A Robot Succeeds in 100% Mirror Image Cognition

Junichi Takeno
1-1-1 Higashimita, Tama-ku, Kawasaki-shi, 214-8571 Kanagawa, Japan

Department of Science and Technology, Meiji University Graduate School
TEL +81-44-934-7454
Fax +81-44-934-7912
takeno@cs.meiji.ac.jp (juntakeno@gmail.com)

Abstract - Humans are capable of identifying their own image when reflected in a mirror. This mechanism is a mystery that has never been solved. I created a program that achieved such awareness on a robot and conducted three experiments. The first was an experiment on a self robot that imitates its own self-image reflected in a mirror. The second experiment had a robot imitating another robot of the same type which was made to perform the same behavior. The last was an experiment using two robots of the same type and the same functions to imitate each other. In these experiments, the program calculated the coincidence rate of behavior between the self robot and the other robot. I found that compared with the case in which the robot performed a behavior according to its own judgment, the coincidence rate was always higher in the case of the mirror image. At this time, when the target moved according to its own judgment in the second experiment, this can be considered as a part of the self, similar to the use of "human hands and feet." From this result, the mirror image can be judged to "exist closer to the self than a part of the self" and can in fact be considered a "self." I thought that the result of these experiments indicated that mirror image cognition of the robot succeeded completely and that this would be the "first example toward explaining physically the mirror image cognition capability of humans." This paper details logical and physical explanations for achieving the results, and in addition, presents several considerations and prospects derived from the experiment results.

Index terms: Conscious system, robot demonstration, mirror test, mirror image cognition, behavior and cognition, self awareness, human consciousness, cognitivism.

I.   INTRODUCTION

Humans can easily identify their own image when reflected in a mirror. This is a rather strange capability because without the aid of something like a mirror humans are not capable of seeing

their own face directly. Humans often say that they know themselves when looking in a mirror. This is, however, not an adequate explanation. Humans are said to become aware of their own image reflected in a mirror when they are about two years old [1].

To investigate the existence of this awareness capability, G. Gallup, Jr. proposed a mirror test in which chimpanzees [2], orangutans, dolphins, Indian elephants, and magpies all succeeded.

Among philosophers and psychologists, Jacques Lacan presented his "hypothesis of the mirror stage" in which this phenomenon was considered to be an important base point in human growth and development [3].

The phenomenon in which humans become aware that the image reflected in a mirror is their own image is said to indicate the existence of self-consciousness. This is because humans make up and dress themselves using a mirror. In other words, one can think that solving the problem of awareness of self image in a mirror can lead to solving the problem of consciousness.

Reference to consciousness, however, creates a difficult situation.

At present, there are two camps: those who do not acknowledge the existence of consciousness and others who do acknowledge it.

It seems that many scientists in the former group take their stand from an engineering viewpoint, while many scientists in the latter see the situation from a scientific viewpoint. This separation is caused by the fact that the phenomenon of consciousness is not described definitely, in other words, the definition is not clear.

As an extreme standpoint of the former, there are opinions that consciousness is a subjective phenomenon and cannot be mathematically described, and therefore its existence is not acceptable. There are also opinions that consciousness is at present not acceptable but various types of human recognition and functions are acknowledged, and that in the future consciousness will be explained mathematically with an evolved integrated connection (called emergence).

The latter group is of the opinion that acknowledges the existence of human consciousness and will try to identify consciousness in the mechanism of the human brain.

It is very clear, however, that trying to elucidate the mechanism for identifying one's self image in a mirror as a problem of consciousness will cause heated debate both for and against.

However, I decided to challenge this investigation in a direction that had not been attempted much, that is, to consider the content of research regarding consciousness that is already known and to define human consciousness physically and mathematically. The reason why such an

approach had not been conducted often by other researchers is that there is a strong mental resistance to attempts that seek to describe human consciousness physically and mathematically. This is caused by the strong belief that humans exist differently from machines. Also the possibility of a major finding in the initial stage is doubtful. This is because the definition of personal consciousness is seen to differ greatly from universal truth.

However, if attempts to define consciousness physically and mathematically in a concrete manner are always put off, we cannot hope to take even a first step toward understanding the mechanism of human consciousness. We can use an evolving method for creating an object like consciousness by combining recognition processes, and even if we can obtain various types of knowledge about the brain and the body in repeated research in brain science, we think that the method for recognizing consciousness returns finally to the "problem of defining consciousness."

In other words, it is natural that even if consciousness is not yet defined clearly, attempting to define "What is consciousness?" is always necessary. We are certain that this process is an important scientific method for understanding human consciousness.

Why should we promote an understanding of human consciousness?

It is natural that achieving an excellent result by understanding human consciousness, that is, the mechanism of thought and action, is very attractive, but I wish to place emphasis particularly on the following three items.

First, this can contribute to understanding brain-related disease including schizophrenia and to the discovery of methods of medical treatment. Second, this allows the development of a method to ameliorate from loss of consciousness caused by some accident. Third, this allows the development of artificial limbs that could be considered to be one's own by individuals suffering limb loss in accidents.

I installed a program in an existing small robot. The program was based on architecture that I created from my subjective definition of consciousness. Although it was designed in a top-down method based on my original idea, the program itself functions in a bottom-up and top down process. The program provides not only a physical explanation of mirror image cognition by driving the robot but also provides an explanation of most items regarding consciousness that are already known [4][5].

The robot imitates the behavior of another robot in front of it according to the program and calculates the coincidence rate of the behavior imitations between itself and the other robot.

