Kinematic analysis of spherical robots

D. EL HAIEK, L. EL BAKKALI, J. EL BAHAOUI

Modeling and Simulation of Mechanical Systems Laboratory

Abdelmalek Essâadi University, Faculty of Sciences

Tétouan, Morocco

dikra_elhaiek@hotmail.com

Abstract— **In this paper, we compare the movement of two serial robots which are used as probe-holder for the application of tele-echography. The first one is a serial spherical wrist with four degree-of-freedom and the structure of the second one is based on a similar mechanical structure, which is inclined with an angle from the normal direction to the patient's skin. The goal is to compare their trajectories on the plane tangential to the skin and the inclination of the end effector axis.**

Keywords— spherical wrist; tele-echography; trajectorie; inclination of the probe.

I. INTRODUCTION

For all kind of abdominal examinations, the ultrasound is widely used. This technique is fast, easy and cheap to perform and the patient can be given a diagnostic immediately. The tele-echography allows a medical expert to perform this clinical act on a distant patient. The doctor, located in expert site, operates a fictive probe. Its motion parameters are sent to a slave robot by satellite or terrestrial links. The robot holds the real ultrasound probe on the patient's body and reproduces the fictive probe movement. Ultrasound images are sent back from the patient site to the medical expert so he can perform his diagnosis in real time like he would perform a classic ultrasound examination [1].

In this work, after the description of the modified kinematic structure 'Estele2', which is a modification of Estele robot, we present its direct geometrical model that is based on Denavit Hartenberg modified parameters. Thus, the simulation of the trajectory and the inclination of the probe axis are compared between the two robots in order to show the effect of the added angle.

II. ROBOT KINEMATIC STRUCTURE

A. Tele echography robot :

Several studies show that the probe movement is a spherical one. The tele echography robot must have a spherical wrist [2]. However, this robot Estele suffer from some limitations. For example, the location of a singularity in the center of its workspace.

It is worthwhile to mention that this central singularity of the spherical wrist is a position often used by the medical expert during an exam. It is the reference position to search an organ and to have a good quality of ultrasound image. To solve this problem, a new kinematic structure has been proposed. This kinematic structure is based on the 4 degree of freedom Estele robot structure, as shown in Fig. 1, where the spherical wrist is inclined with an angle α_0 from the normal direction z_0 to the skin, z_1, z_2 and z_3 are concurrent axes, it renamed Estele2 with $\alpha_0 = 45°$ and $\alpha_1 = \alpha_2 = 40°$ [3] .
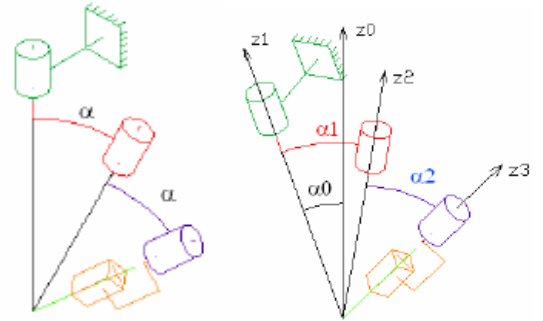

Fig. 1.Estele kinematic structure and Spherical wrist inclined of an angle α0[1].

B. Direct Geometrical Model :

The position and orientation of the end-effector in terms of given joint angles is calculated using DH parameters obtained from the link coordinate frame assignation [3], where $\theta_1, \theta_2, \theta_3$ and r_4 represent the articular variables .

The transformation matrix to R4 from R0 frames is :

$$^0T_4 = \begin{bmatrix} s_x & n_x & a_x & p_x \\ s_y & n_y & a_y & p_y \\ s_z & n_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$s_x = (c\theta_1 c\theta_2 - s\theta_1 c\alpha_1 s\theta_2)c\theta_3 - (c\theta_1 s\theta_2 + s\theta_1 c\alpha_1 c\theta_2)c\alpha_2 s\theta_3$
$+ s\alpha_1 s\theta_1 s\alpha_2 s\theta_3$

$s_y = (c\alpha_0 s\theta_1 c\theta_2 + c\alpha_0 c\theta_1 c\alpha_1 s\theta_2 - s\alpha_0 s\alpha_1 s\theta_2)c\theta_3 + (-c\alpha_0 s\theta_1 s\theta_2 + c\alpha_0 c\theta_1 c\alpha_1 c\theta_2)c\alpha_2 s\theta_3 - (c\alpha_0 c\theta_1 s\alpha_1 + s\alpha_0 c\alpha_1)s\alpha_2 s\theta_3$

$$s_z = (s\alpha_0 s\theta_1 c\theta_2 + s\alpha_0 c\theta_1 c\alpha_1 s\theta_2 + c\alpha_0 s\alpha_1 s\theta_2)c\theta_3 + (-s\alpha_0 s\theta_1 s\theta_2 + s\alpha_0 c\theta_1 c\alpha_1 c\theta_2 + c\alpha_0 s\alpha_1 c\theta_2)c\alpha_2 s\theta_3 + (-s\alpha_0 c\theta_1 s\alpha_1 + c\alpha_0 c\alpha_1)s\alpha_2 s\theta_3$$

