COMPARATIVE SYNTHESIS OF THE SHRUG MECHANISMS FOR HUMANOID ROBOTS

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ABSTRACT
This paper presents a comparative synthesis of mechanisms for robots shrug as a form of nonverbal communication. The research was conducted within the project which develops a social robot Sara. Two solutions are proposed and are both lever mechanisms. The first mechanism consists of 4 links and the second of 6 links. Both mechanisms have per 1 DOF and enable simultaneous shrug. Based on set requirements (high movement speed of shoulders and the smallest possible driving force of the input link) objective function is formed, constrains were defined and optimal synthesis of the mechanisms was performed. Four-bar mechanism has a higher shrug speed, requires higher driving force and has small values of the pressure angle that limits his use. Six-bar mechanism has smaller dimensions, higher stroke length of the input link respectively lower shrug speed, requires significantly smaller driving force and has high efficiency (the pressure angle has high values during the whole movement). Operating direction of the driving force is oposite for the shown mechanisms. The main advantage of the 6-bar mechanism is higher transmission ratio. For smaller workloads (arm mass up to 5 kg) the 4-bar mechanism is more suitable and for a larger workloads (over 5 kg) six-bar mechanism.

Keywords: comparative synthesis, shrug mechanism, nonverbal communication, humanoid robot

1. INTRODUCTION
An important aspect in robot development is to enable the nature of human communication. The robots that will coexist in the immediate human environment have to be able to adapt to humans and the environment in which they are located. For successful operation of robots in immediate human environment, interaction between humans and robots is essential. From the robots is expected to express emotions and to communicate with humans in a simple and intuitive way [1]. Emotions are a significant means of communication which transfer a large number of information in a short time [2]. Even 2/3 of communication between humans is nonverbal communication [3].

In paper is shown a comparative synthesis of mechanisms for robots shrug. The research was conducted within the project which is developing socially acceptable robot that should represent an anthropomorphic mobile platform to explore the social behavior of the robot. Robot will be able to communicate verbally and nonverbally. To express facial expressions biologically inspired eyes are predicted with eyelids and eyelashes. To extend the range of nonverbal communication it is predicted that the robot can shrug when the answer is confusing or the robot does not know what to answer. In addition, it is predicted that the robot have two anthropomorphic arms with 7 DOFs per arm, self-locking neck with 3 DOFs and self-locking multi-segment, human-like lumbar structure with 7 DOFs [4] in order to increase mobility (upper body movements without moving the lower body).

2. STATE OF THE ART
Robots that are able to intuitively express emotions are Kismet [5] Nexy [6], iCub [7] Roman [8], Albert Hubo [9] WE-4RII [10], Kobian [11] Habian [12] etc. Exists two basic ways in which emotions of the robot can be expressed. The first is based on the facial expressions that are achieved by moving specific part of the face (eyebrows, eyes, eyelids, mouth, jaw, etc.) or by using LEDs (create eyebrows and lips on the screen that shows the face) or combining these two ways. The second is based on gestures, mainly arms and neck (head).
3. COMPARATIVE SYNTHESIS

Based on the set requirements, such as high speed movement of shoulders, the smallest possible driving force, high efficiency, small mass and dimension, two solutions are proposed and are both lever mechanisms. The first mechanism (Fig. 1) consists of 4 links and requires small space for incorporation and the second (Fig. 2) has 6 links, higher transmission ratio, but requires more space for incorporation. Both mechanisms have per 1 DOF and enable simultaneous shrug. Based on comparative analysis [13], we have determined that the mechanism A has limited use, because the pressure angle $\alpha$ significantly decreases during shrug. Mechanism B with an advantageous choice of the geometric parameters can have high values of pressure angle during whole movement and thereby high efficiency. The driving force $F_{IN}$ depends from the length of the rods when the pressure angles is above 60°. With an advantageous choice of the geometric parameters the driving force can be significantly reduced. Basic requirements for the highest speed possible of shoulders movement (at large stroke length end-points shoulders for a small stroke length of input link) is opposite to the request for a smaller possible driving force on the input link and the final solution must be a compromise of these two requirements, which will be examined within this paper. Since both of the mechanisms are symmetrical only one-half is analyzed.

