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Sliding Movement Platform for Mixed Reality Application

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Abstract: This paper deals with the conception of a new 6 DoF (Degree of Freedom) platform to reproduce natural motion feeling when the human is completely merged in mixed reality environments. The proposed system is open and supposed to be flexible and adaptable to three different applications: sport, health and rescue. In this paper, we focus on the sport simulation domain, namely the ski sliding movement. We present the mechanical study of this platform, the 6 DOF motion modelling and some mechatronics aspects.

Keywords: Sliding movement, Virtual environment, Mixed reality, Mechanical design, Mechatronic synoptic diagram.

1. INTRODUCTION

3D Interactions in mixed reality environments and their integration in industry, have taken a major boom in recent years and many approaches have been developed. The combination between physical systems and virtual tools is the key issue to conceive and validate this kind of modern platforms. Besides, this type of mechatronic systems is closely depending on new technologies that emerge, namely in actuators and sensors domains. Last years, several simulator systems have been designed especially based on 6 DoF motion platforms. Thus, driving simulators are the most popular examples, they were used in various areas like entertainment, prototyping, research and advanced training (J.S. Freeman et al., 1995; G.Reymond et al., 2000; L. Nehaoua et al., 2011). The main research areas concern typically the driver behavior study (drugs and tiredness effects) (F.Colombet et al., 2008), the human machine interface (HMI) and the validation of new subsystems in vehicles. Nevertheless, motion platforms have been used in other domains as: flight simulators navigation (J.C.F.De Winter et al., 2012) and medical rehabilitation (J. Fung et al., 2004). Moreover, most of these motion simulators use parallel Stewart-Gough platforms where the research works focused in particular on kinematics and dynamics analysis (D. Stewart, 1965; J.B. Sol et al., 2009). However, this kind of simulators has several known disadvantages and challenges, including: high cost, limited behavioural fidelity and discomfort.

Furthermore, several researches proved that Virtual Environment techniques can be used to assess trainee's skills and improve their behaviour in real world while reducing training time, costs and errors (D. Kaufman et al. 1997).

Indeed, virtual reality techniques provide an efficient way to enable people to interact efficiently with 3D objects in virtual environment using their natural senses. Several robust approaches on 3D tracking (F. Ababsa et al., 2006; F. Ababsa , 2011), and natural interaction (S. Ullah et al., 2008) have been developed and evaluated on our Immersive Virtual Reality Evr@ platform.

The main contribution of this paper is the design of 6 DoF motion platform, which should reproduce a real sliding movement in a virtual environment, in particular for ski sport, without using snowy slopes and independently on weather conditions (figure 1).



Fig. 1. Sliding simulator

In order to enhance the perception of realism, our system must support the natural human motion and the real-time rendering of the stereoscopic view on large scale screen. The goal is to offer an accessible and cost-effective Virtual Environment that simulates sliding activities for training professional skier or amateur one who received little or no experiential practices in this sport. In our best knowledge, the most existing platforms for ski training have limited DoF number and could not reproduce a natural human sensation corresponding to the real motion. Our motivation is to extend the degree of freedom to make the simulation experiment more realistic.

The remaining of the paper is organized as follows: Section 2 gives a detailed description of the proposed sliding motion platform; a complete study of the mechanical design is presented with the mechatronic synoptic diagram of the principle blocs. Section 3 gives a modelling issue for the kinematics and the dynamics of the 6 DoF platform. Finally, a conclusion and further works are provided.

2. SLIDING PLATFORM

This project aims to provide the platform Evr@ with a 6 DoF motion simulator able to put a person in natural moving situation within mixed reality environment. The purpose is thus to study the human sensory behaviour in an immersive context, in particular, during a ski scenario. In this section, the platform specifications are presented in details.

