Architecture of a Spatial Disorientation Platform and Serious Game

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Abstract. In recent years there have been several applications for the study of stabilometric mainly in the analysis of disorder, using mechanical structures of one or two degrees of freedom. An architecture of a stabilometric platform is proposed, which can acquire data through a virtual environment, in this case, a Snowboarding environment, since this sport provides greater balance, increases flexibility and strength in the muscles, and strengthens the lower limbs since it can have a displacement movement in one direction. Thanks to this environment, an architecture is proposed to execute several applications, focused on balance rehabilitation. As a result of this proposal, mathematical models were made by applying the Euler Lagrangian theory, and architecture was obtained that can acquire data in real-time, allowing to visualize this data through a sensor, which shows the position of the person with its respective movement. Also, with the implementation of the Self-Assessment Manikin (SAM) a preliminary study was conducted with 10 people in which 70% presented a discussion of different errors in the design and development stage in the virtual environment, also, 10% of the study population showed greater spatial disorientation to one side of the platform. Thanks to this, it was possible to modify the virtual environment and obtain a more efficient response by implementing this method. As future work, it is proposed to develop variable control systems on the platform and a trajectory variation in the virtual environment.

1. Introduction

Human movement can achieve and maintain balance in all activities of daily living. This quality is considered postural stability or postural control and can be defined as the ability to maintain the center of body weight within the base of support in the face of unpredictable displacement [1, 2]. Over the years, mechanical platforms with one or two degrees of freedom have been used to facilitate the analysis of spatial disorientation, posture, and individual balance disorders, including the use of a variety of methods, such as (a) qualitative analysis, the result of which is a description of posture; (b) quantitative tools that refer to different measurement scales, some of these are called Romberg test, Berg scale, Star Tour Balance Test, whose quantitative results are based on subjective analysis of various activities; and (c) high-tech tools, their results are accurate values, representing the displacement of the human center of gravity (CG) projection on the surface. The latter is called stability measurement, which refers to the study of human body balance [3,4].
Since stabilometric is the study of balance and can be used to analyze postural control [5], an architecture is created that can be used to validate features such as balance, motion, control, and interaction. It also brings together the fundamentals of robotics, electronics, and programming, to propose a design of a platform capable of obtaining the dynamic force of the user. For this purpose, the following specifications were considered: a minimum surface of 0.75m, a force that allows the movement of a person weighing 100kg, and a height no greater than 2m [6,8]. Thanks to the architecture implemented, it is possible to recognize the postural movements and the user's center of gravity, thus providing a better quality of life for people with mobility problems. In addition, virtual reality (VR) was used as a tool to support the work of personnel working in these areas, as it consists of a simulation of everyday reality. An environment was designed that can interact similarly as it would in the real world [9]. The integration of VR with the disorientation platform will allow the user to have an immersive interaction, allowing better management of the study of postural control.

Therefore, this paper presents an architecture and the development of a disorientation platform considering its mechanical structure, according to the integration of a virtual reality game.

2. Materials and Methods

This paper proposes an architecture of a stabilometric platform that allows the acquisition of data using an MPU sensor. The user oversees exercising movement on the platform in a transverse plane and has the possibility of interacting in a virtual environment which sends data of the user's position from a commercial embedded device that is connected through serial communication to the virtual reality environment. This sensor is in the center of the platform and using it, data acquisition can be carried out to obtain an analysis of the platform; kinematic calculations are also carried out, which allow the restrictions of the platform to be determined and, likewise, the dynamics calculation is carried out to calculate the motors, which must support approximately a 100kg person (Figure 1). A preliminary test was also carried out with 10 participants, to analyze the behavior of the integration of the virtual environment and the stabilometric platform.

2.1. Platform structure

For the development of the platform architecture, a prototype developed by the Davinci research group of the Universidad Militar Nueva Granada was used, which consists of a robotic platform with two degrees of freedom. It has a four-bar mechanism Figure 2. (a), which supports the impacts and
dynamic loads generated by the user with a working area of 120 × 120 cm, which supports a person of up to 100 Kg, this weight is set to have the motors working at 70% capacity. Likewise, the mechanism is designed for easy replacement in case of breakage. This presents a structural fabrication made with HR steel pipes based on the ASTM A500 manufacturing standard. Translated with www.DeepL.com/Translator (free version) having the structure defined, we proceed to select the motor, for which we start by calculating the kinematics of the person since in this case, it is the final effector. With the kinematics, the restrictions of the amplitude of the platform movements are detailed. For this purpose, kinematic analysis is determined by D-H (Denavit & Hartenberg). Finding the mathematical model that represents the end effector in Cartesian coordinates (Equations 1-3)

\[ x = L_c \cdot \cos \alpha \cdot \cos \beta \]  
\[ y = L_c \cdot \cos \beta \cdot \sin \alpha \]  
\[ z = L_c \cdot \sin \beta \]  

