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Design and Simulation of Graphical User interface for Cables Parallel Robot

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Abstract: In this paper, we have presented the 3D cables parallel robot in pyramid's form. The dynamic equation has been established including the dynamic behavior, in this context; we investigated to use the Runge Kutta method of 4th order to solving non-linear partial differential equation of our system. The main contribution of this work is firstly: a graphical user interface (GUI) has been developed and implemented based on the geometric model, in order to visualizing the position of end effect or, taking account model uncertainties and payload variation. Secondly, we have studied and solved our system's dynamical equation with implementation the PD control. This last, applied for different trajectories so as to test the accurate tracking the desired trajectory simulation using MATLAB software. As a result, the simulation tests on this robot verify the efficiency performance of the proposed controller.

Keywords: Cable parallel robot, Control Simulation, modelling, GUI.

1. INTRODUCTION

Automation and robotic becoming more important due to demanding on cost effective operations and productivity improvement in nowadays [1-3] due to the energy and fuel resources are in pressing for supply and sustainability issue [4-7]. Cable-based parallel robots are a special parallel manipulators robot in which the end-effectors are driven by cables instead of rigid links [2, 8, 9], the movement being provided by the winding and unwinding of cables [10, 11]. The coordinate controller of cable lengths and tensions permit the displacement and the application of efforts on the platform. In addition, it is easy to mount; dismount and transport, in other hand, the main disadvantages of parallel manipulators lie in the nature of the cables that can only work in one direction than the traction [12-14]. The best-known application is the Skycam, a camera controlled by a cables mechanism that has used for tele-diffusion of professional football games. Another area of interest in biomedical applications is tracking the movement of body parts. An example is the CaTraSys (Cassino Tracking System) has used for the identification of kinematic parameters and the mobility of man [15, 16].

One of the key aspects for cable parallel robots is the need of a proper control strategy without breaking the cables. The PD method designed to improve the robustness of robotic system control, as reported for example in [17-19,20]. In particular, an adaptive PD controller can adjust the control torque based on real-time position tracking error in the set-point control of the end-effector.

The aim of this work is to study the performance of proposed technique, in order to control the end effector's position as named point-to-point command on one hand and for following continuous desired trajectories in other hand. Simulation tests with MATLAB Software validate the both application.

This paper organized into three sections. Section 1, the structure of our system, section 2, the dynamic model this robot with five cables is presented. Section 3 presents the controller design and architecture. Finally, we have concluded with a conclusion general.

2. SYSTEM STRUCTURE

Fig. 1 shows the virtual prototype robot with five cables in the form of pyramid. The base is fixed and each point of corner consist a pulley turned by a motor and the same for pyramid's peak, these pulleys attached with cables and each cable has one end attached to the platform and the other end coiled on the pulley for control the position and the orientation of end effector.

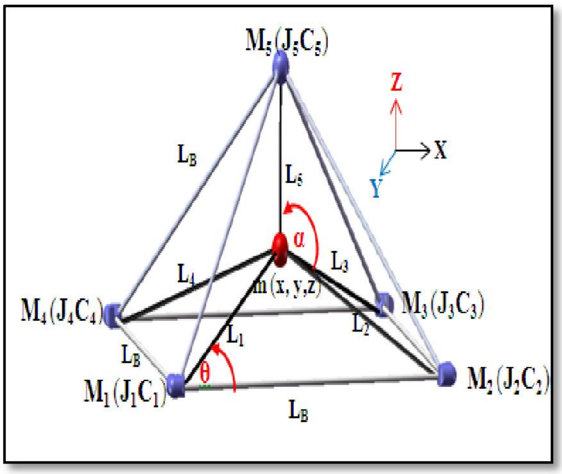

Fig. 1 A virtual prototype of 3D parallel robot

With:

LB: The lengths of the side of the workspace (LB = 0.65 m).

Li (i=1,..5): the lengths of the cables (Li =0.325 m).

