20th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2016, Mediterranean Sea Cruising, 24th September - 1st October, 2016

COMPARATIVE SYNTHESIS OF THE SHRUG MECHANISMS FOR HUMANOID ROBOTS

Marko Penčić, Maja Čavić, Branislav Borovac
University of Novi Sad, Faculty of Technical Sciences
Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia

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 witch 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 α 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.

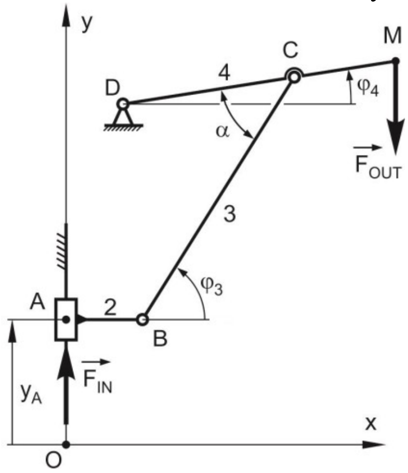


Fig. 1. Kinematic sheme of 4-bar mechanism A

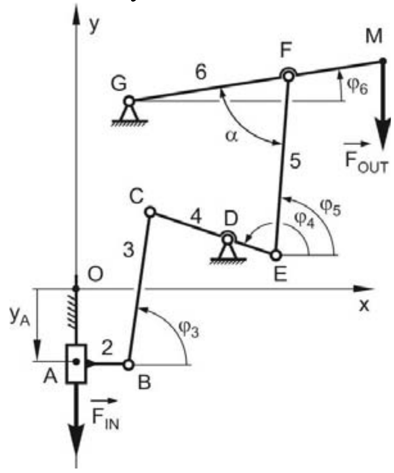


Fig. 2. Kinematic sheme of 6-bar mechanism B

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

$$MIN\, f(x),\ x \in D \tag{1}$$

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

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

$g(x) \leq 0\ i\ h(x) = 0$ - 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:

$$F_{IN} = F_{OUT} \frac{\overline{DM}}{\overline{CD}} \frac{\sin\varphi_3 \cos\varphi_4}{\sin(\varphi_3 - \varphi_4)} \tag{2}$$

where:

$$\varphi_3 = \arctan\left(\frac{y_D - y_A}{x_D - \overline{AB}}\right) + \arccos\left(\frac{\overline{BC}^2 + \left(\left(x_D - \overline{AB}\right)^2 + \left(y_D - y_A\right)^2\right)^2 - \overline{CD}^2}{2\overline{BC}\sqrt{\left(x_D - \overline{AB}\right)^2 + \left(y_D - y_A\right)^2}}\right) \tag{3}$$

$$\varphi_4 = \arctan\left(\frac{y_A + \overline{BC}\sin\varphi_3 - y_D}{\overline{AB} + \overline{BC}\cos\varphi_3 - x_D}\right) \tag{4}$$

Objective function is formed:

$$f(x)=\sum_i\left(\frac{F_{IN}^i}{F_{IN\max}}\right)^2=\sum_i\left(\frac{F_{OUT}\dfrac{\overline{DM}}{\overline{CD}}\dfrac{\sin\varphi_3^i\cos\varphi_4^i}{\sin\left(\varphi_3^i-\varphi_4^i\right)}}{F_{IN\max}}\right)^2 \tag{5}$$

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

$$h_1(x)=\varphi_{4start}=0 \tag{6}$$

$$h_2(x)=\left(y_{M end}-y_D\right)-h_M=\overline{DM}\sin\varphi_{4end}-h_M=0 \tag{7}$$

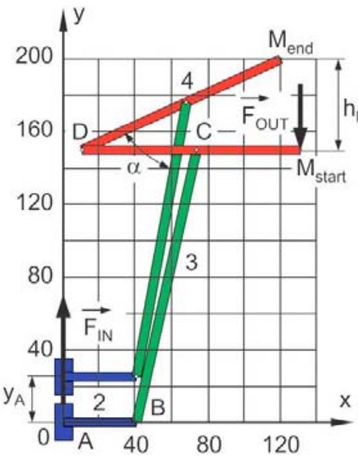
Mechanism must be movable and efficient in all positions during movement. Dynamic efficiency of the mechanism defines the pressure angle that represents the difference of the kinematical parameters:

$$\alpha=\varphi_3-\varphi_4 \tag{8}$$

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 $\alpha\geq 55°$:

