Development of Therapeutic Expression for a Cat Robot in the Treatment of Autism Spectrum Disorders

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Abstract: The purpose of this research is to develop a therapeutic expression for the use of early treatment that will improve the social interactions of children with autism spectrum disorders (ASD). In order to satisfy the purpose, we choose a cat character after surveying requirements and summarize the required actions for a treatment as hugging, eye contacts, copies of body movements and reactions to negative behaviours. The robot has a face mechanism that can express the emotion and a body mechanism to perform hand gesture. We also designed a system controller and sensor interfaces to control its body or interact with children. All the use history of the robot is stored at the memory device to analyze the play patterns of the patient and also used to make the treatment program that can be utilized in the specialized clinic. In this study, the therapeutic expression for the treatment of ASD is suggested and ported in a cat robot, and verified with real action experiment of those functions. This study is kinds of preliminary result before developing a treatment therapy for ASD children using perfect cat robot that has outer skin and furry coat, and followed by expression research for the suitable program that can be applied in the real treatment field.

1 INTRODUCTION

ASD is reportedly the fastest spreading childhood disorder. It is known that one in 150 children is diagnosed with ASD. The main characteristics of children with ASD are that they have social interaction disabilities, communication disabilities, repetitive stereotypy behaviours, and limited attention spans. Existing methods of treatment and education are greatly limited because these children cannot properly express their own emotional states and consequently a new treatment system needs to be developed. Initiatives that use robots to treat ASD children have consistently reported positive results in improved interactions, eye contact, and concentration (Cho et al., 2009; Feil-Seifer and Mataric, 2008; Lee et al., 2010; Robin et al., 2005, Scassellati et al., 2012). ASD children have actively reacted to robots, initiated interactions, and increased exploring stimulus that they liked (Kim et al., 2011). In the previous study, we have investigated the effect of the treatment using robot and how to design such a robot (Kwon et al., 2014). Sometimes robot can be used to treat ASD with making custom scenarios and revising or training robot program just using commercially available robot (Gillesen and Barakova, 2011), and this study results showed that robot has the potential to be used as a treatment and educational medium for ASD children. In this study we conducted FGIs with professional therapists and parents of ASD children in order to discover the motions and abilities the robots need to be utilized in treating ASD children under the situation of Table 1 and 2. According to FGI result analysis, robots were found to need the following motions and abilities. First, it requires the "individualization". This abilities of robots need to be developed on various levels depending on the development of the ASD child in order to conduct individualized treatment. The robot should be responsive to the child's actions instead of leading. Second, it should have "ability to stimulate the senses". This is the ability to express through the various senses according to the situation. It is

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accomplished by visual, textual, olfactory, and auditory sensors to measure touch, temperature, sound, light, color, smell, etc.

Table 1: Background for FGI participants –therapist.

Gen.	Age	Edu.	Expertise	Career
F	34	B.A	Special education	9
M	44	B.A	Speech therapy	21
F	45	M.A	Psychology	8.4
F	55	M.A	Medical Doctor	28
F	29	B.A	Occupational therapy	5.5
M	42	M.A	Rehabilitation therapy	15
F	46	M.A	Physical therapy	23
F	38	M.S.W	Social Work	14.8
F	31	B.A	Occupational therapy	6
F	30	B.A	Occupational therapy	3
F	35	M.A	Art Therapy	6

Table 2: Background for FGI participants –parents.

Relation	Age	Gender(Age)
mother	37	M(6)
mother	42	M(8)
mother	38	M(8)
mother	34	M(6)
mother	50	F(8)
mother	36	M(8)
mother	43	M(8)
mother	39	F(7)
mother	43	M(6)

Third, it should have “interactive motion”. Since eye-contact is an important measure of interaction. During the interaction a robot should be able to move and positively react according to the child’s gaze and eye-contact range. It also has the ability to negatively respond to child’s behaviors that need correcting or aggressive behavior, etc. This also includes the ability to emulate the child’s actions, hugging motion, requesting motion to play with the child, and eating motion as if it is a real pet.

Finally, this kind of robot can be able to “manage all of the behavior” or result of the treatment using operation history. It should have the function for family members or therapists to control the robot with a remote control or the ability to select from a various range of programs according to the child’s conditions with the swappable memory cards. In addition it can notice the changes in the child’s behavior during use of the robot. This therapeutic program should be included user interface for controlling and monitoring the robot. In this paper, we suggest some effective treatment method based on the feedback of the field and robot design to be suitable for making such action.

