Realistic Child Robot "Affetto" for Understanding the Caregiver-Child Attachment Relationship that Guides the Child Development

Hisashi Ishihara
Graduate School of Eng.,
Osaka University, Japan
Email: hisashi.ishihara@ams.eng.osaka-u.ac.jp

Yuichiro Yoshikawa
Graduate School of Eng. Sci.,
Osaka University, Japan
Email: yoshikawa@sys.es.osaka-u.ac.jp

Minoru Asada
JST Erato Asada Project/
Graduate School of Eng.,
Osaka University, Japan
Email: asada@ams.eng.osaka-u.ac.jp

***Abstract*—Children are considered to develop various kinds of their social abilities in communication with their caregivers. Developmental researchers have revealed the quality of the caregiver-child attachment heavily affects the children's developmental passway and sometimes threatens their healthy development. For understanding developmental mechanism under the caregiver-child attachment, a number of theoretical models have been proposed and some child robots have been created to test these models or to find new facts about development. However, most of these robots have not been provided with a realistic childlike appearance or facial expressions, which seem important to induce caregiver's attachment. Since what kinds of treatment robots receive from the "caregivers" appears to depend on what kinds of impression the robots give to their caregivers, more realistic robot that is more close to a real child seems needed. In this paper, we introduce our project to build a new child robot, Affetto, that has realistic appearance of 1- to 2-year-old child, and discuss what kinds of issues on child development can be examined by using it.**

I. Introduction

Child development is achieved in the attachment relationship with caregivers [1]. Developmental researchers have marshalled the styles of children's attachment and caregiver's affection and developmental passway, and they have found that the way of their sensitive replies to the children's attachment needs could affect the developmental passway [2]. Different expression styles of the caregiver's affection are considered to result in different expression styles of the children's attachment needs [3]. In extreme cases when the amount of caregiver's affection is not enough, children's attachment to the caregiver is not shaped well and it can increase the risk of developmental problems [4]. Since the attachment relationship is thus crucial factor that determines the developmental passway and its consequence, developmental mechanism should be explained with the caregiver-child relationship in mind.

A synthetic approach is considered to be a promising way for elaborating developmental theories in which many factors are mutually involved such as child development [5]. Some theoretical models are proposed to explain developmental mechanisms. For example, some researchers have proposed computational models that explain the developmental mechanisms of social abilities such as gaze following or word learning through social interactions with the caregiver (see the survey [5]). In these kinds of interactions, caregivers are known to behave characteristically so as to make children's learning easier, e.g. motionese [6] or motherese [7], and this characteristic is called caregiver's "scaffolding" [8].

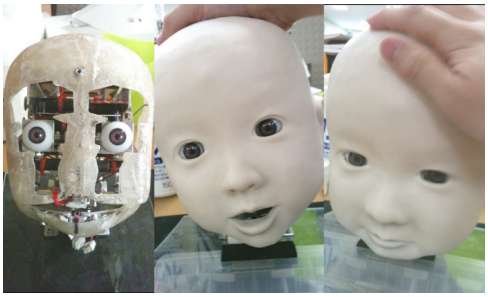

Fig. 1. Internal mechanical structure and appearance of Affetto's head

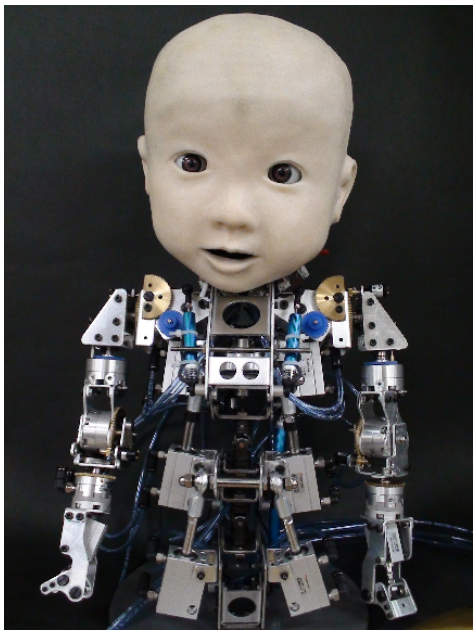

Fig. 2. Head with the internal mechanical structure of the upper torso

Furthermore, Ishihara et al. [9] have proposed the computational model of caregiver-child mutual imitation of vowels that shows the vowel development can be guided by the caregivers' expectations for the development by which they imitate children's immature utterances as more vowel-like sounds and as more accurate imitations of their utterances. The simulation result of their extended model indicates that a kind of motherese in vowel utterance [10] is emerged as a result of the mismatch between the caregiver's expectation and the actual developmental condition of the child [11]. Thus, the possibility that caregiver's developmental expectation [12] guides the child development has been started to be investigated in the synthetic research field.

