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Optimal Synthesis of the Worm-Lever Mechanism for Humanoid Robots Shrug

Marko Penčić[1], Maja Čavić[1], Branislav Borovac[1]

Abstract: Emotions represent a significant means of nonverbal communication and their expression represents an important aspect of social robots functionality. There are two basic ways of expressing emotions. The first one is based on facial expressions that can be realized by moving a particular part of face or by displaying a picture on the screen that represents a face with characteristic features such as eyebrows, eyes, nose and mouth. Combining them is also possible. The second way of nonverbal communication is based on gestures, especially using arms. This paper presents an optimal synthesis of shrug mechanism for humanoid robots. Based on the set requirements the worm-lever mechanism is proposed. It has 1 DOF and enables simultaneous shrug of both shoulders. It consists of a worm which is meshed with two worm gears having different directions of rotation and two four-bar lever mechanisms whose input links are rigidly connected to the worm gears. Based on the kinematic-dynamic analysis the dynamic model is formed, the objective function is defined, the constraints are prescribed and the optimal synthesis is performed. The maximum torque on the input link of the lever mechanism, the driving torque of the complete worm-lever mechanism, the range of transmission angle and the rotation range of the worm gears are determined. The lever mechanism has high efficiency in all positions because the transmission angle has a high value during the whole movement. The worm mechanism enables a significant reduction of driving torque and has acceptable efficiency. The rotation range of the worm gear is small – the mechanism movement is very quick and therefore the shrug speed is large, which was the basic requirement for realization.

Keywords: Social humanoid robot, Shrug mechanism, Worm-lever mechanism, Optimal synthesis, Nonverbal communication, Body language.

1 Introduction

For a successful operation of a robot in the immediate human environment, the interaction between humans and robots is of utmost importance. Robots that will coexist in everyday human environment, must be able to adapt to humans and to the dynamic and unstructured environment in which they be situated. In addition to being absolutely safe for the humans and the objects in their

[1]Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia;
E-mails: mpencic@uns.ac.rs, scomaja@uns.ac.rs, borovac@uns.ac.rs

environment, these robots are expected to be able to realize nonverbal communication and express emotions in a transparent and intuitive way [1 – 3]. Nonverbal communication is a powerful means of communication which can transmit large number of information in a short period of time [4]. Up to 55% of all communication between humans is achieved by nonverbal communication, 38% by intonation – paraverbal communication and only 7% by the content of the message – verbal communication [5]. Paraverbal and nonverbal massages send clear signals regardless of the meaning of the spoken words. Today, researchers are working intensively on improving the interactive elements of robots [6].

This paper presents an optimal synthesis of robots shrug mechanism as a form of nonverbal communication. The research was conducted within the project developing the humanoid robot Sara that will represent anthropomorphic mobile platform for the research of social behavior of the robot. Sara will be able to communicate verbally and nonverbally. To express facial expressions, biologically inspired eyes and eyelids with 8 DOFs are being developed [7]. In order to extend the spectrum of nonverbal communication, the robot will be able to shrug when the question is confusing or when the robot does not know what to answer. In addition, Sara will have two anthropomorphic arms with 14 DOFs, self-locking neck with 3 DOFs [8] and self-locking multi-segment lumbar spine with 7 DOFs [9] to increase the mobility of the robot upper body.

The paper is structured as follows – the first section shows the research motivation; the second section represents the analysis of different ways for achieving nonverbal communication of social robots; the third section shows kinematic and dynamic analysis of the lever and worm mechanism; the fourth section presents optimal synthesis of the shrug mechanism within which the influence of the kinematic parameters on the dynamic efficiency and torque of the complete cam-worm mechanism are examined; fifth section summarizes the paper contribution and outlooks future work.

2 State of the Art

There are numerous papers describing robots that are able to express nonverbal communication in on intuitive and transparent way. Robotic heads for immediate, face to face interaction with humans are Kismet [10], iCat [11], Flobi [12], EDDIE [13], MERTZ [14], ROMAN [15] etc. They are able to express happiness, surprise, calm, sadness, anger etc. Facial expressions of these robots are created by moving the ears, eyebrows, eyeballs, eyelids or lips.

Robots that can realize nonverbal communication by facial expressions and gestures are Nexi [16], iCub [17], Robotinho [18], Probo [19], R1 [20], BERT2 [21], IURO [22], EMYS [23], Albert HUBO [24], KOBIAN [25], HABIAN [26] etc. The facial expressions of these robots are realized by moving a particular part of the face, by displaying it on the screen that represents a face with characteristic elements or by a combination of these two ways, while the gestures most commonly realized are movements of neck and arms of the robot.

