RESEARCH AND DEVELOPMENT OF CONSCIOUS ROBOT

Mirror Image Cognition Experiments using Small Robots

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Abstract: The authors are trying to transplant a function similar to human consciousness into a robot to elucidate the mystery of human consciousness. While there is no universally accepted definition of consciousness, we believe that a consistency of cognition and behavior generates consciousness, based on the knowledge we gained in such fields as brain science and philosophy in the course of our study. Based on this idea, we have developed a module, named MoNAD, which comprises recurrent neural networks and can be used to elucidate the phenomena of human consciousness. We focused on mirror image cognition and imitation behavior, which are said to be high-level functions of human consciousness, and conducted experiments that had the robot imitate the behavior of its mirror image. This paper reports on the results of our additional tests using a new type of robot and basic experiments on discriminating a part of the self from another robot. We found that our experiments on mirror image cognition did not depend on the type of robot used, however the time delay when transmitting control signals to the other robot was an important factor that affected our evaluation of the robot's discriminating the self from the other robots.

1 INTRODUCTION

Human consciousness has been studied in philosophy, psychology, brain science in the past. In recent years, there has been an awareness that human consciousness is closely related to embodiment. From this new perspective, researchers have started to study consciousness using robots with bodies. As mentioned above, although there is no clear-cut definition of consciousness, we will gradually understand what human consciousness, the mind and feelings are through our efforts toward achieving the function of consciousness in a robot. Eventually, we will be able to develop a perfect robot that possesses high-level, human-like functions.

Believing that achieving self-consciousness is the most important goal, we decided to simulate the phenomenon of being aware of one's image in a mirror, which is a proof of the existence of self-consciousness, using a robot. As the first step, we studied several aspects related to consciousness and imitation behaviors of humans. An example of imitation behavior is a mirror neuron (Gallese, 1996). The authors believe that the mirror neuron mechanism has a relationship with imitation behavior. The authors further believe that development of consciousness is closely related to imitation as evidenced by many studies on consciousness and imitation behavior typically represented by Mimetic theory. (Donald, 1991) Based on this belief, we devised the conscious system Module of Nerves for Advanced Dynamics, or MoNAD . The robot equipped with this conscious system calculates data obtained from sensors using the MoNADs of the conscious system, and represents the condition of the self and the other. The robot imitates the behavior of the other and cognizes the self using information obtained as feedback from its imitation behavior. Mirror image cognition, one of the functions of consciousness, will be achieved using imitation behavior and cognition of the self. We have already succeeded in experiments on mirror image cognition using a robot. That was a commercial small robot Khepera II. (Takeno, 2003), (Takeno, 2005) Later, the robot's feelings were incorporated into the conscious system as a subsystem (Shirakura, 2006), (Igarashi, 2007). Additional mirror image tests and new experiments on evaluating the robot's discrimination of the self from others were conducted using new robots. The mirror image cognition experiments were again successful thanks to the functions of emotion and feelings incorporated in the new conscious system.

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2 MONAD CONSCIOUS MODULE

The MoNAD conscious module is a computation model using neural networks (Figure 1) (Figure 2). Specifically, it consists of a cognition system (a), behavior system (b), primitive representation (c), symbolic representation (d), and two sets of inputs and outputs. The cognition system (a) calculates the current cognition using information p1 from external sensors (or information from other conscious modules), feedback information M’ from own behavior, and cognition information p2 from one step before. The behavior system (b) calculates the behavior from input information (S), M’ and p2. The primitive representation (c), where both the information (a) and (b) coexist, is the central core of the MoNAD that achieves consistency of cognition and behavior. The symbolic representation (d) is the layer where the information cognized by the cognition system (a) is represented. There are two types of representation: cognition representation (RL) and behavior representation (BL). Cognition representation (RL) is the representation currently being cognized. RL information is constantly being copied to the behavior representation (BL) and is used for generating the next cognition, provided that no other information is given to BL from other conscious modules. RL and BL are terminals that connect other MoNADs. They support exchange of information with higher-level modules.

A robot can be embodied (capable of acknowledging its own somatic sensation as information) by inputting the feedback information (M’) from the output into the MoNAD module that comprises the conscious system and is described in the next chapter. A high-level conscious function can be achieved by connecting multiple MoNADs. Each MoNAD has its own target orientation. The MoNAD is proactively taught about its orientation through supervised learning.

