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Mechatronic simulator of lever driven wheelchairs

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Abstract

Development of the lever-driven wheelchairs by different authors resulted in creating various lever-human work conditions in which disabled people propel their wheelchairs. This fact implies varying efficiency of human's work during lever wheelchair propulsion. In order to assess which of the world-wide proposed lever propulsion systems is the most efficient from the humans' work point of view a proper simulator was designed. Here described test stand offers the possibility to perform various ergonomic tests, it can also become a training station for the lever wheelchair users. Since the main differences in world known lever propelling system designs concern the lever length and levers axis of rotation position on the wheelchair, the wide regulation of these two parameters, was a decisive factor in designing the mechatronic simulator.

1. Introduction

Lever wheelchairs for disabled people can become an alternative to standard push-rim wheelchairs and hand bikes in terms of the outdoor use thanks to their various ergonomic advantages. Some authors state, that they form a promising, however underdeveloped wheelchair group, that if sufficiently developed, can become very useful [3]. Some designers worldwide already noticed their potential and developed their own implementations of the lever wheelchair concept, however they vary strongly as far as the lever propelling system design parameters are concerned, most of all in the levers' length and the position of their axis rotation. According to our knowledge, only three papers [2, 4,

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6] present research regarding optimization of the lever propelling system: two of them [1, 2] tried to discuss the issue in terms of experimental research and one [6] with use of analytical calculations. Unfortunately authors of these publications didn't manage to answer the most important questions regarding design of lever propelling system in a convincing manner. One of the papers states even, that optimizing this construction parameters is irrelevant, because they don't affect the conditions of human's work significantly.

At the same time we were unable to find up-to-date test stands designed specially for the assessment of the conditions of human's work during the lever wheelchair propulsion. In comparison, it is easy to find test stands developed for this purpose for push-rim wheelchairs [1 ,5].

In order to fill this knowledge gap and contribute to development of the lever driven wheelchair concept we have built a mechatronic simulator which allows assessment of various ergonomic issues regarding lever propelling system, most of all the influence of levers' length and the position of their axis of rotation, on the human's work efficiency.

2. Methodology

Mechatronic simulator presented in Fig. 1 was constructed of various elements which altogether form a lever-drive wheelchair ergometer. The idea of the test stands work is following: patient is sitting on the fixed wheelchair (1) and carrying out propulsion work by pushing two levers (2). Force exerted by the human upper limbs is measured by extensometers on both levers and transferred to two flywheels (7) through changeable gears (6). Each lever is connected to a separately spinning flywheel. The more force exerted by the patient, the faster the flywheels rotate. Rotation velocity of both flywheels is measured and allows computation of wheelchairs velocity and simulation of its motion. Wheelchair ride simulation (fig. 2) is projected in front of the patient which increases the reality of experiment. Changeable load during wheelchair ride which can be an effect of e.g. slope or wind, is simulated through electromagnetic brakes that can slow down the flywheels (7). The brakes are current-controlled via National Instruments Compact Rio system and thus the patient-perceptible load on the levers can be rapidly adjusted.

Wheelchair fixing system (8) is adjustable so that various wheelchairs can be mounted on the test stand and thus anthropometrically various users can be assessed on the simulator. Levers are designed in a manner that allows changing their length from ~300 to 660 [mm], also the test stand allows changing position of the levers axis of rotation (4) both in vertical (250 [mm] range) and horizontal (520 [mm] range) directions. Changing the horizontal position of levers' axis of rotation position (4) in reference to the wheelchair requires moving the platform (3) in the desired direction, whereas a change in vertical direction requires moving (4) up or down on the column (5).

Apart from the above mentioned features the test stand allows also:

- regulation of levers inclination to the wheelchairs symmetry plane within the range of 0 15°;
- bending of levers hand grip within the range of 0-180°;

- rotation of levers hand grip within the rage of 0 -360°;
- changing gears between levers and flywheels (2 planetary gears for each lever, 8 gears each);
- performing tests with or without projection of the wheelchairs ride simulation, it allows especially the assessment of human ability to follow a path shown on the display;
- braking can be accomplished through pushing the levers to the wheelchairs symmetry plane. Measurement of applied force in this direction with extensometers allows changing the current applied to the electromagnetic brakes in a desired pattern.

Altogether the simulator allows assessment and recording of the following mechatronic information during each experiment:

- human's force exerted in the levers' motion plane;
- human's force exerted in the plane perpendicular to the levers' motion plane;
- angular position of the levers in their motion plane;
- flywheels' rotation (angular velocity).