1.2 Evr@

The EVR@ platform is a 3,20m 2,40m semi immersive platform with an active stereoscopy display (figure 2). There exists two tracking possibilities to interact with the virtual environment: the ART Track system which is very accurate and composed of two ARTTrack infrared cameras detecting position and orientation of objects with markers (as in figure 2). Our sliding platform should be integrated with Evr@ to simulate natural body movement in immersive scenarios. In this case, a person will be equipped by markers and tracked by ART track system in order to localize him in the workspace and hence allowing the feedback scenario - motion.

Evr@ platform uses the ART Tracking System to measure simultaneously the position and the orientation of the body. Indeed, the body is equipped by light reflecting markers (retro-reflectors). Two ARTTrack cameras, disposed on both sides of the screen, scan the space work and detect the light that comes from the markers. Their images are processed to identify and calculate potential marker positions (in image coordinates) with high accuracy; a mean accuracy of 0.04 pixels is standard in ART tracking systems. These 2 DoF data are combined to compute the 6 DoF poses of a rigid arrangements of several markers. The result of each measurement are coordinates that describe the position of the markers, and hence the position and orientation of the body carrying the markers. Hence, the used ART Tracking System allows to track the body gesture

when moving in front of the projection screen (up to 4.5 m wide).



Fig. 2. Evr@ virtual reality platform with the 6 DoF mechanical system

1.2 Mechanical design

The mechanical structure is the interface between the slider and the simulation environment. It consists on a 6 DoF Gough-Stewart platform mounted on a 2 DoF x-y table.

The x-y table carries both the 6 DoF platform and the slider. By means of a set of sliders assembled as shown in figure 3, the 6 DoF platform can move on a rail that is 1.60 m long.

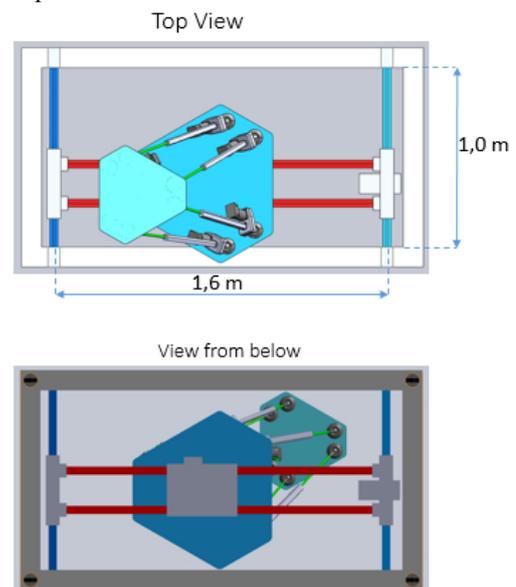


Fig. 3. CAD figure of the x-y table

To this end, a hybrid Nanotec PD4 motors is fixed at a mechanical stand related to the platform's rails. The motor rotation is transformed into a longitudinal motion, which is due to a ball screw-up system. This platform achieves steady linear accelerations up to 0,66g.

To control the 6 DoF motion, six legs have been mounted in parallel between the lower base and the upper platform's chassis frame (figure 4). The various legs consist of two electro thrusts incorporating a high-quality ball screw drive. Each leg is connected on one side, to the lower frame of the simulator by a cylindrical joint, and on the other side by a spherical joint. The six electro thrusts are driven by a hybrid Nanotec PD4 servomotor.

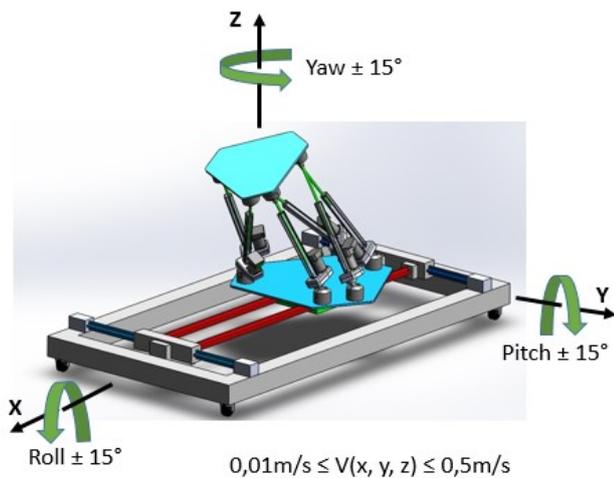


Fig. 4. CAD figure of the 6 DOF Gough-Stewart platform and its possible degrees of freedom

