{1}{n}\sum_{j=1}^{n}\mathbf{c}_j; \quad \Sigma = \frac{1}{n-1}\sum_{j=1}^{n}(\mathbf{c}_j - \mu)(\mathbf{c}_j - \mu)^T, \quad (1)$$

where n is the total number of color training samples $\mathbf{c}_j$. The probability of a pixel with color vector $\mathbf{x}$ belonging to the specific color can be computed as:

$$p(\mathbf{x}) = \frac{1}{2\pi|\Sigma|^{\frac{1}{2}}} e^{-\frac{1}{2}(\mathbf{x}-\mu)^T\Sigma^{-1}(\mathbf{x}-\mu)}. \quad (2)$$

In detection, if $p(x)$ is large than T_c, the pixel is considered to be this color. When the area of the bounding box of connected pixels in a frame exceeds T_a, the object is considered to be detected. In our experiment, T_c is set to be 0.9 and T_a is set to be 25×25.

For face detection, we develop a modified version of a fast face detection method called soft cascade [2], in which the learning algorithm is real Adaboost. The classifier form of the soft cascade is,

$$H_T(x) = \sum_{i=1}^{T} h_i(x), \quad (3)$$

where $\mathbf{x}$ is a test sample and $h_i(x)$ denotes a weak classifier. Given a set of reject thresholds $\{\gamma_1, \gamma_2, ..., \gamma_T\}$, when and only when every partial sum $H_t(x) > \gamma_t$, x will be accepted as a face. This cascade structure makes the detector fast. The Haar feature is used in the detector. The detector is trained on a face image set containing more than 20,000 face images and 100,000 non-face images with the size of 10×10 pixels.

Stimulation Controller
Figure 4 shows the process run in the stimulation controller.

Based on the detection results in the visual cognition component, the stimulation controller determines what actions for the Ratbot to take and delivers a stimulus to the rat-mounted pack. When the target is detected, which means the object of interest is in front of the Ratbot, a MFB stimulus is delivered to the rat-mounted pack. The MFB stimulus acts as motion motivation, making the Ratbot to walk forward.

When there are no targets ahead of the Ratbot, it usually turn left and right to obtain rewards. This behavior developed in the behavior training session is important in searching target object. Once the target is detected, a reward stimulus is sent and the Ratbot will move forward to approach the target. When there are no target detected for 3 seconds, the program randomly sends a SI stimulations to help the Ratbot make turns.

Experiments

Rat surgery
The surgery is operated on a rat to implant electrodes into its brain. Adult Sprague Dawley rats are used in our experiment. During the surgery, the rats are anesthetized with chloral hydrate and placed on a stereotaxic

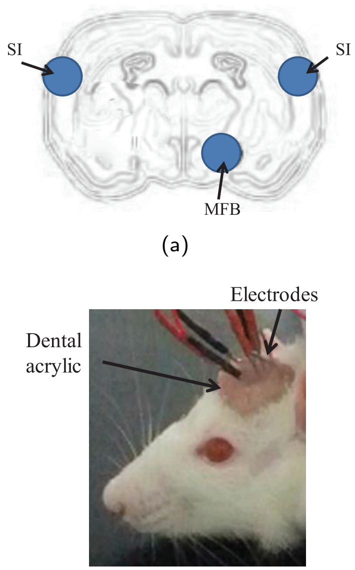

Figure 5: (a) The schematic diagram of electrode locations implanted in the rat brain. (b) A photo of rat head, dental acrylic is used to fix the electrodes.

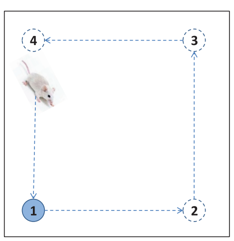

Figure 6: Task design. The Ratbot is expected to walk alone the dash line to approach the target.

apparatus. One millimeter holes are drilled on the skull in order to insert three electrodes into the brain. One of the electrodes is placed in the medial forebrain bundle (MFB) and the other two are implanted symmetrically in the whisker barrel field of the left and right somatosensory cortices (SI). Dental acrylic is used to fix the electrodes to the skull, (see Figure 5). After surgery, at least 7 days of post-operative recovery is needed for each rat.

