Modified PSD MIMO Controller

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Abstract

Redundant actuation of parallel robots cannot be controlled by simple local servo-controllers, because of mutual coupling of systems would lead to controller fighting even for infinitively small disproportion between model and real mechanics system. On the other hand elegant solution of this problem should lead to higher stiffness of the redundant parallel robotics or manipulator system than can be achieved for conventional serial connection of actuated joints. Lower mass of moving parts without actuators load enables faster accelerations and transition speeds as well.

High level controllers can globally solve problem to control robots with higher number of actuators than number of degrees of freedom, but these solutions requires powerful centralized control system. Our solution is based on simpler approach of fast local servosystem loops and global coordinator of trajectory generation and fast loops supervisor. This approach is better suited for distributed controllers and intelligent motors.

The first implementation of described solution was successfully tested on laboratory model of planar parallel robot.

Keywords :
Robotics, PSD, controllers, electronics, algorithms and kinematics

1 Objectives

Important objective of research of redundant parallel robots is achieving of cooperative and optimized behavior of all used actuators, when number of actuators is higher than number of degree of freedom of a robot kinematics. Redundant actuation cannot be controlled by simple local servo-controllers, because of mutual coupling of systems would lead to controller fighting even for infinitively small disproportion between model and real mechanics system. On the other hand elegant solution of this problem should lead to higher stiffness of the redundant parallel robotics or manipulator system than can be achieved for conventional serial connection of actuated joints. Lower mass of moving parts without actuators load enables faster accelerations and transition speeds as well.

2 Introduction

Robotics research group is leaded by Prof. Valášek, Department of Mechanics, Faculty of Mechanical Engineering. Problems of a theoretical high level control, trajectory computation and coordinate transformation are solved by group members from UTIA institute. Our CTU FEL team was responsible for hardware development and some experiments preparation and lower level control. We have offered in cooperation with UTIA members some solution of above described problem.

Results of research were tested on a laboratory model of planar redundant parallel manipulator, which consists of the basic frame with four DC motor drivers actuating over four pairs of arms moveable platform. The kinematic model and a photograph of described system is shown in Fig 1. Such system has three degrees of freedom for actuated platform and redundant actuators. Position of the moveable platform can be described by the vector of independent coordinates for planar position (x, y) and platform winding ψ.

There are four actuated motor coordinates φ_1 to φ_4 and other four ancillary coordinates representing mutual winding of each pair of arms. In contrast to regular serial kinematics, parallel kinematics leads to simpler inverse transformations. Simpler inverse transformations are compensated by more difficult direct transformations. The problem of direct kinematics and actual position in the independent coordinates can be solved by tracking of actual position in the motor coordinates with help of the Jacobian matrix of inverse kinematics transformations. This approach was taken and implemented in our case.

3 High Level Approach

One approach to achieve cooperative behavior of the redundant actuators is to introduce feedback control in the space of independent coordinates (x, y, ψ) and transform computed forces and platform torque into torque request for each drive. The independent forces $\overrightarrow{F}$ to driver torques $\overrightarrow{M}$ transformation can be evaluated from equation $\overrightarrow{F} = \mathbf{J}^T \cdot \overrightarrow{M}$, where $\mathbf{J}$ is Jacobian matrix of inverse coordinate transformation. Next equation is result of applying pseudo-inversion to the matrix $\mathbf{J}^T$

$$\overrightarrow{M} = \mathbf{J} \cdot (\mathbf{J}^T \cdot \mathbf{J})^{-1} \cdot \overrightarrow{F}$$

Advantages of this approach are linear character of transformation and the fact, that Jacobian at certain instant is only static relation, which is not directly dependent on time. The design of controller in the space of independent coordinates has other significant advantages. The complex differential-algebraic equations (DAE) representing system dynamics are transformed to simpler ODE system, for which optimal controller can by designed by more conventional methods. Optimized high-level controllers for this project are developed at the UTIA institute. Prepared are sliding mode controller and predictive controller. Main difficulty of this approach is fast and precise measurement of the platform position in independent coordinates. We do not expect that real system can afford to be equipped by independent spatial position measurement and that means that motor coordinates needs to be transformed to independent coordinates as was described in previous paragraph. Position tracking is very computational intensive task. This was main reason why our first control system based on TMS320C30 DSP was not suitable for high-level controller implementation. Situation was improved by rebuilding hardware setup for PowerPC based system, but dependence of fast control loop with the tracking algorithms