Shrug is one of the most important aspects of the human nonverbal communication. A review of the available literature shows that there are two robots that are able to realize shrug. The first one is WE-4RII [27] having a shrug mechanism with 4 DOFs that enables independent movements of the shoulder in two directions, and the second one is BARTHOC [28], which has embedded elements above the shoulders and their activation simulates shoulder shrugging.

3 Kinematic and Dynamic Analysis

Since shrug is a relatively fast action, the basic requirement for its realization is that the speed of shrug movement has to be as large as possible. The shrug mechanism should have the lowest possible mass and dimensions in order not to overload the spine to which it is connected. The torque for driving the shrug mechanism should be as small as possible. In addition, a high efficiency of the mechanism is requested in all positions during the motion. Two lever mechanisms which in size and power correspond to these requirements were analyzed in the previous researches [29, 30].

Based on the set requirements the worm-lever mechanism is proposed – Fig. 1, which has 1 DOF and enables the simultaneous shrug of both shoulders.

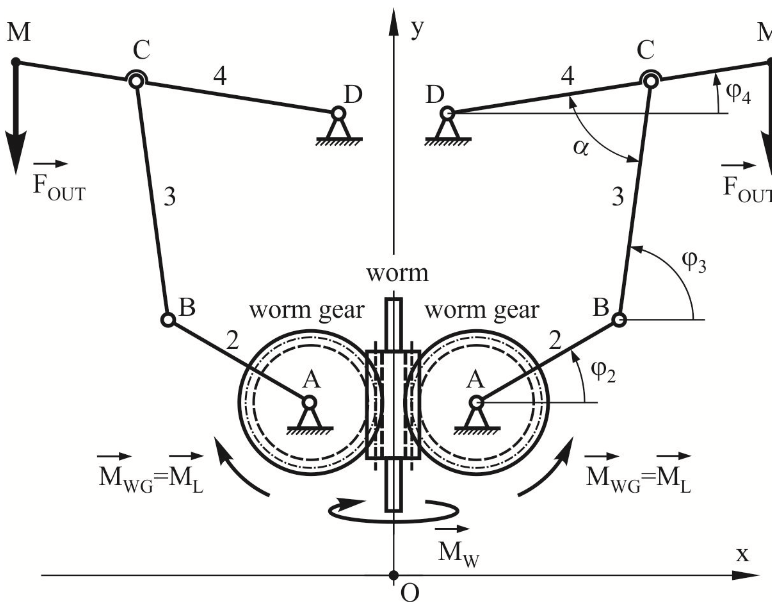

Fig. 1 – *Kinematic scheme of the worm-lever mechanism for humanoid robots shrug.*

It consists of a complex worm mechanism and two four-bar lever mechanisms. The worm mechanism consists of a worm which is meshed to two worm gears with different directions of rotation. Input links of the lever mechanisms are rigidly connected to the worm gears. Therefore, the torques on the worm gears and the torques on the input links of the lever mechanisms are equal, $M_{WG} = M_L$. The lever mechanisms enable high speed of the movement, while the worm mechanism enables significant reduction of the torque. Since shrug mechanism is symmetrical, only one-half of the mechanism is analyzed.

The stroke length of the shoulders end point – vertical stroke of the point M, the transmission angle α, the torque on the input link of the lever mechanism M_L and the torque on the worm M_{WG} – driving torque of the worm-lever mechanism are determined by analysis. The kinematic parameters of the position are angles φ_2, φ_3 and φ_4 – the position angles of links 2, 3 and 4. The input link is link 2 and the operating link is link 4. The position angle of the input link and the dimensions of the mechanism links are considered to be known.

