Force Control based Soft-stuffed Robot Interaction

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ABSTRACT

We propse a novel stuffed-toy robot which expresses its intention through the sense of force and touch. The robot has enough soft that we might want to embrace, and we can also experience his emotions from differences of forces in actions, directly through our hand holding the robot, similar to newborn babies or small animals.
Core technology is fabric based driving mechanism soft to the bone, and force control of the arms by sensing external force. The robot can change stiffness of arms and legs arbitrarily with the control, which enables to express emotions as angry or relief.

Categories and Subject Descriptors

H.4 [Information Systems Applications]: Miscellaneous; D.2.8 [Software Engineering]: Metrics—complexity measures, performance measures

General Terms

New Human Interfaces and Displays

Keywords

soft-stuffed robot,force control,human-robot interaction

1. INTRODUCTION

Many researchers have developed various human-robot interaction systems in the fields of therapy, entertainment, training, facial expression, voice recognition and sensor of sight. Now days, these technologies are used in human-robot interaction widely. In this paper, we propose an interaction system based on force control. The proposed interaction in this system, happens when the user grabs the robot's arms or touches the robot, then the robot will also give some feedback depend on the external force provided by the user.

There are two aspects of the interaction. First, when the user external force is very strong, will cause the robot to refuse to interact with the user, and want to escape from him. Second, if the external force is kind and gentle, the robot will calm down, then do some motions to show its happiness and comfort. As well as, this kind of interaction always happens between people and pets or little babies. In daily life, if parents dandle with their child kindly,and catch child's arms comfortably to wave together for conveying their love, child will be pleased to follow their parents. But sometimes, if the child feels any pain on his arms, he will refuse to move and cry.

2. EXPERIENCE

When you try to hold the stuffed robot, initially he feels afraid of you and struggles harshly to get out of your arms. However when you continue to treat the robot with gentle actions like stroking, rocking and cradling, he will start to feel more relief.As the stuffed robot ' s motions become slower, you can feel his response force weakening.If you try to shake his hand, he will respond amenably.When the robot feels relaxed, you will realize that you are also feeling easiness in the stuffed robot.

3. RELEVANT RESEARCH

3.1 Human-Robot Interaction

Many robots are produced accordingly to the appearance of some real creatures, which can interact with human beings; although the materials, the design and the function of the robots are different. A humanoid robot called CB^2(Child-robot with Biomimetic Body)[1] is developed so that establish and maintain a long-term social interaction. The most significant features of CB^2 are a whole-body soft skin (silicon surface with many tactile sensors underneath) and flexible joints (51 pneumatic actuators). But the robot needs a air compressor because of pneumatic actuators, this is not convenient. And the robot is a bit scary because the robot was designed as human keeping joints and soft skin.

Harry F.Harlow implemented a experiment about the nature of love[2]. His experiment used newborn monkeys and proved that newborn monkey prefer to touch cloth mother than wire mother. Therefore, in this research, a soft-stuffed robot whose movable parts are soft, as shown in the Figure 1, is used as the experiment subject; instead of other robots whose movable parts are hard.

3.2 Soft-stuffed Robot Research

Figure 1: Soft-stuffed Robot

Soft-stuffed robot was originally proposed by M.Siina and T.Ishikawa, using strings to control moveable parts without any machinery for tactile sense[3][4]. Y.Yamashita studied on soft-stuffed robot interaction based on impedance control and an outside camera[Kinect][5]. There were three strings in one arm and leg, and six strings in head to control robot movements for keeping the softness of robot. The soft-stuffed robot had been evaluated by an experiment on its actions and structure, compared with the recent Robot-PHONE[6]. The result indicates that the familiarity with the soft-stuffed robot is better, and users prefer to communicate with the soft robot though touching or catching the arms the robot. Therefore, this paper propose a new method to interact with soft-stuffed robot through force control, which can be accurately feedback to the external force coming from users.

Compliance control(impedance control) is needed to realize the feedback interaction[7]. Also, compliance is easy to show up with soft mechanisms in this kind of interaction, because haptic information could be greatly influenced by the robot's movements at every moment.But it is more difficult to present compliances with a hard arm robot instead of soft arm robot.

In the previous research[5], the impedance control was developed based on tension existed in the strings. And the external force was calculated with tension of strings, detected by force sensor, and resilience force coming from materials of arm. But there was an inaccuracy in this way, because the friction between string and materials should cause hysteresis; so the impedance control could not be realized precisely.

