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# Dynamic parameters optimization of a Gough-Stewart Platform mounted on a 2-DOF moving base

Taha Houda, Ali Amouri, Lotfi Beji, and Malik Mallem

University of Evry / Paris Saclay  
IBISC Laboratory  
40 Rue du Pelvoux, 91020, Evry  
{Taha.Houda, Ali.Amouri, Lotfi.Beji, Malik.Mallem}@univ-evry.fr

## EXTENDED ABSTRACT

### 1 Introduction

It is well known that dynamic parameters play an important role in describing the behavior of a multibody system such as robot manipulators [1]. Hence, an optimized analytical form of the dynamic model must be developed, and the number of mathematical operations should be reduced. Thus, a control based on an optimized dynamic model can be built and easily implemented in real time. The Gough-Stewart platform has been extensively studied in the literature from modeling and control views due to the high stiffness, payload capacity and high accuracy that occur [1, 2]. In addition, the Gough-Stewart platform has retained the attention of industries, and a lot of tests and applications have been developed. One cites, for example, simulators for land vehicles in the automotive industry, flight simulators in the fields of aeronautics and submarine simulators as well as they have been used as manipulators.

The Ibisc laboratory, through the IRA2 team, is currently working on the dynamic optimization and control in the mixed reality environment of the Gough-Stewart platform. As shown by figure 1, the parallel platform (6-DOF) is fixed on two prismatic joints, and where the operator is attached to the moving platform. This platform was conducted and built by our team. Consequently, we are dealing with an 8-DOF motion system which is intended to be used as a simulator for people with reduced mobility (handicapped person) [3]. The system's objectives are to create a real feeling motion when the human is merged into mixed reality environments. This system will be used in several fields such as rehabilitation for people with motor disabilities, rescue environments and a sport simulator for educational purposes. The combination of the small displacement asserted by the parallel platform and the large displacements of sliders, all of these allow a large operator's workspace for several types of sports, such as ski, wake and jetski simulations.

Consequently, an agreement is necessary such that the upper platform trajectories integrating disabled human objectives are stable (to ensure safety). In this paper, we will detail the identification and optimization of the inertial parameter to make the specified and optimal control of the simulator. Hence, we resume our contribution by the following: to fully meet the requirements, a suitable dynamic modeling, a complete coupling study, an optimization of the parameters and an identification (online calculation) are studied by integrating the skier's behavior.

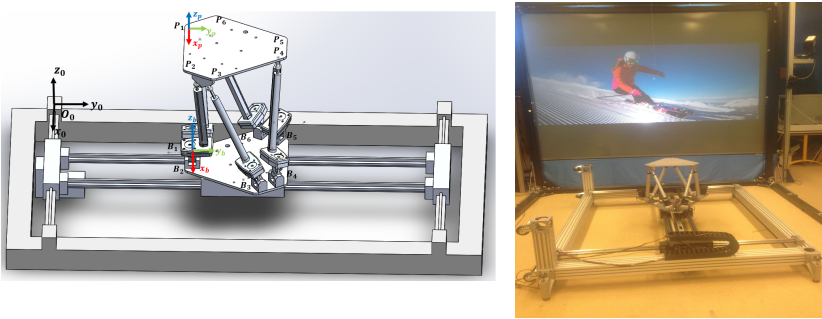


Figure 1: CAD and Real figure of the 8 DOF mechanical system.

### 2 Dynamic parameters Optimization and Identification

Such an operation requires a dynamic based control procedure where all system parameters must to be minimized and identified. With respect to (Denavit-Hartenberg) parametrization and following notations given by Khalil [1], the dynamics of our system depends on 210 dynamic parameters (standard inertial parameters). The first optimization step consists in eliminating the parameters that didn't affect the 8-DOF dynamic model based on the well-known Newton-Euler recursive calculation which reduces the number of inertial parameters by 42 parameters and will just remain 168 inertial parameters.

The second step is to find a linear/nonlinear combination such that only an equivalent parameter appears based on the energetic model of the system. The total energy of the link  $k$   $H_k$  is equal to the sum of the kinetic and the potential energies and it is clear that it can be expressed linearly according to the inertial parameters  $\xi_k^{in}$  [4]

$$H_k = E_k + U_k = (e_k + u_k)\xi_k^{in} = h_k \xi_k^{in} \quad (1)$$

Where,  $h_k = e_k + u_k = [h_{XX_k} h_{XY_k} h_{XZ_k} h_{YY_k} h_{YZ_k} h_{ZZ_k} h_{MX_k} h_{MY_k} h_{MZ_k} h_{M_k}]$

The grouping method is as follows: if one or more column of the link energy  $h_k$  can be expressed as function of the previous link energy function  $h_{k-1}$ , then  $\xi_k^{in}$  can be grouped with  $\xi_{k-1}^{in}$  and another grouped inertial parameter is appears.

$$h_k = \sum \alpha_{k-1} h_{k-1} + const; \quad H_t = h_k \xi_k^{in} + h_{k-1} \xi_{k-1}^{in} = (\sum \alpha_{k-1} h_{k-1}) \xi_k^{in} + h_{k-1} \xi_{k-1}^{in} \quad (2)$$

$$H_t = h_{k-1} (\xi_{k-1}^{in} + \sum \alpha_{k-1} \xi_k^{in}) = h_{k-1} \xi_{R,k-1}^{in}$$

After the second method is applied, 78 inertial parameters can be grouped and then eliminated. Therefore, the entire system depends on 90 inertial parameters instead of 210.

