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THREE DEGREE-OF-FREEDOM MOVEMENT SIMULATOR CONTROL SYSTEM

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ABSTRACT

The simulator for implementing video synchronized three degree-of-freedom movements is considered in the paper. A mechanic part of the simulator is based on the parallel manipulator that is capable of realizing two-coordinate rotations and vertical movements. The approaches for solving both the inverse and direct kinematic problems are presented. The paper describes the control system that has been developed and implemented for the simulator considered. The control system includes a commands generation program, commands reproduction program and hardware controller. Principles that lay in the basis of the control system considered can be reused during similar simulators control systems prototyping.

Index Terms – Movement simulator, parallel mechanism, kinematic analysis, control system.

1. INTRODUCTION

Nowadays the movement systems constructed on the basis of parallel mechanisms are widespread in the spheres of robotics and machine building, especially there where the realization of the programmable spatial movements with given accuracy, good stability and high dynamic behavior is of special interest [1]. Parallel mechanism type selection to use in movement systems is primarily based on the requirements demanded to the complexity of movements and workspace. As it turned out the realization of three degree-of-freedom movements is sometimes sufficient for simulators and virtual reality systems. So, parallel mechanisms of simplified kinematic structure, driven only by three actuators, can be used to provide desired movements for such applications. That significantly optimizes the whole system from the point of its overall cost and construction complexity. However the task of the control system development for such applications is among the issues to solve.

The paper considers the simulator control system for implementing video synchronized three degree-of-freedom movements. As a mechanic part of the simulator is based on the parallel mechanism its brief structural analysis is presented as well. The control system modeling starts with an inverse kinematic problem solution. The inverse kinematic problem solution results in the algorithm, a core part of the control system, that connects parallel mechanism platform position and orientation with shafts angular coordinates of three actuators. The paper presents approached for solving both the inverse and direct kinematic problems.

The control system is implemented as a hardware and software package. The paper examines commands generation program, commands reproduction program and hardware controller that are main parts of the hardware and software package considered.

2. THREE DEGREE-OF-FREEDOM PARALLEL MECHANISM

The 3-DOF (three degree-of-freedom) movement simulator consists of a spatial parallel mechanism, three electric drives and control system. Visual image of the 3-DOF movement simulator is presented in Figure 1.

Figure 1 3-DOF movement simulator

A 3-DOF spatial parallel mechanism is composed of three independent legs connecting the mobile platform with the base. Each of these legs is a serial kinematic chain that is controlled by one electric drive that actuates one of the joints. A kinematic structure of the parallel mechanism is presented in Figure 2. The $A_1A_2A_3$ mobile platform is directly connected to O_1, O_2, O_3 actuators driving shafts by l_1r_1, l_2r_2, l_3r_3 kinematic joints.

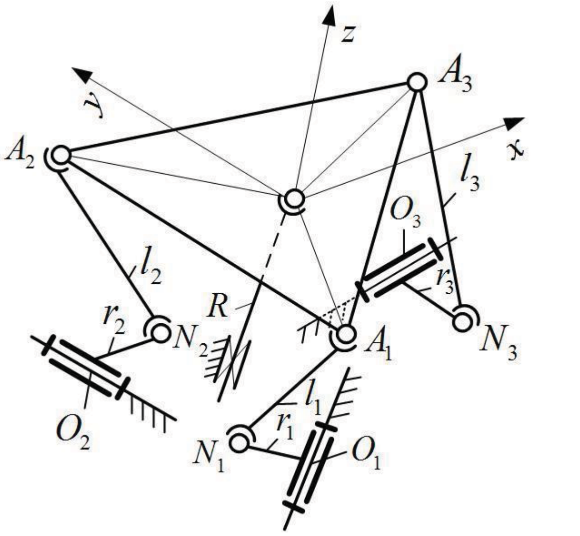

Figure 2 Parallel mechanism kinematic structure

An additional kinematic chain *R* consists of a vertically moving link that is connected with the base by a translational join and with the mobile platform by a spherical joint. The usage of this chain provides stability and rigidity of the whole mechanism.

The parallel mechanism supports *z*-axis displacements and two angular rotations (ψ – yaw, θ – pitch) of the mobile platform about *x* and *y* axes respectively. It provides a large amount of rigidity, or stiffness, for a given structural mass, and thus enables significant positional certainty.

3. KINEMATIC ANALYSIS

The algorithm that connects parallel mechanism platform position and orientation with shafts angular coordinates of three actuators has been put in the 3-DOF movement simulator control system to realize programmable movements of the mobile platform. The inverse kinematic problem has been formulated as the definition of the input variables (actuators shafts angular coordinates $\sigma_1, \sigma_2, \sigma_3$) out of the output variables (platform *z*-axis position and orientation ψ, θ).

Platform position and rotation matrix in a fixed coordinate system has the following view:

$$M = \begin{bmatrix} \cos\theta & \sin\theta\cdot\sin\psi & \sin\theta\cdot\cos\psi & 0 \\ 0 & \cos\theta & -\sin\psi & 0 \\ -\sin\theta & \cos\theta\cdot\sin\psi & \cos\varphi\cdot\cos\psi & z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Analytical conditions for kinematic links imposed on the platform motions can be expressed as:

$$\begin{aligned} \left|\vec{R}^{(A_1)} - \vec{R}^{(N_1)}\right| &= l_1, \\ \left|\vec{R}^{(A_2)} - \vec{R}^{(N_2)}\right| &= l_2, \\ \left|\vec{R}^{(A_3)} - \vec{R}^{(N_3)}\right| &= l_3. \end{aligned} \quad (2)$$

where $\vec{R}^{(A_i)}$ и $\vec{R}^{(N_i)}$ – radius vectors of points A_i and N_i of the parallel mechanism (Figure 2), presented in a fixed coordinate system.