Among several experiments performed with the robot, three important experiments provide a completely physical explanation of the problem of mirror image cognition. This is a 100% success. These experiments succeeded on Sep. 1st, 2004 [4]. The details were presented on Discovery Channel TV (Web) in the USA on Dec. 21, 2005 [6][7]. Three years have passed since this presentation and I felt that the importance of this success had become increasingly clearer. When writing this paper, I reconsidered the experiments and the results by examining various comments that have been made during this period.

Herein, I declare the 100% success of the mirror image cognition achieved by a conscious robot. Also, I present, at the end, several topics that can be considered from the results obtained from the experiments.

II.   WHAT IS MIRROR IMAGE COGNITION?

Mirror image cognition refers to the phenomenon in which humans are aware of their self-image in a mirror. I can identify my own image in a mirror when looking at several images. (Figure 1)

I think other people can also identify their own image in a mirror just as I can, because they use a mirror to get dressed or put on makeup, while looking in a mirror.

Many scientists say typically that this phenomenon is not a theme of scientific study because it is considered to be a subjective matter. But, scientific research is necessary to answer the question, "Why can I identify my own image in a mirror?"

I call this problem "the mystery of mirror image cognition".

I've been trying to solve this mystery using a mechanical system, a robot.

Unlike the many mysteries of humans and animals, all parts and details of a robot are scientifically demonstrable and the processes involved should be understood universally by humans.

Figure 1.   Where am I? (Horta house in Brussels)

I am building a robot that is capable of scientifically demonstrating mirror image cognition.

If we could build a robot that would be capable of scientifically demonstrating mirror image cognition, we would be able to clarify the mirror image cognition of humans by analyzing the robot in detail.

Gallup's mirror test was devised to estimate the presence of a high-level capability for recognizing one's own self image by animal subjects[2].

This mirror test has been reportedly successful when conducted with chimpanzees, orangutans, dolphins, Indian elephants, and magpies.

But it is impossible to conduct a scientific investigation into how these animals attained their capabilities for self-recognition of mirror images.

This is also impossible with humans.

However scientific investigation is possible in the case of a robot.

I believe that the demonstration of a robot will enable us to elucidate self awareness of humans and also scientifically demonstrate existence of consciousness in humans.

I believe the robot is the mirror for scientifically showing existence of "I."

III.   DEVELOPMENT OF A ROBOT TO DEMONSTRATE
MIRROR IMAGE COGNITION

I believe that two methods are available: An engineering-based approach and a conscious system structure.

The former is an attempt to attain the goal through engineering without elucidating the consciousness of humans.

Success of Mirror Test has been "appeared", they claimed.

It is absolutely impossible, however, to account for the human functions of cognition and consciousness (K. Gold [8], P. Haikonen [9]).

For example, clearly, a robot which can recognize family members and their smiling faces can be created without employing the human functions of cognition and consciousness.

The point that I wish to describe here is that the functions of human cognition and consciousness can most certainly also be realized as a set of the recognition and drive program that has no relationship with the "consciousness and cognition" shown in this example. Nevertheless, creating a robot that has the capability of mirror image cognition is a very difficult task when several points are considered as described later (see to 4.2).

I call this an engineering-based approach. Consequently, I think it is natural that a robot created using this approach cannot explain human "cognition and consciousness" at all.

This type of study may be "useful" naturally, but it does not go to the root of my research theme normally.

In the latter, consciousness, a subjective phenomenon that occurs inside the self, is considered a physical phenomenon (J. Tani [10], M. Kawato [11], I. Aleksander [12]).

Subjective functions can be tried to build in a robot. The objective is to reveal the truth objectively and physically through a demonstration performed by the robot.

This technique is a part of scientific positivism.

My approach is in the later.

Compared with the engineering-based approach, success with the conscious system structure often becomes a breakthrough. This is because the former is only making of a part of all the

functions, like a component, but the latter has the possibility of explaining the principle of the whole consciousness. Specifically, while the former can produce almost no expansive hypothesis for the future, the latter has a greater possibility of comprehensively solving unsolved problems and producing more abundant hypotheses. When choosing a method as a scientist, I choose the latter because I acknowledge the scientific rationality of the heliocentric theory by Nicolaus Copernicus (1473-1543) compared with the geocentric theory.

IV.   STAGES IN THE DEVELOPMENT OF A CONSCIOUS ROBOT

I will try to construct a conscious machine.

Although consciousness is a subjective matter, we deem it to be a physical phenomenon and constructed it on a mechanical system.

Mechanical systems, such as robots, allow us to conduct objective and scientific research and observation. They offer a base for scientific observation of subjective phenomena.

We will establish the phenomenon of consciousness as an objective reality using mechanical systems.

The stages are:

(a1) Define the meaning of "consciousness."

(a2) Define a concept model based on the definition of consciousness.

(a3) Replace the concept model with a neural model.

(a4) Incorporate the neural model into a robot.

(a5) Have the robot achieve mirror image cognition of its self.

a.   Define the meaning of "consciousness."

Consciousness can be defined referring to the widely available base of knowledge in the fields of philosophy, psychology, brain science and neurology.

(b1)   Duality   of   consciousness.

Humans can be aware that "they are aware [13]." If duality is achievable, then multiplicity is also achievable. Regarding triplicity and greater multiplicity, we say bodily feeling is missing based on a subjective sensation, we think them to treat as the result of symbol processing like as the 'concept of infinity.' (**Takeno's Triplicity Hypothesis**)

(b2)   Consciousness   has   embodiment. Consciousness is inseparable from any physical body response [14].