Kinematic analysis was performed by the method of closed vector contours. Vector equation is formed and the position of the worm-lever mechanism is defined – only the right side of the mechanism is observed:

$$\overrightarrow{OA} + \overrightarrow{AB} + \overrightarrow{BC} = \overrightarrow{OD} + \overrightarrow{DC}. \tag{1}$$

By projecting (1) on the axes, the following equations are obtained:

$$x_A + \overline{AB}\cos\varphi_2 + \overline{BC}\cos\varphi_3 = x_D + \overline{DC}\cos\varphi_4, \tag{2}$$

$$y_A + \overline{AB}\sin\varphi_2 + \overline{BC}\sin\varphi_3 = y_D + \overline{DC}\sin\varphi_4. \tag{3}$$

where: x_A, y_A and x_D, y_D are the coordinates of immovable points A and D. Solving the system (2) and (3), the position angles of the links 3 and 4 are obtained:

$$\varphi_3 = \arctan a + \arccos b, \tag{4}$$

$$\varphi_4 = \arctan c, \tag{5}$$

where:

$$a = \frac{y_D - y_A}{x_D - \overline{AB}}, \tag{6}$$

$$b = \frac{\overline{BC}^2 + \left(\left(x_D - \overline{AB}\right)^2 + \left(y_D - y_A\right)^2\right)^2 - \overline{DC}^2}{2\overline{BC}\sqrt{\left(x_D - \overline{AB}\right)^2 + \left(y_D - y_A\right)^2}}, \tag{7}$$

$$c = \frac{y_A + \overline{BC}\sin\varphi_3 - y_D}{\overline{AB} + \overline{BC}\cos\varphi_3 - x_D}. \tag{8}$$

Vertical stroke of point M is the difference between *y*-coordinate of point M at the beginning and end of the movement. The position angle of the operating link at the beginning of the movement is $\varphi_4 = 0°$, so the stroke of point M during shrug is:

$$h_M = y_{M\,END} - y_{M\,START} = \overline{DM}\sin\varphi_4. \tag{9}$$

The transmission angle α represents the dynamic efficiency of the lever mechanism and is defined as the difference between kinematic parameters of links 3 and 4:

$$\alpha = \varphi_3 - \varphi_4. \tag{10}$$

As the transmission angle increases, a large proportion of the power is used for overcoming workload and a smaller proportion is used for internal loads, so the mechanism is more efficient. Within the dynamic analysis, kinetostatic equations are formed on the basis of the d'Alembert's principle:

$$\sum \vec{F}(i) = 0, \tag{11}$$

$$\sum \overrightarrow{M}(S_i, i) = 0. \tag{12}$$

where: S_i - is an arbitrary point of the *i*-th link. Equations (11) and (12) contain the workloads on the *i*-th link, the inertial and gravitational forces of the *i*-th link, the forces of friction – dry and viscous, as well as the reactions of *i*-th link with the adjacent links of the lever mechanism. As the mass of the mechanism links is relatively small, inertial, gravitational and forces of friction are significantly smaller in comparison to the workload so they will be neglected in the further analysis. By mechanism decomposition, kinetostatic equations are formed for each link and, at the end, a system of 9 linear equations with 9 unknowns is obtained. The components of the reactions in the joint links and the torque on the input link of the lever mechanism M_L are determined:

$$M_L = F_{OUT}\frac{\overline{AB}\cdot\overline{DM}}{\overline{DC}}k, \tag{13}$$

where:

$$k = \cos\varphi_4 \frac{\sin(\varphi_3 - \varphi_2)}{\sin(\varphi_3 - \varphi_4)}. \tag{14}$$

The worm mechanisms have a wide range of gear ratios and enable a significant reduction of the torque, which is one of the requirements. By increasing gear ratio, the number of teeth in mesh increases and this has a positive effect on backlash reduction. The gear ratio of the worm gearing is determined by:

$$i = \frac{z_{WG}}{z_W}, \tag{15}$$

where: z_{WG} – number of teeth of the worm gear and z_W – number of leads on the worm. The efficiency of worm gearing can be more than 90% when the lead angle is high enough or with the multi-lead worms, but then the gear ratio has to be smaller and therefore the reduction of torque is smaller. When the lead angle is 5° or less, the worm mechanism is self-locking and then the efficiency is small – approximately 30%. The efficiency of worm gears is determined according to:

$$\eta = \frac{\tan \gamma_m}{\tan\left(\gamma_m + \rho\right)}, \tag{16}$$

where: γ_m – lead angle and ρ – friction angle for coefficient of friction in worm gearing. Based on equations (13), (15) and (16), the torque on the worm M_W is defined – the driving torque of complete worm-lever mechanism:

$$M_W = 2\frac{M_L}{i\eta}. \tag{17}$$

Having in mind the requirement for high shrug speed and a small driving torque, it is necessary to determine the efficiency of the worm mechanism. If the center distance of worm gears is defined and if the range of gear ratio is known, the number of leads on the worm can be determined:

