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SIMULATION AND EXPERIMENTAL STUDIES ON THE CONTROL SYSTEM FOR MECHATRONIC REHABILITATION DEVICE WITH KEEP-UP MOVEMENT

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Abstract: *This work contains the results of simulation and experimental studies on crane control system with tracking movement system intended to support the rehabilitation process. This paper presents the kinematics and the basic elements of the drive system in one of the axes of the possible movement of the device. Based on this information the numerical model and the control algorithm of the system created in Matlab SimMechanics has been developed. The simulation results, based on the chosen optimal control mode settings, were compared with the results obtained during the test bench.*

Keywords: Numerical model, Mechatronics, Crane, Drive system.

1. Introduction

One of the conditions for the effective training of both sports and during rehabilitation, is a large repeatability of exercises. Therefore, in recent years the development of mechatronic devices supporting the process of rehabilitation are increasing. An example is the LOKOMAT Hocoma Company which enables simulation of the movement of the lower limbs or Zero-G device developed by Aretech. It allows the realization of different exercises in relieving (Hornby et al., 2005), (Hidler et al., 2011).

As part of the research work carried out at the Department of Theoretical and Applied Mechanics, in Silesian University of Technology was developed mechatronic device in the form of a crane, supporting the process of rehabilitation of patients learning to walk again. The idea of this device is shown in Fig. 1. This device provides the opportunity to work in various modes, and one of them is tracking movement after the moving load. Patient hanging system with adjustable length of rope is located on a gantry cart (indicated by symbol A), which can perform a translational motion in the horizontal plane (along directions OX and OY axes). The trolley moves along the OX-axis with entire crossmember, where drive system of OY-axis is mounted. The crane is driven in a horizontal plane, a motor controller for closed-loop operation responds to feedback with multi-axis sensor for measuring the deviation angles of the rope with added sling. The control system is based on a real-time controller in the steering of drive motors. Develop the best possible control algorithm to ensure optimal operation of the system according to the purpose of rehabilitation, safety and patient comfort (Ławniczek & Duda, 2013), (Gembalczyk & Duda, 2013).

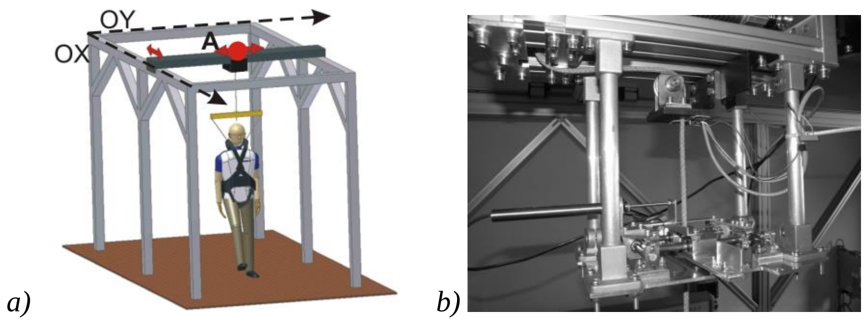

Fig. 1: a) Scheme of mechatronic devices to support walk reeducation; b) System for measuring deviations angles of rope.

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2. The Structure of the Drive System

In order to demonstrate the correlation between the components of the mechatronic system that is proposed device for walk reeducation, was created a block diagram contains the most important elements. Developed diagram was shown in Fig. 2, is suitable for both drive axles.