(b3)   Consciousness   is   closely   related   to   imitative   behavior. We agree with the theory that humans recognize the existence of the self and others through imitative behavior. By repeating this learning behavior, humans establish their own self and develop   their   social   nature   [15][16]. (b4) Discovery of mirror neurons [17].

I made a definition of consciousness by using these considerations.

I found that an important meaning of consciousness is to be aware that one is behaving. And, to think is just identical to behaving.

And finally I decided the definition, "**consistency of cognition and behavior is the origin of consciousness**."

b.   Important points when considering the development of a mirror image cognition robot.

Since birth, no human has ever seen his or her own face. Humans possess no prior information about their own image, in particular their own face.

The first: this means that, at the outset, a robot used for studying mirror image cognition should never be given any complete information about itself.

Humans cannot discern their own self image in a mirror immediately after birth. But they can do so at about 2 years of age.

The second: to solve this mystery of humans, we need to account for the process of development of cognition from the stage of being unable to discern one's own self image in a mirror to the stage of being able to do so.

The third: In addition, we should remember that the information reflected in a mirror is not always perfect. In other words, the reflectivity and flatness of the mirror may not always be 100%. Even if the accuracy of the self-identifying information is preserved, the information of the self image reflected back from a mirror cannot match it theoretically.

And the fourth: the functions enabled by the computer programs embedded in the robot must be able to describe facts that are generally known to be the working of human consciousness.

These facts include, for example, self awareness, multiplicity of consciousness and consciousness of the others.

V.   CONSCIOUS ROBOT AND MIRROR IMAGE COGNITION EXPERIMENTS

Our robot is a small, a commercial robot, Khepera II.   We incorporated a neural network program into the robot. The program uses recurrent networks, called MoNADs, as basic modules (Figure 2).

These networks are arranged hierarchically with three MoNADs at the experiments (Figure 3).

The MoNAD system has huge merits.

The system can solve **the Symbol Grounding Problem** [18] because the system can learn the relation between an environment and the symbol representation.

The system can solve **the Binding Problem** [19] because the system can cycle through cognition-behavior.

MoNAD operating mechanism performs neural-calculation for the current behavior and the current cognition representation using external information from the world, the behavior in one step prior and cognition representation in one step prior. The derived information is used recursively. Relying on recursive information from one step prior means that the past information is used retroactively to determine the behavior (**use of experience**).
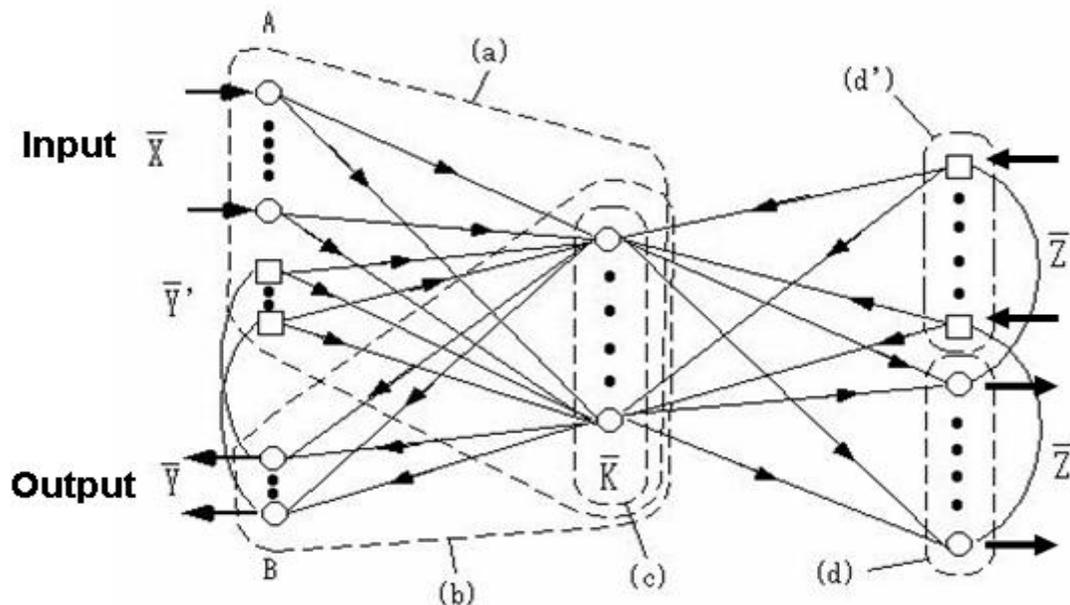

Figure 2.   Module of Nerves Advanced Dynamics (MoNAD). MoNAD has two circulations ($\overline{K} - \overline{Y} - \overline{Y}', \overline{K} - \overline{Z} - \overline{Z}'$) of information that connect to common nerve cell groups $\overline{K}$. One is somatic, and the other is related to representation.

The robot mimics the behavior of a second 'partner' robot in the mirror using the MoNADs.

The robot recognizes the behavior of the self and the 'partner' simultaneously, and calculates the success rate (the coincidence rate) of its imitative behavior.

The success rate was about 70% in our experiments [4].

Although the success rate has not yet reached 100%, we came to the conclusion that the robot discovers its own mirror image 100% physically.