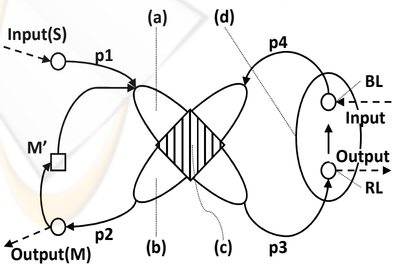

Figure 1: MoNAD Concept Model.

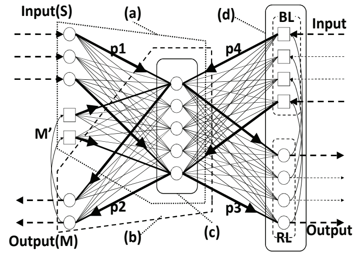

Figure 2: MoNAD Circuitry.

3 CONSCIOUS SYSTEM

3.1 Structure of the Conscious System

The conscious system comprises multiple MoNADs. Specifically, the conscious system consists of three subsystems: reason (e), emotion-feelings (f) and association (g) (Figure 3). The reason subsystem (e) is responsible for conducting and representing rational behavior for the target orientation in response to external stimuli and somatic sensory information. The emotion-feelings subsystem (f) represents feelings in accordance with emotional information generated by external stimuli and changes in the state of the robot’s body. The association subsystem (g) integrates the rational and emotional thoughts. Living organisms are said to generate emotions in response to external and internal stimuli, and the emotions are deeply related to decision-making and adjustment of bodily functions. The authors therefore developed the emotion-feelings subsystem by combining MoNADs that represent fundamental emotions and feelings (Shirakura, 2006), (Igarashi 2007).

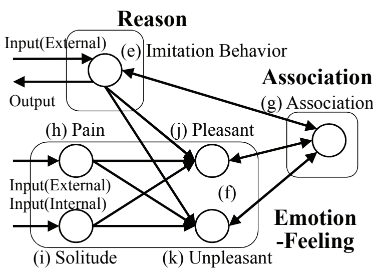

Figure 3: Conscious System Performing Mirror Image Cognition.

3.2 Development of Conscious System for Performing Mirror Image Cognition

To successfully develop a robot with self-awareness, the authors think it necessary to have the robot achieve the phenomenon of being aware of its self image in a mirror using the conscious system. Six MoNADs were used in the conscious system in our experiments (Figure 3). MoNAD (e), a reason MoNAD, imitates the behavior of the image in the mirror. MoNADs (h), (i), (j) and (k) are emotion and feeling MoNADs. MoNAD (h) represents "Pain" which the robot feels when it collides with the mirror. MoNAD (i) represents "Solitude" which the robot senses when it moves too far away from the mirror and misses its mirror image. MoNADs (j) and (k) are feeling MoNADs. They represent "Pleasant" and "Unpleasant" feelings based on the information from MoNADs (h) and (i), or whether the imitation was successful or not. MoNAD (g), an association MoNAD, integrates the imitation behavior information and the information from the feeling MoNADs.

External inputs entering the conscious system include information on the state of the mirror image and information captured by external sensors. Internal inputs are somatic sensations and information from the emotion-feelings subsystem. The input values are calculated at the respective MoNADs. The information represented by the results of the calculation is transmitted to the higher-level MoNADs and finally integrated at the association MoNAD to calculate the representation. The representation is an integration of rational and emotional thoughts.The behavior information generated in the association MoNAD is reflected from the association MoNAD to the respective lower-level MoNADs. The behavior of the lower-level MoNADs is determined by this information. Eventually, a command to implement the selected behavior is given to the drive motors embedded in the robot body. This describes the steps comprising the entire process of cognition behavior of the conscious system.

4 MIRROR IMAGE COGNITION EXPERIMENTS

The authors conducted the mirror image cognition experiments using the *e-puck* mini mobile robots. We installed the conscious system introduced in the preceding chapter in these robots. The robot cognizes its surrounding environment using the built-in infrared sensors and the robot's action is decided by the conscious system. The robot advances, backs up and stops using the built-in motors. A touch sensor is mounted on the front of the robot to detect collision with the mirror.

Experiment 1: Conscious robot A is positioned in front of a mirror where it conducts imitation behavior while watching its mirror image A'.(Figure 4)

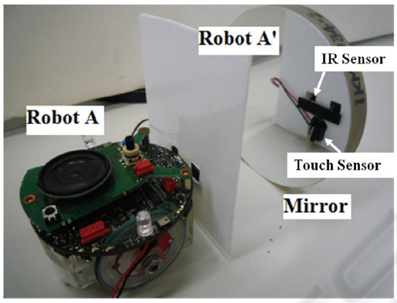

Figure 4: Experiment 1.