$$z_W \cong \frac{7 + 2.4\sqrt{a}}{i}, \tag{18}$$

where: a – center distance of a worm and worm gear in mesh. For the adopted center distance $a = 40$ mm and gear ratio $i = 5 \div 10$, from (18) the number of leads on the worm is obtained $z_W = 3$. The requirement for fast movement implies the use of high-speed worms in which the diametral quotient of a worm is in the range of 7÷10, so it is adopted that $q = 8$. When the worm gearing is without addendum modification, the equation for the center distance has the form:

$$a = \frac{m}{2}\left(q + z_{WG}\right), \tag{19}$$

where: m – module of worm gears. Inserting equation (15) in (19), the equation for operating gear ratio of worm gearing is obtained:

$$i = \frac{2a - mq}{mz_W}. \tag{20}$$

Considering the center distance $a = 40$ mm, the diametral quotient of worm $q = 8$ and the number of leads on the worm $z_W = 3$, the module of worm gearing is $m = 2$ mm. Inserting the parameters in (20), the operating gear ratio of worm mechanism is obtained as $i = 10.$ For determining the efficiency of the worm mechanism, it is necessary to determine the lead angle of worm which is defined by the equation:

$$\tan\gamma_m = \frac{z_W}{q}, \tag{21}$$

and replacing the parameters it is obtained that $\gamma_m = 20.5°.$ Considering that a shrug is a fast and not so frequent action – intermittent drive, for the dry lubricant it can be adopted that the angle of friction $\rho \cong 6°$ [31]. Inserting γ_m and ρ in (16), the efficiency of the worm mechanism is obtained as $\eta = 0.75.$

Based on the preliminary examination, it is concluded that the choice of parameters for worm mechanism is unambiguous and therefore the worm mechanism is not subject to this optimization.

4 Optimal Synthesis

Transmission angle α and the torque on the input link of lever mechanism M_L directly depend on the dimensions and position of the lever mechanism links. It is therefore necessary to examine the influence of kinematic parameters on dynamic efficiency and torque on the input link of the lever mechanism during the whole movement. Optimization problem presents minimization of the objective function for the set constraints:

$$MIN\, f(x),\ x \in D, \tag{22}$$

where: $x = (x_1, x_2, ..., x_m)$ - vector variables, $D = \{x \in R^n \,|\, g(x) \le 0 \wedge h(x) = 0\}$ - a set of solutions that fulfills the defined constraints, and $g(x) \le 0$ and $h(x) = 0$ - constraint vectors. Objective function is formed – minimization of torque on the input link of the lever mechanism:

$$f(x) = \sum_i \left(\frac{M_L^i}{M_{L\max}} \right)^2. \tag{23}$$

Constraints are defined – the values of the vertical movement of the operating link at the beginning h_1 and at the end of the movement h_2 for the stroke length $h_M = 50$ mm:

$$h_1(x) = \varphi_{4START} = 0, \tag{24}$$

$$h_2(x) = (y_{M\,END} - y_D) - h_M = \overline{DM} \sin\varphi_{4END} - 50 = 0. \tag{25}$$

Smaller transmission angles lead to jamming of the mechanism and therefore the constraint is defined – transmission angle for the final position h_M at $\alpha \geq 55°$:

$$g_1(x) = 55° - \alpha = 55° - \left(\varphi_{3END} - \varphi_{4END}\right) \leq 0. \tag{26}$$

Thoracic part of the robot is predicted to accommodate the shrug mechanism and therefore the constraints concerning the dimensions of the mechanism in the form of equality and inequality are set – **Table 1.**

Table 1

Set constraints of equality and inequality.

x_A [mm]	x_D [mm]	$\overline{DM}$ [mm]	$\overline{AB}$ [mm]	$\overline{BC}$ [mm]	$\overline{CD}$ [mm]	y_A [mm]	y_D [mm]	$\varphi_{2\,START}$ [°]	$\Delta\varphi_2$ [°]
40	40	120	30÷70	90÷130	60÷90	25÷75	120÷180	–15÷15	20÷40

