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MODELING AND SIMULATION OF PARALLEL STRUCTURES USED AS FLIGHT SIMULATORS

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ABSTRACT

Modeling and simulation is one of the essential aspects in the robots research field. In order to understand the importance of the graphical simulation it is necessary to consider why and where the simulation systems are mainly used. The industrial tendency is to develop simulation systems, which could be of help for the systems (robots) off-line control and for the robot operational workspace generation. In the paper are presented studies regarding the modeling and simulation of parallel robots used for the development of flight simulators. Starting from the analysis of the extended list of flight simulators requirements the task is to determine the strong and weak points of existing solutions for establishing the possibilities to optimize the main characteristics of a robotic structure for flight simulators. Some variants of 6-DOF developed solutions are presented.

Keywords: *parallel robots, flight simulator, modeling, inverse kinematics, simulation.*

1. INTRODUCTION

Within the simulation system, an important role plays the achievement of a virtual robot functional model, allowing interactive visualization and functional simulation. The first application of the simulation systems is during the design process to test the functionality and the restriction influences. The second application refers to existent robots that could be better programmed, analyzed and optimized. Within the simulation systems, the trajectory visualization and collision detection offers a safer system. The robotized system performance can be tested without any danger for man or robot. New control algorithms can be created and tested before investments in the hardware devices is made.

The majority of the existing simulation systems have been used for the serial robots. Based on the library and the Internet research, where considered more than 900 simulation systems including commercial brands (i.e. RobCad®, SCORob®, Robosoft, RoboWorks™etc.) software for specialized research (i.e ALPHA/Sim®). Only about 2% seems to be adequate to manage the the parallel robots parameters. The parallel robots kinematic and the dynamic models are more complicated and require laborious calculus and longer implementation time. In the parallel robots case each structure must be practically separately generated and studied.

Specialized CAD/CAE/PDM software are very complex and it is not clearly for designer and industrial corporation how to fully utilize the potential of these new tools. Important questions are under discussion e.g. whether an integrated environment or distributed simulation software with communication between different types of simulation should be preferred.

The basic idea of the research is to use the parallel robots advantages for developing flight simulators with high dynamic capacities. The most studies are focused on increasing the flight safe on planes due to the high passengers transport capacity. The flight simulators for helicopters are rare and limited regarding the capabilities to reproduce the real flight conditions, due to the necessity to have a bigger mobility for all 6 DOF. The development of a simulation system is important for the pilot to get a better then the computer games theoretical training. Regarding the movements, the present systems offer only animation and special vision effects skipping the movement simulation.

The different types of flight simulator range from video games up to full-size cockpit replicas mounted on hydraulic, electric or electromechanical actuators [2, 4]. Flight simulators are extensively used by the aviation industry and the military for pilot training, disaster simulation and aircraft development. Today, there are various categories of flight simulators used for pilot training. Contrary to popular belief, flight simulators are not used to train pilots how to fly aircraft. Today's modern simulators are used by commercial airlines and the military alike, to familiarize flight crews in normal and emergency operating procedures. Using simulators, pilots are able to train for situations that they are unable to safely do in actual aircraft. These situations include loss of flight surfaces and complete power loss [7]. It is widely acknowledged that the cues provided by a good visual system provide the bulk of the realism in a flight simulator. However, it has also been shown that pilots consider the provision of consistent motion cues to add substantially to the realism of the simulation and to be helpful in the piloting task [1]. Thus, motion platforms are used on most modern high-end flight simulators in order to provide motion cues consistent with the visual, auditory and control-feel cues to which the pilot is also subjected. Within the motion-related subsystems, the area which has been the subject of the most consistent research effort is the washout subsystem which takes the motions generated by the aircraft equations of motion-which include very large displacements--and filters them to provide simulator motion-base commands. These commands must provide the pilot with realistic motion cues, while remaining within the simulator's motion limits [2].

2. MODELING OF A PARALLEL ROBOT FOR FLIGHT SIMULATOR

2.1. General description

Taking into consideration the imposed requirements for a flight simulator, which should have 6 DOF, the family of type Gough–Stewart parallel structures is the most used for start-up (figure 1).

