High Performance Control of Stewart Platform Manipulator Using Sliding Mode Control with Synchronization Error

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ABSTRACT
This paper presents the design and analysis of a high performance robust controller for the Stewart platform manipulator. The controller is a variable structure controller that uses a linear sliding surface which is designed to drive both tracking and synchronization errors to zero. In the controller the model based equivalent control part of the sliding mode controller is computed in task space and the discontinuous switching controller part is computed in joint space and hence it is a hybrid of the two approaches. The hybrid implementation helps to reduce computation time and to achieve high performance in task space without the need to measure or estimate 6DOF task space positions. Effect of actuator friction, backlash and parameter variation due to loading have been studied and simulation results confirmed that the controller is robust and achieves better tracking accuracy than other types of sliding mode controllers and simple PID controller.

Keywords: Equivalent Control, High Performance Control, Robust Control, Sliding Mode Control, Stewart Platform Manipulator

INTRODUCTION
The Stewart platform manipulator is a 6DOF parallel manipulator having a fixed base and a moveable platform connected together by six extensible legs, see Figure 1. It has advantages of high precision positioning capacity, high structural rigidity, and strong carrying capacity (Fichter, Kerr, & Rees-Jones, 2009; Guo & Li, 2006; Li & Salcudean, 1997; Merlet, 2006; Dasgupta & Mruthyunthaya, 2000). Potential areas of application include flight and other motion simulators, light weight and high precision machining, data driven manufacturing, dexterous surgical robots and active vibration control systems for large space structures (Merlet, 2006; Sirouspour & Salcudean, 2001; Su & Duan, 2000). The control of this highly coupled nonlinear dynamic system has been a
hot research issue in the last few decades. The control of this manipulator can be formulated in either joint space in terms of the length of the legs or task space in terms of Cartesian position and orientation of the moveable platform (Ghorbel, Chételat, Gunawardana, & Longchamp, 2000; Kima, Chobe, & Lee, 2005; Ting, Chen, & Wang, 1999). Each of these approaches has its own advantages and disadvantages. In the joint space approach, the controller is a collection of single input single output (SISO) systems implemented using local information on each actuator length only and the coupling between legs is ignored or is considered as a disturbance (Zhao, Li, & Gao, 2008). The advantage of this approach is that local information required for feedback is obtained easily using simple sensors. This helps to easily implement the individual SISO controllers in parallel resulting in the execution of control algorithm at a reasonably fast speed (Zhao, Li, & Gao, 2008). However, joint space implementation has certain drawbacks. The first one is due to the inherent nonlinear relationship between length of legs and end effector pose, a disturbance in legs may lead to a big error in end effector pose while leg error is small (Paccot, Andreff, Martinet, & Khalil, 2006). The second problem of joint space SISO implementation is lack of synchronization in the individual control loops. The lack of synchronization leads to a large coupling error which results in lesser accuracy. Moreover, the accumulation of coupling errors generates excessive force and may damage the manipulator itself (Zhao, Li, & Gao 2008). Due to these, joint space approach alone cannot achieve high performance (Kima, Chobe, & Lee, 2005; Zhao, Li, & Gao 2008; Davliakos & Papadopoulos, 2008; Sirouspour & Salcudean, 2001).

To solve these problems, many researchers have proposed joint space feedback control methods improved by using feedforward loops. While Su, Duan, Zheng, Zhang, Chen, and Mi (2004) used a tracking differentiator as a feedforward controller to improve joint space PID controller performance, Zhao, Li, and Gao (2008) designed an adaptive controller having feedback and feedforward parts to compensate for synchronization error of joint space control. However, the above schemes cannot achieve high performance, especially at high speeds due to the fact that the linear PD or PID controllers cannot compensate leg dynamics.

On the other hand, in task space approach, the system is treated as multiple input multiple output (MIMO) system and the coupling between legs is visible. Therefore, task space scheme has the potential to give a superior 6DOF tracking performance under various system uncertainties (Kima, Chobe, & Lee, 2005). Nevertheless this approach needs 6DOF end effector pose, which is very costly if sensors are to be used for measurement or is cumbersome if estimation algorithms are to be used (Kima, Chobe, & Lee, 2005; Nguyen, Zhou, & Antraz, 1997).

From the given discussion, it is clear that none of the approaches is without disadvantage. This shows that employing a hybrid control approach which utilize the advantages of both approaches and minimize their disadvantages would be a better solution. Accordingly, some authors have proposed model based control methods which utilize advantages of task space approach with joint space. A first proposal of this sort is that of Beji, Abichou, and Pascal (1998). In their paper, they proposed a control method for an electrically driven manipulator where the desired force is calculated in task space using desired position and velocity signals and the leg dynamics compensation is achieved by a force convergent principle. Similarly Fu and Yu (2006) proposed a hybrid control algorithm where the platform dynamics is calculated in task space and the leg dynamics is compensated in joint space. In that paper, the leg dynamics is calculated using Newton Euler method. However, the method needs task space positions and orientations and the authors did not specify the method used to get the pose of the end effector. Similarly Lee, Song, Choi, and Hong (2003) used inverse dynamics control with approximate dynamics as a feedforward controller and they employed a linear H-infinity controller in the feedback path to compensate for the approxima-
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