2 ROBOT DESIGN

2.1 Required Action and Expression

After surveying of FGI result, we found that actions of a cat robot for a treatment must include making hugs, doing eye contacts, imitating body movements and reactions to negative behaviours as shown in figure 1. In order to perform these acts, the robot has to be designed proper physical structure. Head can be able to move in all directions, and legs should be operated with suitable structure for hugging and negative reactions.

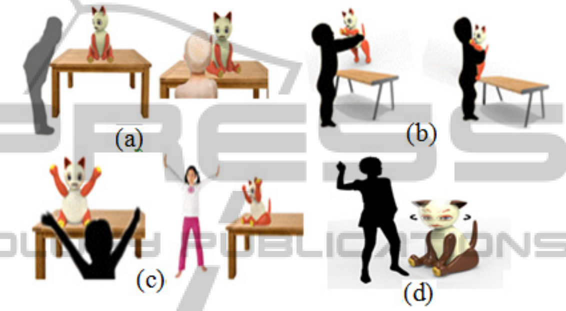


Figure 1: Actions for treatment: (a) eye contacts, (b) hugging, (c) imitating body movements,(d) reaction to negative acts).

At the same time, for treatment of ASD children, it should be required some actions expressing happiness, sadness, anger, and surprise. This robot could make expressions on the face showing the status of emotion just like human. It should be possible to show children in moving ears, eyebrows, and eyelid movement according to emotion, and realized with giving various changes like raising tails of lip up and down.

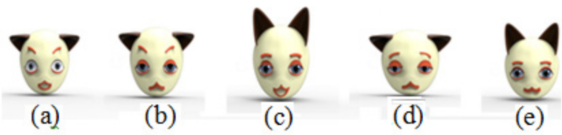


Figure 2: Facial expression: (a) surprise, (b) anger, (c) happiness,(d) sadness,(e) absence of expression.

2.2 Character and Mechanical Design

A referred cat robot is implemented to be covered by furry coat with the same length of furry as a real cat. The ratio between a face and a body is given with 1:2 to show the cuteness of a baby cat. For a better showing of the change on a facial expression, eyebrows is emphasized and eyes are bigger than normal size according to the result of a preference research and tails of eyes is centered. A cat robot has the height of 50cm to be set up at the children's eye level as shown in the Figure 3.

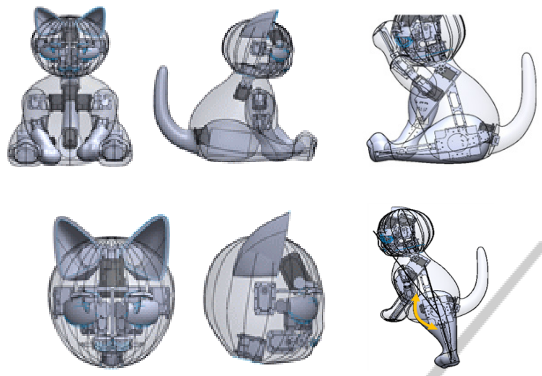


Figure 3: Internal mechanism.

To be looked more like a cat, a shape of face, ears, body are designed. Eyes, a mouth and ears are designed with emphasis on the shape than the real to have the better appearance of the facial expression. Supporting structure is needed inside for electronic circuits. For the structures of body and skeleton, aluminum structures are used to sustain strong and light-weighted. A joint for making movements in set-up angles is equipped with a servomotor.

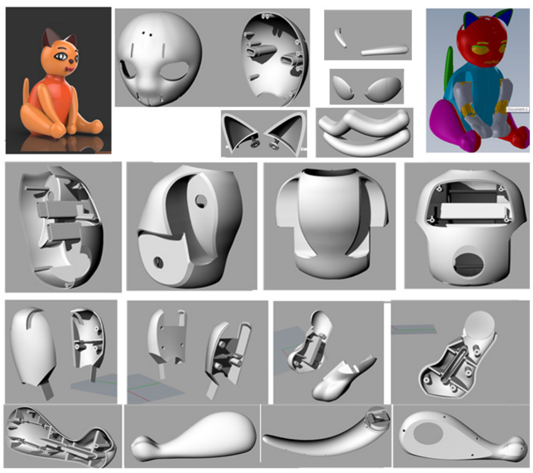


Figure 4: Outward appearance design.