Experiment 2: Conscious robot A and Robot B are connected by control cables. Robot B is physically almost same as robot A. Robot B behaves in the same manner as Robot A in response to commands from Robot A. The two robots are positioned facing each other, and Robot A watches Robot B and imitates its behavior. (Figure 5)

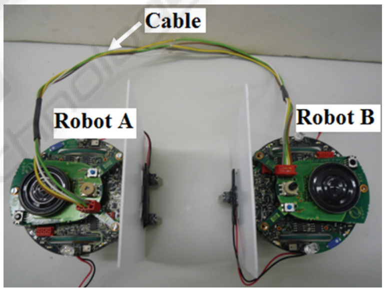

Figure 5: Experiment 2 and 3.

Experiment 3: A time delay was intentionally given to the control signals transmitted via the cables. All other conditions were identical with Experiment 2.

Experiment 4: Conscious robots A and C were placed facing each other. Each robot imitated the behavior of the other robot (Figure 6).

Conscious robot A measures the rate of coincidence of mutual imitation behavior between the two robots.

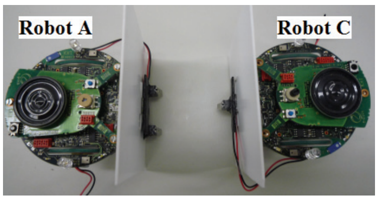

Figure 6: Experiment 4.

5 CONCLUSIONS

In Experiments 1 through 4 described above, the conscious robot measured the behavior coincidence rate between the self and the other robot (Figure 7).

The coincidence rate was about 95% in Experiment 1, and about 76% in Experiment 2, and about 36% in Experiment 3, and about 49% in Experiment 4.In Experiment 1, successful mutual imitation continued steadily without the robots missing the image of the self in the mirror, except in the initial stage where false detection occurred. In Experiment 2, the coincidence rate was temporarily higher than that of Experiment 1, but gradually dropped due to shifting of motion between the two robots and the resulting false detection. In Experiment 3, where a time delay was intentionally given to the control signals (to delay the motion of the other robot), the coincidence rate dropped continually. This particular experiment was conducted to identify to what extent the robot could cognize a part of its body to be a part of itself. In the graph, we can see the point where the coincidence rate with the time delay dipped lower than the coincidence rate of Experiment 2. This is the point where the robot had to abandon the cognition of the image being a part of the self, and it started considering the image to be the other. We have not yet drawn any conclusions about this evaluation, and acknowledge that further study is necessary.

The results of these experiments show that robot A, with its built-in conscious system, could determine that its mirror image A' (Experiment 1) was closer to itself than a part of its body B (Experiment 2), and that robot C, with nearly identical functions to robot A (Experiment 4), was able to determine that mirror image A' was none other than itself. The authors believe that it is possible to achieve self-consciousness in their conscious system because of these successful mirror image cognition experiments. Following on the Khepera II experiments, we successfully conducted more advanced experiments using the e-puck robot. These results show that our conscious system has the potential of generating conscious functions not only in one type of robot but also universally on all types of robots.

6 ADDITIONAL DISCUSSION

The conscious robot developed by the authors cognizes mirror images with a high success rate of 95%. The robot avoided disturbances consciously because we added feelings to the conscious system. However, the robot did not change its behavior until it actually encountered a disturbance. (Igarashi, 2007)

In the future, if the conscious system can learn by itself the various disturbances that the robot may encounter, the robot may be able to change its behavior by anticipating such disturbances. The authors believe that robots will eventually be able to avoid unknown disturbances. Expectation and prospect are functions of human consciousness and are important themes in the study of human consciousness. An expectation function is already implemented in the MoNAD proposed by the authors, but further study is needed to achieve long-term expectation in robots using this MoNAD.

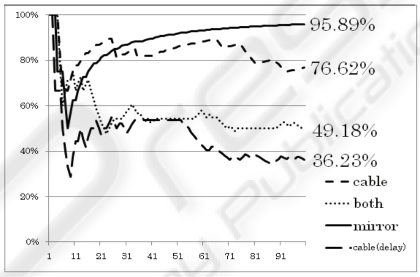

Figure 7: Result of Experiments.

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