Mechanism Design & Dynamic Analysis of the Interactive Emotional Robot

Department of Mechanical Engineering
Korea Advanced Institute of Science & Technology
373-1, Guseong-dong, Yuseong-gu, Daejon, 305-701
kyk@kaist.ac.kr
* Hanwool Robotics Corp.

Abstract

Recent advances in the robotics have been directed to the interaction between humans and robots, which is similar to the relationship between humans and animals. We developed the interactive emotional robot called “RAI” that can be adapted to the human society with the ability of communicating the emotions with humans. Especially, this paper presents the mechanism design and control of the newly-developed robot considering its emotional meanings and operations. The two-wheeled inverted pendulum type mechanism is adopted to this emotional robot, because it can improve the mobility and make the innate clumsy monoaxial bicycle motion. This robot can move freely in a plane with relatively high velocity, keeping the upright balance. Two motors attached on head can make 4 motion sets, and two motors on the wheels can make 8. Therefore, 32 independent motion sets can be achieved from the robot to communicate the emotions with humans.

Keywords: Emotional robot, Inverted pendulum with two wheels, Non-holonomic system

1 Introduction

In the past, the main research trend of the robotics has been confined to the development of industrial robots. On the other hand, recent research topics in the robotics are extended into the development of new types of robots which can be used in the environment such as human’s living space and office rather than factories. One of those new topics is the emotional robot that can communicate the emotions with humans.

The emotional robot can be established with various kinds of mechanisms, but most of them would be categorized into humanoid and pet robot. Humanoid including ASIMO, SDR and PINO [1] has the demerit of high complexity of control, but they are still considered as the most appropriate mechanism for the emotional robot because their external appearance is very similar to humans. In addition to humanoids, pet robot is also frequently adopted because of their human-friendly characteristics, as can be seen in the case of AIBO and BANDAI.

The communication of the emotions consists of perception and reaction. As a first step, the emotional robot perceives information related to the user’s emotional status using various kinds of sensors. Then based on the perceived information, the robot gives back the emotional response with a method related to that specific emotion. In these procedures, the emotions play a central role by stimulating the emotional interaction between the complex organisms including the robot and the external environment, and by determining the internal reactive behavior of the robot [2].

Therefore, the development of the emotional robot requires the verification of the applicability of the mechanism to the emotional robot, considering how effective emotional communication can be achieved using that mechanism.

This paper presents what parameters are important in the control of the adopted mechanism after illustrating why the inverted pendulum robot without casters was adopted for the emotional robot. The dynamics of this mechanism is then introduced with following section on the experiment of control.

2 Design

As shown in Figure 1, the developed emotional robot is composed of a head for the emotional expression and the body with two wheels for the movement in a plane. More detailed design in this head-body-wheel structure was carried out based on the following considerations.

First, the joint regions are made up to protect the internal components from the pollutants of surroundings. Second, the neck is strengthened with multiple plates to make it safe from the external impacts. Third, two motors are attached for pan and tilt motion of head for more diverse emotional expressions as shown in Table 1. Likewise, two independent driving wheels are used for...
its own emotional expression, position control and fast motion in a plane without casters.

Then the emotional actions can be embodied with the designed mechanism including 4 actuators. Two motors attached on head provide the motions like shaking or nodding or its combination. And other two motors connected with driving wheels make rectilinear and curvilinear motion, spinning, and swinging up the body for upright balancing control as shown in Figure 2. Therefore, 32 motion sets can be achieved and each of them can be used as an emotional expression method.

### 3 System Parameters

The system parameters were identified for a deep understanding of the dynamics of the designed and manufactured robot. The coordinate system was defined as illustrated in Figure 3, and important parameters are listed in Table 2.

#### Table 1. Movable parts

<table>
<thead>
<tr>
<th>Movable Parts</th>
<th>2 D.O.F. (pan+tilt)</th>
<th>2 wheels &amp; 2 motors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driving Wheel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is true that four-wheel mechanism such as a car is quite stable, but its motion is so contained that it cannot express the emotions effectively. It is noteworthy that the variety of the expressible emotions is determined by the number of available motions. So, the development of this emotional robot was fulfilled, focusing on high mobility rather than the stability.

#### Table 2. Nomenclature & System Parameters

<table>
<thead>
<tr>
<th>Body</th>
<th>Mass</th>
<th>4.315kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>R. Inertia</td>
<td>0.2212kgm²</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>0.1m</td>
<td></td>
</tr>
<tr>
<td>Wheel</td>
<td>Mass</td>
<td>0.420kg</td>
</tr>
<tr>
<td>R. Inertia</td>
<td>0.0012kgm²</td>
<td></td>
</tr>
<tr>
<td>r</td>
<td>0.075m</td>
<td></td>
</tr>
</tbody>
</table>
4 Dynamics

The designed system is non-holonomic, because it is assumed that no slip takes place between the ground and the wheel. For that reason, the standard nonholonomic form of Lagrange’s equations (3) along with holonomic and nonholonomic constraint equations (1-2) were used to derive the equation of motion.