Task design
To verify the effectiveness of our vision enhanced system, we design an object searching task for the Ratbot, (see Figure 6). A target (a red object or face picture) is placed on one corner of a flat board with the size of $1.5m \times 1.5m$ and the Ratbot is placed on another corner. When the experiment begins, the Ratbot is expected to search for the target and move toward it according to the instruction issued from the stimulation controller. When it reaches the target (place 1 in Figure 6), the target is moved to the next corner of the board in the counter-clockwise direction. And the task continues until it reaches place 4 in Figure 6. We try the task 10 times, 5 for the red object and 5 for face pictures.

In the tasks, we assess the performance of the detection algorithm by computing the average detection rate, false alarm, and detection time. We also record the time for the Ratbot to complete the task and calculate the average walking speed.

Results
Our Ratbot can perform the tasks successfully for almost all 10 testing. When there are no targets in sight of the Ratbot, it turns left or right to search for the target, (Figure 8). Once the target is detected, the Ratbot will move forward to approach the target (Figure 9). In both cases, the Ratbot moves completely by itself and none of human-controlled stimuli are sent.

Table 1 shows the average detection rate, false alarm, and the time cost of detection. In both cases, the time cost is less than 70 ms, which supports the real-time computation on one core of CPU in common personal computer. Table 2 shows the average walking speed.

Conclusion
We have presented a vision-enhanced Ratbot, which is able to detect colored objects and faces. The detection results have been used to trigger a stimulus to guide the Ratbot to move toward the targets. This makes the Ratbot have stronger vision system in performing navigation tasks, i.e., understanding observation like human being.

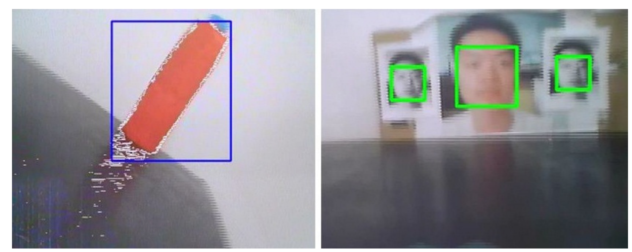

Figure 7: Detection results in two frames captured by the rat-mounted camera. Left: the red bottle detection result. Right: the face detection result.

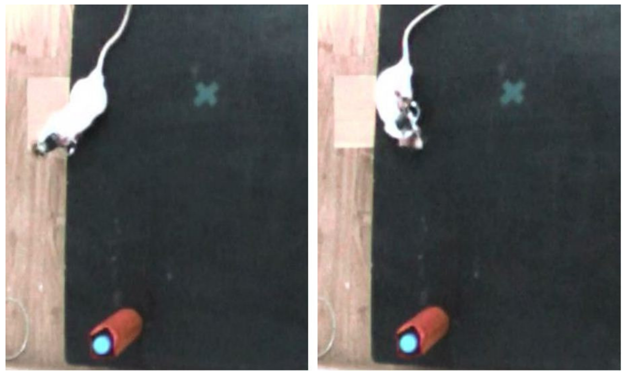

Figure 8: The Ratbot turns left or right to search the target.

Figure 9: When the target is seen, the Ratbot walks forward to approach it. The picture is taken by a bird's-eye camera, the upper right part is the corresponding frame in the rat-mounted camera at the same time.

Table 1: The average detection rate, false alarm, and detection time.

	Red objects	Faces
Detection rate	0.95	0.89
False alarm	0 / frame	0.1 / frame
Time(ms)	20	69

Table 2: The average walking speed.

	Red objects	Faces
Speed (m/min)	4.08	4.34

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