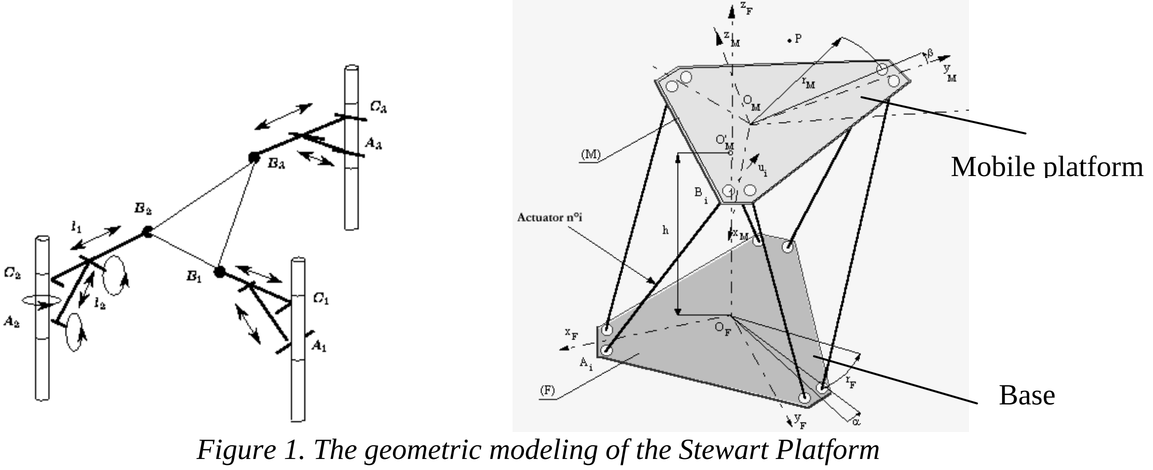


Figure 1. The geometric modeling of the Stewart Platform

Generally, these parallel structures consist of six mobile arms, connected to the base and mobile platform through spherical joints located at each end of the arm. The mobile platform materializes the end effecter. These kind of parallel structures are characterized by a robust mechanical structure and a high dynamic performance, a good ration between the manipulated mass and the own mass. The main difficulty is the complexity of the movement control. Thus the simulation is an important stage in order to test the capabilities of the robot and to develop the adequate control system.

2.2. System synthesis

For parallel mechanisms of F family the number of degrees of mobility is calculated with formula [5]:

$$M = (6-F)N - (5-F)C_5 - (4-F)C_4 - (3-F)C_3 - (2-F)C_2 - (1-F)C_1 \qquad (1)$$

where: M – mobility degree; F - mechanism family; N – number of elements; C_i – number of joints of i class; k – number of chains; n – number of the chain elements; c_i – number of joints of i class on a chain. The number of elements of a parallel mechanism is solving the equation (1) in integer numbers:

$$N = \frac{1}{6-F}[M + (5-F)C_5 - (4-F)C_4 - (3-F)C_3 - (2-F)C_2 - (1-F)C_1] \tag{2}$$

For parallel structures which have identical kinematic chains are the relations:

$$N = kn + 1C_i = kc_i \quad (i = 1,2,...,5;\ j = 0,1,...,4) \tag{3}$$

Using equation (3) it can be obtained the number of elements on a kinematic chain:

$$n = \frac{1}{k(6-F)}\{M - (6-F) + k[(5-F)c_5 + (4-F)c_4 + (3-F)c_3 + (2-F)c_2 + (1-F)c_1]\} \tag{4}$$

In our case F=0 and the mobility degree of the Stewart platform yields as M = 6 .

2.3. Inverse geometrical problem

In inverse geometric problem the actuation displacements are obtained with respect to the position and orientation of the mobile platform. An analytical solution could be obtained and applied in the control algorithms. For solving the inverse geometric problem the transformation matrices method was used, using the Euler angles [5,6].

Introducing the "constraint condition" for each kinematic chain by the dimensional function $F_i' \equiv \|A_i B_i\|^2 - q_i^2 = 0$ (q_i is the linear driving displacement), we have calculated the linear driving displacements q_i, in accordance with the following equation:

$$q_i = \sqrt{(X_{B_i} - X_{A_i})^2 + (Y_{B_i} - Y_{A_i})^2 + (Z_{B_i} - Z_{A_i})^2} \qquad i = 1,2,...,6 \tag{5}$$

where $X_{A_i}, Y_{A_i}, Z_{A_i}, X_{B_i}, Y_{B_i}, Z_{B_i}$ depend on the geometrical parameters and the coordinates of the end-effector Position and orientation).

3. GRAPHICAL SIMULATION OF SOME VARIANTS

The achieved geometric algorithms have been implemented in the developed simulation system [5], it consists of four main modules: Kinematics; Singularities; Workspace; Trajectory. For the graphical modelling three variants of Stewart-Gough platforms have been considered. In all cases the parallel structure mechanisms consist of 6 kinematic chains, every chain includes two elements: the driving and the driven element. Both elements are connected to the mobile platform by universal or spherical joints. The CAD models of the 6 DOF parallel robots are presented in figure 2, figure 3 and figure 4.

