Forward and Inverse Kinematics of a Humanoid Robot Head for Social Human Robot-Interaction

Sebastián Fuenzalida, Keyla Toapanta, Jonathan Paillacho, Dennys Paillacho

ESPOL Polytechnic University,
Escuela Superior Politécnica del
Litoral, ESPOL, Electrical and
Computer Engineering Department,
CIDIS, Campus Gustavo Galindo Km.
30.5 Vía Perimetral, P.O. Box 09-01-
5863, Guayaquil, Ecuadorline
(sebmafue, ktoapant, jspailla,
dpaillac)@espol.edu.ec

***Abstract*—This paper presents an analysis of forward and inverse kinematics for a humanoid robotic head. The robotic head is used for the study of social human-robot interaction, such as a support tool to maintain the attention of patients with Autism Spectrum Disorder. The design of a parallel robot that emulates human head movements through a closed structure is presented. The position and orientation in this space is controlled by three servomotors. For this, the solutions made for the kinematic problem are encompassed by a geometric analysis of a mobile base. This article describes a non-systematic method, called the geometric method, and compares some of the most popular existing methods considering reliability and computational cost. The geometric method avoids the use of changing reference systems, and instead uses geometric relationships to directly obtain the position based on joint variables; and the other way around. Therefore, it converges in a few iterations and has a low computational cost.**

Keywords— forward kinematics, inverse kinematics, parallel robot, humanoid robot head, servo motors, social robot, human-robot interaction

I. INTRODUCTION

Parallel robots represent great advantages over other robots. Its greater precision, greater load capacity, lower weight and the need for less powerful actuators in the structure [1]. This also translates into some disadvantages, a reduced work area and a more complex mathematical calculation for the kinematic problem [2][3]

This study has proposed a parallel robot that emulates movements of a human head using three servomotors. A mobile platform is placed on three support points symmetrically to a transverse axis to a frontal view. The joints have a spherical positioning arrangement for greater repeatability and freedom of movement. For this structure the solution of the direct kinematic problem has been carried out through the analysis of projections of moving and rigid parts to the three coordinate axes in a reference system located at the base of the robot head. For the solution to the inverse kinematic problem, a geometric analysis of the limits of the armor was carried out to find an expression of joint parameters based on the orientation angles of the robot. It is important to note that the variables of interest will be the angles corresponding to the orientation of the robot, leaving its position with respect to the coordinate axes as dependent on it.

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The aim of this work is to analyze the control functions for the movement, both the direct and inverse kinematics, of a humanoid robotic head.

A description of the robotic head were detailed in the next section. In section III, the kinematic model of the robotic head were described. The results of the proposed kinematic model applied to the robotic head are presented in section IV. Finally, in section V conclusions were provided.

II. ROBOTIC HEAD DESCRIPTION

Based on 3D printing technology, the robotic head (see Fig. 1) is a lightweight 21 x 17 x 19 cm (width, height and depth) structure that contains a sliding crank mechanism with a spatial kinematic chain. The front part is composed of a fisheye camera and a display. The screen is in the position where a human being would have his eyes. It is approximately 7 "in size and is a wide angle screen. For the movement, the head has three Dynamixel AX-12A intelligent servomotors that allow pitch, yaw and roll movements (as shown in Fig.2)

The movements of the head together with the facial expressions of the display allow the generation of non-verbal language,which contributes to the social human-robot interaction [4] [5]

Figure 1 Overall robotic head

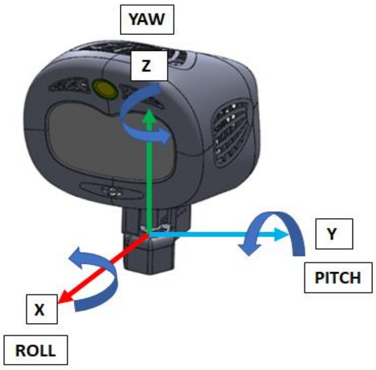

Figure 2 Pitch, Yaw and Roll movements

III. Kinematics of the Robotic Head

A. Forward kinematics

The analysis of the problem of forward kinematics to present expressions of the position variables (linear displacements with respect to three coordinate axes) and orientation (navigation angles) according to the articular variables, the displacements are analyzed according to each coordinate axis of all rigid or mobile sections according to angles of physical inclination of their unions. Thus, the sum of all displacements is the final position with respect to the proposed reference system for the entire system. This is located at the base of the robotic head on the servo motor that controls the rotation of the head to the right or left from a frontal view.

