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MECHATRONIC SYSTEM FOR RECOVERY OF POSTURAL BALANCE

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Abstract: *Bipeds must face an additional challenge compared to other beings trying to find a stable state of equilibrium. These balancing efforts involve many aspects and internal organs and procedures are much more difficult in the case of posture problems. The existence of a postural abnormality requires corrections, otherwise, they may worsen irreparably. One way of postural readjustment and, implicitly, disease prevention, is the therapy with the help of a balanced platform. The article presents research for developing a posture correction and medical recovery device that brings many benefits for a faster recovery in these types of posture problems. This paper shows a novel mechatronic system that can be used in postural balance health problems.*

Key words: *Postural balance, health recovery, Stewart platform, robotics.*

1. INTRODUCTION

The state of health of a human being can be described, in an all-encompassing sense, by the complex, medical, somatic, energetic, and spiritual relationship that it has with the environment, including with other individuals.

One of the most visible factors that reveal the state of health is the attitude and posture of the individual. Posture refers to the position of the body in various poses, and this can influence the condition and efficiency with which we carry out our activities.

Due to the way are built, human beings rely on only two surfaces (foot) and need a whole system of searching and optimizing the state of equilibrium. This system is already developed in the human body and includes the brain, skeleton, muscles, and neural network in the body. In situations of movement and displacement, the search for balance becomes even more complex. In fact, we can say that balance is not sought, but the optimal way to adapt to a continuous imbalance. From the first day of living, we try to adapt to this imbalance.

The main physical component to consider in situations of postural abnormality is the spine. The projection of the center of gravity on the support surface of a human being reveals the existence and severity of this imbalance. The postural factor is divided into three broad categories: relative balance, moderate imbalance, or postural abnormality [1].

Postural balance is the optimal state of balance in which the body is positioned, the most obvious situation being when sitting upright.

2. MEDICAL CONSIDERATIONS

Postural balance is determined by a lot of factors and subsystems that contribute to the establishment of psycho-cognitive and physical-emotional balance. The center of this system is obviously the brain. But it needs a network for information transmission (neural network), sensors (inner ear, visual perception, tactile sensors), and subsystems to establish posture and balance (bone and muscle system). This system includes the brain structures developed for learning and adaptation to the environment directly related to education, experience, attitude about life, etc. This whole system for balancing is called proprioception [2].

Even inside the brain, there is a complex collaboration between the different structures for the most efficient functioning of the whole body and in particular the establishment of postural balance. The vestibular system of the inner ear connects to the cerebellum and the back of the brainstem to regulate the movement of every muscle in the body [3].

Figure 1 shows all the subsystems in the human body that help to establish balance.

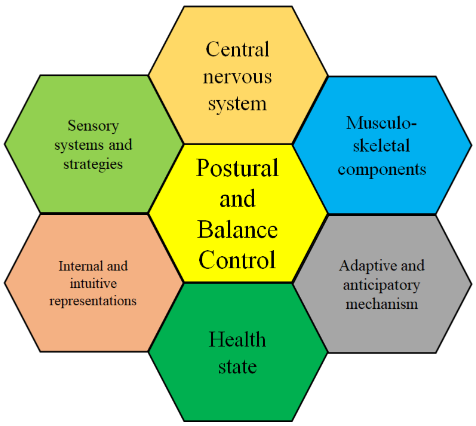

Fig. 1. Balance systems overview.

All proprioceptive information related to contact with the seating surface (position, angles, speed of movement, etc.) is taken and processed in the central nervous system, which develops an adequate neuromotor response to adjust posture.

These proprioceptive signals are continuously adjusted to search for the best equilibrium position [4].

The classic posture correction method uses a simple platform, like in Figure 2.