4. TECHNOLOGY

4.1 System Structure

Figure 2 shows the force control system structure of this research. In order to achieve an accurate interaction between human and soft-stuffed robot, the external force should be detected precisely and rapidly with force sensor.So, as soon as an external force is applied on the arm, the system starts to work depend on the force control administered by the control board. The microprocessor (RENESAS SH7239) and the FPGA (EP3C10E144), are main parts of the robot's control board. Then the control board gives the RE-10 maxon motors a series of commands, to realize the robot's arm to move.

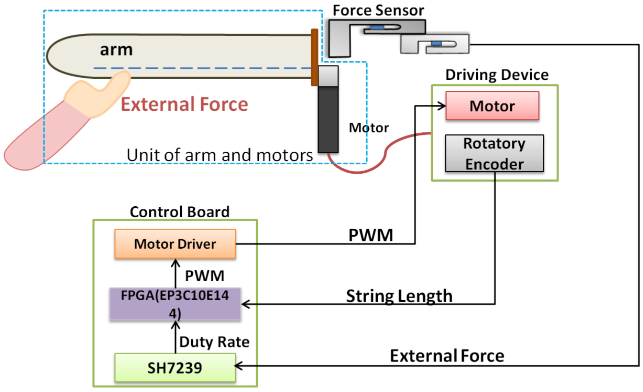

Figure 2: System Structure

4.2 External Force Detection

In this proposal, two photoreflectors(SG-105) ,shown as the Figure 3, installed in individual aluminium cases constitute the force-detection equipment called force sensor, located at the root of arms as the Figure 4. And the force sensor is the only part used to connect arm unit to the body side. The Figure 5 displays the connection between arm unit and body side. The force sensor is able to detect the external force directly under this structure, shown as the Figure 5. Additionally, a new force-sensor structure has been designed so that the external force can be detected in 2 DOF, shown as the Figure3. The Part A can measure the external force F_1 in horizontal direction; Part B can measure the external force F_2 in vertical direction.