We call this robot equipped with hierarchical MoNADs networks a "**conscious robot**" because it achieved mirror image cognition of its self.
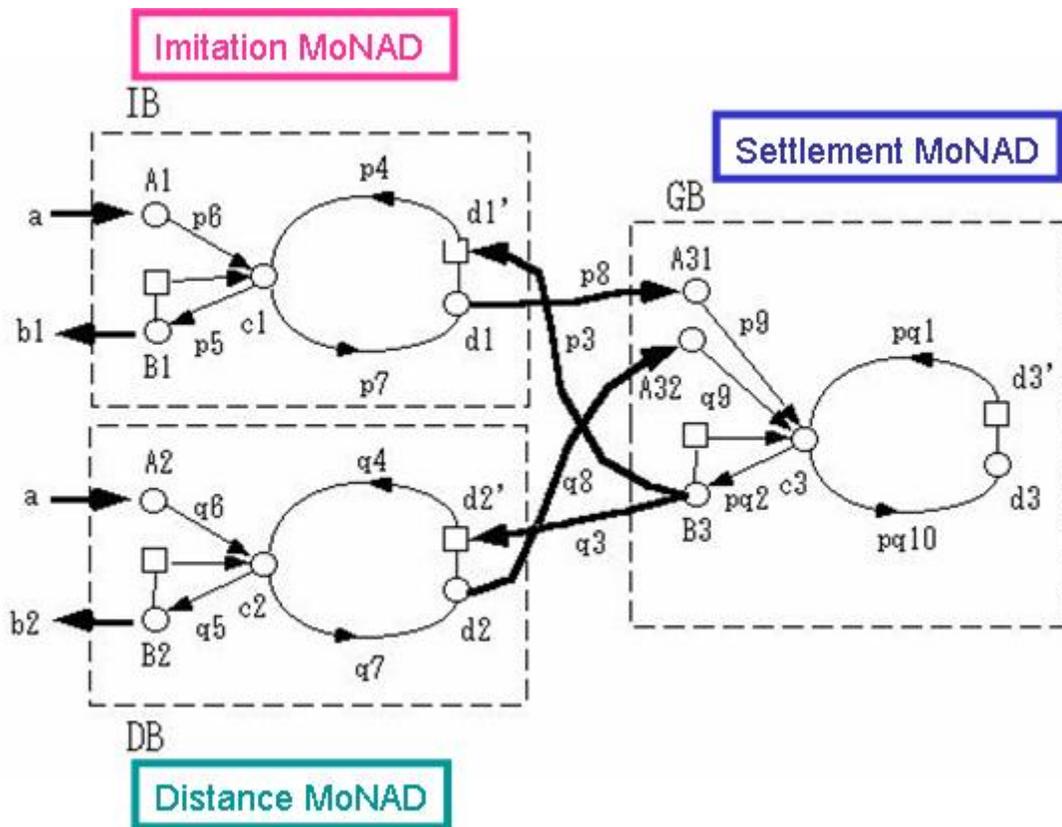
Figure 3. The networks for the experiments are arranged hierarchically with three MoNADs. The imitation MoNAD interprets the behavior of the other and instructs the motors to behave in the same way. The distance MoNAD measures the distance to the other. It instructs the motors to withdraw if the distance is small and to advance if the distance is large. The settlement MoNAD restricts the behavior of related subordinate MoNADs.

a. The conscious robot.

I   incorporated   the   conscious   system   into   the   robot.
Three   kinds   of   MoNADs   were   used   in   the   conscious   system   (Figure   4).
-                                       Imitation   MoNAD
-                                       Distance   MoNAD
- Settlement MoNAD
While repeating the imitative behavior, the consciousness system repeats the calculation to
cognize   the   behavior   of   the   self   and   the   other   simultaneously.
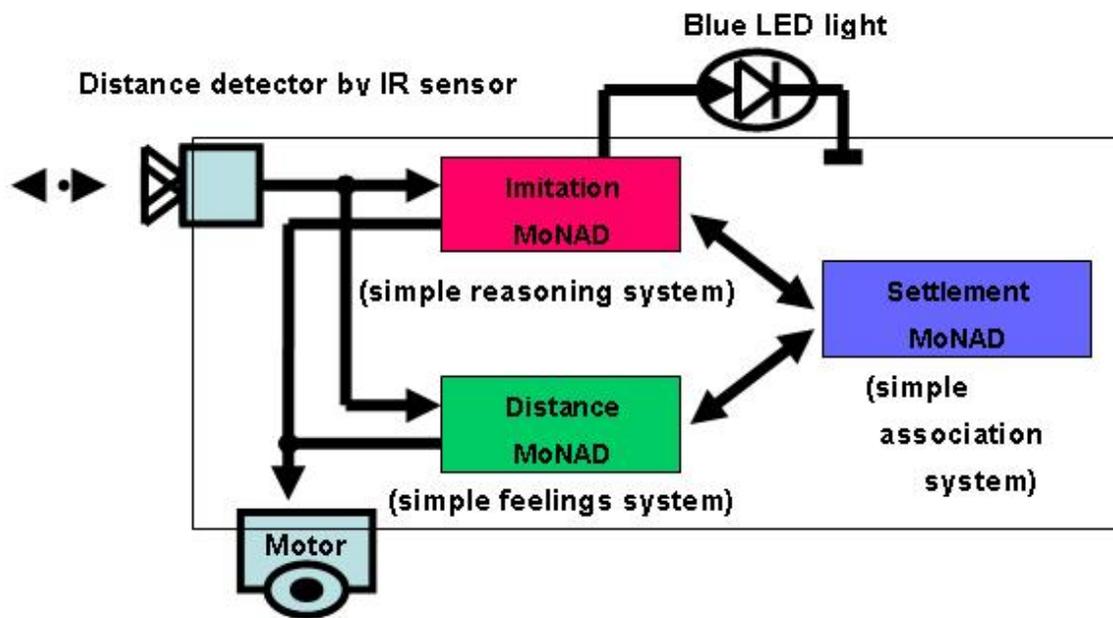
Figure 4. Structure of the mirror image cognition robot. While repeating the imitative behavior, the consciousness system repeats the calculation to cognize the behavior of the self and the other simultaneously. The blue LED lights up for each successful imitation as determined by calculation. The coincidence rate of the imitation is recorded. When the coincidence rate exceeds a threshold value, the other is interpreted as the self.