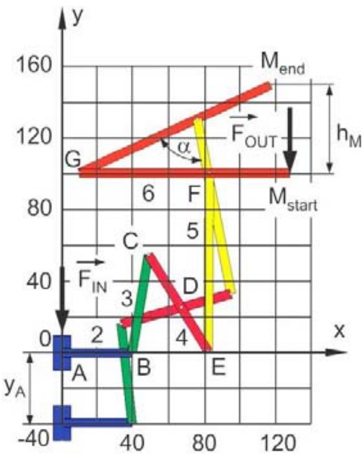
$$g_1(x)=55°-\alpha=55°-\left(\varphi_{3end}-\varphi_{4end}\right)\leq 0 \tag{9}$$

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: $x_D=10$ mm, $x_A=0$ and $x_D=10$ mm, and inequality (min i max) are: $20\text{ mm}\leq\overline{AB}\leq 40$ mm, $130\text{ mm}\leq\overline{BC}\leq 170$ mm, $50\text{ mm}\leq\overline{CD}\leq 90$ mm, $20\text{ mm}\leq y_{Aend}\leq 40$ mm and $130\text{ mm}\leq y_D\leq 150$ mm. In the identical way optimal synthesis of mechanism B is performed. Set constraints of equality are: $x_A=0$, $x_G=10$ mm and $\overline{GM}=120$ mm, and inequality (min i max) are: $20\text{ mm}\leq\overline{AB}\leq 40$ mm, $50\text{ mm}\leq\overline{BC}\leq 90$ mm, $24\text{ mm}\leq\overline{CD}\leq 54$ mm, $12\text{ mm}\leq\overline{DE}\leq 42$ mm, $90\text{ mm}\leq\overline{EF}\leq 110$ mm, $65\text{ mm}\leq\overline{FG}\leq 85$ mm, $60\text{ mm}\leq x_D\leq 120$ mm, $-40\text{ mm}\leq y_{Aend}\leq -20$ mm, $10\text{ mm}\leq y_D\leq 40$ mm and $90\text{ mm}\leq y_G\leq 120$ mm.



Links	Length [mm]
$\overline{AB}$	40
$\overline{BC}$	153.7
$\overline{CD}$	63.5
$y_{A\,end}$ (stroke)	25
y_D	150

Fig. 3. Optimization results of 4-bar mech. A



Links	Length [mm]
$\overline{AB}$	40
$\overline{BC}$	57.2
$\overline{CD}$	35.6
$\overline{DE}$	29.8
$\overline{EF}$	102.3
$\overline{FG}$	74
x_D	68.2
$y_{A\,end}$	40
y_D	26.1
y_G	103

Fig. 4. Optimization results of 6-bar mech. B

In Fig. 3 and Fig. 4 are shown results of the optimization of the proposed mechanisms. For a defined stroke length of shrug $h_M=50$ mm, stroke lenght of input link 2, for mechanism A is $y_A=25$ mm and for mechanism B is $y_A=40$ 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 je 103 N and for the mechanism B is 65 N. Operating direction of the driving force is oposite 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 °.

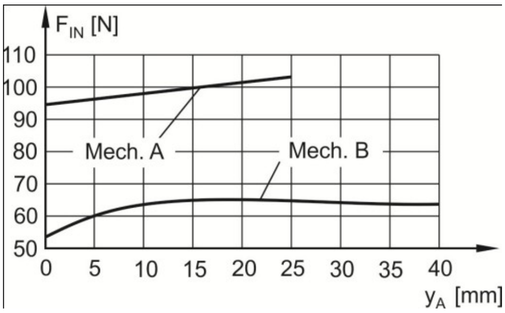


Fig. 5. Change of the mechanisms driving force depending on the stroke length of the input link

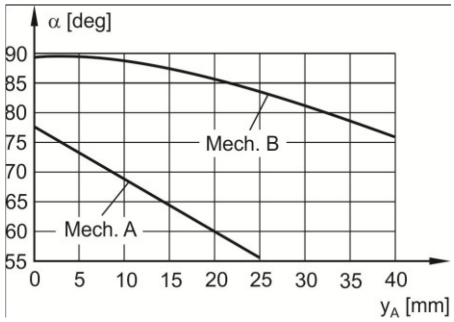


Fig. 6. Change of the mechanisms pressure angle depending on the stroke length of the input link

