Towards Cable Parallel Robot Simulation for Control End Effector Position

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Abstract— **In this paper, we present a Graphical User Interface (GUI) simulator that has been developed using robust generalize predictive control. The proposed control technique is used for dealing with linear system uncertainties. The main contribution of this work is firstly: a graphical user interface has been developed and implemented based on geometric model , in order to, control the position of the end effector with several spatial tests. Secondly, we study the response of differential equations for our system with the proposed control for different trajectories in order to test the accurate tracking of the robot for desired trajectory simulation using MATLAB/Simulink. The Simulation results are carried out to prove the feasibility and effectiveness of the strategy outlined here.**

Keywords- Cable driven robot, Robustness, generalized predictive control, GUI.

I. INTRODUCTION

Cable parallel robots are parallel robots where the end-effector is linked to the base platform by replacing of cable lengths and tensions permit the displacement and the application of efforts on the platform [1, 2]. These robots have few moving parts, with reduced mass, and are most suitable for tasks requiring high performance such as speed and accuracy and provide a large workspace [3].The best-known application is the Skycam, a camera controlled by a cables mechanism that is used for tele-diffusion of professional football games [4]. Another area of interest in biomedical applications such as tracking the movement of body parzts. An example is the Cassino Tracking System (CaTraSys) was used for the identification of kinematic parameters and the mobility of man [5, 6].

These offer incontestable advantages in comparison to the robots of classic architecture, this last it is a type of parallel manipulator used as a transmission way of cables connects a fixe base with a mobile platform. The coordinate controller One of the key aspects for cable driven robots is the need of a proper control strategy to achieve proper motions without

breaking the cables. The Model Predictive method has been designed to improve the robustness of robotic system control, as reported for example in [7, 8]. In particular, a Predictive 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 control the position of end effector for different tests. Furthermore, present a simulation result of this 3D robot permitting to digitalize the appearance of it with generalize predictive control.

II. SYSTEM STRUCTURE

Figure 1 shows our virtual prototype robot with four cables. The base is fixed and each cable is attached to the one end of the platform. As a result of motors moments, cables wrap around the pulley to control the position and the orientation of the end-effector. The four cables-based robot allow a 3D plan movement with 4 degrees of freedom.
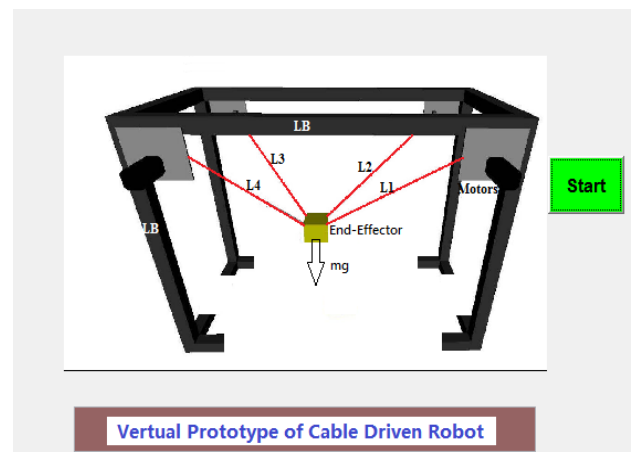

Figure 1. A virtual prototype of 3D parallel driven robot

III.   GEOMETRIC MODELING

In this section, we present the direct and inverse geometric model for our 3D cable-driven robots.

A. *Inverse Geometric Model (IGM)*

The aims of this section, is 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 [9].

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

$$\Theta i = \arctan g(\frac{y-Aiy}{x-Aix}) \tag{2}$$

$$\alpha i = \arctan g(\frac{z-Aiz}{\sqrt{(x-Aix)^2 + (y-Aiy)^2}}) \tag{3}$$

IV.   DYNAMIC MODEL OF THE END EFFECTOR

In this section, we begin by presenting the dynamic equation of the robot with four cables. Then, the response will be simulated in closed loop with the generalize predictive controller. The dynamic model of the actuator is expressed by the following relationship [10]:

$$m\ddot{X} = F_R \tag{4}$$

Where: m :is the mass matrix.

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

$F_R = \begin{pmatrix} F_{Rx} & F_{Ry} & F_{Rz} \end{pmatrix}^T$: is the resultant force of the all tensions applied to the cables.