Where \( L_c \) is the center of gravity \( \alpha \) and \( \beta \) are the tilt angles of the platform Figure 2. (b). With the kinematic model, we proceed to the selection of a motor for the platform, for we consider the dynamics of the system since it provides a mathematical model that relates the joint coordinates and their derivatives to the force parameters. In this case, the classical Euler Lagrange formula is used, which is determined by the kinetic energy and potential energy of the system, thus giving the inertia matrix \( M(q) \), Coriolis \( C(q, \dot{q}) \dot{q} \), and Gravity \( G(q) \), as shown in Equation (4)

\[ \tau = M(q)\ddot{q} + C(q, \dot{q})\dot{q} + G(q) \]  

For the dynamic analysis, the potential and kinetic energy of the four-bar mechanism and of the user who will be on it are considered, Equation (5) and Equation (6):

\[ L_p = \frac{1}{2} I_p (\alpha^2 + \beta^2) \]  
\[ L_h = \frac{1}{2} m_c (V^2) + \frac{1}{2} [\alpha, \beta] I_c [\alpha, \beta] - U_c \]  

where \( L_p \) and \( L_h \) are the lagrangians of the platform and the human respectively. \( I_p \) is the inertia of the platform. \( I_c \) and \( m_c \) are the momentum and mass reflected at the center of gravity of the test subject. According to the above equation, a simulation is performed, where the joint coordinates are constantly changed to present an inclination of 18 degrees considering the kinematic constraints and a constant velocity of 2.5 rad/s in each degree of freedom, obtaining as results the graph in Figure 3. Considering the torque value (\( T_1 \) and \( T_2 \)) generated by the simulation seen in Figure 3, two SGM7G-20AC servomotors are chosen, which have a reduction gearbox with a 32:1 transmission, which achieves over 200 Nm. These motors are in each of the axes of the platform generating two degrees of freedom, to exert the movement.
2.2. Structure of the game

Virtual Reality (VR) has been widely noted as an important technological development that can support the teaching and learning process, it is a tool that allows the creation of simulated environments and spaces so that a person can have an immersion in a virtual environment. Scientific research speaks of three main reasons for the use of VR as a treatment for different pathologies: its effectiveness, greater than the imagination and as effective as the live presentation technique; its greater acceptance by the patient compared to other exposure therapies; and the personalization of the treatment, VR allows maximum control of the environment to which the user is exposed [8]. There are currently countless projects in which serious games are integrated for rehabilitation [9]-[14]. Martina Eckert [15] in her degree project integrates four different game environments (climbing a ladder, rafting (boat type), mole game, and navigation in an airplane), she analyzed to establish which offered a more enjoyable and fun treatment for patients in their rehabilitation process in upper and lower limbs. As a result, he obtained a notorious change in the recovery of the users, but not all the games cause an equal impact to all the people since they caused effects such as dizziness during the process.

A Snowboarding game design is proposed, since the platform allows changing position at the time of executing any action, and through this environment allows the acquisition of inclination data from the platform. A scenario was created which is capable of transmitting coherence of the virtual world compared to the real one, different environments were sought that had mainly two characteristics: a) a skiing competition place and b) a snow environment. Figure 4 shows the location that was chosen to recreate in the serious game. Hakuba Sanosaka Snow Resort is a village in Nagano prefecture, Japan, located in the central part of Honshū Island, in the Chūbu region [16], this place is surrounded by forests and a picturesque scene of the nearby Lake Aoki. Eighty percent of the ski slopes are for skiers and people who want to learn to ski, it is used for entertainment and sport [17].

![Figure 3. Torque motion simulation.](image)

Figure 4. a) Real-life environment "Hakuba Sanosaka, Snow Resort", b) Virtual reality environment, implemented in Unity.
2.3. Data acquisition

To integrate the platform with the virtual environment, the MPU-6050 / GY-521 (MPU) is used, which has a gyroscope and accelerometer, comes integrated I2C interface, which allows obtaining data from three coordinate axes to measure the angular velocity and rotation of the $x$, $y$, $z$ axes. This sensor will allow obtaining the platform inclination data. Using the gyroscope allows to measure, maintain, and modify the direction in space of an object, in this case of the user; in addition, the position and rotation are measured by applying a Coriolis effect correction on the accelerometer.

Therefore, an algorithm was implemented that can recognize the inclination of the $x$ and $y$ axes, which, in this case, pertain to the user's movement in the virtual environment, to the front, and the sides. Likewise, the equation representing the correction applied for obtaining angular acceleration and rotation, equation (7) is shown.

$$\theta = 0.98(\theta_{\text{prev}} + \theta_{\text{gyro}}) + 0.02\theta_{\text{accel}}$$  \(7\)

In addition, a first-order Kalman filter is used with a 500dps configuration for the gyroscope, +/-8g for the accelerometer, and 98Hz cutoff frequency for the output filter. Figure 4 shows the flowchart and coding implemented in the microcontroller. This algorithm is shown in Figure 5.