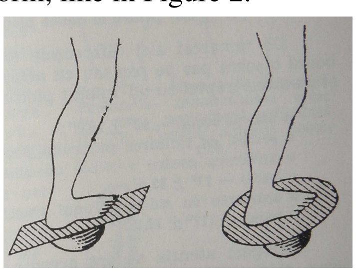

Fig. 2. The simplest platform for balance correction [2]

Medical conditions for which it is recommended to use the balance platform to correct postural imbalance:

- Stroke;
- Multiple sclerosis;
- Presyncope (pre-fainting condition due to decreased blood pressure);
- In conditions with side effects from the use of drugs (dizziness);
- Vestibular neuronitis (infected or inflamed vestibular nerve);
- Perilymph fistula (lymphatic fluid leakage);
- Labyrinthitis (disorders of the inner ear);
- Meniere's disease (degeneration of otoliths);
- MAL de DEBARQUEMENT Syndrome (seasickness) encountered even in the post-training states performed on the treadmill;
- Dizziness in the context of hypotension or cardiovascular problems;
- Joint, muscle, and vision problems;
- Psychiatric disorders associated with dizziness;
- Anemia;
- Dehydration;
- Hypoglycemia;
- Excessive physical activity.

Contraindications to the use of the balance platform:

- Spasmodic disorders (no risk of falling from the device);
- Numbness (feeling of weightlessness);
- In the case of light numbness, however, the device can be used using a protective railing;
- Epilepsy;
- Cardiac stent wearers;
- Very anxious people stating that the device can be used only on the recommendation of the doctor and in the presence of a qualified person and with treatment schemes corrected to the appropriate parameters for adaptability;
- People with unsolved fractures.

In more serious medical cases, it is advisable to consult a doctor to determine the suitability and treatment schedule for this device.

3. PLATFORM FOR BALANCE

Concerns about the use of devices in medical recovery have emerged since ancient times. From simple wooden devices used by humans for thousands of years [5-6], or simple platforms, it has advanced to increasingly complex devices [7] that have culminated with mechatronic devices used in medical recovery procedures [8-11]. The Global Postural System is a medical device consisting of the main system for posture analysis, a set of secondary devices for the acquisition of data during the patient visit, a set of photo-capture devices, and a computer and software for data management [12].

Each device has its own advantages and disadvantages. Some devices are suitable for certain age groups due to specific problems [13] others are more suitable for young people and high-performance athletes [14].

Some devices are based on the evaluation of the pressure in the work platform [15], others on several criteria evaluated simultaneously [16].

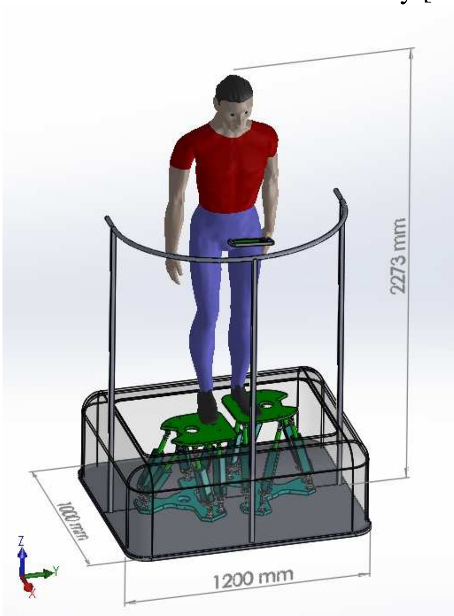

Fig. 3. The concept design of balance platform

Compared to the classic platforms in which the patient exercises his balance through co-contraction movements, in comparison, the developed mechatronic system acts according to a wider range of required and medically approved treatment schemes and can even contribute to the search for the dynamic balance area.

The control of the two platforms during the construction of the real model will be done with the help of programs implemented on an Arduino control board. In addition, the device will be provided with a display for control, checking, and interactive viewing of the procedures in progress.

The patient can adjust and adapt his device to the neuromotor responses i.e. to produce (restore) improvement or even cure posture and balance disorders in stationary or moving stage.

The balance platform is designed based on a hexapod robot with a Gough-Stewart configuration [17]. The hexapod parallel robot model is built on 6 actuators (legs) that must be controlled simultaneously. The proposed model has the concept shown in Figure 3. This system uses two collaborative platforms, which will be controlled by the same control device.

Figure 4 shows a semi-assembly of the motoring part of the device for postural balance. This sub-assembly is a hexapod parallel robot.

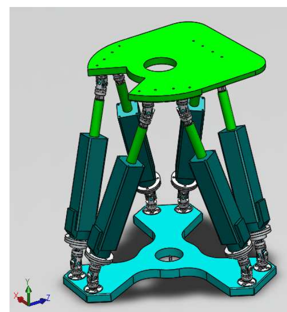

Fig. 4. The semi-assembly of motoring part of the device for postural recovery.

