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## Complex Multi Robot Hybrid Platform for Augmented Virtual Skiing Immersion

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**Summary:** In recent years, the integration of virtual reality in conjunction with mechatronic systems such as motion simulators has become very important in industry in general. The different types of simulators are increasingly being integrated into the various application areas in aviation, at sea and on land. An extension of the simulator in the field of sports and especially functional rehabilitation has gained great importance in the public and private sector. In this context, the goal of our team in the laboratory is to study the design and produce a simulator mastering all low-level elements in order to explore the various possibilities of full control of the integration of a virtual environment into a complex robotic system. In this paper, we aim to validate the precision and shape tracking of motion perception in skiing for simulator users with the Nao robot.

**Keywords:** Handiski, Motion simulator, Motion Cueing Algorithm, Humanoid Robot, Disabled people, Washout filter.

### 1. Introduction

Ski simulators are becoming increasingly popular in the sliding sports industry due to their ability to replicate real-world sliding conditions and provide users with an immersive experience. Ski simulators are simulation devices that replicate the movements and sensations of sliding sports such as skiing, snowboarding and skating. They use advanced technologies to replicate the sliding motions, gravity, and vibrations of snow, such as the Motion Cueing Algorithm (MCA) [1]. These simulators can be used for sports training, injury recovery, mental preparation, and functional rehabilitation [2]. Ski simulators can also be coupled with virtual reality to increase immersion and human sensation [3].

MCAs are computer-based techniques used to simulate the effects of motion in skiers. These algorithms are designed to mimic the physical sensation of motion, such as acceleration and deceleration, by adjusting the visual cues that the skier receives. These cues can include changes in the skier's body position, speed, and slope angle, as well as changes in the skier's body position and motion itself. The MCA produces a trajectory that maximizes human sensation while respecting the physical limitations of the simulator.

Motion simulators are a multidisciplinary engineering system that can be traced back to the early 20th century. One of the first such devices was the Gough-Stewart platform [4], which was primarily used for military training and research [5,6]. This platform has a six-degree-of-freedom range of motion. The upper platform can be mounted in a cockpit and uses a combination of rotating and linear actuators to simulate motion. Over time, motion simulators have evolved significantly thanks to advances in technology and engineering. The hybrid platform was introduced

by coupling the Gough-Stewart platform with the X-rail or XY table to create a more realistic and immersive experience. For example, the Renault Driving Simulator, which adds an X-rail at Technocentre Renault, France [7] and the National Advanced Driving Simulator (NADS) at IOWA, USA [8] and the XY-6 DOF from IBISC Laboratory [9], which adds an XY table. The aim of the project is to contribute to technological progress in the field of rehabilitation and to provide a unique approach to physiotherapy for people with disabilities. For that, a low-cost simulator called the XY-6 DoF was designed and built from scratch in the IBISC laboratory [10]. The XY-6 DoF simulator is characterised by being completely open and allowing low-level access to the platform, which enables the development and adaptation of new algorithms.

In this paper, we aim to validate the precision and shape tracking of motion perception in skiing for simulator users and evaluate the effectiveness of the simulator as a rehabilitation tool. The humanoid robot Nao has a skeletal structure that mimics a human, which enables it to emulate human-like motion patterns. It is also equipped with appropriate sensors to perceive and interact with its environment. The Nao humanoid robot has been used to interact with humans for many years and has proven its efficiency. Nowadays, it is more and more used in robot-robot interaction, replacing humans, such as in the paper [11], which uses the Nao robot for gesture-based interaction between humans and multi-robot swarms. For all these reasons and for human safety, Nao is a good choice to replace humans with a good similarity.

This paper is organized as follows: Section 2 describes the technical and system architecture of the XY-6 DoF simulator. Section 3 discusses the robot coupling and interaction between the XY-6 DoF and the humanoid robot Nao. Finally, Section 4 presents simulations and discussions.

## 2. Technological presentation

The ski simulator system integrates complex multi-robot interaction through the XY-6 DoF platform and the Nao humanoid robot. The XY-6DoF simulator presented in Fig.1 and Fig.2, was designed and developed from scratch by our research team in the IBISC laboratory [11].