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

B. *The Dynamic Comportment of the Motors*

The dynamic comportment of the motor is represented in Figure 2 and its expression is expressed by the following equation.

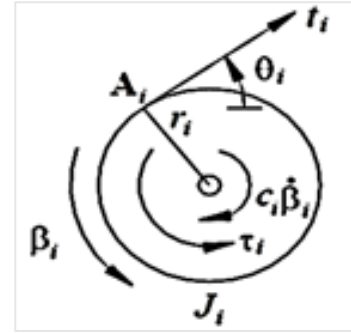$$J\ddot{\beta} + C\dot{\beta} = \tau - rT. \tag{6}$$

Figure 2.   Structure pulley

with:

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

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

We consider that all the rays of the pulley are the same: $r_i (i=1,...,4) = r = 1 \quad cm$

$\tau \ (\tau_1.\tau_2,...\tau_i)^T$ 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:

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

Where Li0 are the initial lengths of the cables:

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

So

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

by subtracting successively (9) with respect to time, we get:

$$\ddot{\beta} = \frac{d}{dt}\left(\frac{\partial \beta}{\partial x}\right)\dot{x} + \frac{\partial \beta}{\partial x}\ddot{x} \tag{10}$$

Finally, the set of equations of the dynamic model can be expressed in a standard form for robotic systems (11):

$$\ddot{X}(t) = M^{-1}(X) * N(X, \dot{X}) + M^{-1}(X) * mg(x) + M^{-1}(X) * S(X) * \tau \tag{11}$$

M(x): Mass matrix of the system, g(x): Vector of gravity terms and m: is the mass of end effector.

V. PROPOSED CONTROL

This section, presents our control demonstration, which has been ensured by means of the implementation. This proposed controller based on the overall system Cartesian dynamics equations of motion (Equation 11) using a Matlab program simulation to achieve reasonable performance for the trajectories.

Consider the following MIMO nonlinear system:

$$\begin{cases} \dot{x} = F(x) + \sum_{i=1}^{m} g_i(x)u_i = F(x) + G(x)U \\ y = h(x) = [h_1(x), \quad h_2(x), \quad \cdots, \quad h_m(x)]^T \end{cases} \tag{14}$$

where x Є Rn, U Є Rm and y Є Rm are, respectively, the state vector, the control vector and the output vector. F(x) and h(x) are smooth vector fields[11, 12].

Generalize predictive controller is designed such that the future output y (t+T) follows the future reference signal yr (t+T) minimizing the quadratic performance index given below:

$$J = \int_0^T e(t + \tau)^T e(t + \tau)d\tau \tag{15}$$

Where: e (t+T) is the future tracking error vector, and $T > 0$ is the prediction horizon.

The outputs of the system and the reference signals predictions are approximated by their Taylor-series expansions up to corresponding relative degree ρ_i:

$$e_i(t + T) \approx \sum_{k=0}^{\rho_i} \frac{T^k}{k!}\left(y_{r_i}^{(k)}(t) - y_i^{(k)}(t)\right) \tag{16}$$

$$e_i(t+T) \approx \begin{bmatrix} 1 & T & \dfrac{T}{2!} & \cdots & \dfrac{T^{\rho_i}}{\rho_i!} \end{bmatrix} \begin{bmatrix} y_{r_i}(t) - & y_i(t) \\ \dot{y}_{r_i}(t) - & \dot{y}_i(t) \\ \ddot{y}_{r_i}(t) & \ddot{y}_i(t) \\ \vdots & \vdots \\ \ddot{y}_{r_i}^{(\rho_i)}(t) & y_i^{(\rho_i)}(t) \end{bmatrix}$$

$$e_i(t + T) = \Gamma_i(T)Y_i(t) \tag{17}$$

The outputs yi time derivatives required in the approximated performance index are expressed as given below using Lie derivatives:

$$\begin{cases} \dot{y} = L_F h_1(x) \\ \ddot{y} = L_F^2 h_1(x) \\ \vdots \\ y_1^{(\rho_1)} = L_F^{(\rho_1)} h_1(x) + L_{g_1} L_F^{(\rho_1-1)} h_1(x)u_1 + \cdots + L_{g_m} L_F^{(\rho_1-1)} h_1(x)u_m \\ \dot{y}_2 = L_F h_2(x) \\ \vdots \\ \vdots \\ y_1^{(\rho_m)} = L_F^{(\rho_m)} h_m(x) + L_{g_1} L_F^{(\rho_m-1)} h_m(x)u_1 + \cdots + L_{g_m} L_F^{(\rho_m-1)} h_m(x)u_m \end{cases} \tag{18}$$