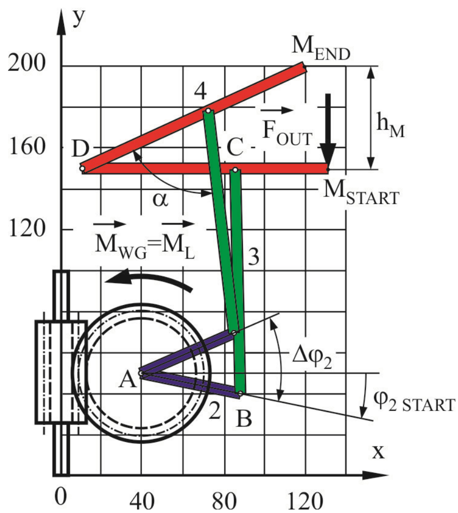

Fig. 2 – *Optimization results of the worm-lever mechanism.*

The optimized worm-lever mechanism is shown in Fig. 2, while **Table 2** gives the constructive and kinematic parameters. For the defined stroke length of shrug and the prescribed constraints, the input link of the lever mechanism and the worm gears are rotated by the same angle $\Delta\varphi_2 = \left|\varphi_{2\,START} - \varphi_{2\,END}\right| = 36°$. Because of the small range of rotation, only a few teeth of the worm gear are in use and therefore it is possible to reduce their dimension and mass. The overall dimensions of the shrug mechanism are 260×180 mm.

Table 2
Results of optimal synthesis.

$\overline{AB}$ [mm]	$\overline{BC}$ [mm]	$\overline{CD}$ [mm]	y_A [mm]	y_D [mm]	$\varphi_{2\,START}$ [°]	$\Delta\varphi_2$ [°]
51.2	111.6	75.2	49.3	151	–11	36

Fig. 3 shows the change of torque on the input link of the lever mechanism, while Fig. 4 shows the change of transmission angle during the whole movement. For the defined workload – the mass of the arm is 4.5 kg, the maximum torque on the input link $M_L = 4.1$ Nm. Having in mind equation (17), the gear ratio $i = 10$ and the efficiency of the worm mechanism $\eta = 0.75$, the driving torque of the complete worm-lever mechanism $M_W = 1.1$ Nm. Transmission angle at the beginning of the movement is 87°, during the movement it grows close to 90° and at the end it is 69°. Therefore the lever mechanism has high efficiency during the whole movement.

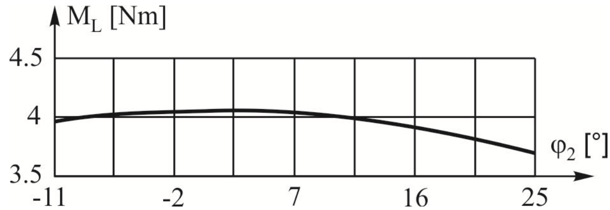

Fig. 3 – *Change of the torque on the input link during the whole movement.*

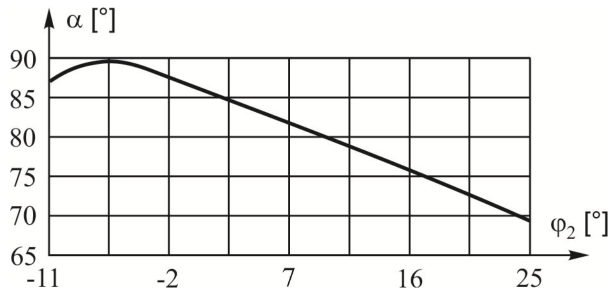

Fig. 4 – *Change of the transmission angle during the whole movement.*

5 Conclusion

The paper presents an optimal synthesis of the worm-lever mechanism for humanoid robots shrug. It has 1 DOF and enables simultaneous shrug of both shoulders. It consists of a worm which is meshed with two worm gears having different directions of rotation and two four-bar lever mechanisms whose input links are rigidly connected to the worm gears. Based on the set requirements – high speed of shrug, high efficiency in all positions and a small driving torque, the structure of the mechanism is adopted and the kinematic-dynamic analysis is performed. Within the kinematic-dynamic analysis, the transmission angle, the torque on the input link of the lever mechanism and the drive torque of the worm-lever mechanism are defined. The transmission angle and the torque on the input link directly depend on the dimensions and position of the lever mechanism links. Therefore, the influence of kinematic parameters on dynamic efficiency and torque on the input link of the lever mechanism during the whole movement is examined. Based on the kinematic-dynamic analysis, a dynamic model is formed and the objective function is defined – minimization of torque on the input link of the lever mechanism. Kinematic constraints are prescribed based on which the optimal synthesis is performed. The maximum torque on the input link of the lever mechanism, the driving torque of the worm-lever mechanism, the range of transmission angle and the rotation range of the worm gears are determined. The lever mechanism has a high efficiency in all positions because the transmission angle has a high value during the whole movement. The worm mechanism enables a significant reduction of driving torque and has acceptable efficiency. The rotation range of the worm gear is small – the mechanism movement is very quick and therefore the shrug speed is large, which was the basic requirement for realization. Further research will include worm-cam and cam-lever mechanisms as an addition to the assortment of shrug mechanisms of socially interactive robots.