On the other side, the upper part of the Gough-Stewart platform is managed such that the slider can hold its equilibrium during the simulation of a given scenario. For this, a ski equipment (camber and boots) are installed on the upper 6 DoF platform with adequate fixations (figure 5). The ski equipment is provided with force sensors to measure the slider force, from his legs and feet, applied on the upper platform. This measurement will be used by the virtual slider dynamics and the platform's trajectories planning blocs.

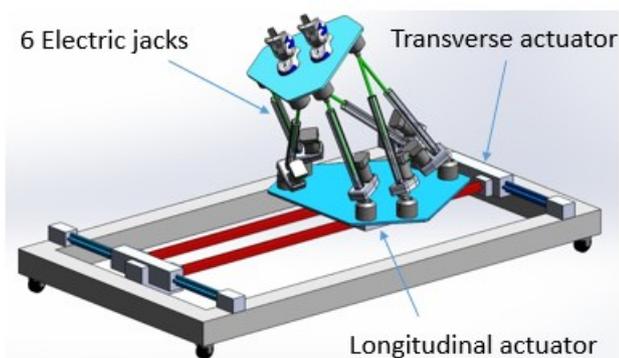


Fig. 5. CAD figure of the 6 DOF Gough-Stewart platform with ski equipment

2.3 Simulator architecture synoptic

The simulator architecture consists on various mechatronic components as it is shown in the synoptic of figure 6. These components are described below.

Visual environment: very common bloc in a simulation environment (driving simulation, flight simulation and others). It provides the visual cues. It is intended for the construction of a 3D virtual environment based on saved database image. Other tricks are added such wind effect, snowflakes and sound to improve the simulation rendering quality. On the other hands, the visual environment received information about slider gesture and posture to compensate for horizon and prevent the slider from the simulator sickness.

Platform's driver: this bloc includes all the embedded system for controlling, power supplying and managing the mechanical platform and sensors. In fact, the platform receives from the trajectories planning bloc only the reference trajectory to be achieved with a desired position, velocity and torque. In the other hands, sensors' signals are transmitted via bus data. No control is computed outside the servomotor drives. This is an important issue to minimize delays which are considered as the most problem for a worse simulation quality (S.K. Singhal et al., 1995). As in driving simulation, the first objective is to create a sensation which should be interpreted as a good cue by the slider. The restitution of full-scale motion or a good reference tracking is not the primary objective in a dynamic simulation.

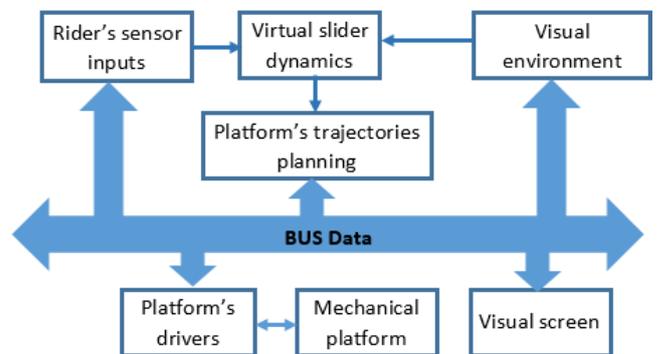


Fig. 6. Simulator mechatronics architecture

Virtual slider model: the slider moves with respect to the visual cues and follows a predefined ski trajectory. However, to achieve this task, we need a slider dynamic model to update the visual environment and mechanical platform position and orientation. In driving simulation, the driver interact with the virtual environment through an instrumented steering wheel and a set of various pedals. These information are used to simulate a virtual vehicle dynamics (H. Arioui et al., 2009). However, in the present case, the slider acts with the virtual environment only through its space posture which creates efforts applied on the upper mobile part of the 6 DoF platform. For this, as described above, the ski equipment is provided with force sensors (under boots) where their signals can be merged with other gesture sensors. The gesture sensor are used to compute, in real time, the slider posture position and orientation by using a simple Kinect or more sophisticated

home platform, Evr@. This solution is less computation consuming compared to the use of slider biomechanical model.