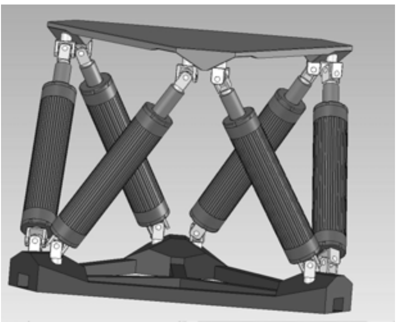


Figure 2. The model I

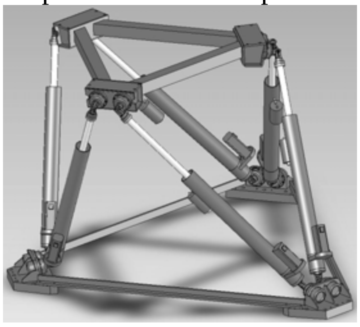


Figure 3. The model II

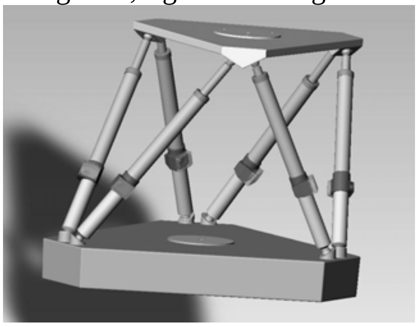


Figure 4. The model III

The model derived from Advanced Motion [10], figure 2, is equipped with twelve universal joints. The design allows the platform to move freely within the maximum excursion envelope without mechanical interference. The motion platform is a steel construction and the robot is actuated using six DC direct drive actuators. This kind of actuators requires minimal support device and offer a good drive and power supply. The second model derived from Rexroth Bosch Company [11], figure 3, is equipped with twelve universal joints too. The design ensures a very good mobility and dynamic behaviour. The motion platform is a steel construction and the driving is made by six electric servo-actuators assuring a good positioning control at high speed and drive forces. The model derived from Deltalab [12], figure 4, is equipped with twelve spherical joints. The major advantage in modelling and simulation of this kind of symmetrical structures is represented by the designing and modelling only for one kinematic chain which it is multiplied for six times. It is not necessary to modelling all six chains that conduct to reducing the total time of modeling of entire structure.

Within the simulation system the virtual graphical model was created, the 3D functional model allows the designer to understand its functionality. The geometric parameters can be modified within the 3D modelling software influencing the simulation environment. The assembly relations between the parts, subassemblies and between parts and subassemblies can be also modified. These facilities enable the possibility to develop a complex relations between the shape of the workspace, links and geometrical dimensions in order to optimize the parallel structure.

All component parts of the presented robots are parameterized modelled, for example the leg of the robot model II, figure 5. As can be observed the dimensions changes can be made very simple. The parameterized modelling allows creating applications, figure 6, correlated with the 3D software.

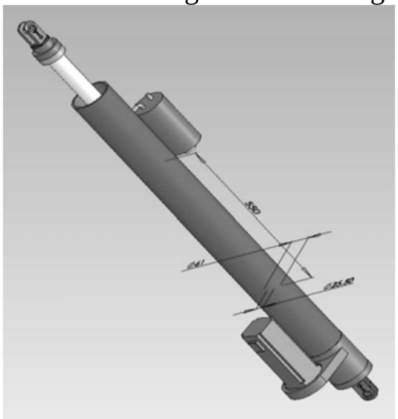
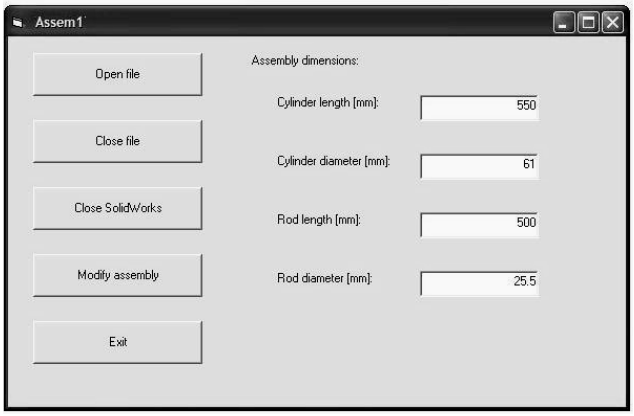


Figure 5. The leg of the robot model I.



Assembly dimensions:

Cylinder length [mm]: 550

Cylinder diameter [mm]: 61

Rod length [mm]: 500

Rod diameter [mm]: 25.5

Figure 6. VBA application.

4. CONCLUSION

Since parallel mechanisms have a complex structure modelling and simulation is not possible without special tools, the proposed approached will lead to solutions that increase the development efficiency.

The presented system was start to create flight simulators, enabling motion visualization, introduction of the kinematic model and extra conditions over the virtual robot, foreseen limit being the hardware computing capacity.

This system was conceived to diminish the costs, reduce the processing time, optimize the use of the resources for implementation or redesign and to assist the specialist for the investments planning. All the modules are designed as an open system that may be extended or modified as many times as the applications demands. The virtual robot advantages are doubled by high realistic environments offering the possibility to develop a robot motion planning considering the kineto-dynamic effects.

5. ACKNOWLEDGEMENTS

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