3. GEOMETRIC MODELING

In this section, we have presented the inverse geometric model for five cable-based robots.

A. Inverse Geometric Model (IGM)

This model aims to determine the lengths of the cables "Li", the angles "Θi" between the X,Y axes and the cables connected to the mobile platform and "αi" between the Z axe the plane X, Y. The inverse geometric model can be expressed by the following equations [21].

$$Li = \sqrt{(x - Aix)^2 + (y - Aiy)^2 + (z - Aiz)^2}$$
; i=1...n.(1)

$$\Theta i = \arctan g(\frac{y - Aiy}{x - Aix}) \quad ; i=1…n. \quad (2)$$

$$\alpha i = \arctan g(\frac{z - Aiz}{\sqrt{(x - Aix)^2 + (y - Aiy)^2}}) \quad ;i=1…n. \quad (3)$$

4. THE DYNAMIC RESPONSE OF OUR SYSTEM

In this section, we begin by presenting the dynamic equation of this robot and its state-space representation. Then, the response ofequation (14)has simulated in closed loop with PD controller [22] .

B. Dynamic Model of the End Effector

The dynamic model of the actuator is expressed by the following relationship [23]:

$$m\ddot{X} = F_R \quad (4)$$

Where:

m :is the mass matrix and $\ddot{X}$:is the acceleration vector of the end-effector.

$F_R = (F_{Rx} \quad F_{Ry} \quad F_{Rz})^T$: is the resultant force of allthe tensions applied to the cables.

$$\begin{pmatrix} m & 0 & 0 \\ 0 & m & 0 \\ 0 & 0 & m \end{pmatrix} \begin{pmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{pmatrix} = \begin{pmatrix} F_{Rx} \\ F_{Ry} \\ F_{Rz} \end{pmatrix} \quad (5)$$

Where:

is the Dynamic Comportment of the Motors.

The dynamic comportment of the motor is expressed by the following equation:

$$J\ddot{\beta} + C\dot{\beta} = \tau - rT. \quad (6)$$

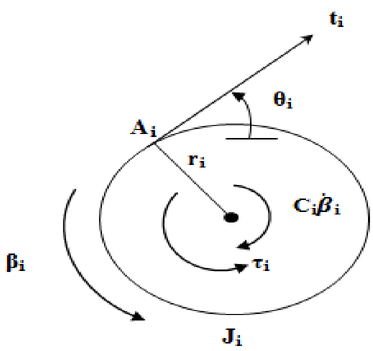

Fig. 2 Structure pulley.

with:

$$Jmat = \begin{pmatrix} J_1 & 0 & 0 & 0 \\ 0 & J_2 & 0 & 0 \\ 0 & 0 & J_3 & 0 \\ 0 & 0 & 0 & J_4 \end{pmatrix}$$

and

$$Cmat = \begin{pmatrix} C_1 & 0 & 0 & 0 \\ 0 & C_2 & 0 & 0 \\ 0 & 0 & C_3 & 0 \\ 0 & 0 & 0 & C_4 \end{pmatrix} \quad (7)$$

We consider that all the ray of the pulleys are the same:
ri = r(i=1.2...5),

$\tau\ (\tau_1.\tau_2,...\tau_i)^T$:is the vector of the torques applied by the motors.
t(t1,t2,…ti)T :is the vector of tension cables.

β :is the angle of rotation of the pulley.
Θi: The angles between cables and the pulley.
So:

$$t = \frac{1}{r}(\tau - J\ddot{\beta} - C\dot{\beta}) \quad (8)$$

Where Li0 are the initial lengths of the cables:

$$L_{i0} = \sqrt{(Aix)^2 + (Aiy)^2 + (Aiz)^2}$$

So

$$\beta = \begin{pmatrix} \beta_1(X) \\ \beta_2(X) \\ \vdots \\ \beta i(X) \end{pmatrix} = \frac{1}{r}\begin{pmatrix} L_{10} - L_1 \\ L_{20} - L_2 \\ \vdots \\ L_{i0} - L_i \end{pmatrix} \quad (9)$$

i=1,.. ,5
by subtracting successively (10) with respect to time, we get:

$$\ddot{\beta} = \frac{d}{dt}\left(\frac{\partial\beta}{\partial x}\right)\dot{x} + \frac{\partial\beta}{\partial x}\ddot{x} \quad (11)$$