Fig. 1. The XY-6 DoF physical ski simulator

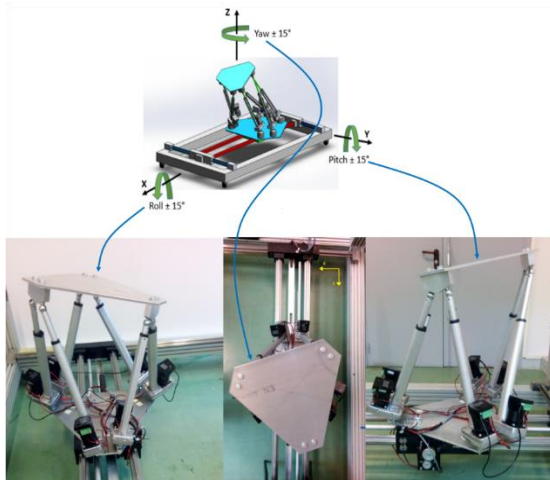


Fig. 2. The pseudo-rotation of the XY-6 DoF simulator

The main advantage of the XY-6 DoF Simulator is that it is a completely open low-level access platform that makes it very easy to create, develop, and evaluate new algorithms. Our hybrid XY-6 DoF simulator takes advantage of the XY Table and the parallel Gough-Stewart platform characteristics.

Linear XY motions from the bottom of the platform and rotational motions from the upper part are generated by 8 PD4- CB Nanotec motors, guaranteeing the system a total of 6 degrees of freedom. Cylinders actuated by the six motors of the upper part allow rotational movements with an angular amplitude of  $\pm 15^\circ$ .

The following table shows the characteristics of the XY-6 degrees of freedom in each direction.

Table 1. XY-6 DoF simulator characteristics.

Axis	Acceleration	Trajectory
X	1.25 (m/s <sup>2</sup> )	115 (cm)
Y	0.71 (m/s <sup>2</sup> )	115 (cm)
Z	0.52 (m/s <sup>2</sup> )	30 (cm)
Roll	0.17 (rad/s <sup>2</sup> )	$\pm 15^\circ$
Pitch	0.17 (rad/s <sup>2</sup> )	$\pm 15^\circ$
Yaw	0.17 (rad/s <sup>2</sup> )	$\pm 15^\circ$

Communication with the Gough-Stewart platform is carried out using a National Instruments card PCI - 8513 CAN, a CAN FD interface (Controller Area Network/Flexible Data-Rate). This device allows communication with the PD4-CB brushless DC motors at 1 Mbps and their control via a special Matlab toolbox. The 8 joints are driven by the Nanotec PD4-CB servo motor, where the rotational movement of the leg is converted into a translational movement by the high-quality ball screw system

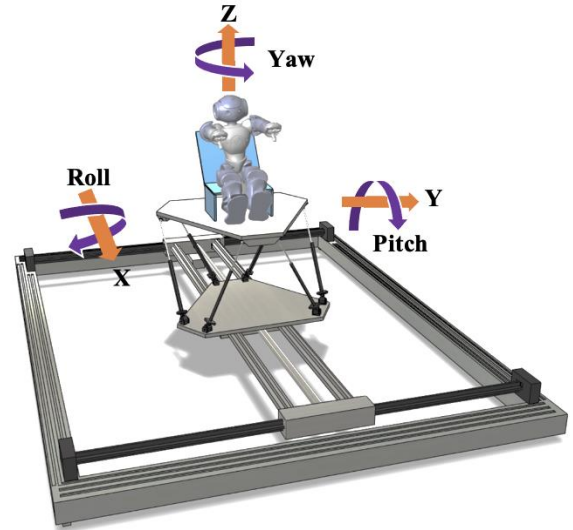


Fig. 3. The XY-6 DoF ski simulator coupled with the Nao robot.

Fig.3 shows the integration of the robot Nao into our simulator XY-6 DoF in an immersive environment. Thanks to the advantages of its pelvic kinematics design, the well-known Nao robot [12,13] was chosen to be integrated into the system, respecting the mechatronic constraints related to handi-skiing context (inactive lower limbs).