The blue LED lights up for each successful imitation as determined by calculation.
The   coincidence   rate   of   the   imitation   is   recorded.
When the coincidence rate exceeds a threshold value, the other is interpreted as the self.

The imitation MoNAD interprets the behavior of the other and instructs the motors to behave in the same way (**a simple reasoning system**).

The distance MoNAD measures the distance to the other. It instructs the motors to withdraw if the distance is small and to advance if the distance is large (**a simple feelings system**).

The settlement MoNAD restricts the behavior of related subordinate MoNADs (**a simple association system**). This MoNAD is not a'central control tower (**a homunculus**)'in this system because its behavior is determined by information from subordinate MoNADs.

The LED controller compares the representation of the imitation MoNADs and lights up the LED when the behaviors of the self and the other agree.
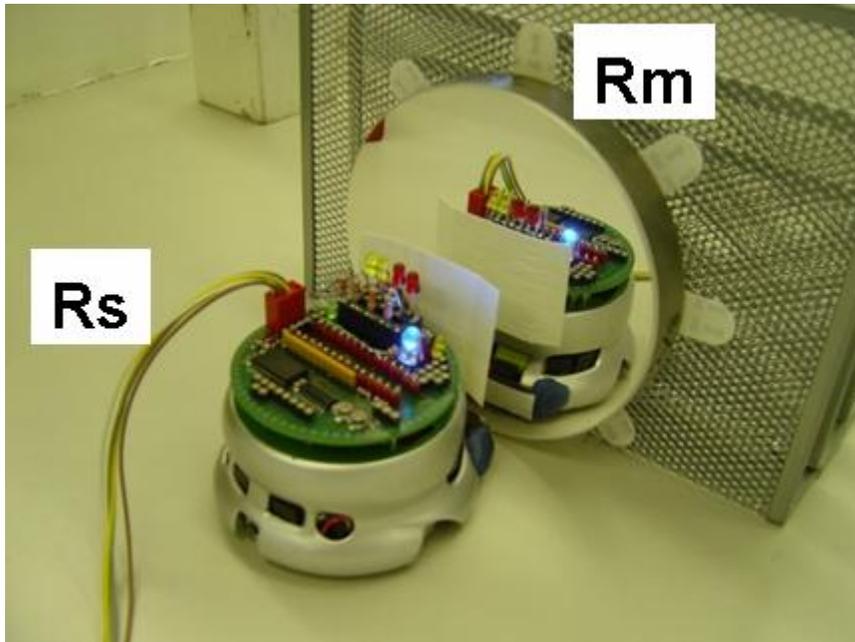
Figure 5. Experiment 1: The robot Rs imitates the action of its own image Rm as reflected in a mirror. You can watch the video (v1) until the year 2013.

b. The experiments

Experiment 1: The robot Rs imitates the action of its own image Rm as reflected in a mirror (Figure 5). The infrared reflectance of the mirror used in our experiments was 98%.

(Reflectance of mirrors typically used in daily life is normally 85%.)

(e1-1) The self robot Rs is equipped with the conscious system.

(e1-2) The self robot Rs performs imitative behaviors relative to its mirror image Rm.
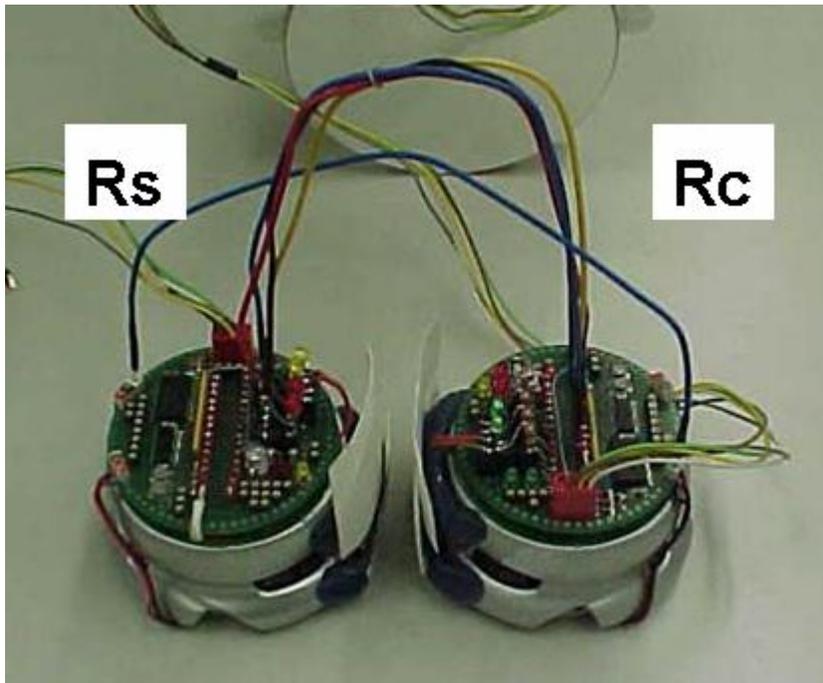
Figure 6. Experiment 2: This experiment is conducted in an environment where the other robot Rc is controlled completely via cables from the self-robot Rs to imitate the behavior. You can watch the video (v2) until the year 2013.