Platform's trajectories planning: to actuate the mechanical platform, a real time trajectory generation must be accomplished. The trajectory should be in concordance with the slider actions, the mechanical platform position and the projected visual scenario. Unless, the simulator sickness can be cause by the lack of coherence between these three entities. In addition, since the platform has a limited kinematics workspace, a special algorithms like washout filters must be employed (S.F. Schmidt and al., 1970; H. Arioui et al., 2010; L. Nehaoua et al., 2008), the washout allows repositioning the platform at its neutral position, under the slider perception's threshold, to start a new acceleration-deceleration cycle.

Nevertheless, unlike the driving simulation, in ski, the slider is in direct contact with a very unevenness ground. This feature must be taken into account by the motion cueing algorithms used in the trajectory generation. More specifically, the x-y moving table will be used to generate longitudinal and lateral acceleration cueing. The 6 DoF, will be used to simulate road unevenness, the roll and the yaw motions.

3. MODELING ISSUES

In this section, the kinematics and dynamics modelling of the mechanical platform is discussed. In particular, the inverse geometric model is presented which allows to give the platform legs elongation with respect to the reference trajectory computed by the trajectories planning bloc. The dynamics model will help in the choice of the appropriate servomotor to be used for the platform actuation.

3.1 Inverse kinematics model

Inverse kinematics consists of defining the actuation joint coordinates, which are the legs' elongations, with respect to the Cartesian coordinates and orientation of the mobile platform.

The present simulator is based on a parallel 6 DoF platform. A base reference frame $R(o, i, j, k)$ is defined at the centre of the platform's base. Next, a body reference frame $R_p(p, i_p, j_p, k_p)$, is attached to the centre of the platform's upper part (figure 7). Each legs is attached to the base at point b_i and to the upper part at point c_i . The configuration of the body frame R_p is characterized by the position vector $r_{op} = [x, y, z]^T$ of its origin p and three Euler orientation angles vector $[\varphi, \theta, \psi]^T$, corresponding to the roll, pitch, and yaw, respectively. Taking the ZYX convention, the rotation matrix is computed as follows:

$$\mathcal{R} = \mathcal{R}_\psi \mathcal{R}_\theta \mathcal{R}_\varphi \quad (1)$$

It is known that legs elongation can be computed by:

$$l_i^2 = r_{b_i c_i}^T r_{b_i c_i} \quad (2)$$

Where $r_{b_i c_i}$ is the position vector associated with each leg:

$$r_{b_i c_i} = r_{b_i o} + r_{op} + \mathcal{R} r_{p c_i} \quad (3)$$

Vectors $r_{b_i o}$ and $r_{p c_i}$ are constant and expressed in their reference frames. The orientation of the reference frame R_p with respect to R is given by the transformation matrix \mathcal{R} .

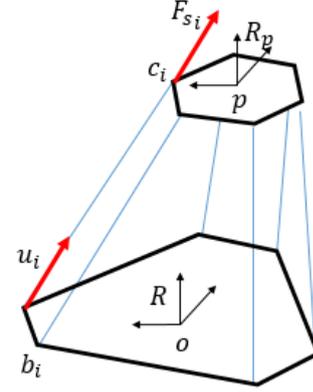


Fig. 7. 6 DoF platform's kinematic

The legs position rate are given by differentiating equation (2) with respect to time, which leads to the well-known equation:

$$\dot{l}_i = [u_i^T (\mathcal{R} r_{p c_i} \times u_i)^T] \begin{bmatrix} \dot{r}_{op} \\ \omega_{op} \end{bmatrix} = \mathcal{J}_{-1} \dot{q} \quad (4)$$