The connections between mechatronic and software layers presented in Fig. 4 highlight the existing multi-robot interaction and the technical methods that allow its observation.

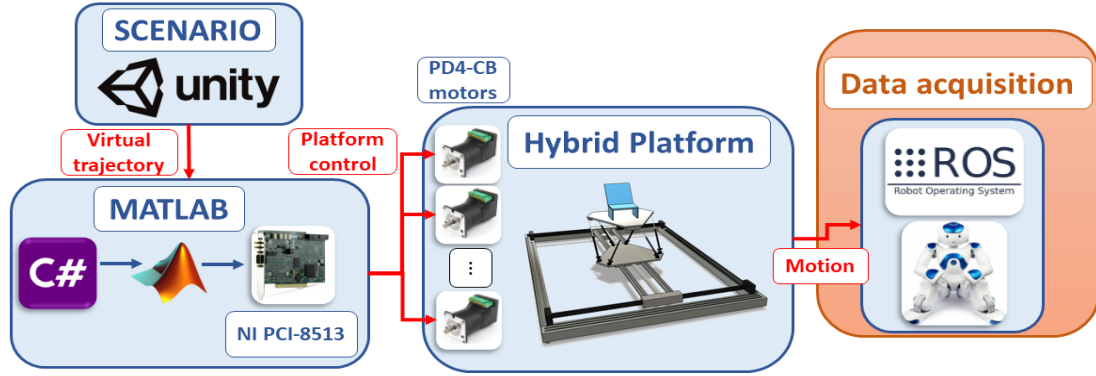


Fig. 4. Technological system architecture.

### 3. Multi-robot interaction

The XY-6 DoF platform tracks trajectory information from the virtual slide scenario designed using Unity software. The dynamic modeling behavior and sliding mode control of the XY-6 DoF robot simulator were developed and validated in a previous research work [3,10,14], where inertial and friction parameters were optimized and identified. The dynamics of the XY-6 DoF simulator can be represented as follows:

$$\Gamma = {}^b J_p^T ({}^b F_e + {}^b F_p) + \sum_{i=1}^6 \left( \frac{\partial \dot{q}_i}{\partial \dot{q}_a} \right) H_i(q, \dot{q}, \ddot{q}) \quad (1)$$

With,  $\Gamma$ - vector of the actuator torques,  ${}^b J_p^T$ - Jacobian matrix,  ${}^b F_e$  - external wrench exerted on the platform,  $\dot{q}_i$ - passive joints speeds,  $\dot{q}_a$ - active joints speed,  $H_i(q, \dot{q}, \ddot{q})$ -is the inverse dynamic model of leg i considering as serial robot,  ${}^b F_p$  - the total forces, is calculated by the following equation:

$$\begin{aligned} & {}^b F_p \\ &= {}^b \Pi_p \dot{{}^b v_p} + \begin{bmatrix} {}^b w_p \times ({}^b w_p \times {}^0 M S_p) \\ {}^b w_p \times ({}^b I_p {}^b w_p) \end{bmatrix} \\ &- \begin{bmatrix} M_p I_3 \\ {}^b M \hat{S}_p \end{bmatrix} {}^b g \end{aligned} \quad (2)$$

Where,  $M_p$ ,  ${}^b I_p$ ,  ${}^b \Pi_p$ ,  ${}^0 M S_p$  are mass, inertia tensor, spatial inertia matrix moment of inertia vector of the platform, respectively.

Parallel and serial robots are a known challenge which is the large number of dynamic parameters,

which requires a lot of processing time, whether in dynamic modeling, identification or control. Therefore, the dynamic parameters of the XY-6 DoF hybrid structure simulator have been optimized and identified in previous works [14]. As a result, the standard 210 inertial parameters are reduced to only 90 basic inertial parameters.

The motion of the XY-6 DoF simulator motion is validated by the acceleration data from the NAO IMU and the robot model, as shown in Fig. 5.

Many works [15,16] highlight interactions in multi-modal robotic systems, such as human-robot and multi-robot interactions, to improve the collaboration and/or the impact between systems. First, the integrated system applies a validation process to the platform motion management algorithms to improve the reliability of virtual trajectory recovery. It provides a reliable solution to assess the motion control of the XY-Gough-Stewart platform and multi-robot interaction.