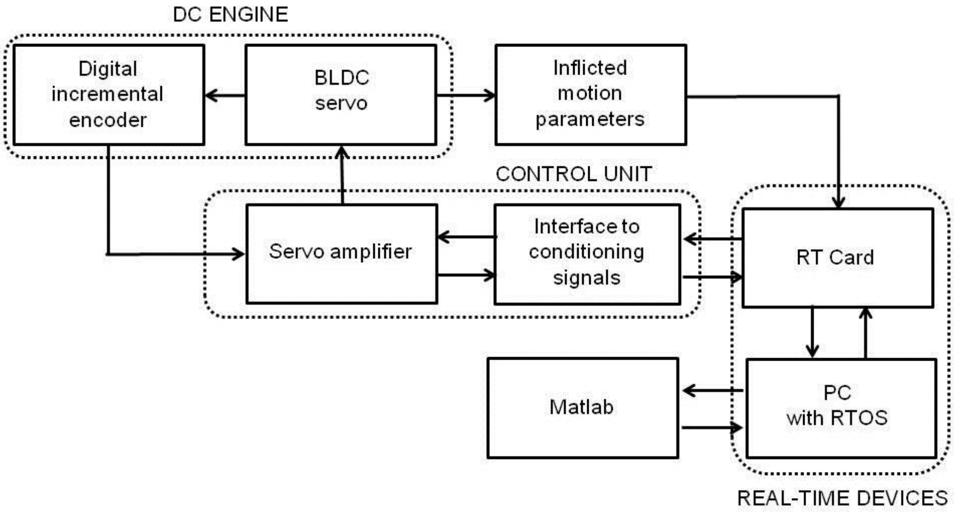

Fig. 2: Block diagram of the mechatronic control system on the laboratory stance.

Steering this mechanism is done using control algorithms developed in Matlab. The CPU where the real-time operating system is installed, using the digital signals (0-10 V), cooperate with real-time card. Real-time card communicates with the system executive. This system used two real-time cards RT-DAC4/PCI. Next elements included in this device is a servo amplifiers and cooperating with them BLDC servo motors equipped with a digital incremental encoders.

The numerical model of the electromechanical drive system was created using the software Matlab/SimMechanics. The mathematical model of BLDC motor (Brush Less Direct-Current Motor) was adopted in the form of simplified equations of motion (Glinka, 2002), (Ławniczek & Duda, 2013), (Świtoński et al., 2004).

Parameters of the motor model were estimated based on experimental studies. Mechanical part of this model was created in the convention of multibody system dynamics.

3. PID Control System

In the proposed tracking mode was used PID controller which on the basis of an error signal selects an appropriate value of the control signal of the drive motor speed. The error signal is equal to the deviation the crane rope from the vertical direction (set value of the inclination angle rope is equal to zero). This angle depends on the coordinates of gantry cart and the position of the patient. The idea of motion control algorithm follower mode of operation is shown in Fig. 3.

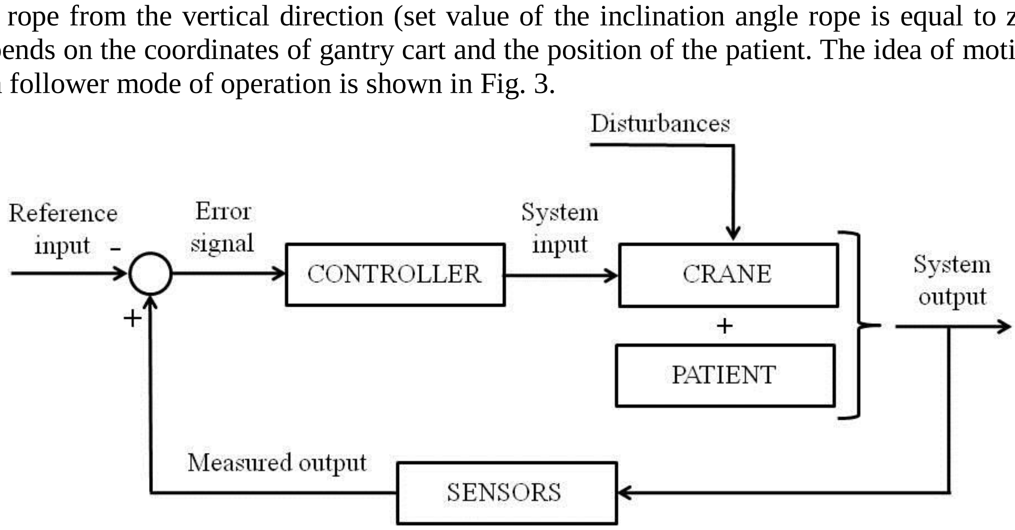

Fig. 3: Block diagram of the control system.

4. Tuning the Parameters of PID Controller

In order to analyse the control system at different values of PID controller gains in Matlab/Simulink was developed a numerical model of the tested device. Initially a displacement movement of the patient was modelled with a constant speed. During the initial selection of the control parameters, was noted that at too high value of proportional gain P indicated that gantry cart was ahead of the moving person. This leads to a situation in which hanging system starts to perform a reciprocating movement along the OX-axis with increasing speed. This situation is shown in the graphs below, which show the movement of the hanging mechanism and the patient (Fig. 4). The second graph (Fig. 5) shows changing the control signal values of the rotational speed of the drive engine.