In the solution for the forward kinematic problem, expressions were developed for the three position variables with respect to the three coordinate axes x, y and z and the three navigation angles (roll, pitch and yaw). The articular variables of each servomotor correspond to: servo motor that moves two free support pieces in two vertices to the mobile base; θ_2, used for a rotation of the entire robotic head to the right or left; y θ_3, that thanks to a structure composed of two mobile segments is equivalent to a linear displacement up or down. For projections, changes of variables are used with respect to spatial phase shifts in the armor. In this case, θ_r, it corresponds to an offset counter for rigid components and, and mobile components and. m_{11} and m_{12}.

$$q_1 = \theta_r - \theta_1 \quad (1)$$
$$q_2 = \theta_r + \theta_1 \quad (2)$$
$$m_{11} = m_1 - \theta_1 \quad (3)$$
$$m_{12} = m_2 - \theta_1 \quad (4)$$

The projections for each coordinate axis were obtained with respect to inclination angles of the proposed joints, represented by m and n and numbered for each link. In turn, the sum of these displacements is written according to the reference system at the base of the robotic head.

$$0 = D * cos\,cos\,q_1 - h * m_{11} * cos\,cos\,n_1 - H * cos\,cos\,m_3 \quad (5)$$

$$0 = -D * cos\,cos\,q_2 - h * m_{12} * cos\,cos\,n_2 + H * cos\,cos\,m_3 \quad (6)$$

$$y = D * q_1 + h * cos\,cos\,m_{11} * cos\,cos\,n_1 + H * m_3\ cos\,cos\,n_3 \quad (7)$$
$$y = D * q_2 + h * cos\,cos\,m_{12} * cos\,cos\,n_2 - H * m_3\,n_3 \quad (8)$$
$$p = \frac{d}{2} - h * n_1 + H * n_3 * m_3 \quad (9)$$

$$p = \frac{d}{2} + h * n_2 - H * n_3 * m_3 \quad (10)$$
$$p = d * cos\,cos\,n_3 - \frac{d}{2} \quad (11)$$

For the linear conversion of the movement of the second servomotor, a sum of an offset is made with respect to the origin of the reference system and the trigonometric relationship with two moving links.

$$l = l_o + pc_2 * cos\,cos\,(\theta_3) + \sqrt{{pc_1}^2 - (pc_2 * (\theta_3))^2} \quad (12)$$

The three position variables (x, y and z) and the three orientation variables (q_r, q_p, and q_y) are described with respect to the general reference system based on the inclination angles of the mobile base and the three servomotors for a simpler calculation.

$$x = p * \theta_2 \quad (13)$$
$$y = l - d * n_3 \quad (14)$$
$$z = p * cos\,cos\,\theta_2 \quad (15)$$
$$q_{yaw} = \theta_2 \quad (16)$$
$$q_{pitch} = n_3 \quad (17)$$
$$q_{roll} = m_3 \quad (18)$$

For the resolution of this system of equations between different methods it can be done by substitution, remembering that the values of the trigonometric ratios will always be positive. Thus, having roots in trigonometric identities being the range of angles from 0 to 90 ° the value will necessarily be positive.

$$n_1 = \frac{H * n_3 * m_3 + d * (1 - cos\,cos\,n_3)}{h} \quad (19)$$
$$n_2 = \frac{H * n_3 * m_3 + d * (cos\,cos\,n_3 - 1)}{h} \quad (20)$$
$$cos\,cos\,n_2 = \sqrt{1 - n_2)^2} \quad (21)$$
$$cos\,cos\,n_1 = \sqrt{1 - (n_1)^2} \quad (22)$$
$$cos\,cos\,m_{11} = \frac{l - d * n_3 - D * q_1 - H * m_3\,n_3}{h * cos\,cos\,n_1} \quad (23)$$
$$cos\,cos\,m_{12} = \frac{l - d * n_3 - D * q_2 + H * m_3\,n_3}{h * cos\,cos\,n_2} \quad (24)$$
$$m_{11} = \sqrt{1 - m_{11})^2} \quad (25)$$
$$m_{12} = \sqrt{1 - m_{12})^2} \quad (26)$$

B. Inverse kinematics

In order to find expressions of the controllable joint variables, the positions of the three servomotors, depending on the position and orientation variables, the moving parts will be analyzed. The length of the two completely non-rigid sections will remain constant. This idea is key to knowing that, if you find an expression for the distance between the two location points at each end of the piece, you must remain constant for any movement. Thus, using the reference established for the entire system, the displacements are considered to find an initial point and an end point. The Euclidean distance in this three-dimensional space will be calculated based on the navigation angles, joint variables and dimensions of the parallel robot components.

The case of solving the problem of inverse kinematics will be covered in finding an expression that relates the variables θ_1, θ_2 and θ_3 with respect to the position and orientation variables. As it has been verified the position variables have been formulated dependent on the orientations. It was chosen among the three available variables to control the orientations, navigation angles (q_r, q_p, and q_y).