On the other hand, some child-type robots are created [13], [14], [15], [16], [17], [18] and used for finding new developmental facts and for validating hypothesized developmental mechanisms. Some researches have investigated the robot's learning process through social interactions with humans [19], [20], [21]. However, because most of them assumed preliminarily-fixed or "forced" interactions, it seemed difficult to simulate the condition where the caregivers willingly interact with the child with affection or developmental expectation.

What kinds of robots can establish the attachment relationship with human caregivers and can receive caregiver's scaffolding? Breazeal proposed a communication system based on drives, emotions, and facial expressions for a robot [22] and found that these elements influence to establish and maintain social interactions which seemed appropriate for the social learning between a robot and human caregivers [23]. However, her robot did not have a faithful childlike appearance and therefore how a childlike appearance affects the interaction with human caregivers was not investigated. Nagai et al. [24] have conducted an interaction experiment where human subjects are told to show a small robot the process of cup stacking and they have found that subjects tend to move cups in a exaggerated manner when the robot has an attention system modeled after young children's one. This finding indicates that the "childlikeness" could induce the caregiver's discriminative behavior such as motionese and supports the approach to building "childlike" robots for investigating what kinds of interactions are induced by what kinds of childlikenesses. However, most of existing child robots are not faithfully modeled after children in appearance or do not have a wealth of childlike facial expressions, of which Breazeal pointed out the importance.

Therefore, we started the project to create a new child robot "Affetto" which is modeled after 1- to 2-year-old child realistically in appearance and it can show various kinds of facial expressions and affective gestures. In this paper, we introduce the design concept of this robot and then the specifications of the current version. Finally, what kinds of studies will be possible with this robot is discussed.

II. Design Concept

Here we introduce some basic concepts of designing of Affetto.

A. Maximizing possible childlike impression

What kind of impression the robot gives to the human caregivers affects how it is treated by them [25]. We aimed to build a robot whose impression is close to the one of a child as much as possible. This age is selected because we are planning to simulate social developments which is considered to proceed greatly in the period on this robot.

1) Realistic appearance: We designed the appearance of the Affetto so as to be close to the one of a child. Android research has revealed that humans make unconscious interpersonal responses in front of an android that closely resembles human beings [26]. Childlike appearance is considered to be important for a robot to be responded by human caregivers as a child.

2) Actual child size: We determined the size of each body parts so that they are close to those of 1- to 2- year-old Japanese boys based on a child body database [27]. Child size robots are considered to be less imperative and to be treated carefully and additionally the way they interact physically with objects or humans is considered to resemble the child's one.

3) Smile-based facial expression: Facial expressions are realized by means of deformation of the smiling face. This is because child's smile seems a reward for a caregiver and therefore seems the most important expression to induce affective interaction with the caregiver.

B. Admissibility for physical interaction

The second concept is to enable the robot to be interacted physically. Physical interaction with the caregiver is regarded as one of the most important interaction for developing child's stable attachment.

1) Passive actuators: Some pneumatic actuators were implemented in joints which would be subjected to external forces such as human caregiver's touching. Though pneumatic actuators are difficult to control, they are flexible to external forces and therefore suitable for the robots to interact physically with humans.

2) Tender skin: We covered (or will cover) the robot with soft skin, which decreases the risk to injure human caregivers. Additionally, it possibly increases human's willingness to touch.

3) Reduction in weight: We designed the body structure as light as possible to increase motion performance and decrease the risk to injure humans. To be more precise, we applied a box structure as a basic component and pneumatic actuators, which have high power-to-weight ratio.

C. Easiness to modify

The third concept is to design the robot so that modifications can be done easily for continuing upgrading.

1) Variable deforming points in face: We applied the deforming mechanism, by which deforming points can be changed easily. This mechanism is because there is a possibility to change the pattern of facial expression in future experiments.

2) Packed motors and controllers: DC motors for facial expressions and their controllers were gathered at one section respectively for the less annoying maintenance.

III. Specifications of the Head

Affetto's internal mechanical structure and appearance are shown in Fig. 1. The mechanical structure, at which DC motors and their controllers are mounted, is covered with an outer shell of fiber-reinforced plastic and the shell is covered with a soft face skin mask of urethane elastomer gel. The outer shell and the face mask are made with a clay sculpture of a face modeled after a picture of a young boy, because it was difficult to make a mold of smiling face directly with an actual child.