Experiment 2: This experiment is conducted in an environment where the other robot Rc is controlled completely via cables from the self-robot Rs to imitate the behaviour (Figure 6).

(e2-1) The other robot Rc is placed in front of the self robot Rs without a mirror set in between them. Robot Rc is physically almost identical to robot Rs.

(e2-2) Both robots are connected by control cables. Commands are transmitted through the cables to make the other robot behave in the same way as the self robot.

(e2-3) The other robot is equipped with a software program of the simple reflex system to implement the given command.

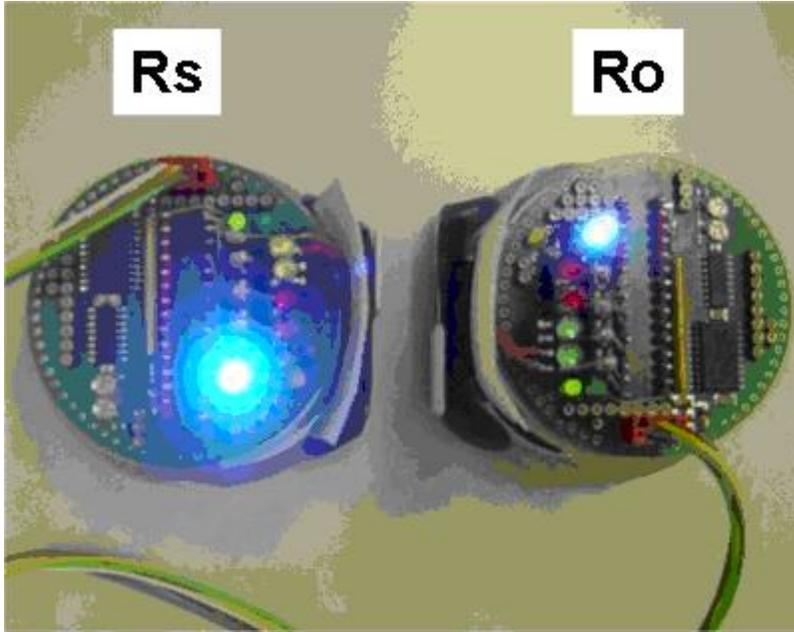(e2-4) The self robot imitates the behavior of the other robot Rc.

Figure 7. Experiment 3: The robot Rs, equipped with the same hardware and software, imitates the other robot Ro. Both robots repeatedly imitate each other.

Experiment 3: The robot Rs, equipped with the same hardware and software, imitates the other robot Ro. Both robots repeatedly imitate each other (Figure 7).

(e3-1) The cables that make the other robot behave in the same way as the self robot are removed from the robots.

(e3-2) The reflex system software is removed from the other robot Rc and the same conscious system as that for the self robot Rs is incorporated. With this, the self robot Rs and the other robot Ro are exactly the same in terms of both hardware and software except each individuality.

(e3-3) The self robot and the other robot imitate each other.

c.   Observation of results of experiments

Coincidence rate of the mirror image robot Rm is about 70%.

Coincidence rate of the controlled robot Rc is about 60%.

Coincidence rate of the other robot Ro is about 50%.

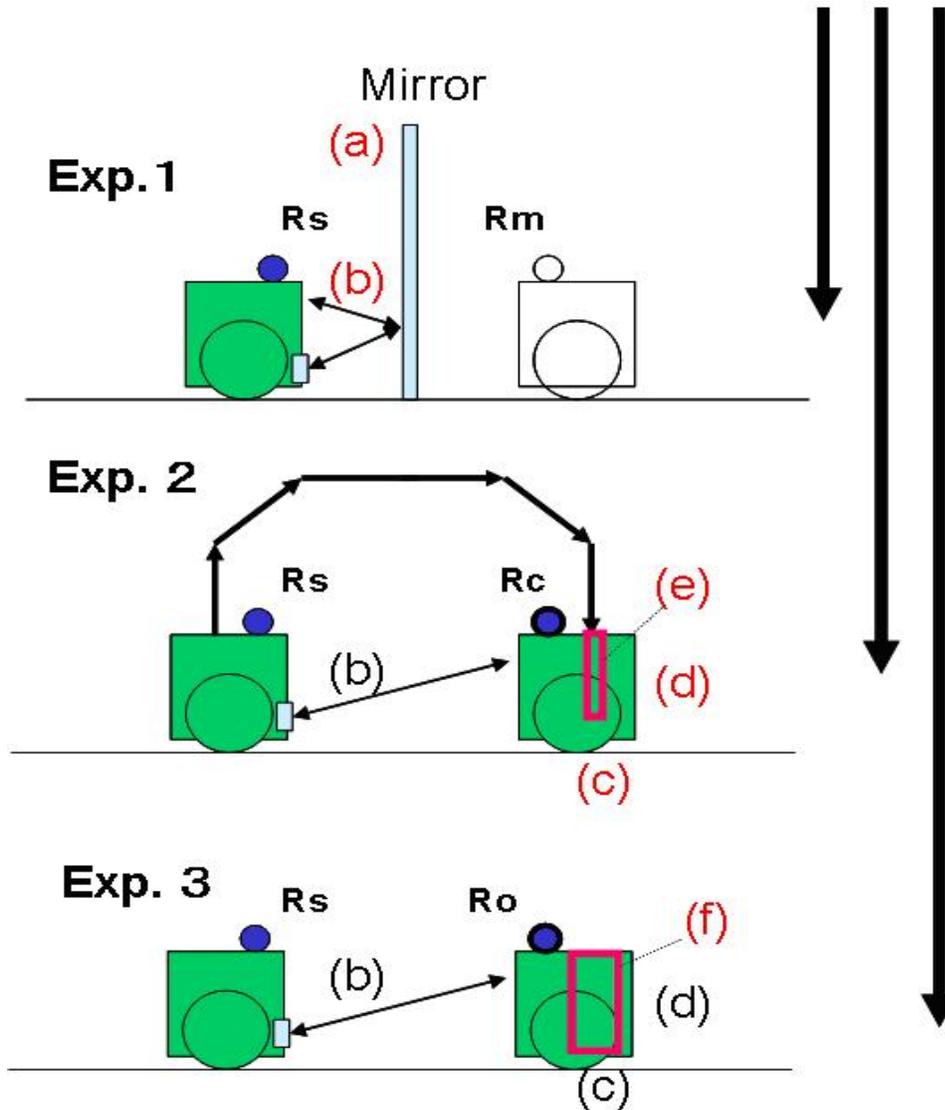Each of these values changed without intersecting one another.