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 lenght of the input link is two times smaller than the stroke lenght 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 his 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 oposite 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

[1] Embgen S., Luber M., Becker-Asano C., Ragni M., Evers V., Arras K.O.: Robot-Specific Cues in Emotional Body Language, Proc. of the 21st IEEE ROMAN Inter. Symp. on Robot and Human Interactive Communication, Paris, France, 2012, pp. 1019–1025, doi: 10.1109/ROMAN.2012.6343883

[2] Knapp M.L., Hall J.A., Horgan T.G., Nonverbal Communication in Human Interaction, Belmont, California, Wadsworth Pub., 2013.

[3] A. Mehrabian, Silent Messages: Implicit Communication of Emotions and Attitudes, Belmont, California, Wadsworth Pub., 1981.

[4] Penčić M., Borovac B., Kovačević D., Čavić M.: Development of the Multi-Segment Lumbar Spine For Humanoid Robots, Thermal Science – International Scientific Journal, 2016, doi: 10.2298/TSCI151005040P

[5] Breazeal C.: Emotion and Sociable Humanoid Robots, International Journal of Human-Computer Studies, 2003, vol. 59, pp. 119–155, doi: 10.1016/S1071-5819(03)00018-1

[6] *Knox W.B., Stone P., Breazeal C.: Training a Robot via Human Feedback: A Case Study, Proc. of the ICRS* Inter. Conf. on Social Robotics, Bristol, UK, 2013, pp. 460–470, doi: 10.1007/978-3-319-02675-6_46

[7] Metta G., Natale L., Nori F., Sandini G., Vernon D., Fadiga L., von Hofsten C., Rosander K., Lopes M., Santos-Victor J., Bernardino A., Montesamo L.: The iCub humanoid robot: An open-systems platform for research in cognitive development, Neural Networks, 2010, vol. 23, no. 8–9, pp. 1125–1134, doi: 10.1016/j.neunet.2010.08.010

[8] Berns K., Hirth J.: Control of Facial Expressions of the Humanoid Robot Head ROMAN, Proc. of the IEEE/RSJ Inter. Conf. on Intelligent Robots and Systems, Beijing, China, 2006, pp. 3119–3124, doi: 10.1109/IROS.2006.282331

[9] Oh J.H., Hanson D., Kim W.S., Han I.Y., Kim J.Y, Park I.W.: Design of Android type Humanoid Robot Albert HUBO, Proc. of the IEEE/RSJ Inter. Conf. on Intelligent Robots and Systems, Beijing, China, 2006, pp. 1428–1433, doi: 10.1109/IROS.2006.281935

[10] Takanishi A., Ogura Y., Itoh K.: Some Issues in Humanoid Robot Design, Robotics Research: Results of the 12th Inter. Symp. ISRR, Springer Berlin, Heidelberg, 2007, pp. 357–372, doi: 10.1007/978-3-540-48113-3_32

[11] Zecca M., Endo N., Momoki S., Itoh K., Takanishi A.: Design of the Humanoid Robot KOBIAN – preliminary analysis of facial and whole body emotion expression capabilities–, *Proc. of the* 8th *IEEE-RAS* Inter. Conf. on Humanoid Robots, Daejeon, Korea, 2008, pp. 487–492, doi: 10.1109/ICHR.2008.4755969

[12] Zecca M., Macrì G., Mizoguchi Y., Monaco V., Endo N., Itoh K., Dario P., Takanishi A.: Evaluation of the KOBIAN and HABIAN Emotion Expression Humanoid Robots with European Elderly People, ROMANSY 18 – Robot Design, Dynamics and Control: Proc. of the 18th CISM-IFToMM Symp., Springer Vienna, Vienna, 2010, pp. 449–456, doi: 10.1007/978-3-7091-0277-0_53

[13] Penčić M., Čavić M., Savić S., Borovac B.: Comparative Analysis of the Shrug Mechanism for Humanoid Robots, *Proc. of the* 3rd Inter. Conf. on Electrical, Electronic and Computing Engineering IcETRAN, Zlatibor, Serbia, 2016.