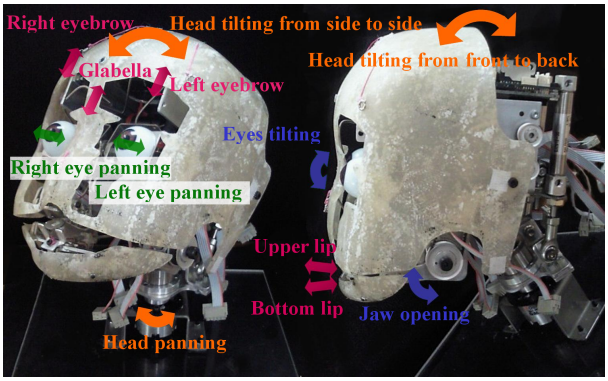

Fig. 3. Locations of the DOFs (red arrows represent actuations by wires, blue ones by a timing belt, green ones by link mechanisms, and orange ones by air cylinders)

The head with the skin is 170 millimeters in height, 140 millimeters in width, and 150 millimeters in depth. Affetto has currently 12 DOFs in the head as shown in Fig. 3. DC motors are mounted on the inside of the center box structure and their controllers are mounted on the top of it, and the space for artificial vocal organs, which will be implemented in the future, is provided under the center box. Rotary shafts of DC motors are bulging outward and pulleys are attached to some of these shafts to pull the wires connected to the inner side of the face skin. Five DOFs at eyelids and lips are realized by these wires, two DOFs at the jaw and eyes (up and down) are actuated through a timing belt, and two DOFs at eyes (left to right) are actuated by link mechanism. Figure 4 shows what kinds of expressions can be realized by these mechanism.

An universal joint is attached under the center box as a neck and the head's roll axis and pitch axis are actuated by two air cylinders mounted beside the joint in parallel. An air rotary actuator is attached under the universal joint to actuate the yaw axis of the head.

IV. Specifications of the Upper Torso

The mechanical structure of the upper torso is shown in Fig. 2. It has totally 19 DOFs (5 DOFs in the body trunk and 14 DOFs in the both arms). The body trunk is composed of four box structures and lower three boxes are serially-connected with two universal joints. The roll axis and the pitch axis of each joint are actuated by two air cylinders located beside the joint in parallel. The highest box and the second highest box are connected with an air rotary actuator, which moves the yaw axis of the highest box. Two boxes that correspond to blade bones are attached to the both sides of the highest box and each of them is actuated up and down by an air cylinder. The arms which have twelve air actuators to bend and twist their joints are connected to these boxes.

Fig. 4. Examples of the facial expressions

The upper torso is 26 centimeters in height (from the bottom of the lowest box to the top of the highest box). The total weight of the mechanical structure and actuators, and potentiometers of the upper torso is less than 3 kilograms. Outer shells and parts of skin will cover these internal components. Hands will be developed and be equipped too.

V. Possible Studies with a Realistic Child Robot

A. Experimental investigation of inducing factors of caregiver's scaffolding

Since Affetto has realistic child appearance and facial expressions, we will be able to examine how these features induce what kinds of the caregiver's scaffolding. Though the results of a neurocognitive experiment [28], a behavioral experiment with animals [29], and computational simulation [11] suggest the motherese could be a result of the caregivers' adjustment of addressing children based on the cognition of them, the precise mechanism of how the motherese is induced (or why caregivers use the motherese) has been little tried to be revealed. The robot which is close to a child is expected to be helpful for attacking this kind of issue as a controllable stimulus which can be recognized as a child.

B. Real-world simulation of the development in the attachment relationship which is closer to the child's one

Though Breazeal proposed a communication mechanism aiming to achieve the robot's development which is facilitated

by human caregiver's scaffoldings, it was difficult to consider the development of her robot as a real-world simulation of the child development since her robot was different from a child in many aspects including the appearance.

Caregivers are known to tend to treat their children as the individuals with the mind [30] and tend to expect their development [12]. These caregiver's characteristics are considered to facilitate the social development and a computational model has been proposed to explain the mechanism such the development [9]. This developmental mechanism should be simulated in the real world with robots to investigate it more realistically and therefore the robots which can be treated as individuals with mind and expected to develop are required. For this reason, the project to build Affetto has been started. What kinds of elements of the children are the keys to the such a development and how the development is accomplished are expected to be attacked with Affetto.