Figure 8. Increasing complexity of other robots: Rm is more complex than Rs (a)(b).

Rc is more complex than Rm (c)(d)(e). Ro is the most complex (f).

VI.   WHY DO COINCIDENCE RATES DIFFER DEPENDING ON THE ROBOT?

All the robots used in our experiments were commercially same robots.

It means that all robots had nearly identical physical characteristics and functional specifications

in the original.

Robot Rc used in Experiment 2 was used as robot Ro in Experiment 3.

The differences of coincidence rate arise from the difference of complexity of each partner robot, I found. The complexity is defined from physical properties and functional specifications of each robot (Figure 8).
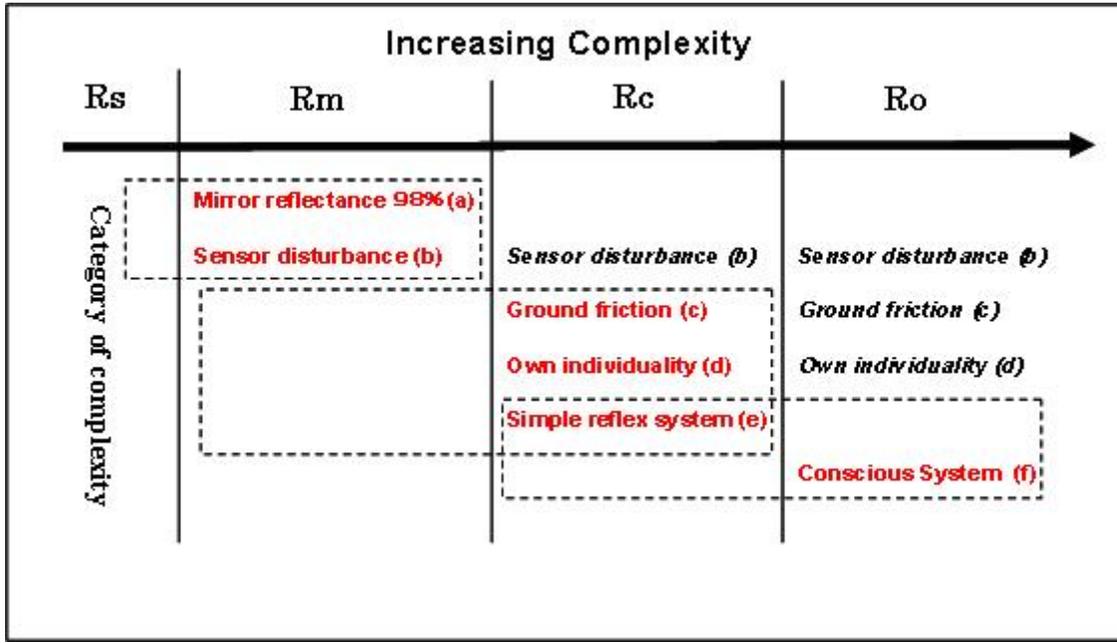

Table 1 Summary of the complexity.

Rs vs. Rm: The physical properties of robots Rm and Rs were identical because robot Rm is simply the mirror image of robot Rs. Rm is, however, more complex than Rs from the viewpoint of influence of mirror reflectivity (a) that never reaches 100% and external disturbance to infrared sensor (b).

Rm vs. Rc: The other robot Rc is physically more complex than the other (the mirror image) robot Rm. Although Rc has no problem in recognizing the mirror reflection compared with Rm, it has more complexity due to the problem of different friction (c) that occurs in the actual movement of the robot on the floor surface, the different personality of the robot (d) resulting from the slightly different functions of its motor and sensor, and the mounting of the simple reflex system (e). Consequently, the physical complexity can be considered larger in the overall system.

Rc vs. Ro: The other robot Ro is functionally more complex than the other robot Rc.

Ro is more complex than Rc because it is equipped with the conscious system (f). This is because the conscious system is a more complex program than the simple reflex system.

In other words, the difference between Rc and Ro may be considered caused principally by the increased functional complexity.

An overview of the complexity is given in Table 1.

VII. CONCLUSIONS

The cable-controlled robot Rc can be considered to be a part of the self robot Rs because it was connected by cables and moved according to instructions from Rs.

According to the results of our experiments and physical observations, the success rate of the mirror image robot Rm was always higher than that of the cable-controlled robot Rc.

Therefore, I conclude that:

The robot Rs decides that the mirror image Rm is a part of the self and controlled from the self like the robot Rc.

According to our experiments, the self robot Rs determines whether the other robot is the self or the other based on the behavior coincidence rate (success rate). The threshold is 60% for the robot Rs.

Specifically, with a success rate 60% or above, the self robot judges that the other is the self.

