Hybrid Position-force Control for a Stewart Platform

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***Abstract*—This paper presents the development of a hybrid position-force controller for a Stewart platform to perform tasks with contact between the mobile platform and their work environment. This contact is relevant, due to the restriction between the platform motion and the work surface. The controller was designed based on the concept of admittance, which relates the position commands to the robot with the difference between the contact force and a given reference. To demonstrate the performance of the designed controller, a test based on a drawing task is presented. The experimental set up includes a Stewart platform with a load cell as the contact sensor installed in the mobile platform and a marker as a tool. The drawing task was performed on a white dry board mounted over an oscillating actuator. The results of this experiment demonstrate the adequate behavior of the controller given that the drawing could be done, even without using the knowledge of the trajectory of the board. This enables the Stewart platform for tasks that involve physical interaction with the environment.**

***Index Terms*—hybrid control, parallel robot, admittance control, Stewart platform, drawing manipulator**

I. Introduction

The widespread of applications where a manipulator has to accomplish a task that requires mechanical interaction between the manipulator and its environment, motivated the proposal of several position-force controllers [1], [2]. Given that the response of the environment is not known, a position controller is not enough, and the interaction measurement and its feedback take an important role to fulfill the desired goal. Most of the proposed force control methods (Impedance control, force-position parallel control, hybrid control, etc.), complement the position control, as they give flexibility in the degrees of freedom where the contact is crucial.

This project, focus on hybrid position-force control for a drawing task. In [3] this technique is described as a combination of force/torque feedback with position data to satisfy position and force trajectory constrains inherent to a specific task coordinate system. Many manipulators used for drawing tasks are serial robots. This is the case of the humanoid manipulator described in [4]. However, some authors have faced this task using parallel manipulators. In [5], authors implemented a damped hybrid control in a Stewart platform to draw an ellipse in a plane. The force feedback was realized by 6 single-axis load-cells, each placed in one link between the actuator and the moving platform. Those signals did the feedback of a pure force control that commanded the actuator torques.

In this project a 6 DOF (degrees of freedom) load-cell is placed in the end-effector to register the contact force data, and its feedback will be combined with the data of the encoders to command the actuators through an admittance model. The proposed task is to draw a given curve in a moving plane surface. Position commands are used to control two degrees of freedom perpendicular to the surface, while the contact direction is driven by a force controller. The plane surface oscillates in the perpendicular direction of the drawing plane. The knowledge of the motion of the surface is not used for the contact control. In order to achieve this objective, a position-force hybrid controller is implemented in the Stewart platform.

This article will be structured as follows: First the approach of the methodology is described with more detail. Next a dynamic modeling and the controller description are developed, followed by the description of the experimental setup and the validation test. Then, the results of the test are presented and discussed. Conclusions and future work recommendations are presented in the last section.

II. Approach

A number of tasks require displacing a tool over a surface to make a specific work, while contact interaction is maintained in the normal direction of the surface. Some examples are polishing, grinding and drawing. To complete the task within quality tolerances, it is necessary to keep the contact force in a narrow range.

Moreover, in some cases the motion of the environment is partially unknown, affecting and perturbing the contact force. For instance, the deflection of the target surface can cause oscillations that should be considered in the manipulator motion control to get an effective result.

Therefore, the controller has to command at least two DOF of the output motion in position, in order to produce the labor over the surface, but in the direction perpendicular to the surface, the control needs to

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command the manipulator position based on the contact force. If the surface tries to go further from the drawing tool, the manipulator needs to move towards it in order to keep the contact force previously settled. On the other hand, if the environment moves towards the drawing tool, it means that the contact force will increase and can damage the tool or the target surface; hence, the manipulator needs to depart from the surface, decreasing the contact force.

One feature that is very relevant in force control is the stiffness between the manipulator and the environment because the system dynamics are highly sensitive to it. A large stiffness, can cause system instability due to the requirement of very fast response to perturbations.

III. CONTROL MODEL

A. Dynamic Model

Considering the Stewart platform as a multi-body system, its dynamics can be solved using the principle of virtual work described in [6].

$$F_p = -[J_p]^T T - \sum \left([J_{i,1}]^T F_{i,1} + [J_{i,2}]^T F_{i,2} \right). \quad (1)$$

F_p, $F_{i,1}$ and $F_{i,2}$ are the sum of applied and inertia wrenches about the center of mass of the moving platform, cylinder and piston respectively; and $[J_p]$, $[J_{i,1}]$ and $[J_{i,2}]$ are the Jacobean matrices that relate the end-effector velocity with the piston rate displacement, the cylinder center of mass velocity and the piston center of mass velocity.