Since the variable corresponding to yaw is directly equal to the angle from the control of the second servomotor, it remains to find the expressions for two variables in two equations to obtain a solution to the kinematic problem.

The equation of the Euclidean distance (27) of the mobile sections at points of two points each has been used (28) and (29). The coordinates of these points are described based on the armor variables and navigation angles (30).

$$\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} = h \quad (27)$$

$$(-H * cos\ cos\ m_3 - (-D * cos\ cos\ q_1))^2 + (l - d * n_3 + H * m_3\ n_3 - D * q_1)^2 + (d * cos\ cos\ n_3 - \frac{d}{2} + H * n_3 * m_3 - \frac{d}{2})^2 = h^2 \quad (28)$$

$$H * cos\ cos\ m_3 - D * cos\ cos\ q_2)^2 + (l - d * n_3 - H * m_3\ n_3 - D * q_2)^2 + (d * cos\ cos\ n_3 - \frac{d}{2} - H * n_3 * m_3 - \frac{d}{2})^2 = h^2 \quad (29)$$

$$d * D * n_3 * (q_1 - q_2) + H * D * cos\ cos\ m_3 * (- cos\ cos\ q_1 + cos\ cos\ q_2) + H * m_3\ n_3 * (2 * l - D * q_1 - D * q_2) - 2 * d * H * m_3\ n_3 \quad (30)$$

IV. Results

Once the solutions of the equations were found for inverse and inverse kinematics, it was obtained the six values of position and orientation using a numerical analysis technique, the method of bisection with interactions. Then proceeded to solve by means of a program where the equations raised in this study, to know the position of the servo motors at any point.

θ_1	θ_2	θ_3	q_r	q_p	q_y	x	Y	z
0°	0°	45°	0°	0°	0°	0 cm	76 cm	29 cm
4.98°	5°	26.24°	5°	5°	5°	2.51 cm	77.85 cm	28.67 cm

Table 1 Robot Orientation Data

It can be seen that the robotic head can adopt the desired orientation with its position variables dependent on the specified navigation angles (see Fig. 3).

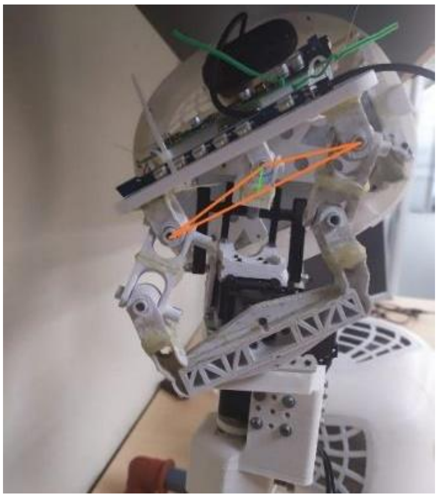

Figure 3 Robot Head

V. Conclusions

New processes were developed for the generation of solutions to the forward and inverse kinematic problem. These geometric analyzes applicable to any structure allow to find expressions between variables of interest independent of the order of resolution of the problems. In addition, by having intervals defined by the geometry itself, it simplifies the mathematical calculation with a direct obtaining of the spatial equations and reduction of positions as false positives.

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References

[1] M. J. Uddin, S. Nahavandi y H. Minh Trinh, *Kinematic and Dynamic Modelling of a robotic head with linear motors,* 2011

[2] J S. Kucuk y B. Zafer, *Industrial Robotics: Theory, Modelling and Control,* 2006.

[3] L. Kelmar y P. K. Khosla, *Automatic generation of forward and inverse kinematics for a reconfigurable modular manipulator system,* 1990.

[4] Paillacho, D.; Angulo, C.; Diaz, "*An exploratory study of group-robot social interactions in a cultural center*," IEEE/RSJ Int. Conf. Intell. Robot. Syst. (IROS 2015), pp. 44–48, 2015.

[5] M. Díaz-Boladeras, D. Paillacho, C. Angulo, O. Torres, J. González-Diéguez, and J. Albo-Canals, "*Evaluating Group-Robot Interaction in Crowded Public Spaces: A Week-Long Exploratory Study in the Wild with a Humanoid Robot Guiding Visitors Through a Science Museum*" Int. J. Humanoid Robot., vol. 12, no. 04, p. 1550022, 2015.

[6] F.J. López, S. Vergara, M.A. Vargas, A. Palomino, D. Pinto, D. Vilariño, *Diseño y modelo dinámico de robot esférico de 3–DOF para cuello robótico de robot humanoide*, 2017

[7] MacDorman, K.F., and Ishiguro, H. (2006). *The Uncanny advantage of using androids in social and cognitive science research,* 2006