Where q is the upper platform configuration vector, \mathcal{J}_{-1} is the inverse Jacobean matrix and ω_{op} is the body frame angular rate which can be expressed with respect to the roll-pitch-yaw angles vector as following:

$$\omega_{op} = \gamma \dot{q}_r \quad q_r = [\varphi, \theta, \psi]^T \quad (5)$$

3.2 Inverse dynamics model

In this section, a simple dynamics formulation of the 6 DoF platform will be demonstrated. The primary objective is to propose a control scheme adapted for our sliding application and to characterize the platform's capabilities. We suppose that the 6 DoF platform and the x-y table are completely decoupled. Also, the legs dynamics is assumed to be small with respect to the platform's upper part dynamics and slider dynamics. Hence, the system is composed by four bodies: the platform's upper part, the slider's bust and the two slider's legs. Finally, the slider motion is considered to be free with respect to the platform motion.

The inverse dynamics model is derived from the Jourdain's principle (G. Rill, 1997). The equation of motion is expressed by: $M \dot{v} = Q$. Here, $\vartheta = [u_{op}^T, \omega_{op}^T]^T$

Where: $u_{op} = [u_x, u_y, u_z]^T$ and $\omega_{op} = [p, q, r]^T$ are the position and angular rates of the platform's upper part in its body reference frame.

The mass matrix M is given by:

$$M = \sum_{i=1}^4 m_i \left(\frac{\partial v_{oi}}{\partial \vartheta} \right)^T \frac{\partial y}{\partial \vartheta} + \left(\frac{\partial \omega_{oi}}{\partial \vartheta} \right)^T I_i \frac{\partial \omega_{oi}}{\partial \vartheta} \quad (6)$$

And the generalized effort vector Q is the sum of the generalized external effort Q_a and the generalized residual accelerations effort Q_R given by:

$$Q_a = \sum_i \left(\frac{\partial v_{oi}}{\partial \vartheta} \right)^T F_i + \left(\frac{\partial \omega_{oi}}{\partial \vartheta} \right)^T M_i \quad (7)$$

$$Q_R = \sum_i m_i \left(\frac{\partial v_{oi}}{\partial \vartheta} \right)^T a_{R,i} + \sum_i m_i \left(\frac{\partial v \omega_{oi}}{\partial \vartheta} \right)^T (I_{i \in R} + \omega_{oi} \times I_i \omega_{oi})$$

In the body reference frame R_p , the linear and angular velocity vectors of the slider's legs ϑ_{oj_i} , ω_{oj_i} and bust ϑ_{os} , ω_{os} are given by:

$$\begin{aligned} \vartheta_{oj_i} &= \vartheta_{op} + \omega_{op} \times r_{pj_i} + \dot{r}_{pj_i} \quad i = 1, 2 \quad (8) \\ \vartheta_{os} &= \vartheta_{op} + \omega_{op} \times r_{ps} + \dot{r}_{ps} \\ \omega_{oj_i} &= \omega_{op} + \omega_{pj_i} \\ \omega_{os} &= \omega_{op} + \omega_{ps} \end{aligned}$$

In this equation, the angular rate ω_{pj_i} of slider's legs are neglected. Consequently, the mass matrix is given by:

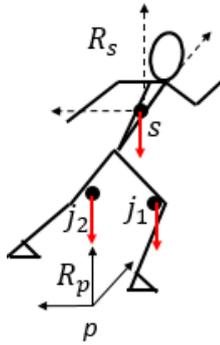


Fig. 8. Slider kinematic

$$M = \begin{bmatrix} \sum_{i=1}^4 m_i I_3 & -\sum_{i=1}^2 m_{j_i} \tilde{r}_{pj_i} - m_s \tilde{r}_{ps} \\ * & \sum_{i=1}^4 I_i + \sum_{i=1}^2 m_{j_i} \tilde{r}_{pj_i}^2 - m_s \tilde{r}_{ps}^2 \end{bmatrix} \quad (9)$$

The * symbol means that the mass matrix is symmetric.

