

Analysis of a 6-DOF parallel robot motion simulation

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Abstract. The paper presents the geometrical model of a parallel topology robot of MSSM type, operated as a flight simulator. Certain strokes of the driving kinematical joints lead to the simulation of real limit situations, which are dangerous for the human operator, such as a sudden pitch movement. The variations of different motion parameters are analyzed. SolidWorks software was used in the modeling and simulation processes.

1. Introduction

The mechanism of a parallel topology guiding device usually contains a fixed platform and a mobile one, linked together by open kinematical chains. Different structures of such mechanisms are presented in [1-4].

Parallel topology guiding devices are known for their high rigidity, superior positioning accuracy, and high speed in operation.

They have various applications, including: tool positioners for numerical control machine tools [5], guiding devices in surgery [6-8], and equitation, car or flight simulators [9].

The position-orientation matrix of the reference system attached to the robot's characteristic point can be determined in an analytical or in an experimental manner [10].

In order to study the workspace, the kinematics and dynamics of parallel topology robots, diverse modeling and simulation software environments can be used. Thus, in [11], the influence of a parallel topology robot links lengths on its workspace, as well as its shape and volume is studied, by using SolidWorks software. In [9], kinematical and dynamic analyses are accomplished with SolidWorks software, and in [12], a dynamic analysis is done with Adams software, in order to study the parallel robot behavior in operation. Also special mechanical transmissions used in robot structures, such as double harmonic transmission, are analyzed in dynamic conditions [13].

Approaches in strength and fatigue analyses of parallel topology guiding devices components are accomplished in [14] and [15] respectively.

Usually, parallel topology robots are electrically or pneumatically driven, by using different types of actuators [16]. In recent years, variants of driving the robot joints with polymeric artificial muscles [17] or shape memory alloy actuators [18], [19] are studied.

The paper presents the geometrical model of a parallel robot of MSSM (Minimal Simplified Symmetric Manipulator) type [1], [2], [9], [11], the input parameters necessary for the desired movement of mobile platform and the variation of certain kinematic and dynamic parameters.

SolidWorks software was used in the modeling and simulation processes, together with SolidWorks Motion module.



2. 3D Model of the Parallel Robot

The proposed parallel topology guiding device mechanism has the structure $FP_3+6\cdot SPS+MP_3$ [9], [11], or MSSM, corresponding to [1], [2]. It contains 2 platforms, a fixed one FP_3 , and a mobile one, MP_3 , linked by 6 identical open kinematical chains SPS. Every open kinematical chain is composed by 2 binary links, 1 driving prismatic joint (P) and 2 spherical joints (S). Both at fixed platform level and at mobile platform level, the centers of the spherical joints belonging to different kinematical chains are coincident 2 by 2, thus forming double spherical joints.

The minimum distance between the centers of the 2 spherical joints of the same kinematical chain SPS is 800 [mm], the maximum distance is 1300 [mm], consequently the maximum stroke of the driving prismatic joint is 500 [mm] [9].

The 3D model of the parallel robot, obtained by using the SolidWorks tools, is presented in Figure 1. For the application of flight simulator, the 3D models of a seat and a human operator were considered [9].