4. LOAD CASES

The most complex and challenging part of the simulation is the strategy for moving the platform. This strategy means correlating the actuation curves of the actuators with the required movement of the mobile platform.

The following load cases have been proposed for the simulation model:

- Vertical movement with symmetry and asymmetry, amplitude 10 cm, at maximum frequency 2 Hz;
- Alternating movements in horizontal advance, amplitude 30 cm, and maximum frequency 1 Hz;
- Lateral advance movement, alternating horizontal, amplitude 40 cm, at maximum frequency 2 Hz (adduction-abduction);
- Alternating movements by an arc of one platform, rotation on one leg with a radius of the circle 30 cm, at maximum frequency of

movements 0.5 Hz (external-internal rotation along the axis of the pivot leg);

- A combination of horizontal and vertical movements at maximum frequency 1 Hz.

Each load case keeps the normal axis to the platform in the same direction during movement. The cases are at maximum speed load because the system is assessed at extrema.

The movement of the two platforms must take into account both workspaces of each hexapod and the relative positioning of one platform relative to the other. The collaborative strategy is based on the next criterion: minimum distance between the two platforms [18-19].

The dynamic simulation model also includes a 70 kg manikin with a high center of gravity at 1.2 m from the soles.

Must be a posture correction strategy adapted to each patient according to sex, weight, height, medical problems, etc.

5. RESULTS

As there is no space to present all the graphs for each calculation load case, the following results are only for the last case, which is a combination of movements in X and Z directions. The curve of the imposed trajectory is an ellipse at the center of platform (see Figure 5). The width of the ellipse in the local system is 400 mm and its height is 100 mm.

The movement on the above ellipse is done with a constant speed of 941.8 mm/sec i.e., for the frequency of the request cycle 1 Hz.

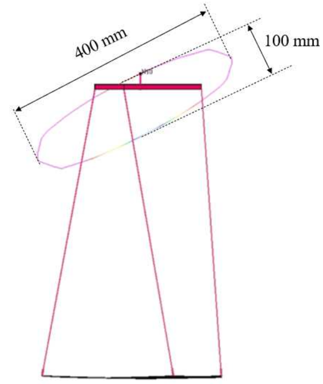

Fig. 5. The trajectory imposed at the center of the platform

The plots of displacements, speeds, and accelerations on X and Z of the center of the platform, respectively, are shown in Figure 6. The displacements are amplified by 100, and the speeds by 10, for better visualization of all curves. The displacements are marked with empty squares, the velocities with full squares, and the accelerations with the sign-x. The red curves are for the X direction and the blue ones for the Z direction. The platform has no movement in the Y direction.

The simulation was made using CalculiX software.

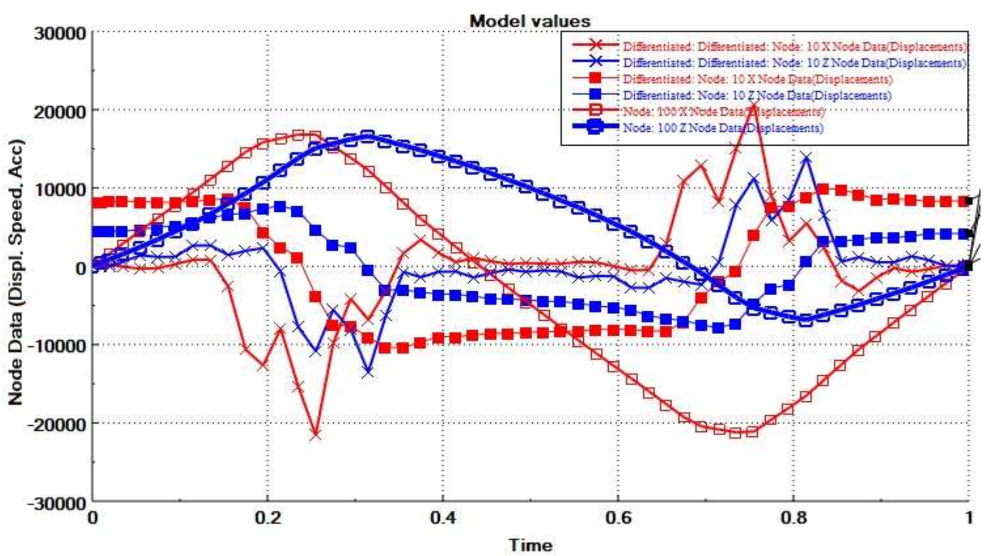

Fig. 6. Displacement, speed and acceleration in the X and Z directions of the center of platform