Substituting (11) we obtain:

$$t = \frac{1}{r}\left(\tau - J\left(\frac{d}{dt}\left(\frac{\delta\beta}{\delta X}\right)\dot{X} + \frac{\delta\beta}{\delta X}\ddot{X}\right) - C\frac{\delta\beta}{\delta X}\dot{X}\right) \quad (12)$$

Finally, the set of dynamic equation model can be expressed in a standard form for robotic systems (13):

$$\ddot{X}(t) = M^{-1}(X) * N(X,\dot{X}) + M^{-1}(X) * S(X) * \tau \quad (13)$$

Where:

$$M = r * m + S(X) J \frac{\delta\beta}{\delta X} \quad (14)$$

And

$$N(X,\dot{X}) = S(X)(J\frac{d}{dt}\frac{\delta\beta}{\delta X} + C\frac{\delta\beta}{\delta X}\dot{X}) \quad (15)$$

$$\tau = \begin{bmatrix} \tau_1 \\ \tau_2 \\ \cdot \\ \cdot \\ \tau_5 \end{bmatrix} \quad (16)$$

5. CONTROL LAW AND ARCHITECTURE

This section, presents our control architecture, which has been ensured by means of implementation the Proportional, and Derivative (PD) controller, this last, based on the overall system Cartesian dynamics equations of motion (Equation 16). To achieve simulation results performance, we have been used Matlab programme. The establishment of the control law along X,Y and along Z is:

$$\begin{cases} U_X = K_P e_X(t) + K_D \dot{e}_X(t) \\ U_Y = K_P e_Y(t) + K_D \dot{e}_Y(t) \\ U_z = K_P e_z(t) + K_D \dot{e}_z(t) \end{cases} \quad (17)$$

The control architecture as shown in Fig. 3 is made up of three different parts: the PD controller, then the tension calculation and finally, the pulley angle β to determine the cable lengths Li.

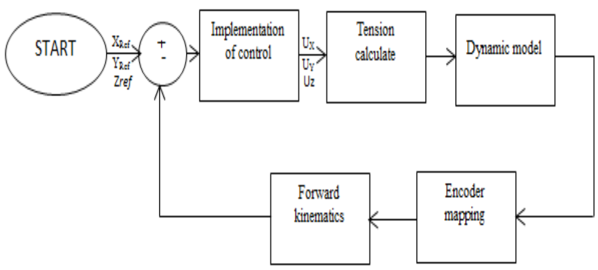

Fig. 3 Control Architecture.

6. SIMULATION RESULTS

In this part, we present the simulation response for 3D cables-parallel robot with 5 cables, for dynamic equation, which has a non-linear equation system, for this purpose, we use a Runge Kutta method as a numeric solution. This last, developed as the following formulae [25]:

y(x1) ≈y0+ (k1 + 2k2 + 2k3 + k4)/6,
k1 = hfo, , fo ≈ f(x0, y0),
k2 = hf (x0 + h/2, yo + k1/2),
k3= hf(x0 + h/2, y0 + k2/2),
k4 = hf(x0 + h, y0 + k3).

