DEVELOPMENT OF THREE-DIMENSIONAL ANIMATION OF SPHERICAL MOTION PLATFORM USED IN VIRTUAL REALITY SYSTEMS

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Abstract: the paper is concerned with development of the high-performance and simple system of the motion effect simulation on the operator and his working place. In result of scientific-research work the multipurpose, simple and reliable mechanical system for spherical motion reproducing of the operator work place has been designed. Developed animation model of spatial motion visualization of the platform and operator permits to evaluate the overall dimensions of the motion simulator, possible position area of operator, determine the ways of compact prototype creation and script of man body motion in space. Description of different types of movable platforms**,** geometry of the spherical motion platform on the basis of the four-bar linkage and its three-dimensional model has been presented.

1. Description of the research object

Motion simulators are widely applied in virtual reality systems: trainers for truck drivers and aircraft pilots; entertainment; medical research application. The motion simulator is planed to use also in telexistence technology [1], giving a human being to have a real-time sensation of being at a place other than where he or she actually exists and being able to interact with the remote environment by means of master-slave robotic system. Remote environment can be real, virtual or a combination of both.

The purpose of the motion simulator is to give perception of continuous dynamic motion inside a vehicle or robot to the human nervous system. It is accomplished by a combination of realistic audio and visual presentation, which generates inputs of the human physiological system. In driving simulators, the driver interacts with a virtual vehicle model reproducing the behavior of a real vehicle under given environmental conditions (road, wind) and under given driven commands (action on steering-wheel, pedals). Motion perception is obtained by means of the simulator cabin movement generated by a computer model. The cab is moved by platform ideally reproducing the motion of a seat of the vehicle driver. Thus the kinematic parameters of the real actions of moving vehicle, included in computer model are transformed into platform motion variables, producing an equivalent motion perception to the driver.

Up-to-date motion simulators can be classified into two categories:

- ✓ Fixed-base simulators, which generate image and sound in order to produce the sensation of continuous motion perception. These low-cost systems are used for entertainment and also for driver training application.
- ✓ Moving-base simulators: they are complex and expensive systems as generate motion sensation by the use of hydraulic or electric, or pneumatic moving platform, complemented with reproduction of the visual-audio cues. Motion cues, received by nervous system of the human vestibular apparatus, are fundamental for many fields of application.

Let's consider briefly several fundamentally different kinematic schemes and real constructions used in moving-base motion simulators: Gough-Stewart platform; spherical platform based on arc guiding rails. *Gough-Stewart platform* – six-degree of freedom (DOF) parallel mechanism with six identical kinematic chains, composed of a universal joint, a prismatic actuator, and a spherical joint. *Parallel mechanism* – closed-loop mechanism in which the mobile platform is connected to the base by at least two independent kinematic chains. In order to change the position of the mobile platform relative to the base all the six legs move in a coordinated direction and produce the desired displacement. Gough V.E. and Whitehall S.G. devised a six-linear jack system for use as a universal tire testing machine [2]. Stewart D.A. developed a six-degree of freedom platform manipulator for use as an aircraft flight simulator [3]. *Advantages* of the Gough-Stewart platform: high-precision motion in space; great stiffness; operates with high velocity and acceleration. *Disadvantages* of the Gough-Stewart platform: small workspace; extremely difficult displacement analysis and direct kinematic formulation; significant friction in the ball joints; large cost of the precise spherical joints.

Spherical motion platform using arc guiding rails was developed during project SIMUSYS: "*Innovative high-performance motion simulation system for entertainment, research and training applications*" in the university of Saragossa (Spain) [4]. The SIMUSYS driving simulator is formed by 4-DOF spherical motion platform providing 3 rotation motion (roll, pitch and yaw) around the 3 axis; 1 translation motion (heave, along the Z-axis); a driving-post compatible with the motion platform; a image and sound generation system (*Fig.1*). The basic spherical surface is created by means of curved sliding guides.