Next step is to compute the residual acceleration to evaluate Q_R . Form (L. Nehaoua et al., 2013), the linear and angular acceleration vectors of the slider's legs a_{oj_i} , ϵ_{oj_i} and bust a_{os} , ϵ_{os} are given by:

$$a_{oj_i} = \dot{\vartheta}_{op} + \dot{\omega}_{op} \times r_{pj_i} + \ddot{r}_{pj_i} + \omega_{op} \times (\vartheta_{oj_i} + \dot{r}_{pj_i}) \quad (10)$$

Where: $a_{R,j_i} = \ddot{r}_{pj_i} + \omega_{op} \times (\vartheta_{oj_i} + \dot{r}_{pj_i})$

$$a_{os} = \dot{\vartheta}_{op} + \dot{\omega}_{op} \times r_{ps} + \ddot{r}_{ps} + \omega_{op} \times (\vartheta_{os} + \dot{r}_{ps})$$

Where: $a_{R,s} = \ddot{r}_{ps} + \omega_{op} \times (\vartheta_{os} + \dot{r}_{ps})$

$$\epsilon_{oj_i} = \dot{\omega}_{op} + \omega_{op} \times \omega_{pj_i} + \dot{\omega}_{pj_i}$$

Where: $\epsilon_{R,j_i} = \omega_{op} \times \omega_{pj_i} + \dot{\omega}_{pj_i}$

$$\epsilon_{os} = \dot{\omega}_{op} + \omega_{op} \times \omega_{ps} + \dot{\omega}_{ps}$$

Where: $\epsilon_{R,s} = \omega_{op} \times \omega_{ps} + \dot{\omega}_{ps}$

From these equations, some suppositions can be done to simplify the dynamics model which leads to:

$$\begin{aligned} a_{R,j_i} &= \omega_{op} \times \vartheta_{oj_i} \quad (11) \\ a_{R,s} &= \omega_{op} \times \vartheta_{os} \\ \epsilon_{R,j_i} &= 0 \\ \epsilon_{R,s} &= \omega_{op} \times \omega_{ps} \end{aligned}$$

The last step is to evaluate the generalized external effort Q_a vector. External effort are mainly the gravity force and legs' thrust force. From the first equation of (7), the contribution of the gravity force is:

$$Q_{a,g} = \begin{bmatrix} (m_p + \sum_{i=1}^2 m_{j_i}) g^p + m_s g^s \\ -\sum_{i=1}^2 m_{j_i} \tilde{r}_{pj_i} g^p - m_s \tilde{r}_{ps} g^s \end{bmatrix} \quad (12)$$

Where g^p , is the gravity vector expressed in the body reference frame R_s and g^s is the gravity vector expressed in the bust reference frame R_s (figure 8).

For thrust actuation forces along the legs elongation, the associated generalized effort can be found by expressing the virtual power done by these six forces, so:

$$Q_{a,Fs,i} = \left(\frac{\partial i_i}{\partial \vartheta} \right)^T F_{s,i} \rightarrow Q_{a,Fs} = j_{-1} F_s \quad (13)$$

Finally, equations (7) to (13) define a first order differential equation $M \dot{\vartheta} = Q$ which can be solved directly to find the platform's configuration ϑ or inversely to find the thrust forces F_s . A linearized version of this model can be used to tune the inner control loops of the platform's servomotors (L. Nehaoua, 2008).

4. CONCLUSIONS

In this paper we presented the design of 6 DOF low cost platform which bring more realism to sliding movement.

This system could be adaptive to many other applications like rehabilitation for people with motor disabilities, rescue environments and educative issues. We have exposed the kinematics and dynamics modelling of the mechanical platform within the slider, but have not developed the parameters identification. Our mechanical structure (xy table combined with Stewart) is smaller comparing to the state of the art and can generate similar movement sensation.