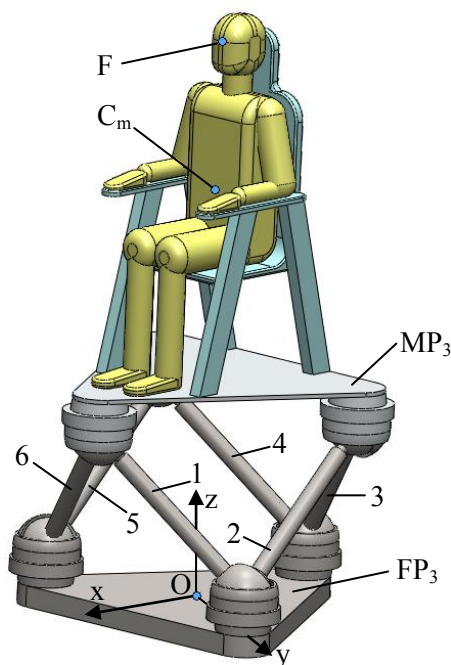


Figure 1. 3D model of the parallel robot, with the seat and human operator models fixed to the mobile platform, where [9]: FP_3 - the fixed platform; MP_3 - the mobile platform; 1-6 - kinematical chains of SPS type; O - the origin of the fixed reference system; C_m - the center of mass of the human operator model; F - frontal point on the forehead of the human operator model; Oxyz - fixed reference system.

The components have materials chosen from the SolidWorks database. The 3D model of the human operator has the height of 1.75 [m] and the mass of 75 [kg]. In order to obtain the proposed weight of this model, a custom material with the mass density of $1007.27 \text{ [kg/m}^3\text{]}$ was defined [9].

3. Simulation of Parallel Robot Motion

The simulation of parallel robot operation was accomplished in a SolidWorks Motion study. The gravitational acceleration of $9806.65 \text{ [mm/s}^2\text{]}$ was defined.

A linear motor is defined for every kinematical chain between the platforms. The motors are considered hydraulically driven, with a maximum speed limit set to 1 [m/s]. The friction forces were neglected in the simulation process.

In order to obtain the desired motions, certain strokes of the hydraulic motors are established, determining the lengths between the centers of the spherical joints of the same kinematical chain, from 1 to 6. For every hydraulic motor, the relative displacement between the hydraulic cylinder and the piston versus time is imposed, which determines the variations of velocity and acceleration. Thus, input parameters of the hydraulic motors are presented in Figure 2.