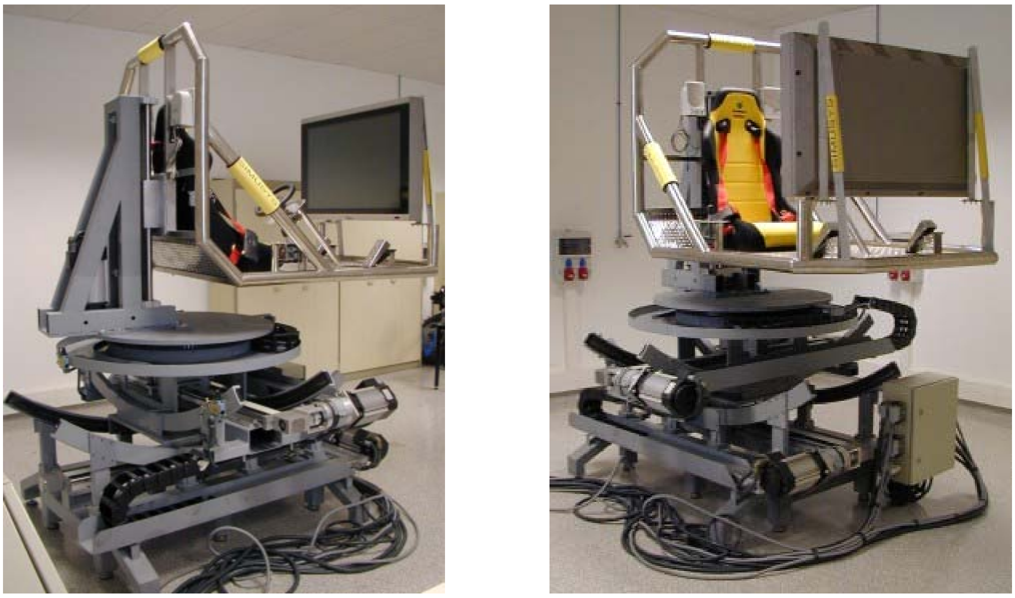

Fig.1

Advantages of the spherical motion platform: motion realization does not require coordinate transformation; very small friction loss as far as roll and pitch motions are based on sliding guides; wide range of operator positions in space; relatively small energy consumption. *Disadvantages*: difficult realization of the curved sliding guides with high-quality working surface; providing the safe zone for alongside objects is required; reduced motion fidelity because of system application with 4-DOF.

The purpose of presented scientific work was development of the rational variants of the movable platform of the spherical motion on the basis of four-bar linkage in order to create simulator with more simple structure in comparison with above-mentioned types, sufficient fidelity of motion and small energy consumption. In addition the restrictions about sphere of permissible positions of operator cochlea center with radius r=10 mm and angle of chair tilting to the vertical axis for extreme positions α=20° should be secured.

2. Geometry of the of the spherical motion platform on the basis of the four-bar linkage

It is well known, that linkages are applied for end-effector displacement on compound trajectory. Trajectory of the motion of the spherical platform center in projections on plain represents symmetrical arc relatively vertical axis *Z*. In order to create this trajectory to make the most efficient use of the four-bar linkage with equal length of input and output crank. Spherical motion simulation by using second four-bar linkage located orthogonally to the first one sophisticates structure and considerably magnifies the overall dimensions. To simplify design the scheme with usage of one four-bar linkage mounted on the platform making rotational motion relative to the vertical axis *Z* has been developed. Thus the spherical motion has been realized by combination of tilting motion created by the four-bar linkage and rotational motion of the supporting platform. Operator tilting simulation in the plane orthogonally to the four-bar linkage position is created by Coriolis force acting on the operator head. The scheme of the four-bar linkage being used as base is shown in *Fig.2* with the following designations: 1 – input crank; 2 – connecting rod; 3 – output crank; l_1 – length of the input crank; l_2 – length of the connecting rod; l_3 – length of the output crank; *A, B, C, D* – lower kinematic pairs. The closed vector loop approach has been applied for geometry and kinematic analysis of the platform on the basis of four-bar linkage [5]. The link positions are defined by the angles φ_2, φ_3 under given value of angle φ_1. In order to determine the main geometric relationships expediently to consider two vector loops *ABD* and *BCD*.