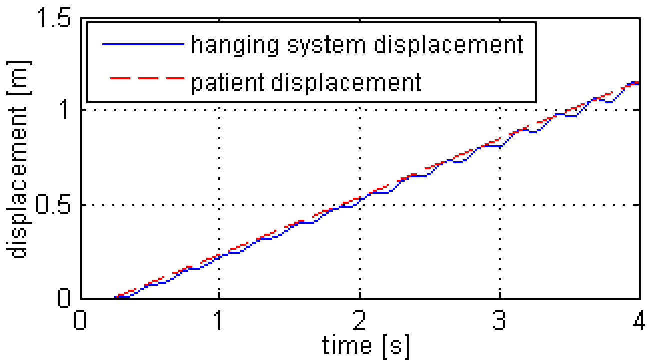

Fig. 4: Patient and trolley crane displacement as a function of time.

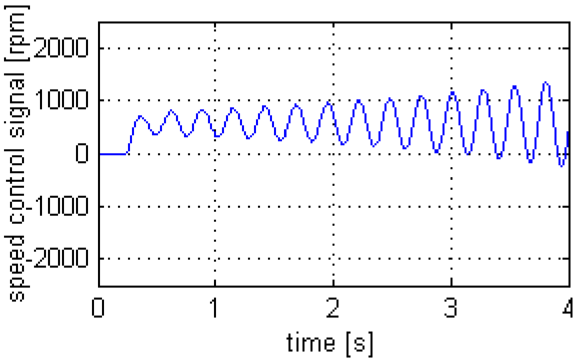

Fig. 5: A graph of speed control signal of the drive motor.

The same phenomenon was observed on a real object. Due to the patient safety and fear of mechanical damage of the device itself, tests of such settings were interrupted in the initial phase. An additional element of potentiating the action of gantry was distortion of signals from the measuring system of the deviation angles of rope – which was the feedback control signal.

Gantry movement discussed above causes both dangerous (can lead to the fall) and uncomfortable conditions for rehabilitation. When tuning the optimal values of PID controller gains was minimized both the angle of the rope and change the speed of the gantry cart while in motion (1). This was to ensure the smooth work as much as possible the vertical position of the rope (in this position hanging system has least impact on natural human movement).

$$F(\varphi) \cdot a + F(\ddot{x}) \cdot b \rightarrow min \qquad (1)$$

$$F(\ddot{x}) = \int_{t=0}^{T} \left| \frac{d^2x}{dt^2} \right| \qquad (2)$$

T – the final simulation time; F(φ) – the function of deviation angles of rope in time; $F(\ddot{x})$ – the function that describes the change of the linear velocity of gantry cart in direction OX-axis; a, b – parameters defining the impact in functions of deflection angle of and changes the linear velocity gantry cart to minimize the objective function.

The parameters *a* and *b* are selected such that both functions (deflection angle of the rope and gantry cart speed changes) had a comparable effect on the objective function. For such formulated problem, assuming the patient's motion with a constant speed, the optimization process is carried out to tune the PID parameters using gradient method. The obtained values (P = 300, I = 0, D = 10) was implemented in the control system in real object. Obtained characteristics were different from received during the simulation, which was a result of the fact that man was not move with uniform motion. After taking into account the numerical model the patient's movement as recorded during the test, then re-attempt to the tuning of the optimal PID parameters. Results did not differ significantly from the previous ones. The results of numerical and experimental studies were similar nature. The graphs below show a comparison of the deviation angles of rope obtained during the simulation and the experiment (Fig. 6). In Fig. 7 shows the displacement of the patient and the gantry cart recorded during the tests on the real object.