Due to Jacobean matrices are functions of the actuators' unit vectors, (1) becomes in a nonlinear function. However, I the platform works in range where those vectors do not have significant changes, it is possible to assume that this equation can be considered al linear.

B. Hybrid Control

In this case it is desired that the contact force between the tool and the surface keep a constant value through the complete test, while the tool is performing the work over the surface.

To lead the contact force between manipulator and environment to a reference F_{ref} and the measured signal, commands the platform motion through a control scheme based on the mechanical admittance. This relates the applied force over a system with its kinematic behavior through the admittance constant Y (2).

$$\frac{dy}{dx} = F\, e_F. \quad (2)$$

where e_F is the difference between the actual contact force and the reference (force error) as showed in (3).

$$e_F = F_{ref} - F_c. \quad (3)$$

A simple PID controller is included in order to modify the signal that goes to the admittance controller. The PID tuning was performed using the closed loop Ziegler Nichols method experimentally. Fig. 1, shows the block diagram of the complete system.

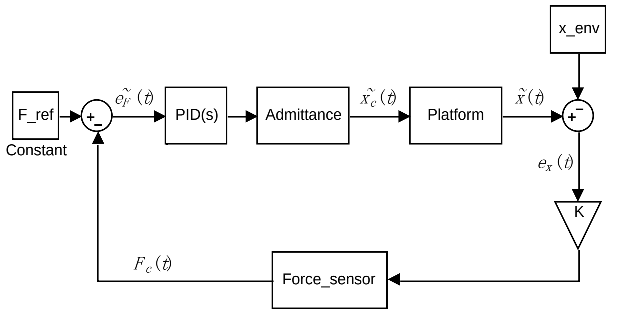

Figure 1. Block diagram scheme.

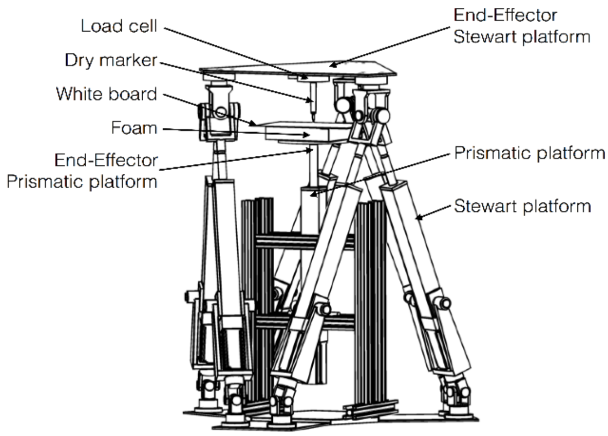

Figure 2. Experimental setup

IV. VERIFICATION TEST

A. Experiment Setup

To verify the operation of the system, the setup showed in Fig. 2, was designed. It is composed by a Stewart platform (6DOF) with a load cell ATI SI-33030 in its mobile platform and a marker. The target surface is a dry white board mounted on an EXLAR linear actuator. This actuator is controlled independently form the Stewart platform, and its trajectory is not communicated or included in the control loop of the Stewart platform. To decrease the stiffness of the target surface foam was installed bellow the board.

The controller was programmed in Simulink and then downloaded to a control computer using the xPCTarget software [7].

The coordinate system is defined as follows: the xy plane is parallel to the target surface and the z direction is the normal direction of the target surface. In this way, the position control is used to command x and y coordinates and the admittance control commanded the z coordinate.

B. Protocol

The experiment was conducted according the following protocol:

1) The end-effector was placed high enough to avoid the contact between the marker and the target surface.
2) The oscillating motion of the target surface is initiated.

3) The force control routine starts, moving the marker towards the target surface until contact is reached.
4) After the reference contact force is reached, the drawing routine starts.

V. Results

A. Setting Parameters

The drawing shape was selected to be a spiral expanding to a diameter of 8 [cm] and then contracting to the original point.

The trajectory commanded to the linear actuator to move the target surface is a triangle wave with an amplitude of 5 [cm] and a period of 9 [s].