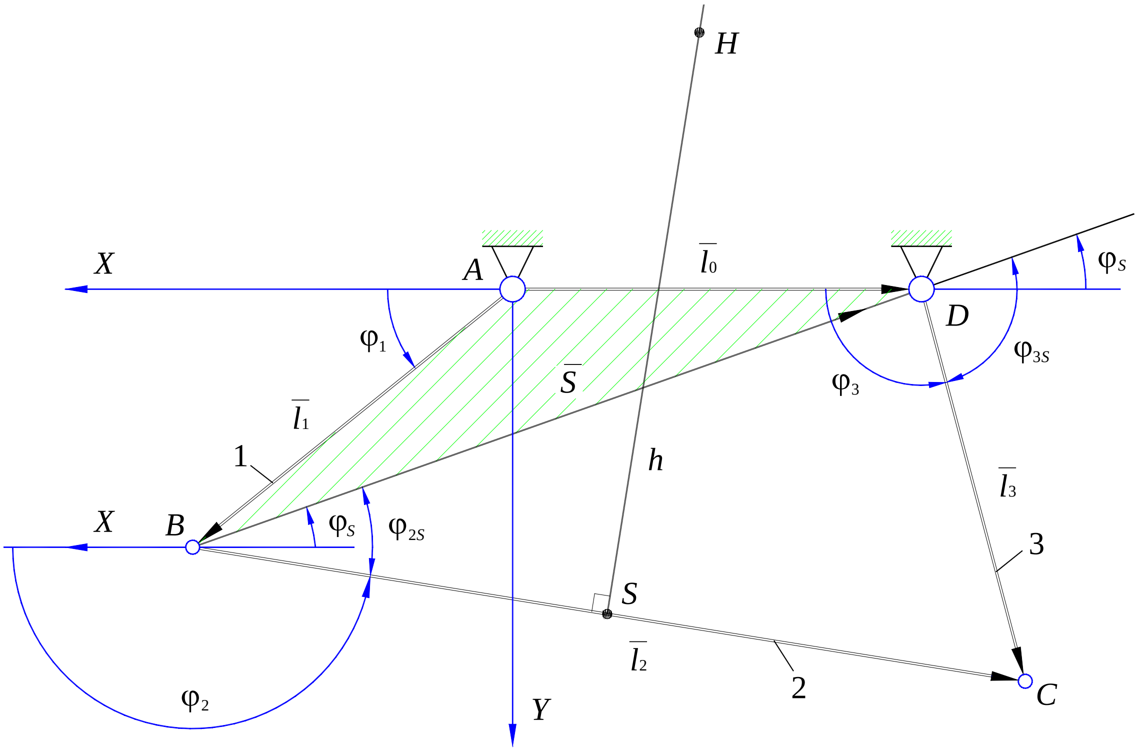

Fig.2

The vector equation for *ABD* contour is expressed as:

$$\bar{l}_1 + \bar{S} = \bar{l}_0 \tag{1}$$

To this vector equation correspond two scalar equations, representing the vector projections on the orthogonal axis *X* and *Y*:

$$\begin{cases} l_1 \cdot \cos\varphi_1 + S \cdot \cos(\varphi_S - \pi) = -l_0 \\ l_1 \cdot \sin\varphi_1 + S \cdot \sin(\varphi_S - \pi) = 0\,. \end{cases} \tag{2}$$

Then:

$$\operatorname{tg}(\varphi_S - 180) = \frac{l_1 \cdot \sin\varphi_1}{l_0 + l_1 \cdot \cos\varphi_1} \tag{3}$$

Hence, the angle φ_S can be defined from:

$$\varphi_S = \pi + \operatorname{arctg}\left(\frac{l_1 \cdot \sin\varphi_1}{l_0 + l_1 \cdot \cos\varphi_1}\right) \tag{4}$$

The module of the vector *S* is written as:

$$S = \left| -l_1 \cdot \frac{\sin\varphi_1}{\sin\varphi_S} \right| \tag{5}$$

And from Δ*BCD* we have two equations:

$$\begin{cases} l_2^2 = l_3^2 + S^2 + 2 \cdot l_3 \cdot S \cdot \cos\varphi_{3S} & (6) \\ l_3^2 = l_2^2 + S^2 - 2 \cdot l_2 \cdot S \cdot \cos\varphi_{2S} & (7) \end{cases}$$

Then, from Eq.6:

$$\varphi_{3S} = \arccos\left(\frac{l_2^2 - l_3^2 - S^2}{2 \cdot l_3 \cdot S}\right) \tag{8}$$

From Eq.7:

$$\varphi_{2S} = \arccos\left(\frac{l_2^2 - l_3^2 + S^2}{2 \cdot l_2 \cdot S}\right) \tag{9}$$

The angle φ_2 between the connecting rod and X axis is calculated from the Eq.(10) and the angle φ_3 between the output crank and X axis is calculated from the Eq.(11):

$$\varphi_2 = \varphi_S - \varphi_{2S} \tag{10}$$

$$\varphi_3 = \varphi_S - \varphi_{3S} \tag{11}$$

As far as the restriction area of the operator head center positions and angle of chair tilting α to vertical axis Z for extreme positions are given, then to meet these conditions it is necessary to determine the coordinates of the operator head center and connecting rod center (the attachment place of the chair and platform coincides with the connecting rod center in projections on frontal plane) under input crank rotation. It is convenient to attach the coordinate system center to the point S located on the middle of line BC under equilibrium state of four-bar linkage while Y axes is directed to the upward. Then coordinates of the connecting rod center under movement are determined by the equation system:

$$\begin{cases} X_S = \frac{l_2}{2} \cdot \cos(\pi - \varphi_2) - l_1 \cdot \cos\varphi_1 - \frac{l_0}{2} \\ Y_S = \sqrt{l_1^2 - \frac{(l_2 - l_0)^2}{4}} - \left(\frac{l_2}{2} \cdot \sin\varphi_2 + l_1 \cdot \cos\varphi_1\right) \end{cases} \tag{12}$$

Coordinates of the operator head center H under movement can be derived from the equation system:

$$\begin{cases} X_H = X_S + h \cdot \sin\varphi_2 \\ Y_H = Y_S + h \cdot \cos(\pi - \varphi_2), \end{cases} \tag{13}$$

here h – the distance from the connecting rod center S up to the operator head center H (1220 mm).