$$n_x = -(c\theta_1 c\theta_2 - s\theta_1 c\alpha_1 s\theta_2)s\theta_3 - (c\theta_1 s\theta_2 + s\theta_1 c\alpha_1 c\theta_2)c\alpha_2 c\theta_3 + s\alpha_1 s\theta_1 s\alpha_2 c\theta_3$$

$$n_y = -(c\alpha_0 s\theta_1 c\theta_2 + c\alpha_0 c\theta_1 c\alpha_1 s\theta_2 - s\alpha_0 s\alpha_1 s\theta_2)s\theta_3 + (-c\alpha_0 s\theta_1 s\theta_2 + c\alpha_0 c\theta_1 c\alpha_1 c\theta_2 - s\alpha_0 s\alpha_1 c\theta_2)c\alpha_2 c\theta_3 - (c\alpha_0 c\theta_1 s\alpha_1 + s\alpha_0 c\alpha_1)s\alpha_2 c\theta_3$$

$$n_z = -(s\alpha_0 s\theta_1 c\theta_2 + s\alpha_0 c\theta_1 c\alpha_1 s\theta_2 + c\alpha_0 s\alpha_1 s\theta_2)s\theta_3 + (-s\alpha_0 s\theta_1 s\theta_2 + s\alpha_0 c\theta_1 c\alpha_1 c\theta_2 + c\alpha_0 s\alpha_1 c\theta_2)c\alpha_2 c\theta_3 + (-s\alpha_0 c\theta_1 s\alpha_1 + c\alpha_0 c\alpha_1)s\alpha_2 c\theta_3$$

$$a_x = (c\theta_1 s\theta_2 + s\theta_1 c\alpha_1 c\theta_2)s\alpha_2 + s\alpha_1 s\theta_1 c\alpha_2$$

$$a_y = -(-c\alpha_0 s\theta_1 s\theta_2 + c\alpha_0 c\theta_1 c\alpha_1 c\theta_2 - s\alpha_0 s\alpha_1 c\theta_2)s\alpha_2 - (c\alpha_0 c\theta_1 s\alpha_1 + s\alpha_0 c\alpha_1)c\alpha_2$$

$$a_z = -(-s\alpha_0 s\theta_1 s\theta_2 + s\alpha_0 c\theta_1 c\alpha_1 c\theta_2 + c\alpha_0 s\alpha_1 c\theta_2)s\alpha_2 + (-s\alpha_0 c\theta_1 s\alpha_1 + c\alpha_0 c\alpha_1)c\alpha_2$$

$$p_x = (c\theta_1 s\theta_2 + s\theta_1 c\alpha_1 c\theta_2)r_4 s\alpha_2 + s\alpha_1 s\theta_1 r_4 c\alpha_2$$

$$p_y = -(c\alpha_0 s\theta_1 s\theta_2 + c\alpha_0 c\theta_1 c\alpha_1 c\theta_2 - s\alpha_0 s\alpha_1 c\theta_2)r_4 s\alpha_2 - (c\alpha_0 c\theta_1 s\alpha_1 + s\alpha_0 c\alpha_1)r_4 c\alpha_2$$

$$p_z = -(s\alpha_0 s\theta_1 s\theta_2 + s\alpha_0 c\theta_1 c\alpha_1 c\theta_2 + c\alpha_0 s\alpha_1 c\theta_2)r_4 s\alpha_2 - (s\alpha_0 c\theta_1 s\alpha_1 + c\alpha_0 c\alpha_1)r_4 c\alpha_2$$

III. ROBOT PATH SIMULATION

In this study, we have realized the probe path simulation by using a direct geometrical model of the tele-echography robot Estele and Estele2.
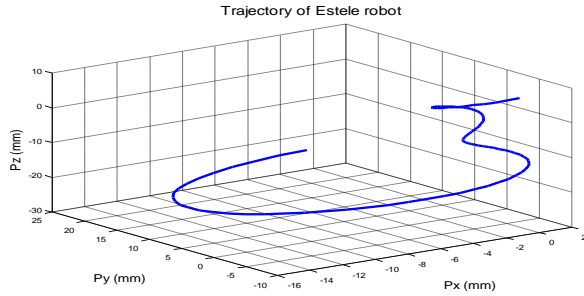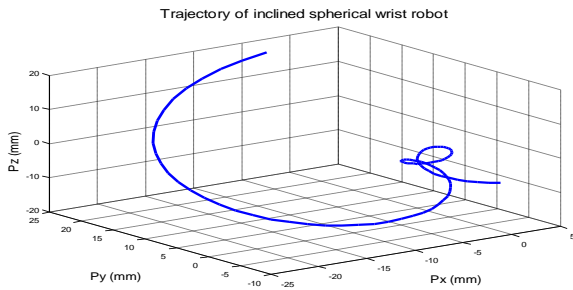

Fig. 2.Trajectory of Estele robot.