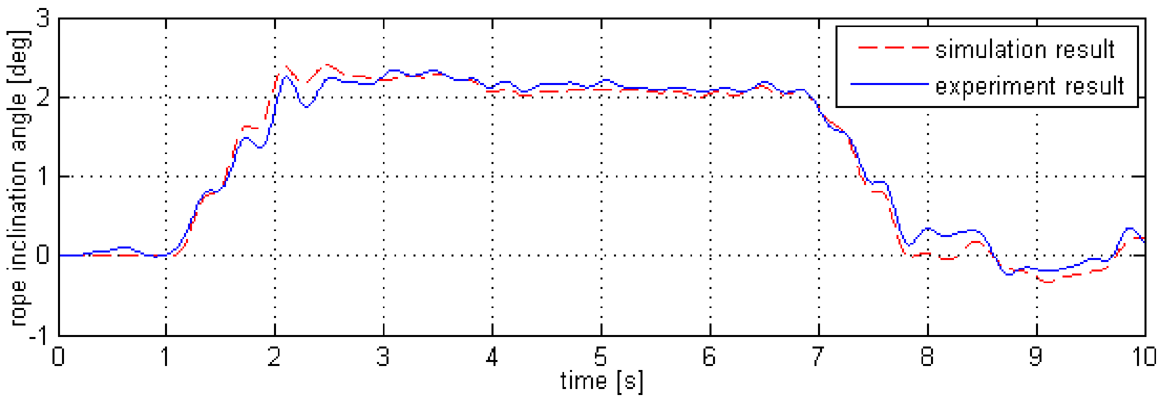

Fig. 6: Changing the angle of inclination rope in crane as a function of time.

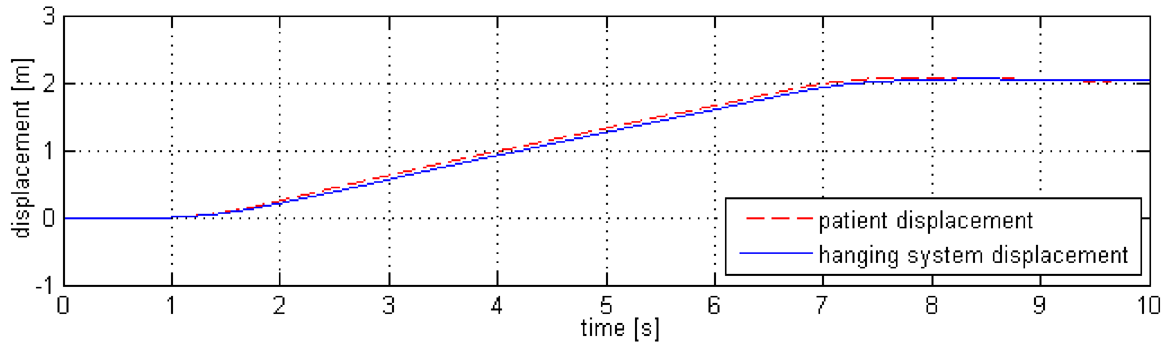

Fig. 7: Registered patient and the crane hanging system displacement as a function of time.

5. Conclusions

The developed control algorithm allows for the implementation of keep-up mode of rehabilitation crane movement after moving patient. It was designed for movement in the direction of one axis of the device, however, can easily be implemented in a second direction of action. The developed control system provides a small inclination angles of rope (less than 3 degrees), thus the force transmitted by the rope will act mainly on the vertical direction. Properly selected controller settings exclude the possibility of the patient's overtake by gantry cart, causing loss of balance and introduces entire structure to vibrate with a large amplitude.

The above conclusions show that the developed control algorithm provides the basic requirements for devices used in rehabilitation process.

The proposed numerical model, despite its simplifications (omitted drag force on the guides and simplifies motor control), shows a satisfactory convergence of the results obtained during the test bench.

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References

Glinka, T. (2002) Electric machines, induced with permanent magnet. Gliwice: Wydawnictwo Politechniki Śląskiej. (in Polish)

Ławniczek, R., Duda, S. (2013) Model of the control system for lifting mechanism in special purpose gantry crane. Gliwice : Wydaw. Katedry Mechaniki Teoretycznej i Stosowanej, (in Polish).

Hornby, T.G., Zemon, D.H., Campbell, D. (2005) Robotic-Assisted, Body-Weight–Supported Treadmill Training in Individuals Following Motor Incomplete Spinal Cord Injury. Physical Therapy, Vol. 85, No. 1, pp. 52-66.

Hidler, J., Brennan, D., Black, I., Nichols, D., Brady, K., Nef, T. Zero, G. (2011) Over ground gait and balance training system. Journal of Rehabilitation Research & Development, Vol. 48, No. 4, pp. 287-298.

Świtoński, E. et al. (2004) Modeling of mechatronics drive systems. Monografia, Gliwice (in Polish).

Gembalczyk G., Duda S. (2013) Design and validation of devices for measuring the force and the angle of inclination rope in crane. Modelling in engineering, Vol. 16, No. 47, pp. 76-81 (in Polish).