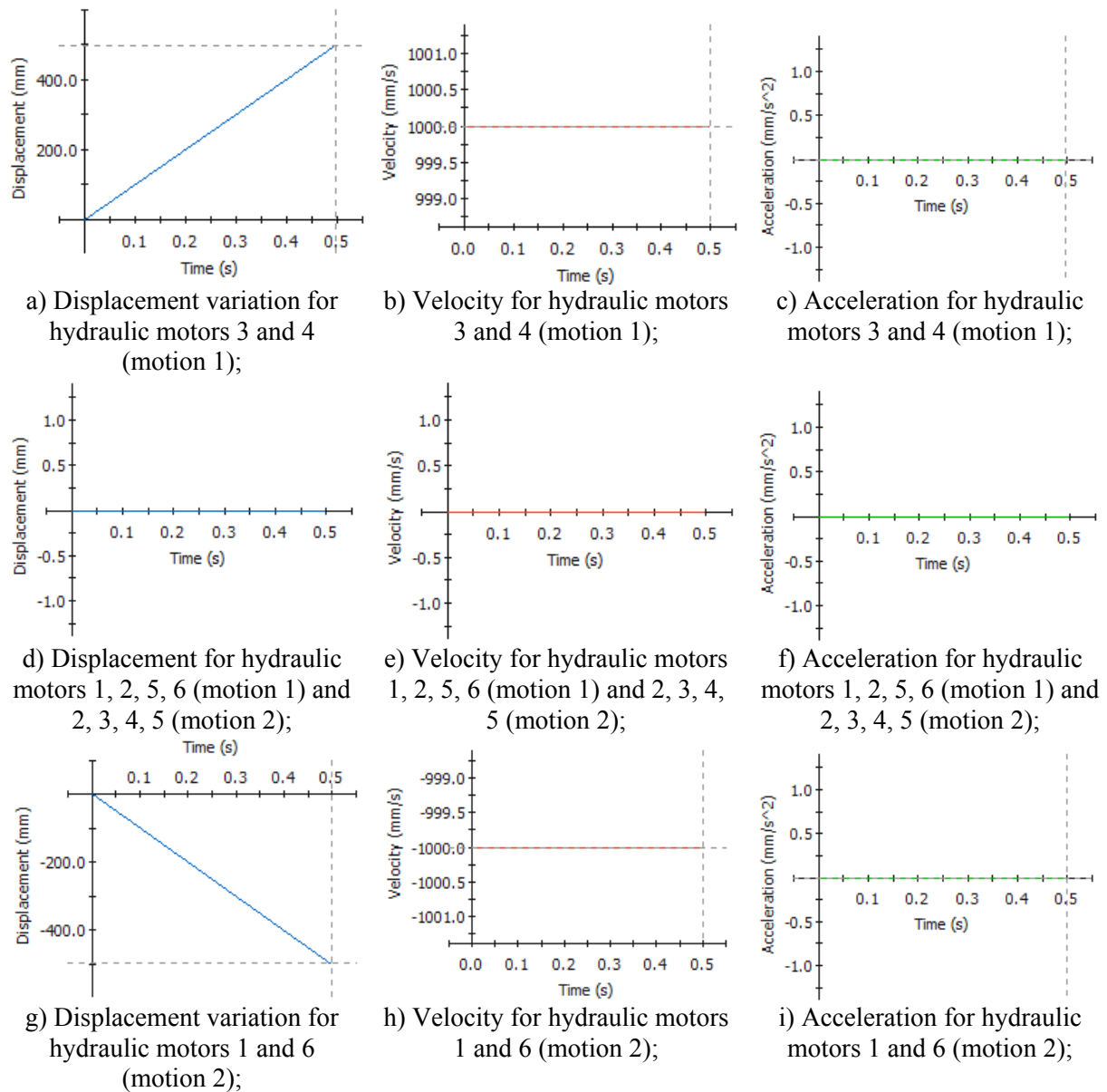


Figure 2. The variations of input parameters of the hydraulic motors

The lengths $L_1 \div L_6$ between the centers of the spherical joints of the same kinematical chain, from 1 to 6, are presented in Table 1.

Table 1. Variation of lengths $L_1 \div L_6$ between the centers of the spherical joints.

Length	Motion 1		Motion 2	
	Initial position ($t_0 = 0$ s)	Final position ($t_f = 0.5$ s)	Initial position ($t_0 = 0$ s)	Final position ($t_f = 0.5$ s)
L_1 (mm)	1300	1300	1300	800
L_2 (mm)	1300	1300	1300	1300
L_3 (mm)	800	1300	1300	1300
L_4 (mm)	800	1300	1300	1300
L_5 (mm)	1300	1300	1300	1300
L_6 (mm)	1300	1300	1300	800

The considered motions are combinations of translations along x and z axes and a pitch type rotation around y axis (according to the Oxyz reference system presented in Figure 1, with a corresponding tilt of mobile platform, as shown in Figure 3. In motion 1, the mobile platform back side is ascending, while in motion 2, the front side is descending. The total duration of motion is set to 0.5 [s].