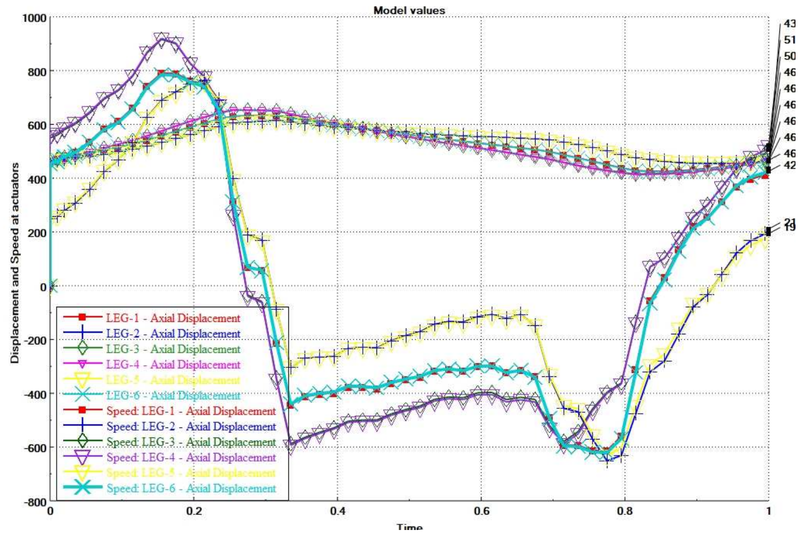

Fig. 7. Axial displacements and speed in each actuator

6. CONCLUSIONS

Connecting the conscious and subcortical brain, the amygdala, and the emotional system implies that the psycho-emotional criterion (system) of the patient increases the interest and confidence in using the device. (Based on the reward system that further motivates him to use the platform or vice versa by the risk of falling which means activating the punishment system).

Starting from the disadvantages of the classic platforms, ie the patient's fear of using them and the existence the risk of falling (muscle deficiency, balanced joints, neuromotor deficiencies, or more serious balance disorders) this mechatronic device was developed in which the platform has a much wider range of movements imposed in complex and coordinated directions: alternating movements in different directions, precise angular movements, elliptical, circular movements, etc., continuous, simultaneous or correlated between the two platforms.

The device thus designed can provide the patient with more security and motivation, becoming very useful in muscle and joint deficiencies, in balance disorders (labyrinthitis), and significantly reduces the patient's fear compared to classic devices.

The essence of the motion and control strategy of a Gough-Stewart platform is shown in Figure 7 with axial displacements and speed in each actuator to obtain the required trajectory from Figure 5. It is observed that some curves overlap almost perfectly (e.g., curves for actuator 1 with those for actuator 6, etc.). This is because the trajectory of motion is in the XOZ plane and the system has symmetry with respect to this plane.

Based on these simulation results, the performance of the hexapod system can be evaluated, as well as the level of excitation that occurs in the patient by assessment of the accelerations. This will allow the adjustment of the recovery strategy for each patient. This motion strategy will be implemented in the robot control system for the experimental model to be built.

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SISTEM MECATRONIC DE RECUPERARE A ECHILIBRULUI POSTURAL

Ființele bipede trebuie să facă față unei provocări suplimentare față de celelelate ființe în căutarea stării de echilibru stabil. Aceste eforturi de stabilire a echilibrului implică multe aspecte și organe interne iar procedurile sunt mult îngreunate în cazul unor probleme de postură. Existența unei anomalii posturale necesită corecții, altfel acestea se pot agrava iremediabil. O modalitate de reajustare posturală și, implicit, de prevenire a îmbolnăvirilor, este terapia cu ajutorul unei platforme de balans. Articolul prezintă cercetări pentru dezvoltatea unui dispozitiv de corecție a posturii și de recuperare medicală care aduce multe avantaje pentru o recuperare mai rapidă în aceste tipuri de probleme de postură.

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