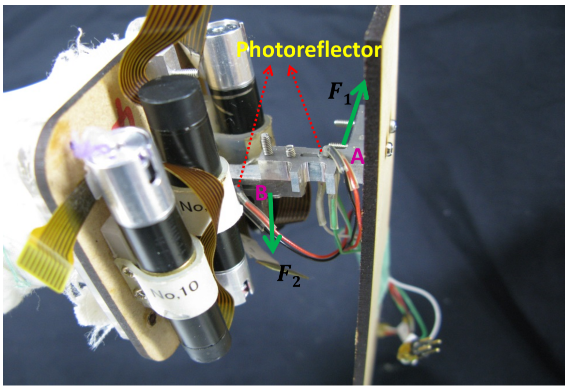

Figure 3: Structure of Force Sensor

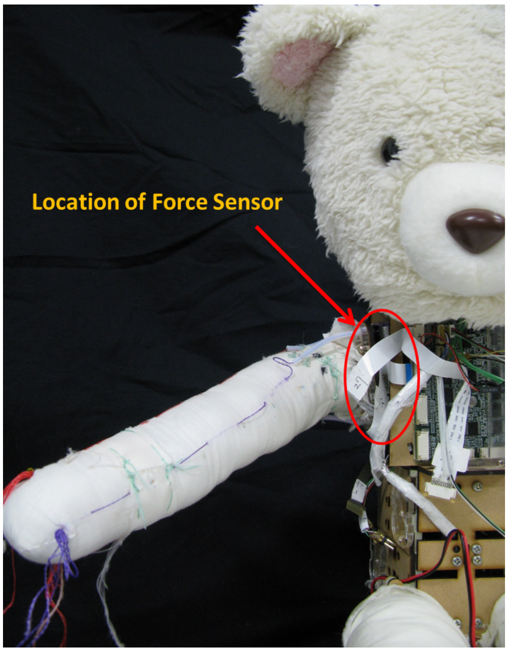

Figure 4: Location of Force Sensor

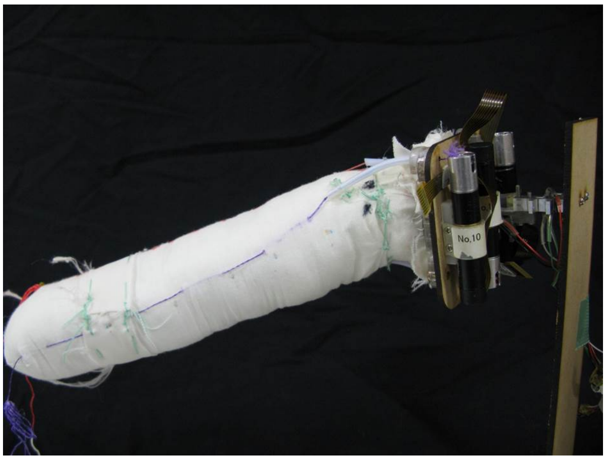

Figure 5: Connection between arm and body

When an external force is applied on the arm, the aluminium cases will deform , and then the groove widths will change to be wider than before, shown as the Figure3.Because the distance, between photoreflector and surface of aluminium case, has been changed by the external forces, it is easy to quantify the the external force through measuring this changed distance.The Figure 6 shows the distance-changing process of the case deformation.

4.3 Impedance Control Equation

After the control board obtains the external force from the force sensor, the increment length of string will be calculated by the Equation 1 [7] directly. In the Equation 1,$(1 - Ab_{in})\,\Delta x_{tgt}\,(t)$ part is damper influence on strings; $k_{in}(x_{cur} - x_{in})$ part is resilience force coming from materials of arm. The external force F_e will be more and more weak over time; the calculation happens many times depending the control board clock frequency Δt.

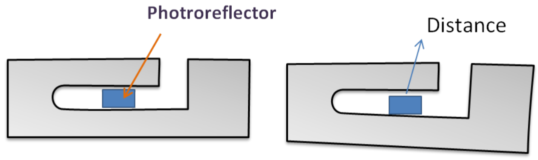

Figure 6: Force Sensor Deformation before and after

$$\begin{aligned}\Delta x_{tgt}\,(t + \Delta t) &= A\,(F_e - k_{in}(x_{cur} - x_{in})) \\ &+ (1 - Ab_{in})\,\Delta x_{tgt}\,(t)\end{aligned} \quad (1)$$

Δx_{tgt} : Increment of target string length for local motor controller
F_e : Measured external force
A : Constant to adjust sensitivity of impedance control
k_{in} : Desired spring constant
b_{in} : Desired damper coefficient
Δt : Control period(cycle)
x_{cur} : Actual string length
x_{in} : Desired string length

4.4 Behaviour Control

As mentioned before, robot would try to follow the external force or resist the external force. There are two modes in this interaction controlled by k_{in} of the Equation 1.

One mode is that the robot wants to communicate with user. In this mode, value of k_{in} is a little small, and there are many goals of x_{in} depend on emotions of robot. Although at the beginning of the interaction,the user would feel robot arms a little heavily because robot just starts to follow him, but the arms will be more and more light due to the force control. This interaction process can be realized by changing x_{in} in the Equation 1. Therefore, it is important to predict the value of x_{in} which is the key point to target the position of robot arms.

The other mode is that the robot refuses to move the arms. This mode needs large value in k_{in} enough to offset the external force coming from user.

5. RESULT AND FURTHER WORK

From November 9th to 10th,2013, the soft-stuffed robots were demonstrated in Ishikawa-YUME-MIRAI Exhibition2013. Thousands of people came to play with the soft-stuffed robots, and their age groups are very different, from a few months old to 90 years old. Some children, under 3 years old, just stared at the robots and were afraid to touch them because the robots were moving. But instead of that, many children above 3 years old, were pleased to grabs the robots and did not want to leave from them. It is interesting that fathers often asked us the mechanism of the motions, comparing with mothers only care about the softness and want to hold up the robots all the time. Of course, some old people said the robots were cute and wanted to buy one in future if the robots would become commodity. These photos show the communication scenes between users and robots as the Figure 7.

Figure 7: Scenes in Ishikawa-YUME-MIRAI Exhibition2013

In the future,Our goal is to realize a heart-touching robot by feeling of touch and feeling of force. For example, it will be a new medium for pet therapy inside hospitals where real pets are not allowed.Moreover, the stuffed toy robot can be "the robot that people want to live with". They will be new partners for people of all ages, and will lighten-up our daily lives.

6. REFERENCES

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