C. The investigation of the dynamics of affective interaction

Developmental researchers have found that children develop their social abilities in affective interactions with the caregivers and such interactions shape caregiver-child attachment relationship [1]. How do the children keep their caregivers to such interactions? Facial expressions of the children are considered to have important role to attract the caregiver's willingness to interact with the child and how they affect the quality of the interaction has been examined in human-robot interaction [22]. However, the influence of human-like appearance has not been investigated, even though the appearance of the robot is known to affect the human emotions [31].

On the other hand, several developmental mechanisms through social interactions such as mutual imitation or joint attention have been proposed (see the survey [5]). However, how these interactions are shaped, maintained, and taken over by other kind of interactions have not been discussed well and not been assumed in the developmental mechanism.

The investigation of how the human/child-like appearance influence the quality of the affective interaction is expected to be attacked with Affetto and this will contribute to explain the developmental mechanism through the natural communication situation composed of several kinds of social interactions.

D. Pursuit of the childlikeness and its social effect

Currently, Affetto has the childlike characteristics mainly in appearance. However, children's childlikeness seems to be felt with other modalities, such as auditory sense (ex., immature but energetic voice), tactile sense (ex., elastic body or vital warmth), or olfactory sense (ex., milky smell) and they could emphasize the childlike impression synergistically. Furthermore in appearance, many factors seem influence the childlikeness, such as the styles of the reactions or the quality of the movements. These childlike behaviors sometimes clear the atmosphere and sometimes surprise the caregivers. How do these childlikenesses influence the social interaction and how do they contribute to the child development? We will pursuit for the childlikeness by upgrading Affetto to study on these questions.

VI. Conclusion

In this paper, we introduced our new child robot "Affetto" designed with the realistic childlikeness and its influence on social interactions and the child development. Caregiver-child attachment relationship is considered to be a basement of the social development and therefore the robots which could establish attachment relationships with human caregivers like the children are required for simulating child developments and investigating their mechanisms in the real world. Though Affetto is still under construction, it will develop their body and mind.

Acknowledgment

This study is partially supported by Grants-in-Aid for Scientific Research (Research Project Number: 22220002) and for JSPS Fellows.

References

[1] J. Bowlby. *Attachment and loss: Volume 1: Attachment*. New York: Basic Books, 1969.

[2] E. Meins, C. Fernyhough, R. Wainwright, M. D. Gupta, E. Fradley, and M. Tuckey. Maternal mind-mindedness and attachment security as predictors of theory of mind understanding. *Child Development*, Vol. 73:6, pp. 1715–1726, 2002.

[3] M. H. van IJzendoorn. Adalt attachment representations, parental responsiveness and infant attachment: A meta-analysis on the predictive validity of the adult attachment interviewer. *Psychological Bulletin*, Vol. 117, pp. 387–403, 1995.

[4] K. Lyons-Ruth. Rapprochement or approchement: mahler's theory reconsidered from the vantage point of recent research on early attachment relationships. *Psychoanalytic Psychology*, Vol. 8, pp. 1–23, 1991.

[5] M. Asada, K. Hosoda, Y. Kuniyoshi, H. Ishiguro, T. Inui, Y. Yoshikawa, M. Ogino, and C. Yoshida. Cognitive developmental robotics: a survey. *IEEE Trans. on Autonomous Ment. Dev.*, Vol. 1:1, pp. 12–34, 2009.

[6] R. J. Brand, D. A. Baldwin, and L. A. Ashburn. Evidence for 'motionese': modifications in mothers' infant-directed action. *Developmental Science*, Vol. 5, pp. 72–83, 2002.

[7] A. Fernald and T. Simon. Expanded intonation contours in mothers' speech to newborns. *Developmental Psychology*, Vol. 20:1, pp. 104–113, 1984.

[8] S. T. Williams, A. M. Mastergeorge, and L. L. Ontai. Caregiver involvement in infant peer interactions: scaffolding in a social context. *Early Childhood Research Quarterly*, Vol. 25:2, pp. 251–266, 2010.

[9] H. Ishihara, Y. Yoshikawa, K. Miura, and M. Asada. How caregiver's anticipation shapes infant's vowel through mutual imitation? *IEEE Trans. on Autonomous Ment. Dev.*, Vol. 1:4, pp. 217–225, 2009.

[10] P. K. Kuhl, J. E. Andruski, I. A. Chistovich, L. A. Chistovich, E. V. Kozhenikova, V. L. Ryskina, E. I. Stolyarova, U. Sundberg, and F. Lacerda. Cross-language analysis of phonetic units in language addressed to infant. *Science*, Vol. 277, pp. 684–686, 1997.