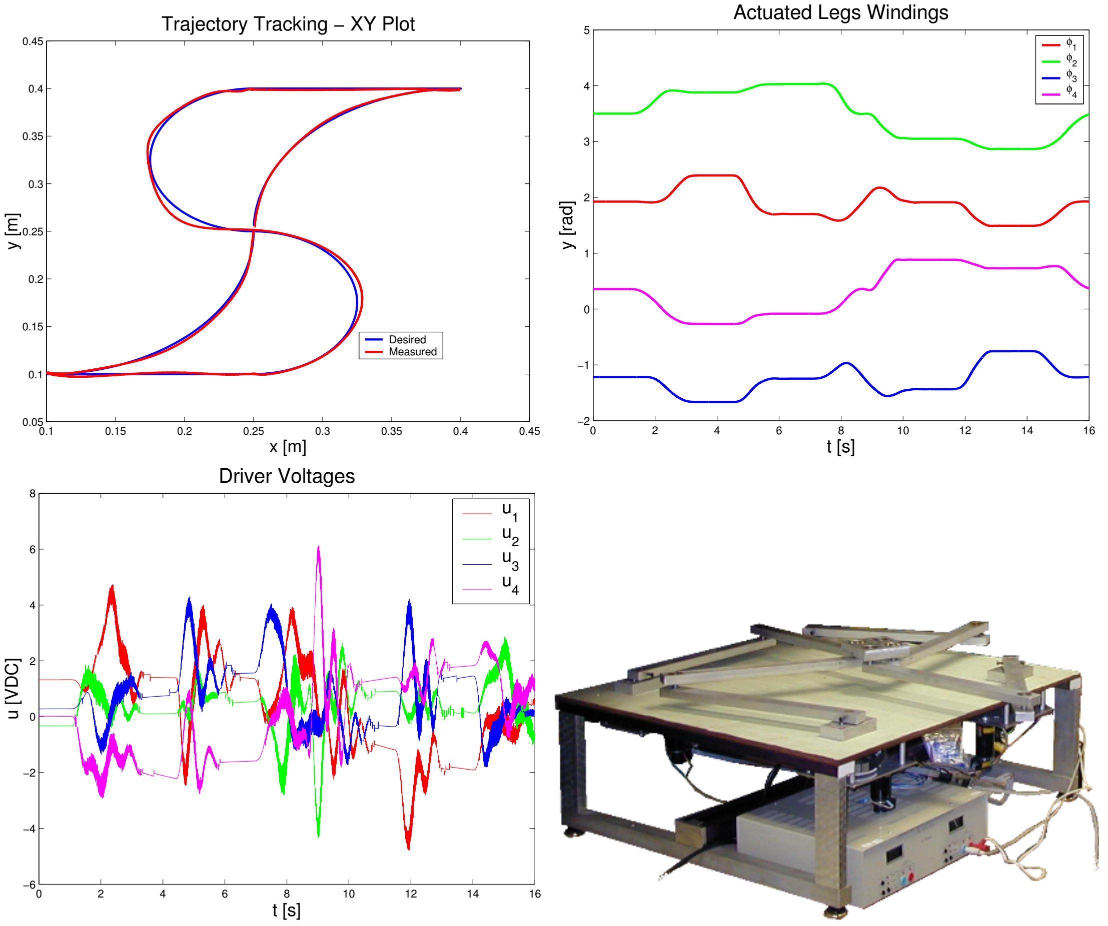

Figure 1: Measured Results with PSD Controller

negatively influences performance of the controller.

4 PSD With Reduction of Antagonistic Forces

Second way to achieve cooperative actuation is to use conventional servo system for each driver and to add subsystem solving minimization of antagonistic forces. Each local controller loops computes in such case one component of the actual driver torques $\overrightarrow{M}$. The vector of actual driver torques $\overrightarrow{M}$ can be described as sum of torque vectors $\overrightarrow{M}_F$ and $\overrightarrow{M_{ant}}$. Vector $\overrightarrow{M_F}$ is oriented in direction that contributes to independent forces and winding torque to positioned platform. The vector of antagonistic torques $\overrightarrow{M_{ant}}$ is oriented in the space orthogonal to the direction of $\overrightarrow{M_F}$ and represents component of torques that has no influence on the platform position because of redundant drivers coupling. Main source of antagonistic forces when local controllers are used, is integration of difference of requested and actual positions of drivers which cannot be eliminated by growing forces. The differences in such case are caused by any infinitively small discrepancy of model used for computation of requested dependent (redundant) motor coordinates. The first theoretical solution of this problem is to add block solving reduction of antagonistic forces or torques in the vector $\overrightarrow{M}$ to the vector $\overrightarrow{M_F}$ at the output of the conventional servosystem build from cascade of PSD controllers. This solution is practically impossible, because of resulting control system has non-observable internal states, which are not stabilized by feedback loop (sum of the position errors grows to infinity). The next solution proposed by our team is better suitable for practical realization. The conventional PSD controllers were equipped by direct outputs of summed errors and sum injection inputs. Block for eliminating antagonism between torques was rebuild for computation of antagonistic component of torques and was connected to PSD sum outputs. Negative gained output of this block was connected to the sum injection inputs. This way sum of errors is stabilized and antagonistic component of torques can be arbitrarily reduced. There are more advantage of this solution. The reduction block is not in main control loop and has no negative influence of dynamics behavior of the system. Transfer matrix of the reduction block can be computed from already evaluated Jacobian. One of possible decomposition of torques based on transformation to the actual resulting forces and then back to driver torques can be described by next equations

$$\begin{aligned}
\overrightarrow{M} &\rightarrow \overrightarrow{F} \rightarrow \overrightarrow{M_F} \\
\overrightarrow{M_F} &= \mathbf{J} \cdot (\mathbf{J}^T \cdot \mathbf{J})^{-1} \cdot \mathbf{J}^T \cdot \overrightarrow{M} \\
\overrightarrow{M_{ant}} &= \overrightarrow{M} - \overrightarrow{M_F} \\
\overrightarrow{M_{ant}} &= (1 - \mathbf{J} \cdot (\mathbf{J}^T \cdot \mathbf{J})^{-1} \cdot \mathbf{J}^T) \cdot \overrightarrow{M}
\end{aligned}$$