![Figure 5. MPU sensor flowchart](image)

3. Results

As a result, the integration of a mechanical and electronic architecture of a stabilometric platform with a virtual environment was obtained. Accordingly, the motors and degrees of freedom of the platform allow the movement of the user in different positions, with the help of the environment, the user's posture is measured using the center of pressure, in different coordinates (Figure 6). In this case, the 2GDL platform is designed to provide greater stability in the user's posture allowing the movement during the VR game to be more immersive and real, using for this purpose the kinematic parameters
(Alpha and beta) given by the sensor. In addition, with the help of data acquisition, it is possible to have the result of the three axes according to the acceleration and with the communication of the module by I2C, it allowed to work efficiently with the controller and the virtual environment.

Likewise, for the analysis of spatial disorientation, it was possible to measure the user's movement when picking up coins in the environment. This disorientation makes it possible to record, measure, and analyze the force that the subject perm when moving since he/she has a change of position and disorientation in his/her sway base (center of pressure). As a result of a preliminary test of 10 people, it was possible to obtain the swinging coordinates and analyze that 10% of the people exerted a greater force to the right, limiting their orientation in the environment. With the integration of the virtual environment and the platform, a validation was made with random users where it was proposed to interact with the environment and give an opinion according to the response time and execution of each movement. For this purpose, the instructional design of the SAM model was used, which corresponded to a preparation phase, iterative design, and its corresponding implementation. Thanks to this model it was possible to identify potential problems and their correction, starting with the response time using the sensor and the mechanical structure of the platform.

In addition, using the mathematical model, it was possible to establish the specifications of the motors in front of the parallel mechanism, resulting in obtaining a simulation that generates the maximum touches to perform a constant movement. Likewise, from this, the restrictions of both the 4-bar mechanism and the test subject were considered. Table 1 shows the different disorientation platforms that exist in the market, and the one proposed in which the shape of the mechanism provides stable support to the plantar pressure platform, thus obtaining more information on the user's behavior. Unlike the other platforms, this one presents a virtual environment and free software, thus leaving more freedom for the realization of future projects.

### Table 1. Comparison between platforms

| Platform    | Motorized | user | Measurement of the physical behavior of the patient | Open-Source Software |
|-------------|-----------|------|----------------------------------------------------|----------------------|
| Huber 360   | X         | X    | X                                                  |                      |
| Dynamic SPS | X         | X    | X                                                  |                      |
| GeaHD       | X         | X    | X                                                  |                      |
| Kine-sim    | X         | X    | X                                                  |                      |
| Biodex SD   | X         | X    | X                                                  |                      |
| Davinci     | X         | X    | X                                                  | X                    |
Over the years there has been a great evolution with this type of technologies for rehabilitation, an example that is assimilated with the platform being used is Computer Assisted Rehabilitation Environment (CAREN) [18], which is a platform that performs a movement based on a virtual environment, for people who have suffered injuries by improvised explosive devices during an operation. The difference of the one presented in this article is that the architecture proposes a system that interacts with the user in an inverse way giving a better user experience, adding an extrinsic and intrinsic motivation, with an immersion in a Snowboarding game. This platform is also free software and has the possibility of implementing various impedance control systems, where it allows a variety of difficulty on the platform and for the user in the virtual environment, in addition, something characteristic is that it has the possibility of lateral movements of inclination.

With the help of real-time data acquisition, variable control systems for trajectories can be realized as future work to analyze whether the body weight center is adequate when exercising a movement.

4. Conclusion

In conclusion, by means of serial communication, it was possible to obtain real-time data of the user's movement, considering the connection of the Frames per second (FPS) in a virtual environment. In addition, through the movement of the platform and the connection of the MPU, it was possible to receive the user's swing position, with its respective coordinates, allowing to control the user's inclination speed. On the other hand, with the 10 participants, 10% of the study population showed greater spatial disorientation towards one side of the platform and through the SAM method, 70% presented a discussion of different errors in the design and development stage in the virtual environment. Also with the help of the SAM method, it was possible to perform a background research phase in which a disorientation platform was proposed with a virtual environment which in the design phase, the necessary calculations for the mechanical part were developed and the game was designed, so that it could be checked if integration between the two parts could be made, as a conclusion it was possible to modify some parameters of the game through validation tests with different users. It was possible to obtain the variation of the degree of difficulty of the game, thanks to incentives in the scenario, obtaining greater immersion in the virtual environment. Likewise, the data of speed, acceleration, and a few modes sent by the MPU are saved.

From the mechanical and electronic design, a suitable motor was determined, which supports an average person with a maximum weight of 100kg, which can be used for rehabilitation considering that in this having a free software control system can be implemented which allows the user to experience various difficulties of force. In addition, through the platform of two 2DOF and the pressure platform, it was possible to determine the plantar pressure exerted by the user allowing to obtain the coordinates of inclination through the virtual reality serious game.

Considering the platforms found in the market, the Davinci platform presents a wider range of utilities, since it is free software that allows the addition of different systems without affecting the platform's status. Likewise, involving the virtual environment, makes the user more comfortable in each of the therapy sessions.

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