The interaction evaluation will be done through the inertial and articular information coming from NAO. Afterward, a human motion perception model will be integrated into the system to improve the emulation of human sensory capabilities within NAO.

Fig. 6 shows the homothety between the present integration of multi-robot interaction and the objective integration of robot-robot human interaction (outlined in red). This future integration will provide a tool for measuring the quality of immersion for simulators by estimating through sensor data the impact of the movements of the virtual scenario and the platform on a human.

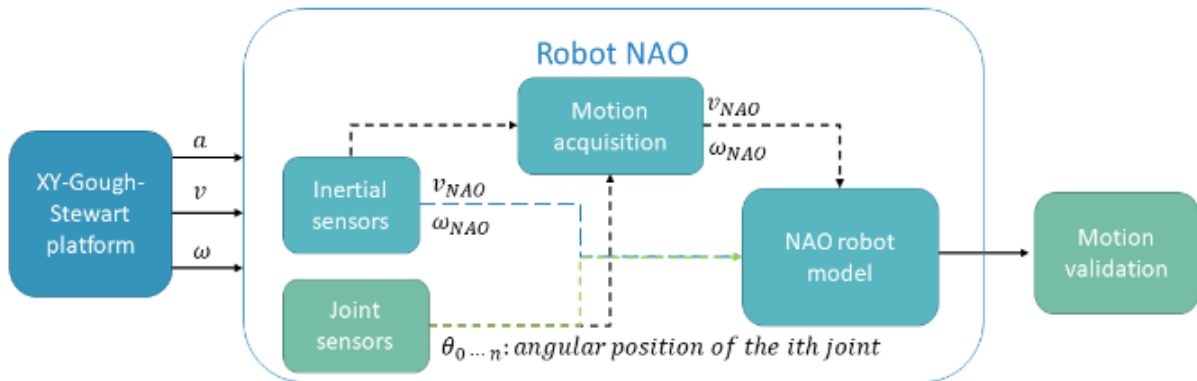
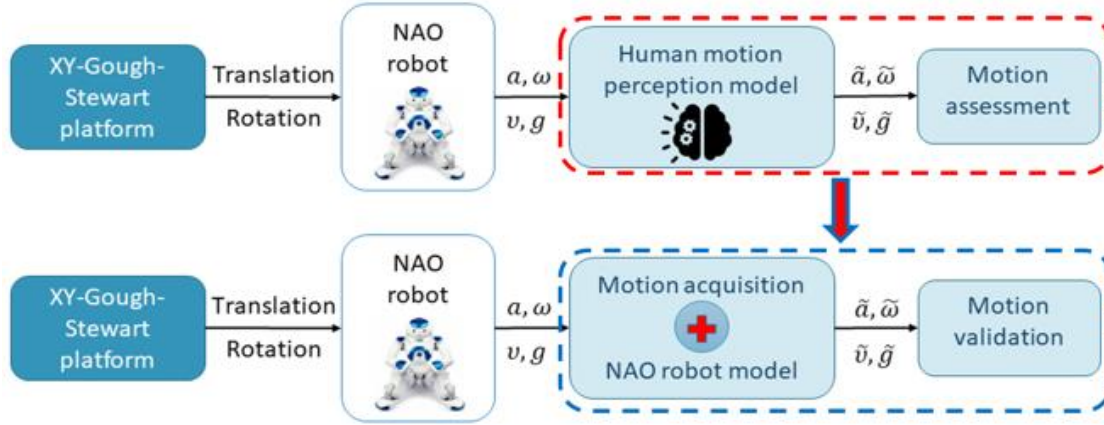


Fig. 5. XY-6 DoF simulator/NAO robot interaction.