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7 References

[1] C. Breazeal: Toward Sociable Robots, Robots and Autonomous Systems, Vol. 42, No. 3-4, March 2003, pp. 167 – 175.

[2] B. Siciliano, O. Khatib: Springer Handbook of Robotics, Springer, Berlin, Germany, 2016.

[3] S. Embgen, M. Luber, C. Becker-Asano, M. Ragni, V. Evers, K.O. Arras: Robot-specific Social Cues in Emotional Body Language, 21st IEEE International Symposium on Robot and Human Interactive Communication, Paris, France, 09-13 Sep. 2012, pp. 1019 – 1025.

[4] M.L. Knapp, J.A. Hall, T.G. Horgan: Nonverbal Communication in Human Interaction, Wadsworth Publishing - Cengage Learning, Boston, MA, USA, 2014.

[5] A. Mehrabian: Silent Messages: Implicit Communication of Emotions and Attitudes, Wadsworth Publishing, Belmont, CA, USA, 1981.

[6] G. Trovato, M. Zecca, T. Kishi, N. Endo, K. Hashimoto, A. Takanishi: Generation of Humanoid Robot's Facial Expressions for Context-Aware Communication, International Journal of Humanoid Robotics, Vol. 10, No. 1, March 2013, p. 1350013.

[7] M. Penčić, M. Čavić, M. Rackov, B. Borovac, Z. Lu: Drive System of the Robot Eyeballs and Eyelids with 8 DOFs, 12th IFToMM International Symposium on Science of Mechanisms and Machines, Iasi, Romania, 02-03 Nov. 2017 (to be published).

[8] M. Penčić, M. Čavić, B. Borovac: Analysis of Mechanisms for Achieving Different Ways of Power Transmission and Motion of the Anthropomorphic Robots Upper Body, 5th International Conference on Power Transmission, Ohrid, Macedonia, 05-08 Oct. 2016, pp. 115 – 122.

[9] M.M. Penčić, B.A. Borovac, D.I. Kovačević, M.V. Čavić: Development of the Multi-segment Lumbar Spine for Humanoid Robots, Thermal Science, Vol. 20, Suppl. 2, Aug. 2016, pp. S581 – S590.

[10] C. Breazeal: Emotion and Sociable Humanoid Robots, International Journal of Human-Computer Studies, Vol. 59, No. 1-2, July 2003, pp. 119 – 155.

[11] A.J.N. van Breemen: Animation Engine for Believable Interactive User-Interface Robots, IEEE/RSJ International Conference on Intelligent Robots and Systems, Sendai, Japan, 28 Sept. - 02 Oct. 2004, pp. 2873 – 2878.

[12] F. Hegel, F. Eyssel, B. Wrede: The Social Robot 'Flobi': Key Concepts of Industrial Design, 19th IEEE International Symposium on Robot and Human Interactive Communication, Viareggio, Italy, 13-15 Sept. 2010, pp. 107 – 112.

[13] S. Sosnowski, A. Bittermann, K. Kuhnlenz, M. Buss: Design and Evaluation of Emotion-Display EDDIE, IEEE/RSJ International Conference on Intelligent Robots and Systems, Beijing, China, 15 Jan. 2007, pp. 3113 – 3118.

[14] L. Aryananda, J. Weber: MERTZ: A Quest for a Robust and Scalable Active Vision Humanoid Head Robot, 4th IEEE-RAS International Conference on Humanoid Robots, Santa Monica, CA, USA, 10-12 Nov. 2004, Vol. 2, pp. 513 – 532.

[15] K. Berns, J. Hirth: Control of Facial Expressions of the Humanoid Robot Head ROMAN, IEEE/RSJ International Conference on Intelligent Robots and Systems, Beijing, China, 09-15 Oct. 2006, pp. 3119 – 3124.