After, we implement the Cartesian PD controller in this dynamic equation in order to reduce the tracking error (ex = Xdesired – Xactual). The parameters for the dynamic equation(13) are: point mass m = 0.01 kg; rotational shaft/pulley inertias Ji (i = 1,…,5) =

0.0008 kgm2; shaft rotational viscous damping coefficients Ci (i = 1,.., 5) = 0.01 Nms and ri = r = 1cm (for all i = 1,…, 5) and the values of coefficient for different trajectories are Kp=2500 , Kd=150. So we have put the reference of our system in the centre of the workspace (0,0,0). Fig 4, 5, 6 and 7 show the develop of graphical user interface (GUI) for point to point command as a result this interface can enter the coordinates of any point into the workspace, when clicked on the **ON**, the end effector displaced directly to this target point with a high speed and precision. Furthermore, this graphical interface after thesimulation tests canplot thetrajectories of end effector figure 7.

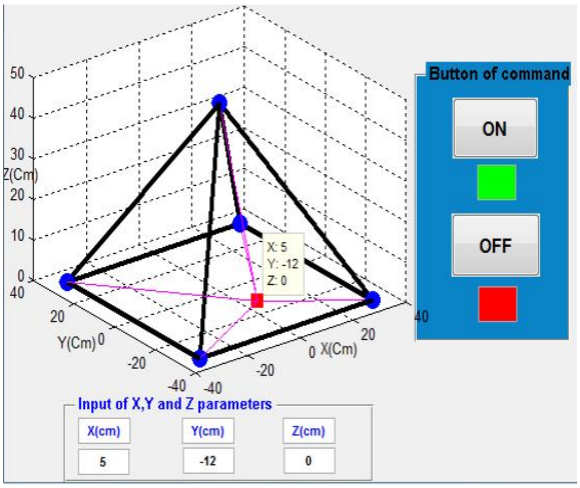

Fig. 4 Plot the displacement the end effector to position one

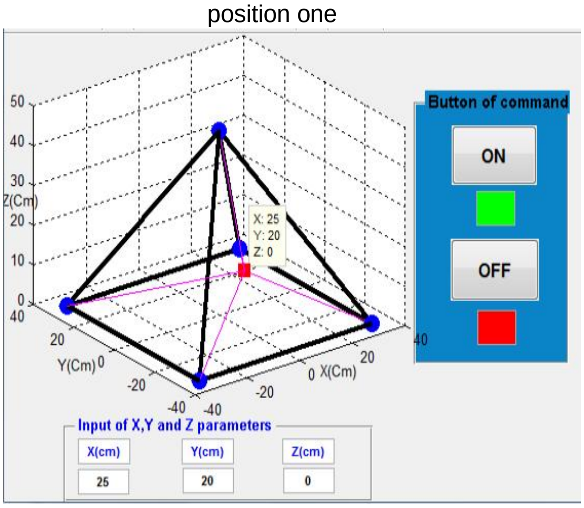

Fig. 5 Plot the displacement the end effector to position two.

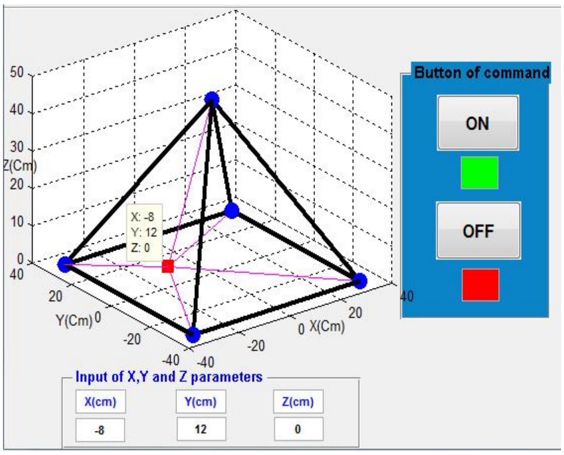

Fig. 6 Plot the displacement the end effector to position tree.