As a whole, it would be embodied with 21 joints including actions of legs and tail. At the same time, an outward appearance is designed to protect the designed inner part and structure. The outward appearance is designed for the tight joint with the structure of inner part. To assemble the parts using each hole of the parts prepared in the inner part structure design, outward appearance design was processed separately by two parts.

2.3 Joint and Electrical System Design

Cat robot for the ASD treatment should be considered the action against the user's abnormal behavior. Its structure also has to sustain strong external force with strong material like aluminum alloy. In addition to reduce the weight, it should be made by many empty spaces on the skeleton as soon as possible. For the treatment of emotional expression to a face part, intelligent controller units related with the movement should be considered in the body portion and the tail portion. It maybe takes after real cat and be able to do similar movement. Head unit is very important to represent the emotion. It has parts of the eyes with forehead, eyebrows, mouth, and ears like a cat, which are operated with 10 motors. Furthermore the each parts of the face are arranged separately and controlled by each individual motors, so they can move independent and express the required emotions. In the upper leg, three joint are placed with the motion of shoulder and elbow that can be used to make some human-friendly gesture. In the right and left hip portion, high torque driven legs are designed to make stand-down or stretching. And one joint is placed to express the pleasant feeling by waving a tail. In connecting the head and neck of the body, two degrees of freedom is implemented with the motion of shaking and nodding, so cat robot has a total of 21 degrees of freedom.

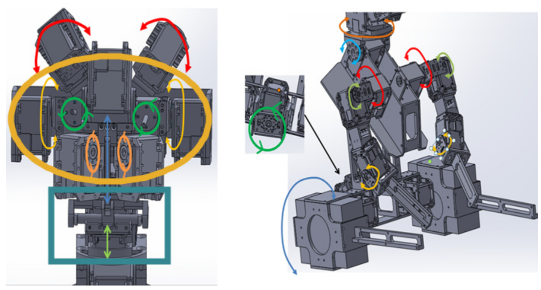


Figure 5: Motor movements in body and face.

Generally cat robot has an initial posture sitting at table, and be excluded the walking function of real cat. It just vents main body using hip joints to make up-down motion of body. Especially hip motors are so powerful enough to drive whole body and withstand the load variation from external. In addition various types of sensor system were installed on the skin or under the skin in order to give robot-human interaction like intelligent behavior and sympathetic action.

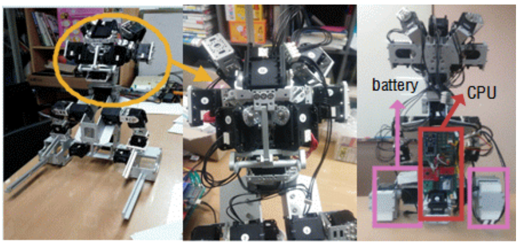


Figure 6: Cat robot skeleton and motor installation.

2.4 Controller Design

The operations of each part of the body and interactions between robot and ASD children are detected by wide range of internal and external sensors of the robot. Several capacitive contact sensors were installed on head, back, belly, and upper legs, which can detect the user's touch. Touch information from the sensors are stored in micro SD that is plugged in main controller and be made available for the analysis and making treatment program in the future. In addition sound generating device is designed to generate cat voice according to various situations. The cat sound can be reproduced through audio Codec with electrical speaker. Sound effect is essential to make interaction with each other, especially in ASD treatment. An infrared sensor can catch the motion when somebody moves within a boundary of certain distance. It can be able to measure the distance between user and robot and also direction of movement, so it can be used to increase intimacy with robot. In the waist, a 3-axis accelerometer was installed to measure the robot orientation to check if the robot was tilted, lifted, or if user try to hug according to the user's feeling.

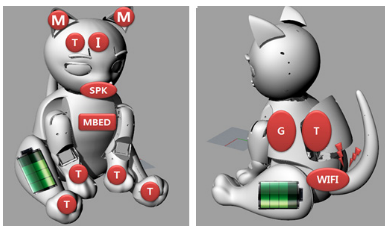


Figure 7: Sensor deployment (T:touch,G:gyro,I:infrared).