For the identification of the inertial parameters an identification energy model has been applied in the following form:

$$\mathbf{Y} = \int T^T \dot{q} dt = \Delta h(q, \dot{q}, v_p, w_p) \xi, \quad T = \Gamma - \text{diag}(\text{sign}(\dot{q})) F_s - \text{diag}(\dot{q}) F_v \quad (3)$$

$\Gamma \in \mathbb{R}^8$  is the vector of generalized torques,  $q = [q_a, q_p]$ ,  $\dot{q} = [\dot{q}_a, \dot{q}_p]$  where  $q_a \in \mathbb{R}^8$ ,  $q_p \in \mathbb{R}^{2 \times 6}$  are the active and passive joint positions,  $(V_b \times \omega_b)$  and  $(V_{up} \times \omega_{up}) \in (\mathbb{R}^3 \times \mathbb{R}^3)$  are the speed vectors of the base and the upper platform respectively,  $F_v, F_s$  are the viscous and dry friction coefficients and  $\xi = [\xi^{in}, \xi^f]$  where  $\xi^{in}, \xi^f$  are the inertial and friction parameters respectively.

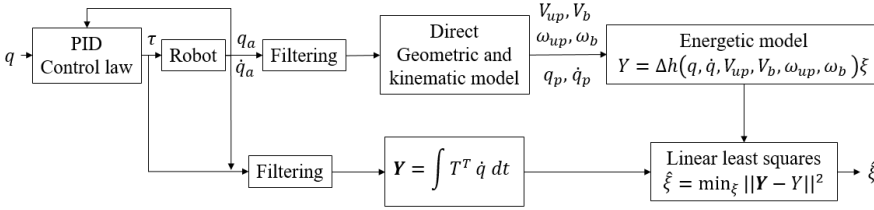


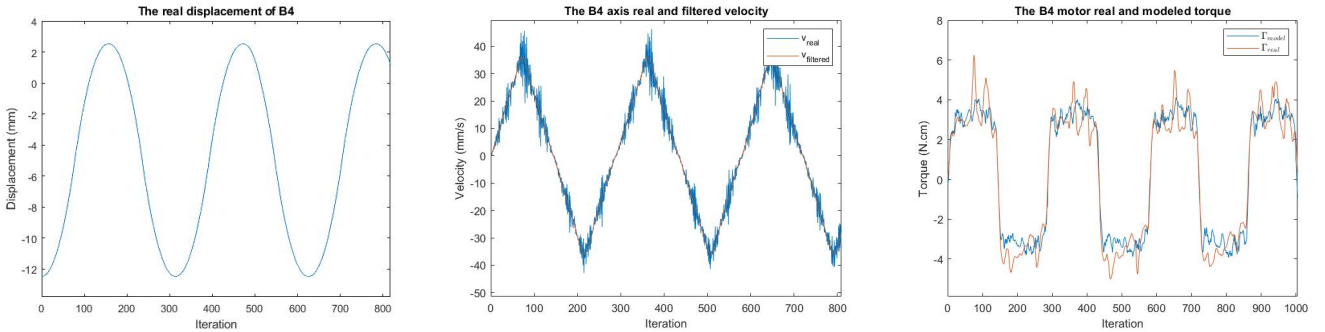
Figure 2: schematic diagram of the energy model least-squares method.

### 3 Identification Results

All detected variables such as displacements, velocities and torques were filtered in order to eliminate the high frequency which is harmful for the identification procedure. In order to verify the identification results, a torque construction from the model using the lagrangian formulation and the identified parameters is performed. The lagrangian is equal to the total kinetic energy differentiated by the total potential energy:

$$L = E - U = e_k \hat{\xi}_k^{in} - u_k \hat{\xi}_k^{in}; \quad \Gamma_{Model} = \Gamma_{\hat{\xi}_m} + \Gamma_{\hat{\xi}_f} \quad (4)$$

An example of the displacement, velocity, and torque detected and constructed of the leg  $B_4P_4$  is shown below.



The  $B_4P_4$  axis friction was taken in two directions to take into account the dissymmetry of the friction model, we note 1 and 2 for the first and the second direction, respectively:  $F_{s1} = 1,39 N$ ,  $F_{v1} = 56,98 N.s/mm$ ,  $F_{s2} = 1,33 N$ ,  $F_{v2} = 58,31 N.s/mm$ , Finally, the mass hold it by the first sliding joint is  $M_{s1} = 33.7 kg$ , by the second joint is  $M_{s2} = 20.56 kg$  and by the six axes  $M_{Rp} = 6.15 Kg$ .

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