Fig. 3.Trajectory of inclined spherical wrist robot .

Figures 2 and 3 show the path followed by the point of contact probe / skin obtained in 3 dimensions during an ultrasound examination in order to evaluate the maximum limits that the robots can reach for a given joint angles.

We note that the two robots follow the same form of the path (spherical movement) except that there is a difference at the beginning of the simulation.

IV. TANGENT TRANSLATION TO THE SKIN

In this part, we focus on the magnitude of the various components of displacement from these trajectories. At each instant of acquisition, we get the position of the probe relative to a fixed reference.
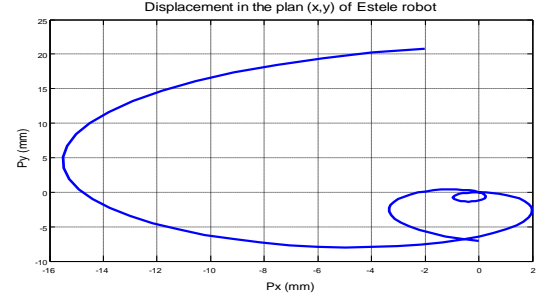

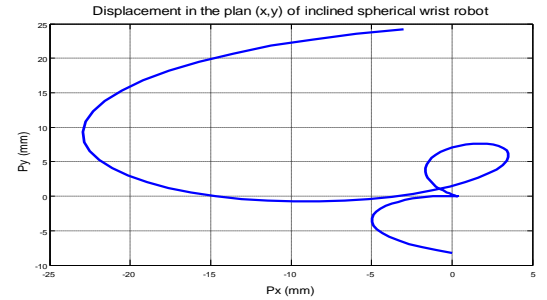Fig. 4.Displacement of the probe tangent to the skin of Estele robot

Fig. 5. Displacement of the probe tangent to the skin of inclined spherical wrist robot

Figures 4 and 5 show the projection on the plane (x. y) of the preceding trajectories shown in Fig.3 and Fig.4. The initial position of the probe of robot Estele2 is given by (0, -8.192) and the robot Estele is (0, -7.071).

The maximum translation for a path is calculated as the distance between the initial position and the farthest point of this position by applying the following relationship:

$$d_{xymax} = \max_{Tr}(p_x^2 + p_y^2)^{1/2} \qquad (2)$$

In this study, the largest displacement tangential to the skin in Fig.4 is of the order of 27.8901 mm, whereas for inclined spherical wrist robot is about 32.342 mm.

It is noted that the tangential displacement of the inclined robot is greater than Estele robot, this will allow us to conclude that the added angle increase the amplitude of the probe movement.

V. INCLINATION OF THE PROBE

In the spherical movement, we are interested in the maximum inclination of the probe with respect to its original configuration, which is considered normal to the skin.

The inclination of the probe is represented by the trajectory of the end point of the unit vector of the axis z_s of the probe projected in the plane (x.y), where (O_s, x_s, y_s, z_s) is the frame attached to the probe.

The inclination of the probe is shown in the following
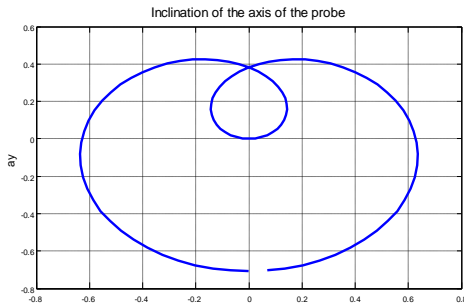
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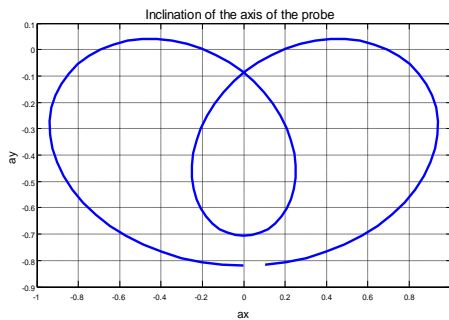

Fig. 6.inclination of Estele robot

Fig. 7.inclination of inclined spherical wrist robot

The point (0.0) corresponds to an inclination of zero degrees of the probe, it corresponds to a position normal to the skin.

The farthest point from the point (0.0) corresponds to a position with a maximum inclination. So, the maximum inclination of Estele is 45°. But for the other robot, we see that the probe doesn't pass throught the position (0.0) for a given joint angles, but we can conclude that the inclination doesn't exceed 53°, which these values respect the data specification of tele-echography application .

CONCLUSION :

In this present paper the comparison of the path and the inclination followed by the probe between two spherical robots of tele-echography application was presented. The inclined robot present an increase in displacement due to the added angle. we can say that the Estele2 robot is larger than Estele robot.

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