All the proposed motion is determined by number of commands that ordered from operator on the web through Wireless Internet (Wifi), and robot behavior and actions is set by downloading command on the web. In this way many working robots in different field are available to play in the response of the robot and easily collect data as a useful therapeutic effect, and the teacher or operator can control the robot remotely as a medium of treatment. Motors for driving the joint are one of the two types of ROBOTIS MX-64 (6.0Nm) or AX-32 (2.6Nm), which are controlled using the RS485 communication with only two lines in controlling multiple motors(Robotis,2014). Main MCU was designed to perform all of the control with easiness. It is based on Mbed, 32-bit ARM ® Cortex ™-M3(LPC1768) interfaced with various sensors and driver to control actuator (MBED, 2014). The total power consumption of the motor 21 can be driven at the same time, so we should take into account of the critical situation. 3000mAH, 3.7V Lithium-ion battery is used with several combinations and finally to produce 6000mAH 11.2V. The entire actuator and the controller about the connection of the sensor are shown in a block diagram and a specification is summarized in Table 3.

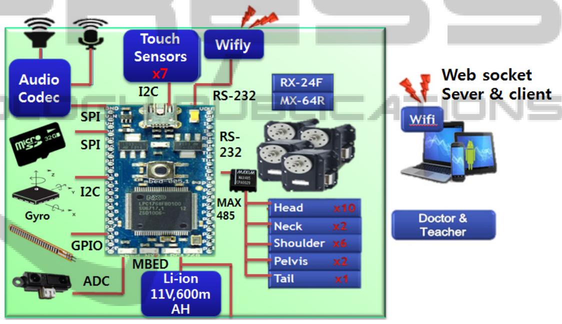


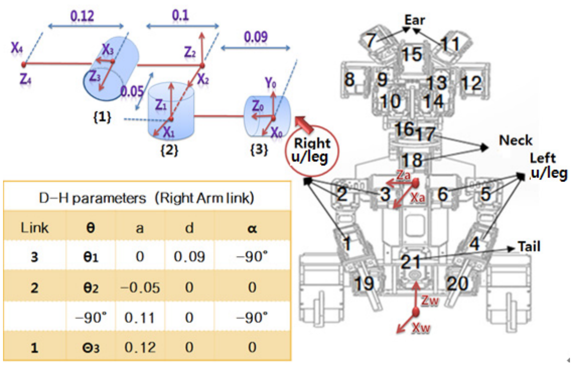
Figure 8: Block diagram of the controller.

Table 3: Robot specification.

Actuator	total number of motors (21)
	Dynamixel RX-24F(2.6Nm) : 14
	Dynamixel MX-64(5.3Nm) : 7
Weight	5Kg(including battery)
Height	50Cm
Inner skin	plastic
Outer skin	artificial fiber(antibiotic, flavor)
CPU	Mbed(NXP LPC1768 기반,Cortex-M3)
Sensors	
Touch	MPR121 based (I2C)
Sound	VS1053 based (SPI)
Balance	L3GD20 based (I2C)
Speaker	AS04008CO-WR-R, 8Ω
Battery	LG Chemistry 18650,11V, 6000mAh(3.7V 3000mAh Lion, 6)
Network	Wifly(RN-171)

3 ANALYSIS OF ROBOT

In order to move robot joints properly, motor control system is designed under the analysis of operation. At the same time, since there are various sensors attached to robot, intelligent system should be implemented to identify with an operation. The picture below shows the overall appearance of cat robot without skin that will be implemented in the near future. In order to give leg motion, we should make plan for the predefined joint motion. Based on this concept, all the kinematic analysis of the each link joint is performed as follows. First, the kinematic parameters of motor 21 are defined after setting the joint coordinate system by D-H representation. 10 joints among 21 are placed in the head for emotional expression and require the predefined action, but others in the body, and legs must be designed the motion based on this analysis. Joint analysis starts from doing by setting a coordinate system at upper leg and the neck part separately. So they can be divided into 3 individual coordinate systems. First, origin of overall world coordinator is expressed in the center of the sitting robot and other one is located in the middle of both upper legs, and last one is in center point of neck. In analysis process, we only consider upper leg coordinate system because it should be used to make lots of gesture, but others are needed only predefined function. The link allocation and kinematic analysis of leg can be expressed with the coordinate system as shown in Figure 9.



D-H parameters (Right Arm link)				
Link	θ	a	d	α
3	θ1	0	0.09	−90°
2	θ2	−0.05	0	0
	−90°	0.11	0	−90°
1	Θ3	0.12	0	0

Figure 9: Coordinate system.