In other words, the judgment of the self or the other by the robot is based upon the behavior coincidence rate of the '**part of the body**" of the self.

Therefore we conclude that, on the condition that all the robots used in our experiments have the same normalized functional specifications, a 100% cognition rate has been achieved.

VIII. INVESTIGATIONS AND PROSPECTS

a. An elucidation.

The mirror image robot Rm is closer to the self robot Rs than robot Rc which is part of the self (from the results of our experiments).

Humans sense that their mirror image is as part of the self (**Self-Body Theory**).

In other words, I found a physical meaning in the fact that humans can recognize that an image in a mirror is their own self.

According to these investigations, the self image in the mirror is the other that is separated from the self. It is the special 'other,' however, that generates the sense of being part of the robot's own body.

The LED lights up not because the behavior coincidence rate has reached 100% between the self robot and its mirror image. The robot recognizes that the mirror image is closer to the self than being just part of the self.

In other words, the robot's recognition that it is closer to the self than part of the self has reached 100%.

We have thus solved the mystery: the robot ambiguously recognizes its mirror image, and the mirror image is felt to be a part of the robot's own body.

b. The mirror box therapy.

The human brain can feel existence of a lost limb.

When a person loses a limb, for instance in an accident, there is sometimes a feeling that the limb still exists. This is called the **phantom limb** phenomenon.

Phantom limbs may be accompanied by '**phantom pain**.'

Dr. V.S. Ramachandran, an American neurologist, has successfully eliminated patients' phantom pain using his mirror box.

My theoretical description that "The mirror image of the self is part of the self-body" provides the physical grounds for the mirror box therapy conducted by him.

c. The mirror stage.

This investigation is also a physical demonstration (Self-Body Theory) of the mirror stage hypothesis introduced by the French psychopathologist Jacques Lacan (1901 – 81).

Mirror Stage Hypothesis asserts that infants, at an early stage in the development of their neural systems, grow up and establish the self in stages as they recognize their mirror image and become aware of the integrated physical body.

This is because, in my theory, to be able to "cognize the self image using the cognition result of self behavior and the behavior of others" or to succeed in mirror image cognition, cognition of

the self and others is necessary in advance. The Mirror Stage can be considered to be the stage in which self behavior and the behavior of others can be cognized discriminately and the relationship between the self and others (meanings of the self and others) can be cognized.

The results of our experiments using robots for mirror image cognition support the mirror stage hypothesis of Lacan in that infants become aware of the self using their mirror images and develop cognition.

d. Can the self robot discriminate itself from any other robots?

No, it can't.

If the other owns a performance that physically exceeds the capability of the self (mobility, sensing ability, etc.), the robot will determine that the other is part of the self.

In truth, no conceivable super-robot can exceed the performance of its own mirror image.

This observation provides physical grounds for believing that any artificial limbs exceeding the capacity of the self, even if they are not the real own living limb, are a real part of the self.

Namely, the artificial limbs can be judged as a real part of the self (**Artificial Limb Hypothesis**).

This hypothesis will become welcome news to persons who have lost limbs and must live their lives with artificial limbs. This is because the hypothesis provides a physical theory in which an artificial limb is "accepted by the brain as one's own limb."

e. Mysteries of the illusions of reality

From the result of Experiment 1, we may theoretically say that the behavior coincidence rate of a robot cannot reach 100% due to various natural interferences.

This leads to the hypothesis that human recognition is always ambiguous (**Ambiguous Recognition Hypothesis**).

As proved in experiments, two-point discrimination on the skin of a human is not always successful depending on location [20].

You cannot always discern the sex of humans you might see walking along the street.

Doctors cannot always make an accurate diagnosis of internal disorders.

Although this hypothesis is already considered to be true, the following mystery remains.

The mystery is that humans feel 'certainty of their existence' despite any ambiguous senses.

For example, that is phenomena of phantom limbs and phantom pain.

These phenomena are called "**illusions of reality**."

Humans' recognition function consists of bio-machines.

Because machines are involved in the recognition function of humans, various interferences from the external world (including physical interferences from the human body) affect the process of recognition in the brain, and thus the result of recognition is always ambiguous, both theoretically and physically.

Nevertheless, the brain never fails to realize the existence of reality, even when based upon such ambiguous recognition.

This mystery is called the illusion of reality.

f.   Considering the human brain from the mirror image cognition robot

The MoNAD module that I proposed can explain many phenomena of human consciousness. It is natural outcome because my definition of consciousness is derived from the knowledge of human consciousness phenomena. According to scientific knowledge, the human brain is composed of about 100 billion cells and information is contained in each cell and is output from the cells. Also information is passed from one brain cell to another. To some extent, some information is passed from a part of the brain to another part for communication and is circulated based on some rules. For example, information that passes from the body through the spinal cord and enters from the low part of brain into the occipital lobe, information processed from the lobe to the parietal lobe, information processed from the parietal lobe to the frontal lobe, information exchanged between the frontal lobe and the center of brain, and information from the center of brain to the body are known [21]. Although the possibility that the function of human consciousness is influenced by unknown substances remains, I think that we should try to identify the function of consciousness using only scientific knowledge that is already known. In other words, I estimated that human consciousness was generated by not only information circulating in the brain itself but also the circulation of information between the brain and the body. I estimated the existence of the MoNAD from the circulation of such information and judged that human consciousness may be physically explained using it. Since the robot that used this MoNAD had successful mirror image cognition, it is natural to think that the MoNAD structure of the brain can provide the first step toward physically explaining human consciousness (**Brain-MoNAD Hypothesis**).

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