Vectors $\vec{R}^{(A_i)}$ can be expressed through matrix M:

$$\vec{R}^{(A_i)} = M \cdot \overline{R}_{(A_i)}, \quad (3)$$

where $\overline{R}_{(A_i)}$ – radius vectors of points A_i, presented in a platform coordinate system.

Conditions (2) and (3) were used for the inverse kinematic problem calculation algorithm working out.

For the case of the investigated mechanism the direct kinematic problem solving implies the determination of the output variables (platform *z*-axis position and orientation ψ, θ) out of the input variables (actuators shafts angular coordinates $\sigma_1, \sigma_2, \sigma_3$). As it turned out of the geometric analysis carried out the direct kinematic problem is a difficult task to be solved only by an analytical geometric approach. The more convenient way is to apply optimization methods to solve the equations set that connects the input variables with the outputs. As a result the appropriate computing program for direct kinematic problem solving has been implemented in MATLAB/Simulink environment deploying the Optimization Toolbox. The optimization is based on Levenberg-Marquardt and Gauss-Netwton algorithms.

4. SIMULATOR CONTROL SYSTEM

A new developed simulator is intended for implementing specified laws of motion in a three-dimensional space. The simulator on a hardware and software level can simply be represented in the following structure chart (Figure 3). The simulator control system consists of a commands generation program, commands reproduction program and hardware controller. The commands generation program renders and splits input video data into scenes, enables to set platform position and orientation for every scene, generates appropriate control commands in XML format for every scene. The interface of the commands generation program is presented in Figure 4.

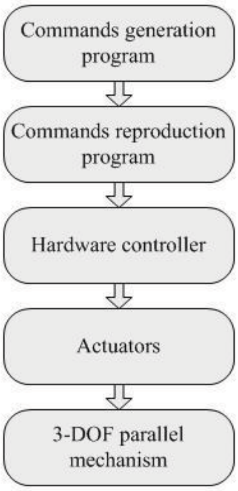

Figure 3 Simulator structure chart

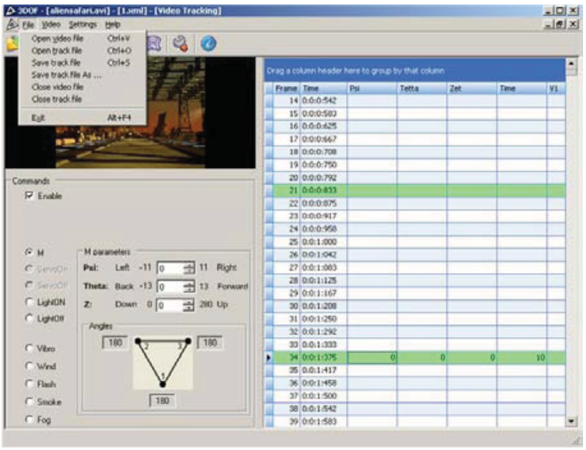

Figure 4 Commands generation program interface

The commands generation program stores results in xml-file that is the input data source for the commands reproduction program. The program consists of the following main modules:

− *Video data rendering module*. The module enables to associate and synchronize input video file data with platform control commands. The module was developed with the help of Microsoft.DirectX and Microsoft.PlayBackPlayer libraries;

− *Input-output module*. The module provides data input-output and displays the working characteristics in a real time mode. It also enables data output of current platform position, instructions execution time, calculated velocities and accelerations of actuators shafts, information about execution errors occurred;

− *Inverse kinematic problem solution*. The module implements the inverse kinematic problem solution for the given platform position and orientation;

− *Performance characteristics calculation module*. The module implements actuators performance characteristics calculation to provide the specified law of motion of the mobile platform;

− *Optimization module*. The optimization module aims to increase performance and operation life of the three 3-AC motors used in the movement simulator. The module is intended for optimizing the commands execution sequence so that to minimize the cases of reversible operation mode of the motors. It’s achieved by minimizing the reversible angular motions of the motors shafts in the area of 90° and 270° (Figure 5).

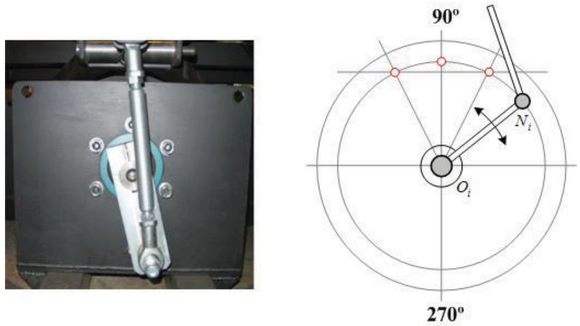

Figure 5 Motors shafts motions

The commands reproduction program is intended for reading the generated control commands and interaction with the hardware controller via RS-232C interface.

The hardware controller is a Mitsubishi FX3U-48 controller with software installed. It interacts with the commands reproduction program, implements received control commands, and reports about errors occurred if any. The hardware controller controls three 3-AC motors through Mitsubishi FR-A700 inverters. The inverters have special setups for a selected functional mode. The deployment of FX series controller in conjunction with FR-A700 inverter is recommended by Mitsubishi Electronics company for position control systems containing asynchronous motors [2]. The advantage of this circuit is in information interoperability on all levels of interaction.

The deployment of the considered hardware and software package allowed to create the three degree-of-freedom movement simulator TVR-4D-3DOF-6S that provides the dynamic platform motions with the following performance characteristics: platform up-down motion of ±0,28 *m*, pitch angle of ±14º, roll angle of ±13º, maximum platform velocity and acceleration of 0,56 *m/s* and 0,9 m/s^2 respectively.

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