Forward kinematics is calculated as follows based on the upper legs and shoulders with DH parameters

$$A_3=\begin{bmatrix} C\theta_3 & 0 & -S\theta_3 & 0 \\ S\theta_3 & 0 & C\theta_3 & 0 \\ 0 & -1 & 0 & 0.09 \\ 0 & 0 & 0 & 1 \end{bmatrix} A_2=\begin{bmatrix} C\theta_2 & 0 & -S\theta_2 & -0.05C\theta_2 \\ S\theta_2 & 0 & C\theta_2 & -0.05S\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_{dummy}=\begin{bmatrix} 0 & 0 & 1 & 0 \\ -1 & 0 & 0 & -0.11 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} A_1=\begin{bmatrix} C\theta_1 & -S\theta_1 & 0 & 0.12C\theta_1 \\ S\theta_1 & C\theta_1 & 0 & 0.12S\theta_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Using this result from kinematics, leg joint angles are derived by the inverse kinematics and created the movement of joints. Generally in planning the trajectory of the object, Euler angle representation is so popular. To acquire distal positions, Jacobian for each posture is derived with velocities of hand gesture between robot and human. The process of inverse kinematics was transplanted into the main controller with a MBED module to work in real time. When doing jobs with robot, we should give several discrete points to the robot which are going through between the point and point. At this time, the intermediate points with respect to a given discrete points are obtained by interpolation, and robot can move the target points smoothly using these points. We use cubic-spline interpolation passing through each point from the position and velocity, and acceleration in the form of the continuity of the operation of the robot performing the interpolation and finally could be controlled smoothly. In this analysis, robot trajectory is derived at some positions from the start to 10 seconds during hand gesture.

In order to get the trajectory points, we applied the interpolation using spline curve that is called to Natural cubic interpolation. The coefficients of the polynomial are determined as follows (Hazewinkel, et al., 2001).

$$S_i(x)=\frac{z_{i+1}(x-x_i)^3+z_i(x_{i+1}-x)^3}{6h_i}+\left(\frac{y_{i+1}}{h_i}-\frac{h_i}{6}z_{i+1}\right)(x-x_i)$$
$$+\left(\frac{y_i}{h_i}-\frac{h_i}{6}z_i\right)(x_{i+1}-x) \quad , \quad h_i=x_{i+1}-x_i \quad (2)$$

Here, z is determined by the boundary condition coefficient values. Figure 10 shows the result of trajectory planning under the Table 4 condition. We can find the smoothness during all of the working time. After checking the value of planning the movement of joints with respect to the gesture of robot, therapeutic operation can be realized in the real robot.

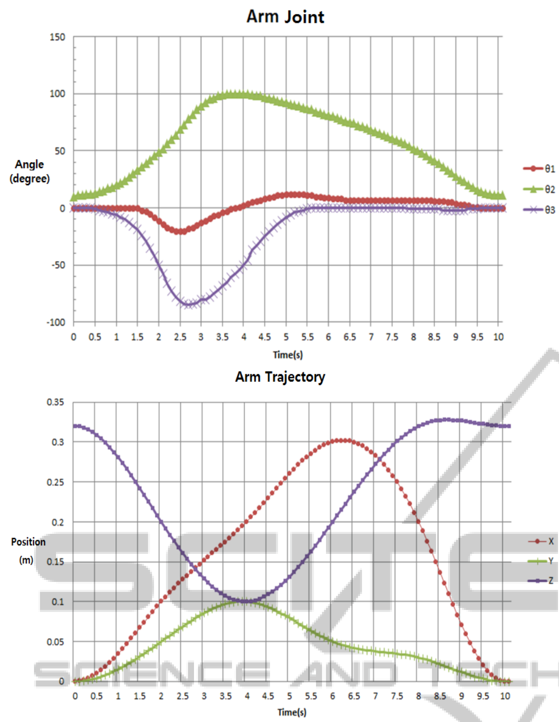


Figure 10: Trajectory planning.

4 EXPERIMENT

The required operations of the robot based on the analysis above are implemented to show usability. To do this, read the value of the current angles of each motor and stored them in the micro SD card, and generated the required operation on the basis of the stored data. In order to move smoothly, trajectory of the action was generated by using via points which were recorded from offline operation. Some of operations that are needed to be used in treatment operation were performed.