![Fig. 1. Kinematic scheme of 4-bar mechanism A](image1)

Optimization problem presents minimization of the objective function for the set constrains:

$$MIN f(x), x \in D$$

where: $x = (x_1, x_2, ..., x_n)$ - vector variables,

$D = \{ x \in R^n | g(x) \leq 0 \land h(x) = 0 \}$ - a set of solutions that fulfills the defined constraints, and

$g(x) \leq 0 \land h(x) = 0$ - vectors constraints.

Exists two basic requirements for realization. First that the shrug speed must be as high as possible (at large stroke length $h_m$ end-points M shoulders for a small stroke length $y_A$ of input link 2) and the second that the force produced by the actuator $F_{IN}$ must be significantly smaller than the force of workload $F_{OUT}$ (arm mass). The driving force of the mechanism A is determined according to:

$$F_{IN} = F_{OUT} \frac{DM \sin \varphi_3 \cos \varphi_4}{CD \sin (\varphi_3 - \varphi_4)}$$

where:

$$\varphi_3 = \arctan \left( \frac{y_D - y_A}{x_D - AB} \right) + \arccos \left( \frac{BC^2 + \left( x_D - AB \right)^2 + \left( y_D - y_A \right)^2 - CD^2}{2BC \sqrt{\left( x_D - AB \right)^2 + \left( y_D - y_A \right)^2}} \right)$$

$$\varphi_4 = \arctan \left( \frac{y_A + BC \sin \varphi_3 - y_D}{AB + BC \cos \varphi_3 - x_D} \right)$$
Objective function is formed:

\[
 f(x) = \sum_i \left( \frac{F_{i}^N}{F_{i}^{N\text{max}}} \right)^2 = \sum_i \left( \frac{F_{\text{OUT}}^i \frac{D}{C} \sin \phi_i - \phi_i \cos \phi_i}{F_{i}^{N\text{max}}} \right)^2
\]  

(5)

Constrains for the operating link are defined (start \( h_1 \), the end \( h_2 \) and stroke length \( h_M = 50 \text{ mm} \)):

\[
 h_1(x) = \phi_{\text{start}} = 0
\]  

(6)

\[
 h_2(x) = (y_{\text{end}} - y_D) - h_M - \frac{D}{C} \sin \phi_{\text{end}} - h_M = 0
\]  

(7)

Mechanism must be movable and efficient in all positions during movement. Dynamic efficiency of the mechanism defines the pressure angle that represents the difference of the kinematical parameters:

\[
 \alpha = \phi_a - \phi_a
\]  

(8)

With increasing pressure angle most of the power is used for overcoming workload, and lesser for internal loads, so the mechanism is more efficient. Smaller pressure angles lead to mechanism jamming. Therefore, constrain of pressure angle is defined for the end position \( h_M \), at \( \alpha \geq 55^\circ \):

\[
 g_1(x) = 55^\circ - \alpha = 55^\circ - \left( \phi_{\text{end}} - \phi_{\text{end}} \right) \leq 0
\]  

(9)