The transfer matrix of reduction block is then equal to $1 - \mathbf{J} \cdot (\mathbf{J}^T \cdot \mathbf{J})^{-1} \cdot \mathbf{J}^T$ multiplied by negative feedback gain K_r. Other more general but computationally more demanding solution of torques decomposition is to use SVD method.

Jacobian is not directly dependent on time and can be recomputed at many times lower frequency than the fast servosystem loop. Even gain of injection can be relatively small and in such case injection can be computed at lower frequency than the fast loop. This could be big advantage for real big parallel robotic systems, because distributed control with intelligent motors could be used for fast local loops and reduction of antagonistic forces can be achieved by supervisor trajectory and high level controller node interconnected with actuators only by fast control area network. Simplified functional diagram of tested controllers is shown in Fig 2.

Described solution has even second advantage for system stability and dynamics behavior. Reduction loop operates in vector space orthogonal to degrees of freedom of kinematics system, which means that there is no negative dynamics influence or time delay contribution to controlled system.

5 Conclusion

Described solution was successfully tested on laboratory model. One of many experiments with trajectory tracking is shown in Fig 1. The second experiment shown in Fig. 3 documents necessity of antagonistic forces reduction and performance of our approach. The positioned platform was commanded to the one position and than the gain of reduction loop K_r was zeroed for 15 seconds. The integration components of PSD started to increase out of control. The eduction was applied again after specified time and antagonistic components of torques were again stabilized. We expect, that future combination of high-level controller with described fast local loops could lead to advanced hierarchical control system with excellent dynamics properties.

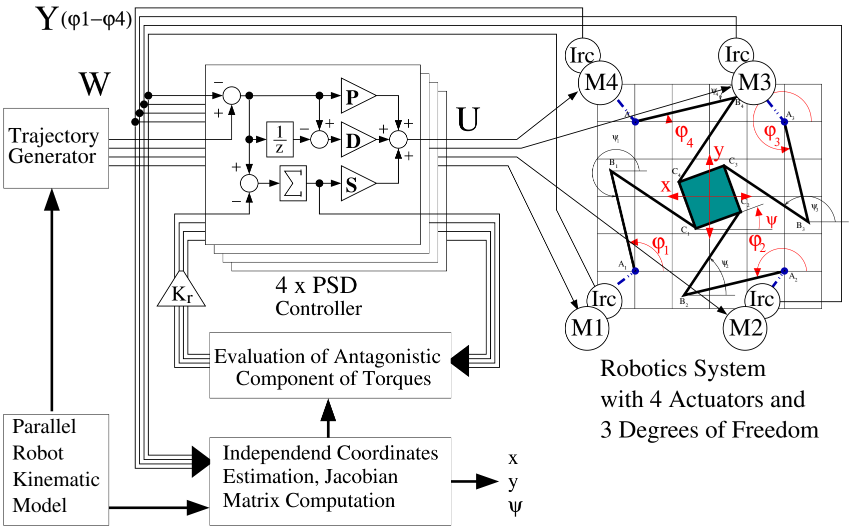

Figure 2: PSD Controller with Antagonistic Forces Reduction

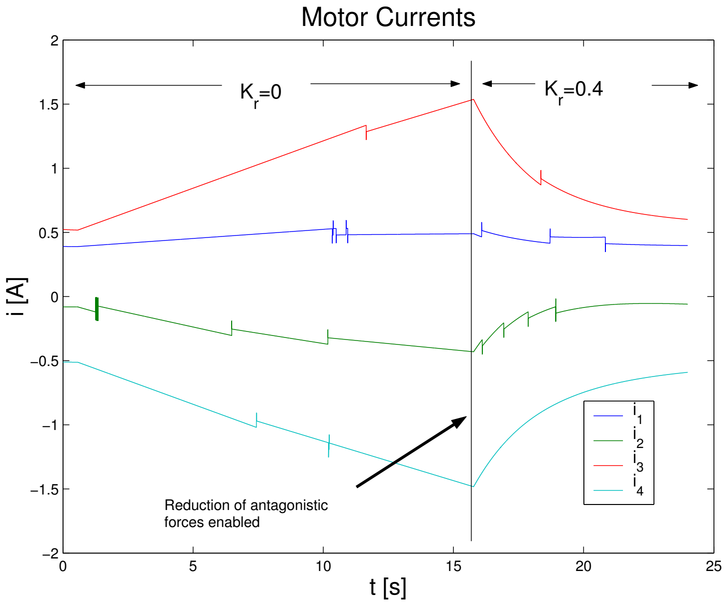

Figure 3: Dependence of Forces on the Reduction Gain

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Acknowledgments

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