4.1 Expression of Negative Feedback

First, the expression of negative behavior is tried to give negative action to ASD children. The behavior is predefined with required action in advance. Depending on the sensor operation the head turning from side to side is expressed in the middle of action and this kind of expression showing the unpleasant emotion allows patients to lead more reliably. The history of negative behavior is memorized and reported to doctor as an aid of treatment. As shown in the Figure 11, a robot is shaking his head from sid e to side with some hand gesture, and also a negative sound is generating to express such action.

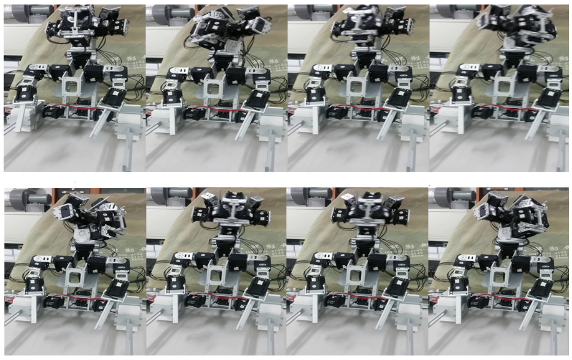


Figure 11: Behavior of negative feedback.

4.2 Imitation and Gesture

Some typical behaviors of cat are implemented using body and hands together according to user action. Hand or back movement is kinds of checking operation whether the action has been completed or not. Lifting up hands can make the patient easier to handle the robot or hug easily. At the same time robot makes crying sound in the middle of action and sometimes change the shape of the eyebrows or the mouth to imitate the actual animal action. These actions are not finished yet because outer skin was not implemented in cat robot. Figure 12 shows the imitation gesture using hand and legs with respect to Table 4 information.

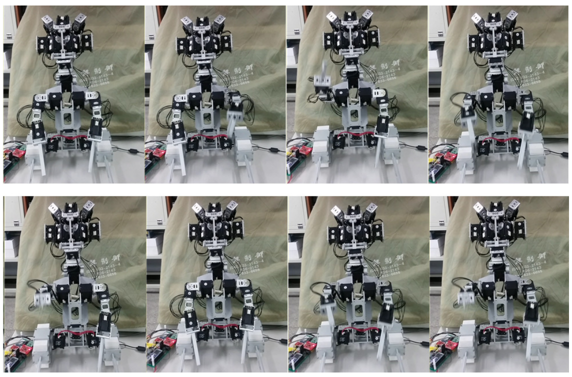


Figure 12: Imitation behavior.

Table 4: Joint angles of the gesture.

Motor	3	4	6	7	8	12	15	16
start	202.2	141.8	147.3	157.6	145.6	160.8	99.3	157
via1	192.9	150.9	250.6	136.2	125.4	170.8	115.9	192.8
via2	192.9	150.9	250.6	136.2	127.1	175.2	115.9	155.6
via3	192.9	150.9	250.6	136.2	127.7	171.7	115.9	155.6
end	192.9	150.9	250.6	136.2	145.3	155	100.6	155.6

If somebody rubs belly, it responds with the action of alternating hands to express the good feelin g and also performs hand gestures with facial expres sion. At the same time it makes some typical cat sou nd opening a mouth. During this operation, the shoul der joint 3 and 6, were lifted up and down most of time and elbow joint 6 and 7 were worked intermittent.

4.3 Facial Expression

Several expressions can be made using face such as folding ears, lifting eyebrows and changing the lip shape. In this experiment, movements of upper and lower lip, eyebrow, and ear pieces are designed and implemented the sequential action with various emotional combinations. Furthermore in case of implementation of the entire face covered with fur and skins, we could express precise facial expression.

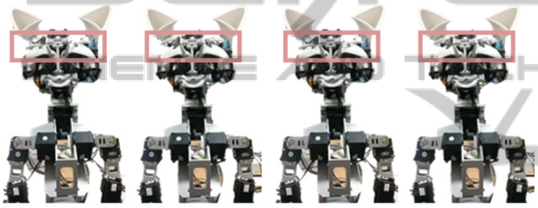


Figure 13: Eyebrow movement.

Some structure is designed to make the eyelids w inding, floating, and working separately in wink operation. Robot emotions using eyebrow is an impo rtant part of a cat and given by 2 degrees of freedom to be able to express a different look. The eye behavior is shown in the Figure 14.