The program for graphical modelling of motion of the four-bar linkage and head centre has been developed using C++. The image of computation result integrating into AutoCAD environment has been presented in *Fig.3* (upper curve – trajectory of the operator head centre; lower curve – connecting rod centre).

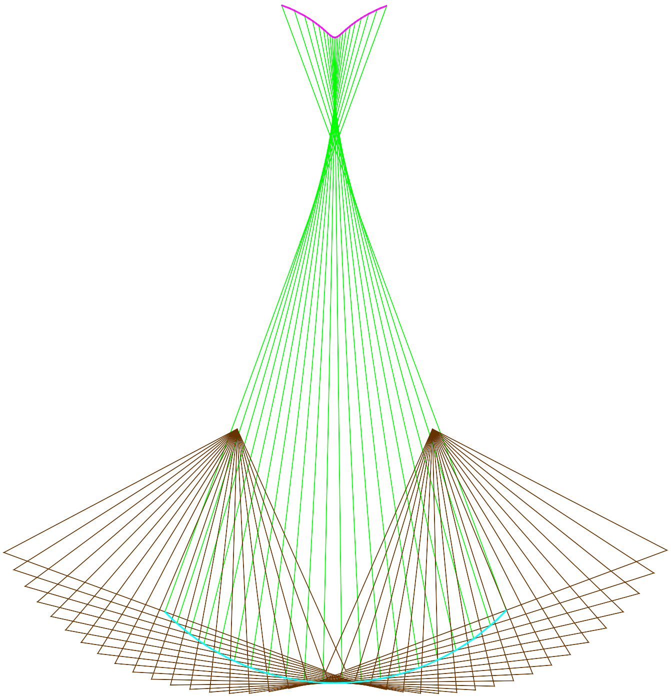

Fig.3

3. Development of three-dimensional animation of the motion simulator platform

The rational prototype of the four-bar linkage with requirement account of minimum value of required power of motor, compact size and minimum acceleration of the operator head center has been accepted on the basis of results obtained during geometry, kinematic, force analysis and synthesis. After calculation of main component strength the three-dimensional assembly of the motion simulator has been created using SolidWorks (*Fig.4*). Animation of spherical platform operation has been obtained by simultaneous rotation of the supporting platform and tilting motion of the four-bar linkages and written in *.avi* format.

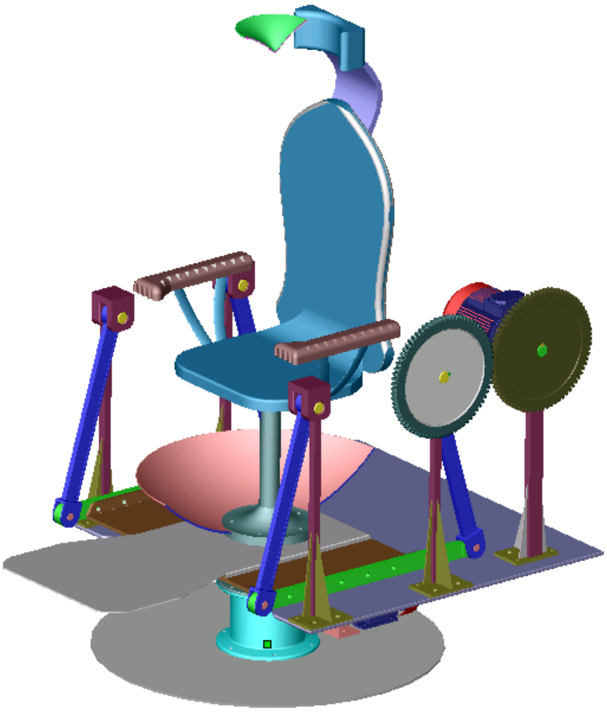

Fig.4

4. Conclusions

Developed construction of the spherical motion platform permits under simplicity of the main detail manufacturing and low system cost to diminish the overall dimensions of structure in 1,8 times and reduce the required motor power in 1,4 times in comparison with analogs. The given dependences obtained under kinematic, force analysis, synthesis and calculation of main component strength allow to design similar mechanisms for application system creation. Animation model of spatial motion visualization of the platform and operator permits to evaluate the overall dimensions of the motion simulator, possible position area of operator, determine the ways of compact prototype creation and script of man body motion in space. Thus the results of performed scientific research can be taken as basis of creation of the fundamentally new general-purpose equipment for application in virtual reality systems, which requires minimal investment of financial resources. This research was performed under supporting of Centre de Robotique Integree d’lle de France.

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