Our future work will focus on control algorithms to validate the platform movement and integrate a visual feedback for haptic sensation. In order to enhance the immersive experience, a virtual reality Head-Mounted Display (HMD) could be used.

REFERENCES

- F. Ababsa, M. Mallem, Robust camera pose tracking for augmented reality using particle filtering framework. *Machine Vision and Applications*, vol 22, n°1, pp. 181-195, 2011
- F. Ababsa, M. Mallem, Robust line tracking using a particle filter for camera pose estimation. *VRST 2006*, pp. 207-211
- H. Arioui, S. Hima, L. Nehaoua, 2 DOF low cost platform for driving simulator: Modeling and control, *IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*, Singapore, 2009.
- H. Arioui, L. Nehaoua, S. Hima, N. Seguy and S Espi, Mechatronics, Design and Modelling of a Motorcycle Riding Simulator, *IEEE/ASME Transactions on Mechatronics*, vol. 15, no 5, pp. 805-818, Octobre2010.
- J. C. F. De Winter, D. Dodou and M. Mulder, Training effectiveness of whole body flight simulator motion: A comprehensive meta-analysis, *The International Journal of Aviation Psychology* 22, 164-183. 2012.
- J.S. Freeman and al., The Iowa driving simulator: An implementation and application overview. *SAE Technical Paper Series*, (950174), 1995.
- J. Fung and al., Locomotors rehabilitation in a complex virtual environment, *International Conference of the IEEE EMBS*, 2004, pp. 4859-4861.
- D. Kaufman, W. Bell, Teaching and Assessing Clinical Skills Using Virtual Reality, *Studies in Health Technology Informatics: Medicine Meets Virtual Reality*, 39, 1997, 467-472.
- L. Nehaoua, H Mohellebi, A. Amouri, H Arioui, A Kheddar and SEspi, Design and Control of a Minimum-Clearance Driving Simulator, *IEEE Transactions on Vehicular Technology*, vol. 57, no. 2, pp. 736-746, March 2008.
- L. Nehaoua, Parameters identification for motorcycle simulator's platform characterization, *1st Mediterranean Conference on Intelligent Systems and Automation (CISA 2008)*, Jun 2008, Algeria, pp.133– 138, AIP Conference Proceedings.
- L. Nehaoua and H. Arioui, Review on single track vehicle and motorcycle simulators, in *19th IEEE Mediterranean Conference on Control and Automation (MED'11)*, pp. 940-945, Corfu, Greece, 2011.
- L. Nehaoua, H. Arioui, N. Seguy and S. Mammar, Dynamic modeling of a two wheeled vehicle: Jourdain formalism, *Vehicle System Dynamics*, vol. 15, no. 5, pp. 648-670, 2013
- G. Reymond, A. Kemeny, Motion cueing in the Renault driving simulator, *Vehicle System Dynamics*, 34(4), 2000, pp. 249-259.
- G. Rill, Vehicle modelling for real time applications, *Journal of the Brazilian Society of Mechanical Sciences*, vol. 19, no. 2, pp. 192-206, 1997
- S.F. Schmidt and B. Conrad, Motion drive signals for piloted flight simulators. *Technical report, National Aeronautics and Space Administration, Washington DC*, 1970. NASA CR-1602.
- S.K. Singhal and D.R. Cheriton, Exploiting position history for efficient remote rendering in networked virtual reality. *Presence: Teleoperation and Virtual Environment*, 4(2):169193, 1995.
- J. B. Sol, and F. Thomas, Kinematics of line-plane subassemblies in Stewart platforms, *In proc. of ICRA*, page 4094-4099. IEEE, (2009).
- D. Stewart, A platform with six degrees of freedom, *Institution of Mechanical Engineers*, vol. 180(15), 1965, pp. 371-384.
- S. Ullah and al. Augmenting 3D interactions with haptic guide in a large scale virtual environment, *VRCAI 2008*.