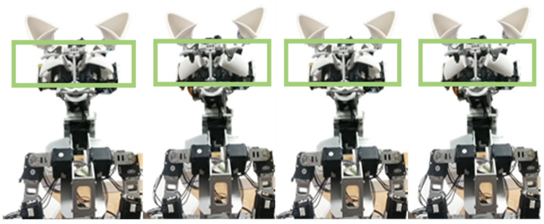


Figure 14: Eye movement.

The frame structure and the outer covering of the eye with consideration of the connection structure are carefully performed in order to move the eye brows variously according to emotions. From the right side it shows the eye expression such as closed or open eye fully or half. The lip movements are ex pressed with the middle structure of face and sides of lips. It can be closed, open, and also make some shapes to express anger, sadness and surprise, etc.

Figure 15: Lip movement.

The ear has the function only up and closing. It is deemed that no other action is required other than the above operation. The two ears are designed to move independently. We can express the emotion like a surprise or contentment using this ear.

4.4 Eye Contact

Another method for expressing emotion is eye contact that can be useful to expand user communication.

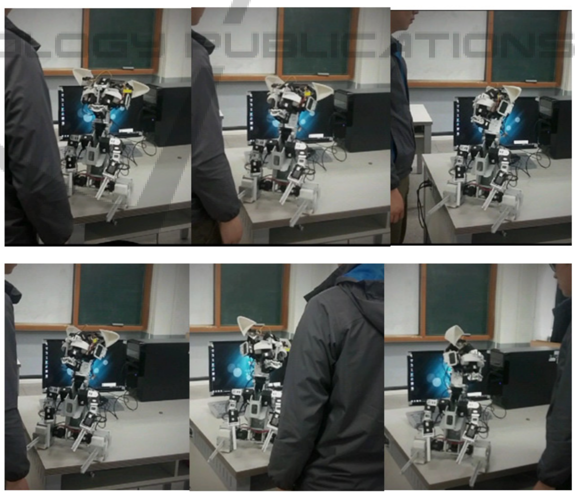


Figure 16: Eye contact.

In order to perform this operation, first detect a human body by a position and direction sensor on the body frame. In this experiment, the user moves from left to right and robot head is moving accordingly with the movement of user

4.5 Hug

Hugs are the most intense action between a robot and ASD children as a way of self-expression. Because of the complexity of the operation, we should convey partial reaction step by step according to suitable reaction that can be carried out. First, when the intension of embrace is detected, the robot stretches out its legs. After that it trims the shape of upper leg according to the body shape of the patient. Upper left in the Figure shows user approaching to robot, then board sensor of the robot detects the intension with the robot touch. Finally it controls its leg and upper legs to fit the user body. Until now, the performance of hugs is unnatural because it has no outer skin and furry coat. In the near future, more comfort hug method will be revised with the support of outer skin.

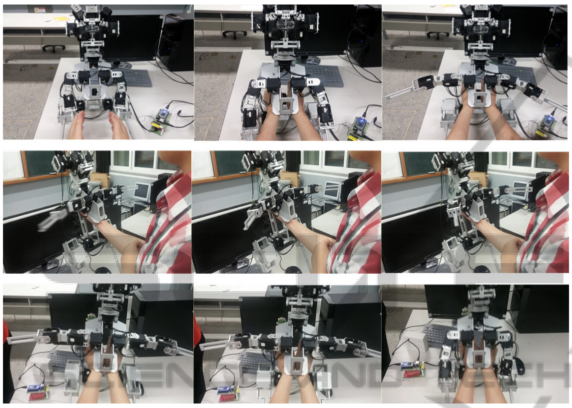


Figure 17: Hugging.

5 CONCLUSIONS

The design of a robot having a cat character is suggested in order to make positive treatment effects for the ASD children. The operations related with the various facial expressions and body gestures with appropriate interaction between robot and patient are suggested and implemented with analysis of engineering issue. The suitable motors and intelligent sensor system that can measure and control the robot are also designed. The basic emotional expression using facial movements for the treatment are performed to express anger, sadness, and surprise. Various types of treatment action are also suggested using body, and legs like hugging, eye contacts, and some behaviors. As shown in the result, cat robot can express therapeutic action with the proper interaction. In the future, more realistic problem to control a robot will be studied with the outer skin and appropriate artificial furry coat. In addition, the realistic therapy program will be designed after getting feedback from real treatment place. These kinds of studies using face and body parts of animal robot is expected to cause the diversification of robot usages in the future.

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