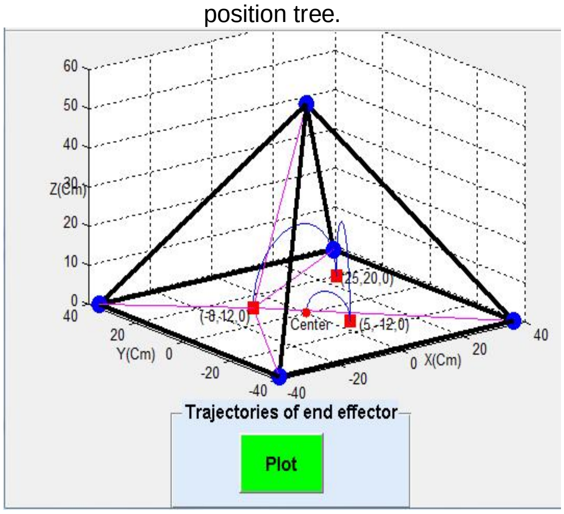

Fig. 7 the trajectory of end effector for drawn the different tests

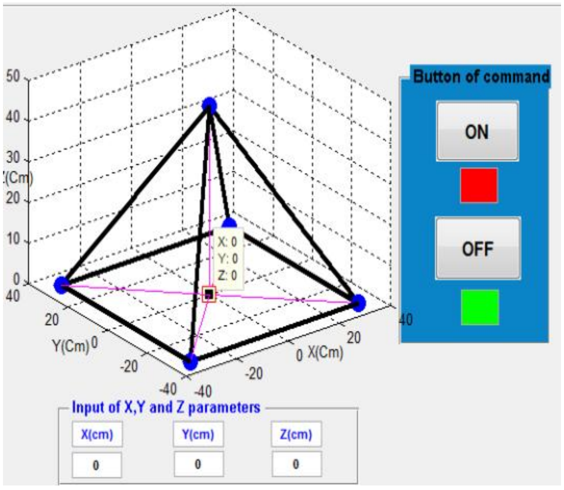

Fig. 8 Meter the end effector on initial position.

For illustrate the role of the five motors , we use another interface for shows how to control the end effector in vertical position figure 9.

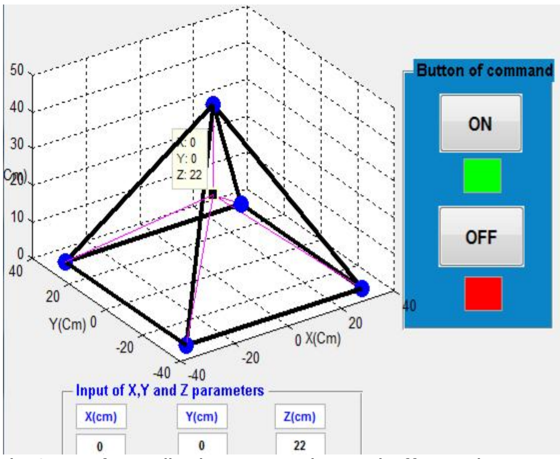

Fig.9 test for a displacement the end effector in vertical position.

For more illustrate the role the proposed control, we simulate the continuance trajectories, figure 10 and 12 show that, how the real path follow the desired path for the circular and spiral trajectories. The circular trajectory in 2D (Fig. 10) shows that the desired and actual path are almost agreed with each other and in figure 11 shows the cables lengths necessary to drawn thisdesured trajectory for this, we note that, the cable number five is constant (2 m) i.e in tracking position. Figure 12 shows the spiral trajectory in 3D plan, which clarified also the performance of this control. Figure 13 shows the variation cables length necessary to drawn the spiral trajectory.

So that, as a results for the both similartests found in Fig. 10 and 12 previous avery good results.

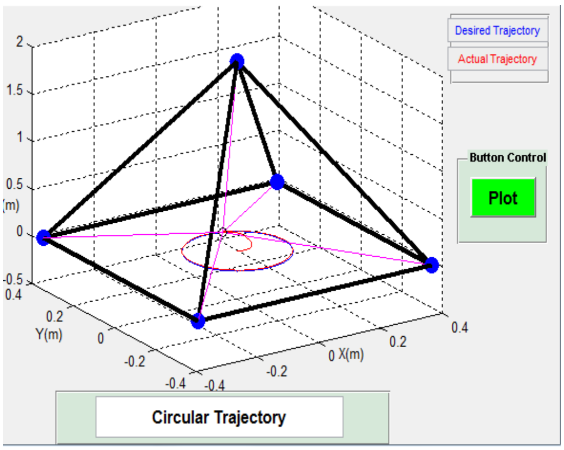

Fig. 10 Plot the desired path and actual path for a circular trajectory.