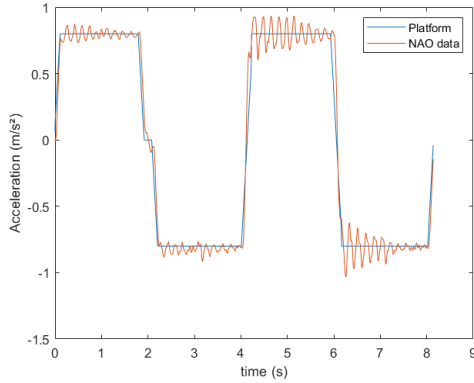




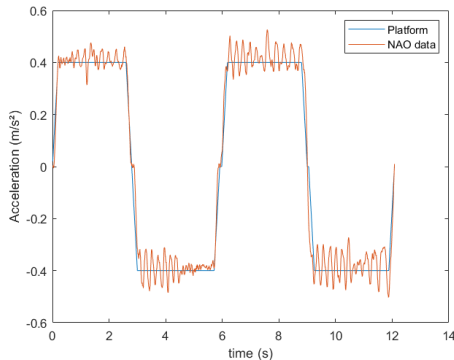
**Fig. 6.** Multi-robot and robotic human interaction.

#### 4. Experimental results

The validation of the platform controlled motion is illustrated in the following figures through the study of multi-robot interaction. In this work, we have neglected the Z-axis and yaw rotation as they have a minor effect on the ski motion sensation comparing to the X and Y axes and roll and pitch rotation. Translation motions on axis X and Y in Figures 7 and 8 are oscillatory movements of one meter in amplitude. Similarly, the rotational motions illustrated in Figures 9 and 10 are oscillatory angular movements from -10 to 0 degrees. The platform behaviors are obtained by extrapolating the platform position from XY motors through the kinematic model.

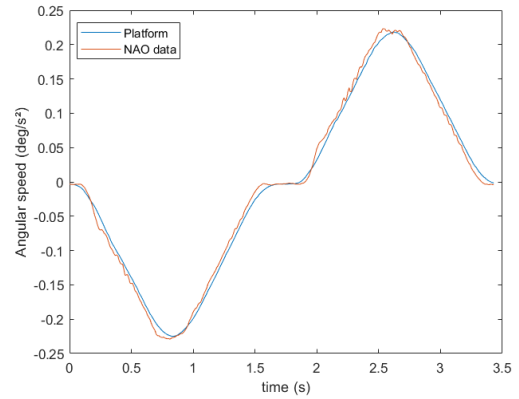


**Fig. 7.** Motion validation for X-axis movement.

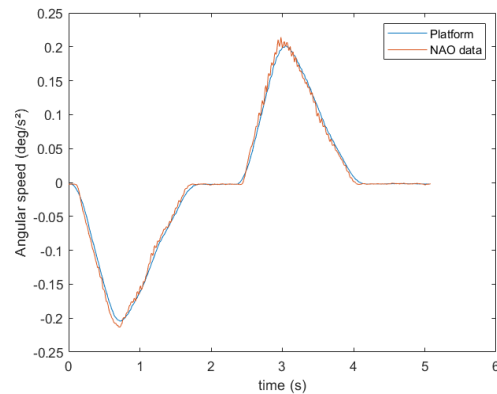


**Fig. 8.** Motion validation for Y-axis movement

Observing the NAO robot's dynamic behavior in Fig. 7 and 8 validates the platform's accurate behavior tracking for an axis movement. However, some oscillations are observed for high dynamics. They result from slight platform vibrations due to axis friction and IMU acquisition noise. Rotation motions do not suffer from axis friction. Thus, the angular speed behavior tracking is also precise but also less noisy.



**Fig. 9.** Motion validation for Pitch movement



**Fig. 10.** Motion validation for Roll movement

This study validates the ability of NAO to perceive the multi-robot interaction and the interest in integrating it into our system for future work.

## 5. Conclusions

In this paper, we have presented an original robotic platform system. The final goal is an operating system for a better immersive sliding simulator.

As a first step, we validated the response with a device like the Nao humanoid robot, which is a real human homothetic system. The embedded sensors give us all the information we need to properly assess the robot-robot interaction and system behavior.

Experimenting with all the systems gives us realistic feedback. According to our research plan, the global behavior is in accordance with our goals.

The obtained result is realistic and follows the acceleration shape. As we can see in Fig.7 to Fig.10, the response is very close to the real motion.

The direction of our future work is to manage all different parts of the system to achieve human perception integration and realize a better immersive way.

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