The reference contact force F_{ref} value was set to 2 [N]. This value was found experimentally writing by hand with the marker on the board over a scale.

For the admittance constant selection a preliminary value of -10 [m/sN] was chosen. It was latter adjusted to -7.8 [m/sN] according to the quality of the drawing (a solid line drawing) on the board with no motion.

The Zigler-Nichols tuning values for the PID were $K_p = 0.47$, $K_i = 1.42$ and $K_d = 0.02$

B. Test Results

Fig. 3, a), shows the contact force variation between 0 and 4 [N]. This values allows the quality of the drawing to be good enough (solid line) Comparing the displacement signal in the z coordinate with force plot, it is possible to see that the force peaks occur when the linear actuator reach the extreme points of its trajectory. In these points, during the change of direction, the controller commanded the robot displacement trying to keep the contact force near to the reference F_{ref} value.

Fig. 3, b) shows a 3D plot of the marker (end-effector) trajectory of one cycle, from this it is possible to state that the movement was very stable along the entire cycle, showing 3 dimensional displacements both while drawing the expanding spiral as well as while drawing the contracting spiral. Finally, Fig. 3, c) presents the trajectory projected in the xy plane that corresponds to the selected drawing shape. This demonstrates the designed control accuracy in situations where the target surface motion occurs with rapid velocity changes.

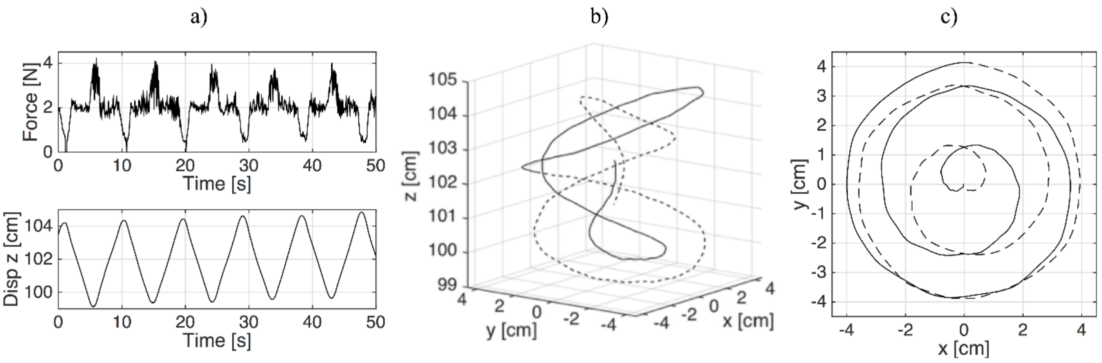

Figure 3. Force and position trajectories obtained from the test. a) Force and displacement in z cord, b) 3D End-effector trajectory, c) Displacement projection in xy plane. Expansion (continuous line) and contraction. (Dashed line)

Finally, Fig. 4, shows the variation of actuators' unit vectors during the test. As it was mentioned before, it is possible to demonstrate the low variation of the Jacobean matrices, leading the system to a linear model approximation when it works near the operation point. This explains why the designed linear controller works well around this point.

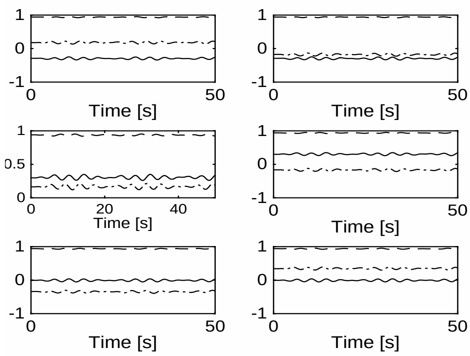

Figure 4. Actuator unit vectors. Continuous line corresponds to x coordinate, dashed line to the y coordinate and dash-dot line to the z coordinate of the each unit vector

VI. Conclusions

According with the presented results, low variation of the contact force and smooth trajectories obtained during the test, it can be inferred that the hybrid position-force controller is good enough to accomplish tasks involving controlled contact forces even if motion of the target surface is not known.

However, the stiffness of the contact is crucial for the success of the task, constraining their application to a condition in the vicinity of the task initial setting. An adaptive scheme could be explored to deal with this inconvenience.

As future work we will adapt the results of the proposed controller to control the interaction between the Stewart platform and a human while performing a cyclic motion.

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