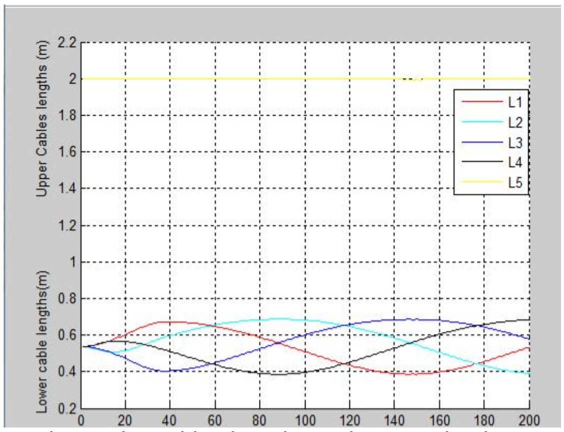

Fig. 11 the cables lengths to drawn a circular trajectory in the 2D plane.

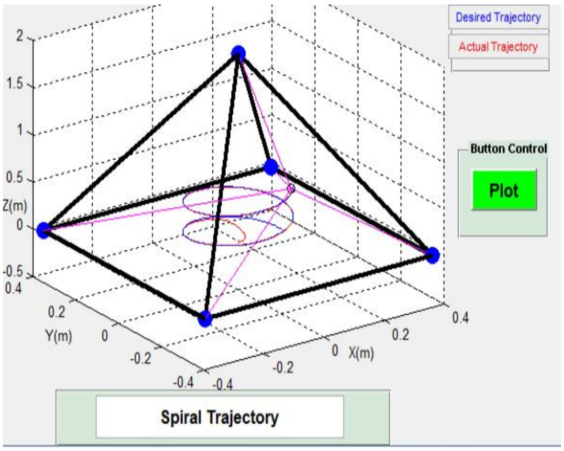

Fig. 12 Plot the desired path and actual path for a spiral trajectory.

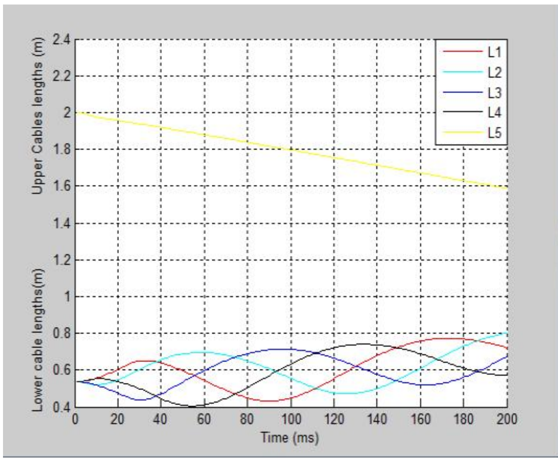

Fig. 13 the cables lengths to drawn a spiral trajectory in the 3D plane.

As seen in the different tests ofpoint-to-point command and the tests of continuous trajectories, we found that, the PD controller validate the efficacy of the precision for 3D cablesparallel robot.

7. CONCLUSION

This paper presented a simulation study for different tests of a novel 3D cables parallel robot subject with five cables, with the implementation of PD as a control. In this way, we have developed a user interface graphic to control the displacement of end effector based on: point to point command and according to the predefined point, considering that the cables tensions values which limited with tmin and tmax (always positive) and the cables lengths do not exceed the workspace. Furthermore, we have simulated some results for continuous trajectories. The obtained results have demonstrated the effectiveness and feasibility the performance of the proposed technique.

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