\[ \sum_{i=1}^{m} a_j \dot{q}_i + a_j = 0 \]  

\[ \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}_j} \right) - \frac{\partial L}{\partial q_j} - \sum_{i=1}^{n} \lambda_i a_j = Q_i \]  

\[ X^T = (x_c, y_c, \theta_m, x_L, y_L, \theta_L, x_E, y_E, x_G, y_G, Z_G, \phi, \psi) \]  

The configuration variables were selected as given in Eq. (4). They are the position \( x, y \) and rotation angle \( \theta \) of each wheel \((X_c, Y_c, \theta_c, X_L, Y_L, \theta_L)\); the position of center point between two wheels \((X_c, Y_c)\); the special position of the mass center of body \((X_E, Y_E)\); the inclination angle \( \phi \) and yaw angle \( \psi \) of body \((\theta, \phi)\). Constraint equations were then found as given in Eqs. (5) and (6).

\[ X_G - X_c - L \sin \psi \cos \phi = 0 \]
\[ Y_G - Y_c - L \sin \psi \sin \phi = 0 \]
\[ Z_G - L \cos \psi = 0 \]
\[ X_c - b \sin \phi - X_L = 0 \]
\[ X_c + b \cos \phi - X_K = 0 \]
\[ Y_c - b \cos \phi - Y_L = 0 \]
\[ Y_c + b \cos \phi - Y_K = 0 \]

\[ \dot{X}_c \cos \phi + \dot{Y}_c \sin \phi = R \dot{\theta}_c \]
\[ \dot{X}_K \cos \phi + \dot{Y}_K \sin \phi = R \dot{\theta}_K \]
\[ - (\dot{X}_K + \dot{X}_c) \sin \phi + (\dot{Y}_K + \dot{Y}_c) \cos \phi = 0 \]

\[ T_{body} = \frac{1}{2} I_\theta \phi^2 + \frac{1}{2} J_\psi \psi^2 + \frac{1}{2} M_\phi V^2 \]
\[ T_{wheel} = \frac{1}{2} I_\theta \dot{\phi}^2 + \frac{1}{2} J_\psi \dot{\psi}^2 + \frac{1}{2} M_\phi (X_e^2 + \dot{Y}_e^2) + \frac{1}{2} M_e (X_e^2 + \dot{Y}_e^2) \]
\[ T_{body} = \frac{1}{2} I_\theta \phi^2 + \frac{1}{2} J_\psi \psi^2 + \frac{1}{2} M_\phi V^2 \]

\[ V = M_\phi g h = M_\phi g (R + Z_G) \]

\[ L = T_{body} + T_{wheel} - V \]
\[ = \frac{1}{2} I_\theta \dot{\phi}^2 + \frac{1}{2} J_\psi \dot{\psi}^2 + \frac{1}{2} M_\phi V^2 + \frac{1}{2} I_\theta (\dot{\phi}^2 + \dot{\theta}_c^2) + I_e \dot{\phi}^2 \]
\[ + \frac{1}{2} M_e (X_e^2 + \dot{Y}_e^2) - M_\phi g (R + Z_G) \]  

Then the Lagrangian of Eq. (9) can be obtained from the kinetic and potential energy of the robot as given in Eqs. (7) and (8). And the equations of motion associated with the configuration variables can be derived substituting Eq. (9) for the Lagrangian \( L \) in Eq. (3).

Finally, the obtained 23 equations including 13 Lagrangian equations and 10 constraint equations can be used to find the value of the 23 unknowns such as 13 configuration variables and 10 Lagrangian multipliers. By comparing the number of constraint equations and configuration variables, the degree of freedom was determined by three. This indicates that the robot moves, satisfying no-lateral and no-tangential slips with three independent coordinate variables.

5 Upright Balancing Control

The designed inverted pendulum robot is unstable in itself, so upright balancing control is required first to grant more natural and effective emotional expressions to the emotional robot.

As the first step, the system was treated as a simplified one-dimensional inverted pendulum as shown in Figure 4 rather than planar robot [3].

The implemented controller for the simplified system is shown in the Figure 5, and overall flow is charted in the Figure 6. The inclination angle of the robot is given back by feedback sensor such as tilt sensor (CXTA 01) by Crossbow™. And the 11W Maxon™ DC motor was selected as actuator according to the results of Mathb simulation as shown in Figure 7 that numerically computed the necessary power for the driving wheel’s axis. The simulation proved that upright balancing control is possible for this system, so the emotional expression through various motion sets of two-wheeled inverted planar robot is expected to be a feasible idea.
6 Conclusion

The mechanism that is applicable to the emotional robot was suggested. Main driving part is composed of two independent wheels for high mobility, and it is expected that the mechanism itself will be appealing because of its clumsy motion like monoaxial bicycle. Two motors attached on head will play an important role of expressing various kinds of emotions with its pan & tilt motions. The durability and safety of the system were considered in design.

The equation of motion of this nonholonomic system was derived with a standard nonholonomic form of Lagrange’s equation after the important system parameters were identified. The upright balancing control was carried out as the first step to the expression of the emotions with diverse motion sets. It was proved that the suggested mechanism can be controlled, so the emotional expression with the designed mechanism would be possible.

More complex control of the motions of head and main driving part will be tackled. Then the control algorithm and motion sets will be connected with the emotional information process.

Acknowledgements

This work was supported in part by the Brain Korea 21 Project.

References