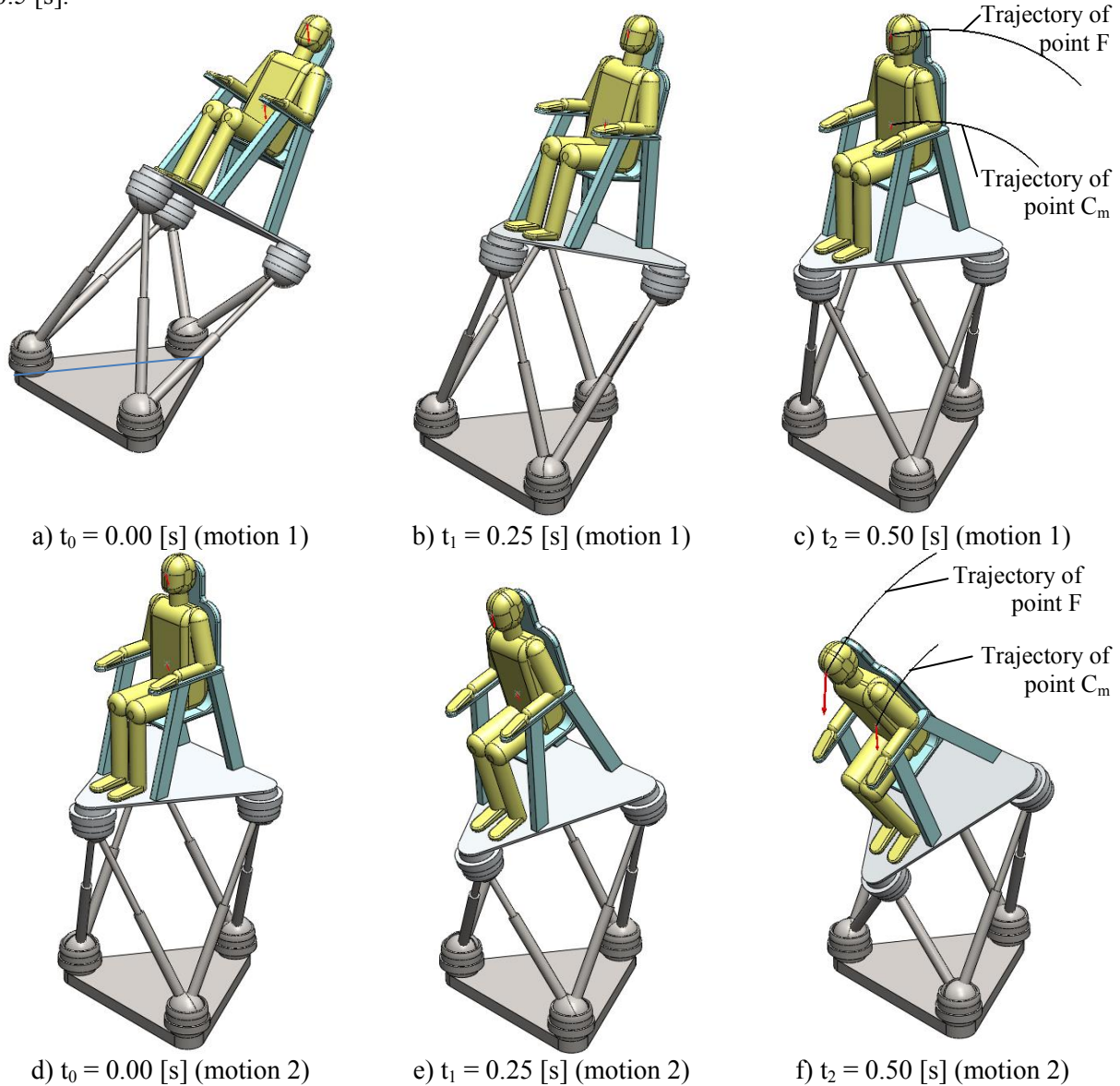


Figure 3. Initial, intermediate and final positions-orientations of the mobile platform while executing motion 1 (a, b, c) and motion 2 (d, e, f)

As results, velocity and acceleration variations of the frontal point (F) and of the center of mass (C_m) of human operator are obtained, as shown in Figure 4.