[11] H. Ishihara, Y. Yoshikawa, and M. Asada. Caregiver 's auto-mirroring and infant 's articulatory develeopment enable sharing vowels. *Proceedings of the Ninth International Conference on Epigenetic Robotics*, Vol. Vol. CD-ROM, , 2009.

[12] S. A. Miller. Parents' beliefs about children's cognitive development. *Child Development*, Vol. 59:2, pp. 259–285, 1988.

[13] C. Breazeal and B. Scassellati. how to build robots that make friends and influence people. *Proc. IROS99*, pp. 858–863, 1999.

[14] G. Metta, F. Panerai, and G. Sandini. Babybot: a biologically inspired developing robotic agent. *Proc. SPIE*, Vol. 44, pp. 42–53, 2000.

[15] H. Kojima. *Socially Intelligent Agents: Creating Relationships with Computers and Robots*, chapter Infanoid: A Babybot that Explores the Social Environment, pp. 157–164. Springer US, 2002.

[16] T. Minato, Y. Yoshikawa, T. Noda, S. Ikemoto, H. Ishiguro, and M. Asada. Cb2: a child robot with biomimetic body for cognitive developmental robotics. *in Proc. IEEE/RSJ Int. Conf. Human. Robots*, 2007.

[17] G. Sandini, G. Mertta, and D. Vernon. The icub cognitive humanoid robot: an open-system research platform for enactive cognition. *In 50 years of artificial intelligence*, pp. 358–369, 2007.

[18] K. Dautenhahn, C. L. Nehaniv, M. L. Walters, B. Robins, H. Kose-Bagci, N. A. Mirza, and M. Blow. Kasper - a minimally expressive humanoid robot for human-robot interaction research. *Applied Bionics and Biomechanics*, Vol. 6:3,4, pp. 369–397, 2009.

[19] L. Steels and F. Kaplan. Aibo's first words: The social learning of language and meaning. *Evolution of Communication*, Vol. 4:1, pp. 3–32, 2002.

[20] Y. Nagai, M. Asada, and K. Hosoda. Learning for joint attention helped by functional development. *Advanced Robotics*, Vol. 20:10, pp. 1165–1181, 2006.

[21] N. Iwahashi. *Robots That Learn Language: A Developmental Approach to Situated Human-Robot Conversations*, pp. 95–118. I-Tech Education and Publishing, 2007.

[22] C. Breazeal. A motivation system for regulating human-robot interaction. *in Proc. fifteenth National Conf. on Artificial Intelligence*, pp. 54–61, 1998.

[23] C. Breazeal and B. Scassellati. Infant-like social interaction between a robot and a human caregiver. *Adaptive Behavior*, Vol. 8:1, pp. 47–72, 2000.

[24] Y. Nagai, A. Nakatani, and M. Asada. How a robot's attention shapes the way people teach. *In Proc. of the 10th Intl. Conf. on Epigenetic Robotics*, pp. 81–88, 2010.

[25] T. Kanda, T. Miyashita, T. Osada, Y. Haikawa, and H. Ishiguro. Analysis of humanoid appearances in human-robot interaction. *IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 62–69, 2005.

[26] T. Minato, M. Shimada, S. Itakura, K. Lee, and H. Ishiguro. Evaluating the human likeness of an android by comparing gaze behaviors elicited by the android and a person. *Advanced Robotics*, Vol. 20:10, pp. 1147–1163, 2006.

[27] Research institute of human engineering for quality life. Child physical characteristic database. http://www.hql.jp/database/children/.

[28] Y. Matsuda, K. Ueno, R. Waggoner, D. Erickson, Y Shimura, K. Tanaka, K. Cheng, and R. Mazuka. Processing of infant-directed speech by adults. *Neuroimage*, Vol. 54:1, pp. 611–621, 2010.

[29] D. Burnham, C. KItamura, and U. Vollmer-Conna. What's new, pussycat? on talking to babies and animals. *Science*, Vol. 206, p. 1435, 2002.

[30] E. Meins. *Security of attachment and social development of cognition*. Psych. press, 1997.

[31] C.-C. Ho, K. F. MacDorman, and Z. A. D. Pramono. .human emotion and the uncanny valley: A glm, mds, and isomap analysis of robot video ratings. *In Proceedings of the Third ACM/IEEE International Conference on Human-Robot Interaction*, 2008.