Introducing (18) in the approximated performance index (16) yields:

$$J \approx (A(x) - B(x,U))^T \Pi(T)(A(x) - B(x,U)) \tag{19}$$

Finally, the control law minimizing the approximated performance index is obtained by solving the system:

$$\frac{dJ}{dU} = \left(\frac{d(A(x) - B(x,U))}{dU}\right)^T \Pi(T)\left(A(x) - B(x,U)\right) = \mathbf{0}_{(\rho+m)\times 1} \tag{20}$$

Consequently, the control law is given by [12]:

$$U = D^{-1}(x)Diag((\Pi_i^{ss})^{-1}\Pi_i^s)A(x)$$
$$= D^{-1}(x)Diag((k_i)A(x) \tag{21}$$

The control architecture as shown in Figure 3 is made up of three different parts: the generalize predictive controller, the tension calculation and pulley angle β to determine the cable lengths Li.
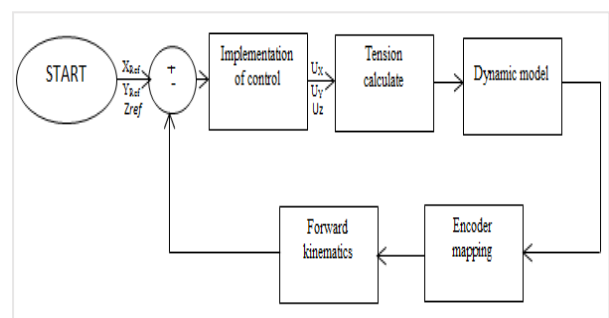
Control Architecture

VI.   RESULTS THE SIMULATION

which has a non-linear equation system, for this purpose, we use a Runge Kutta method as a numeric solution and then we implement a Cartesian generalize predictive controller in this dynamic equation for reduce the tracking error $ex = (X_{desired} - X_{actual})$. parameters for the dynamics equations of motion (11) for four cables are: point mass m = 0.01 kg; rotational shaft/pulley inertias $J_i = (i = 1,...,4) = 0.0008$ Kgm^2 . shaft rotational viscous damping $C_i = (i = 1,...,4) = 0.01$ Nms and $r_i (i = 1,...,4) = r = 1$ $cm.$ So we put the reference of our system in the center of the workspace (0,0,0). Figure 4, 5, 6, 7 shows a graphical user interface of implementation the point-to-point command. i.e the user of this interface can enter the coordinates of any point into the workspace, when clicked on the plot, the end effector displaced directly to this point with a high precision, and also, this interface can initialization the case of this robot (Figure 7), these technique based on inverse geometric model.
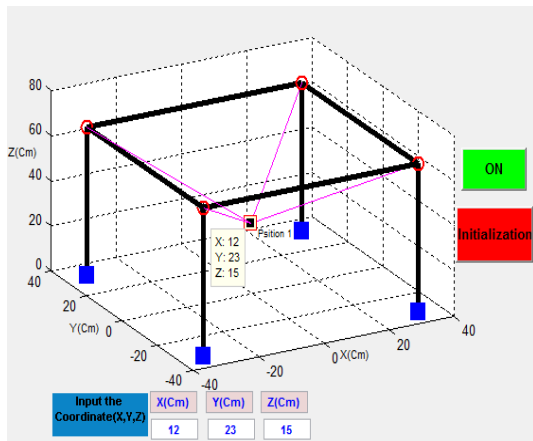