Thoracic (chest) part of the robot is predicted to accommodate the shrug mechanism. Therefore the limitations of equality and inequality are set. Equality constraints are: \( x_D = 10 \text{ mm} \), \( x_A = 0 \) and \( x_D = 10 \text{ mm} \), and inequality (min i max) are: \( 20 \text{ mm} \leq AB \leq 40 \text{ mm} \), \( 130 \text{ mm} \leq BC \leq 170 \text{ mm} \), \( 50 \text{ mm} \leq CD \leq 90 \text{ mm} \), \( 20 \text{ mm} \leq y_{\text{end}} \leq 40 \text{ mm} \) and \( 130 \text{ mm} \leq y_D \leq 150 \text{ mm} \). In the identical way optimal synthesis of mechanism B is performed. Set constraints of equality are: \( x_D = 0 \), \( x_A = 10 \text{ mm} \) and \( G_M = 120 \text{ mm} \), and inequality (min i max) are: \( 20 \text{ mm} \leq AB \leq 40 \text{ mm} \), \( 50 \text{ mm} \leq BC \leq 90 \text{ mm} \), \( 24 \text{ mm} \leq CD \leq 54 \text{ mm} \), \( 12 \text{ mm} \leq DE \leq 42 \text{ mm} \), \( 90 \text{ mm} \leq EF \leq 110 \text{ mm} \), \( 65 \text{ mm} \leq FG \leq 85 \text{ mm} \), \( 60 \text{ mm} \leq x_D \leq 120 \text{ mm} \), \( -40 \text{ mm} \leq y_{\text{end}} \leq -20 \text{ mm} \), \( 10 \text{ mm} \leq y_D \leq 40 \text{ mm} \) and \( 90 \text{ mm} \leq y_G \leq 120 \text{ mm} \).

<table>
<thead>
<tr>
<th>Links</th>
<th>Length [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB 40</td>
<td></td>
</tr>
<tr>
<td>BC 57.2</td>
<td></td>
</tr>
<tr>
<td>CD 35.6</td>
<td></td>
</tr>
<tr>
<td>DE 29.8</td>
<td></td>
</tr>
<tr>
<td>EF 102.3</td>
<td></td>
</tr>
<tr>
<td>FG 74</td>
<td></td>
</tr>
<tr>
<td>x_D 68.2</td>
<td></td>
</tr>
<tr>
<td>y_A 40</td>
<td></td>
</tr>
<tr>
<td>y_D 26.1</td>
<td></td>
</tr>
<tr>
<td>y_G 103</td>
<td></td>
</tr>
</tbody>
</table>

In Fig. 3 and Fig. 4 are shown results of the optimization of the proposed mechanisms. For a defined stroke length of shrug \( h_M = 50 \text{ mm} \), stroke length of input link 2, for mechanism A is \( y_A = 25 \text{ mm} \) and for mechanism B is \( y_A = 40 \text{ mm} \). The dimensions of the mechanisms A and B are 150x120 mm respectively 143x120 mm. Fig. 5 shows the change of the driving force and Fig. 6 change of the pressure angle depending on the stroke length of the input link. For the defined workload (arm mass is 4.5 kg), the driving force of mechanism A is \( 103 \text{ N} \) and for the mechanism B is 65 N. Operating direction of the driving force is opposite for the shown mechanisms. The pressure angle of mechanism A at the start of the movement is 78°, on the end is 56. The pressure angle of mechanism B at the start of the movement is 89°, during movement slightly increasing and on the end is 76°.
4. CONCLUSION

Two solutions are proposed for robots shrug as a form of nonverbal communication and both are lever mechanisms. The first mechanism consists of 4 links and the second of 6 links. Both mechanisms have per 1 DOF and enable simultaneous shrug. Four-bar mechanism A has a higher shrug speed (stroke length of the input link is two times smaller than the stroke length of the operating link), but requires a higher driving force to overcome the workload (the driving force is almost two and a half times higher than the force of workload) and has small values of pressure angle which constrains its use (during movement the pressure angle rapidly decreases so that at the end of movement exceeds the proposed minimum). Six-bar mechanism B have smaller dimensions, higher stroke length of the input link respectively a lower shrug speed, requires significantly smaller driving force for overcoming workload (driving force is slightly higher than the force of workload) and have a high efficiency (the values of pressure angle are high during the whole movement). Operating direction of the driving force is opposite for the shown mechanisms, which is significant when designing the drive. The main advantage of the mechanism B is higher transmission ratio (mechanism A requires two times higher actuator per torque or for the same actuator, mechanism B will overcome double workload. Four-bar mechanism have less number of parts and is simpler to produce. For smaller workloads (arm mass up to 5 kg) the mechanism A is more suitable and for a larger workloads (over 5 kg) mechanism B.

5. REFERENCES