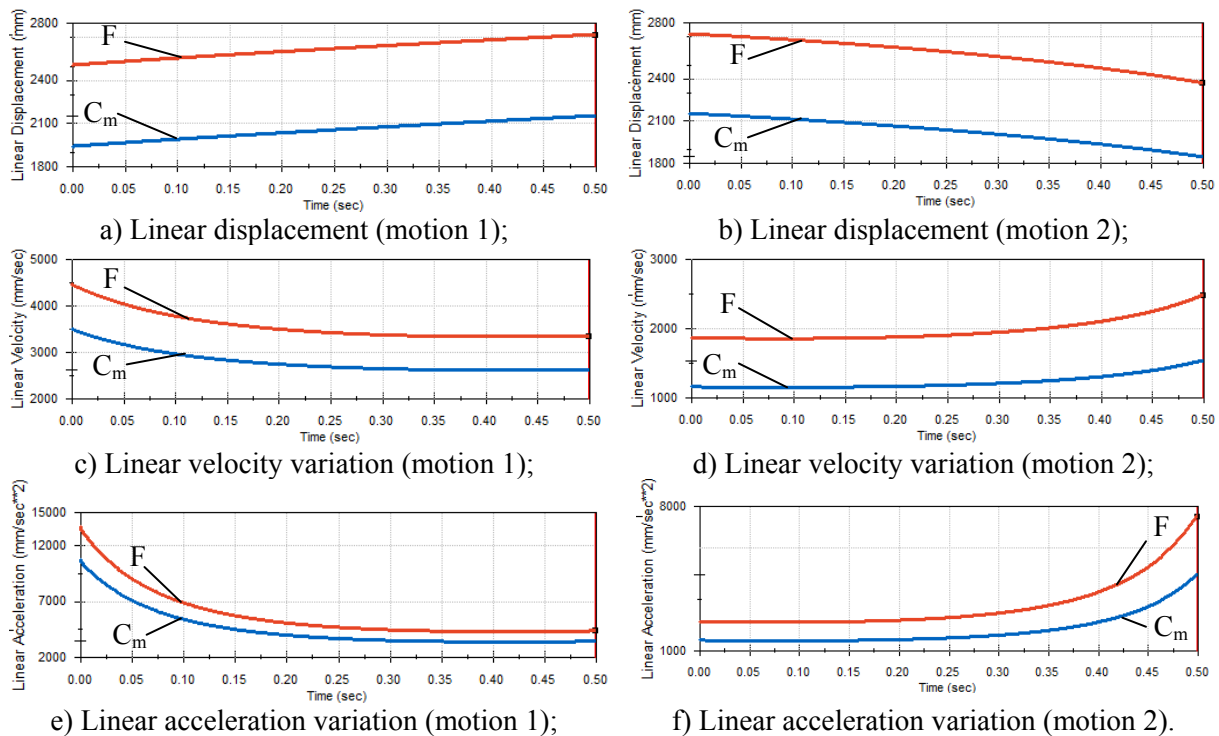


Figure 4. Linear displacement, velocity and acceleration variations of the frontal point (F) and of the center of mass (C_m) of human operator

In motion 1 (ascending of the mobile platform back side), the elevations of the characteristic points C_m and F increase, the velocities have higher values at the beginning of motion, 4459 [mm/s] - point F, and 3495 [mm/s] - point C_m , then decrease to 3345 [mm/s] - point F, and 2622 [mm/s] - point C_m ; the acceleration decreases from 13641 [mm/s²] - point F and 10692 [mm/s²] - point C_m , to 4334 [mm/s²] - point F and 3397 [mm/s²] - point C_m .

In motion 2 (descending of the mobile platform back side), the elevations of the characteristic points C_m and F decrease, the velocities have lower values at the beginning of motion, 1859 [mm/s] - point F, and 1151 [mm/s] - point C_m , then increase to 2478 [mm/s] - point F, and 1535 [mm/s] - point C_m ; the acceleration increases from 2408 [mm/s²] - point F and 1492 [mm/s²] - point C_m , to 7580 [mm/s²] - point F and 4695 [mm/s²] - point C_m .

4. Conclusions

Considering the results of simulation process, the following conclusions can be drawn:

- for both motions studied, even though the pistons of hydraulic motors have a constant velocity, the displacement, the velocity and the acceleration of points F and C_m have a non-linear variation, due to the structure of the parallel robot;
- the velocities and the accelerations have the highest values at the beginning of motion 1, but this situation is harmless for the human operator which uses the seat belt in the flight simulator.

This manner of simulation and determination of motion parameters can be used for various mechanical systems.

As further research, the friction forces that occur in the spherical kinematical joints can be considered in the simulation process.

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