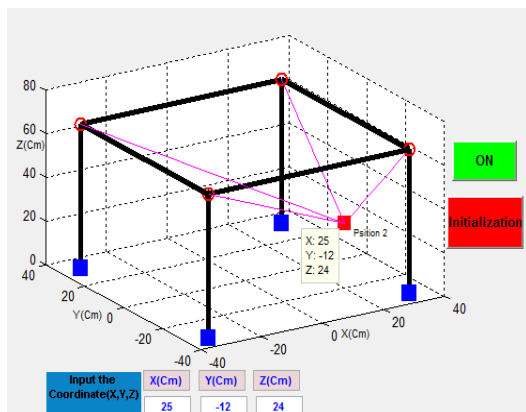Figure 3.   Plot the displacement of end effector (position 1)

Figure 4.   Plot the displacement of end effector (position 2)

For illustrate the role of our robust control, we use another high level graphical user interface command according to the object's colors, when, we have clicked on the color object , the end effector move and displace to this target object in workspace, this simulation technique based on the learning method.
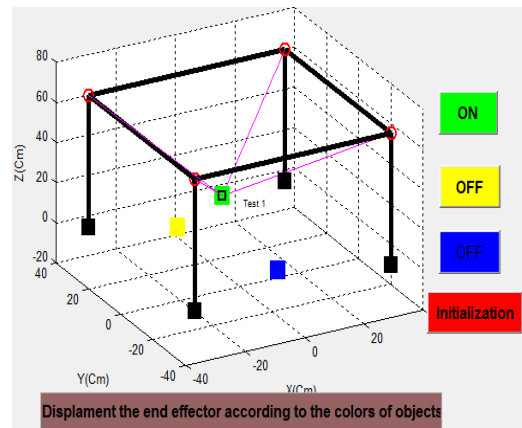

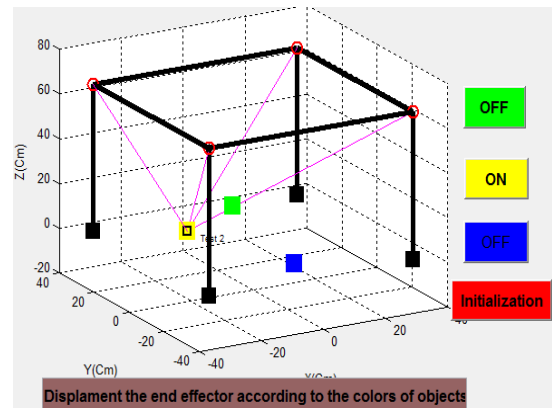Figure 5.   Displacement the end effector according to the green color

Figure 6.   Displacement the end effector according to the yellow color

For more illustrate the role of our control, we simulate the continuance trajectories, Figure 8 shows that the desired and actual path for square trajectory. The actual path is in good agreement with the desired path. This shows the simulation and the control is very good results.
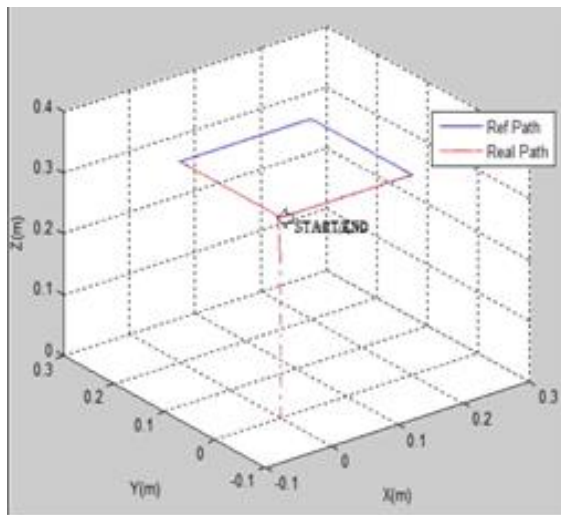
Figure 7.   Plot the desired path and actual for square trajectory

VII.   CONCLUSION

This paper presented a simulation results for different tests of a novel 3D cable base robot with four cables, this last, we have designed as a control the generalize predictive mode. Then, we developed an user interface graphic with a simulation program to control the displacement of end effector based on: point to point command , according to the color of the objects and according to the a predefined point, we assume that , the tensions values are limited with tmin and tmax which always positive and the cables lengths do not exceed the workspace. In addition, we have presented some results for continuance trajectories. The simulation results have demonstrated the effectiveness and feasibility of the proposed control and suitable for improving the performance response.

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