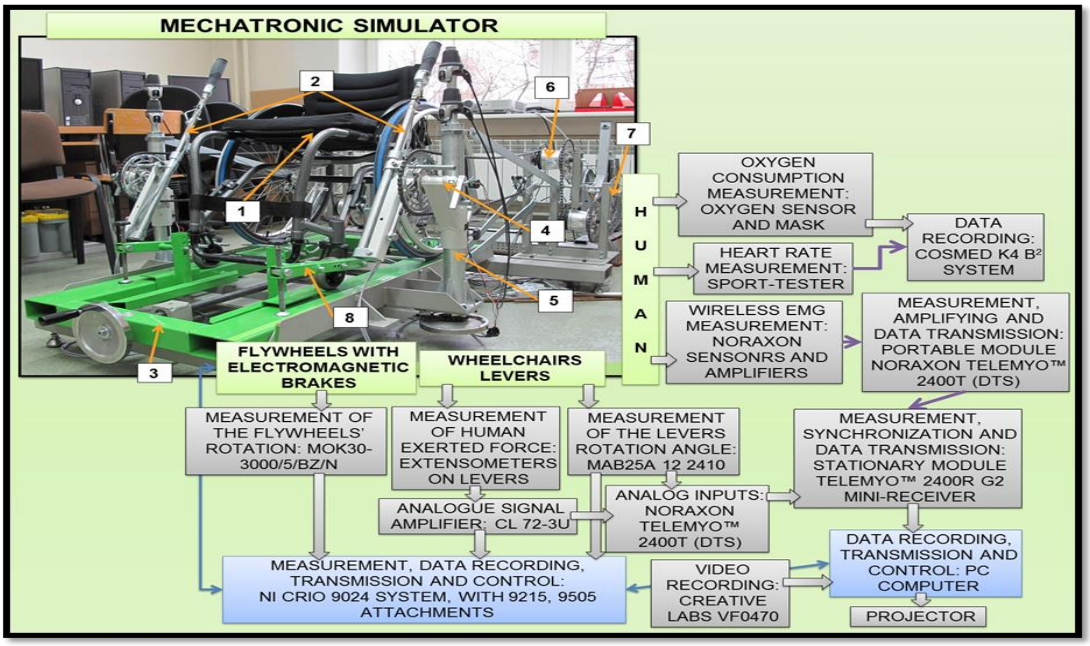

Fig. 1. Overall view of the mechatronic simulator mechanisms and schematic illustration of data management process. Legend: 1 – wheelchair; 2 – levers; 3 – wheelchair's platform; 4 – lever's axis of rotation; 5 – column for the vertical movement of lever; 6 – changeable gears; 7 – flywheel along with electromagnetic brake; 8 – adjustable wheelchair fixing point. Fields with green background – objects from which measurements were taken and effectors (electromagnetic brakes); fields with grey background – elements responsible for all data-management processes except control; fields with blue background – elements responsible for all data-management processes including control; grey arrows – cable data transmission; violet arrows – wireless data transmission; blue arrows – cable data transmission in both directions.

During an experiment carried out on the simulator apart from mechanical-related data, the biomechanic information regarding human's work can be recorded. The use of three various measurement techniques beginning with basic heart rate measurements, through oxygen consumption analysis, finishing with electromyographic muscle work assessment, combined with the information gathered regarding external work carried out by human, allows decent assessment of the human-lever drive system. Carrying out experiments with the use of the proposed measurement techniques will allow calculation of one of the most interesting and important parameters: human work efficiency during the wheelchair propulsion.

Real time measurement of rotational velocity and control of the electric current applied to the electromagnetic brakes attached to the flywheels allowed creation of a simulation display presented in fig. 2. In the beginning only a simple ride model was implemented to provide data necessary for the ride simulation, however development and implementation of a more complex wheelchair ride model is possible. If carried out, the test stand could simulate e.g. various riding conditions regarding terrain type. Also, further development of the simulation environment will allow the test stand to become a proper training station for users who are not familiar with the techniques used during wheelchair propulsion by levers.

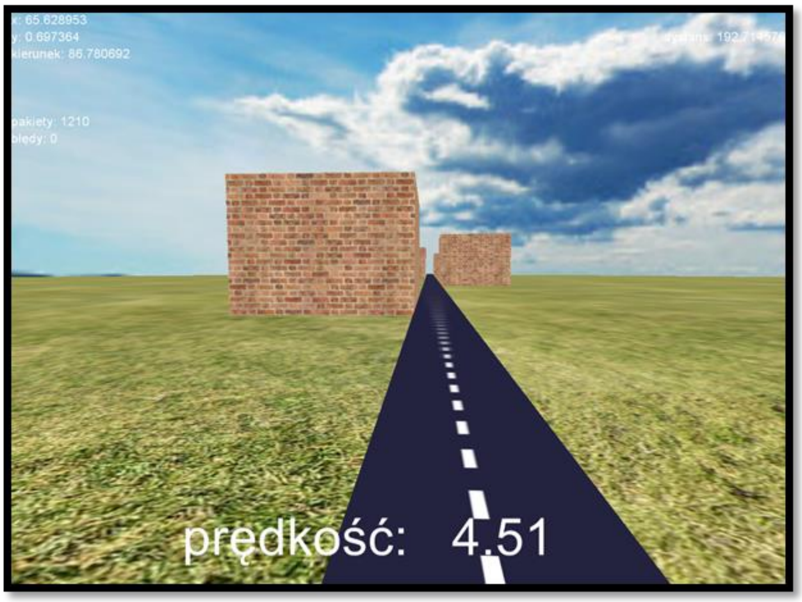

Fig. 2. Simulation of wheelchairs ride generated and displayed in real time by the mechatronic simulator. Legend: „prędkość" – wheelchairs velocity [km/h]; „dystans" – travelled distance [m]; „kierunek" – riding direction [°]

3. Conclusions

The mechatronic simulator presented in this paper is the only currently available simulator of the lever driven wheelchairs known to the authors. It allows carrying our tests regarding ergonomic human's work conditions with lever propulsion system in different configurations and thus comparison of the market-available solutions. Application of the proper measurement techniques of the human's work on the simulator can allow e.g. the assessment of human work efficiency or local muscle fatigue.

Moreover the mechatronic simulator can be used as a training station for users willing to get familiar with the lever drive concept. It is also possible to treat the presented mechatronic simulator as a refined ergometer that can serve rehabilitation purposes.

Acknowledgements

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