[16] W.B. Knox, P. Stone, C. Breazeal: Training a Robot via Human Feedback: A Case Study, 5th International Conference on Social Robotics, Bristol, UK, 27-29 Oct. 2013, pp. 460 – 470.

[17] G. Metta, L. Natale, F. Nori, G. Sandini, D. Vernon, L. Fadiga, C. von Hofsten, K. Rosander, M. Lopes, J. Santos-Victor, A. Bernardino, L. Montesano: The iCub Humanoid Robot: An Open-systems Platform for Research in Cognitive Development, Neural Networks, Vol. 23, No. 8-9, Oct/Nov. 2010, pp. 1125 – 1134.

[18] F. Faber, M. Bennewitz, C. Eppner, A. Gorog, C. Gonsior, D. Joho, M. Schreiber, S. Behnke: The Humanoid Museum Tour Guide Robotinho, 18th IEEE International Symposium on Robot and Human Interactive Communication, Toyama, Japan, 27 Sept. - 02 Oct. 2009, pp. 891 – 896.

[19] J. Saldien, K. Goris, B. Vanderborght, J. Vanderfaeillie, D. Lefeber: Expressing Emotions with the Social Robot Probo, International Journal of Social Robotics, Vol. 2, No. 4, Dec. 2010, pp. 377 – 389

[20] H. Lehmann, A.V. Sureshbabu, A. Parmiggiani, G. Metta: Head and Face Design for a New Humanoid Service Robot, 8th International Conference on Social Robotics, Kansas City, MO, USA, 01-03 Nov. 2016, pp. 382 – 391.

[21] D. Bazo, R. Vaidyanathan, A. Lentz, C. Melhuish: Design and Testing of a Hybrid Expressive Face for a Humanoid Robot, IEEE/RSJ International Conference on Intelligent Robots and Systems, Taipei, Taiwan, 18-22 Oct. 2010, pp. 5317 – 5322.

[22] M.A. Hsieh, O. Khatib, V. Kumar: Experimental Robotics, Springer, NY, USA, 2016.

[23] J. Kędzierski, R. Muszyński, C. Zoll, A. Oleksy, M. Frontkiewicz: EMYS - Emotive Head of a Social Robot, International Journal of Social Robotics, Vol. 5, No. 2, March 2013, pp. 237 – 249.

[24] I.W. Park, J.Y Kim, B.K. Cho, J.H. Oh: Control Hardware Integration of a Biped Humanoid Robot with an Android Head, Robotics and Autonomous Systems, Vol. 56, No. 1, Jan. 2008, pp. 95 – 103.

[25] M. Zecca, Y. Mizoguchi, K. Endo, F. Iida, Y. Kawabata, N. Endo, K. Itoh, A. Takanishi: Whole body Emotion Expressions for KOBIAN Humanoid Robot - Preliminary Experiments with Different Emotional Patterns – 18th IEEE International Symposium on Robot and Human Interactive Communication, Toyama, Japan, 27 Sept. - 02 Oct. 2009, pp. 381 – 386.

[26] V.P. Castelli, W. Schiehlen: ROMANSY 18 - Robot Design, Dynamics and Control, Springer, NY, USA, 2010.

[27] T. Zielinska, C. Zielinski: ROMANSY 16 - Robot Design, Dynamics and Control, Springer, NY, USA, 2006.

[28] M. Hackel, S. Schwope, J. Fritsch, B. Wrede, G. Sagerer: A Humanoid Robot Platform Suitable for Studying Embodied Interaction, IEEE/RSJ International Conference on Intelligent Robots and Systems, Edmonton, Canada, 02-06 Aug. 2005, pp. 2443 – 2448.

[29] M. Penčić, M. Čavić, S. Savić, B. Borovac: Comparative Analysis of the Shrug Mechanisms for Humanoid Robots, 3th International Conference on Electrical, Electronic and Computing Engineering, Zlatibor, Serbia, 13-16 June 2016, pp. ROI1.3-1 – ROI1.3-5.

[30] M. Penčić, M. Čavić, B. Borovac: Comparative Synthesis of the Shrug Mechanisms for Humanoid Robots, 20th International Research/Expert Conference on Trends in the Development of Machinery and Associated Technology, Mediterranean Sea Cruising, 24 Sept. - 01 Oct. 2016, pp. 249 – 252.

[31] V. Miltenović: Machine Elements – Forms, Calculation and Appliance, Faculty of Mechanical Engineering, Niš, Serbia, 2009. (In Serbian).