DESIGN OF A CONTROLLABLE WHEELCHAIR ERGOMETER FOR SIMULATION OF REAL LIFE CONDITIONS

J. González-Quijano, J. Sánchez, P. Raya, J.C. Moreno, J.L. Pons and A. Gil

***Abstract*—The assessment of wheelchair users in sports and rehabilitation at several levels, requires of ergometric systems to execute controlled tests with simultaneous measurements of physiological and biomechanical variables. Such systems must simulate the real conditions. A number of ad-hoc ergometers have been developed but the majority of the devices fail to permit adaptation of the users's current wheelchair. This paper reports the design of a novel controllable wheelchair ergometer for simulation of different types of propulsion and analysis of metabolic cost and biomechanics during.**

I. Introduction

Wheelchair ergometers are platforms that allow the simulation of wheelchair motion. A few instrumented and computer-controlled ergometers have being proposed in order to simulate the wheelchair propulsion, with preliminary evidence towards clinical application [1]. Designs can vary according to the construction, level of adaptability, number/modes of simulation and sensor systems, [2]. Most models consist of static platform with rollers where a common wheelchair can be placed tied to the supporting structure with straps [3]. Others use a special static chair where wheels rotate by the direct action of motors coupled to them with help of gears [4]. A proper method to calculate the applied 3D forces during propulsion is very important to train new wheelchair users or improve paralympic locomotions. The design consists of a wheelchair mounted on a support, with a high level of adjustability to users and testing conditions. The ergometer enables the realization of stationary exercises with a realistic simulation of different types of propulsion, in combination with the measurement of biomechanical and metabolic parameters.

II. METHODS

The system design comprises the mechanical structure, actuation, sensor and control components, see figure 1.

A. Structure

With the goal of investigating the influences of variations in mechanical parameters in wheelchair users, the ergometer is conceived as a platform with adjustable positions (wheels, seat, backreast) and sizes of wheelframes. The specifications of the emplacement where chair, motors, electronics and the master computer have to be placed are the maximum height of 2 m and maximum area of 1.50 m x 2.30 m.

Adjustable wheels camber (wheel inclination angle), horizontal and vertical position makes that the final structure for the wheels fixing has to be done like this:

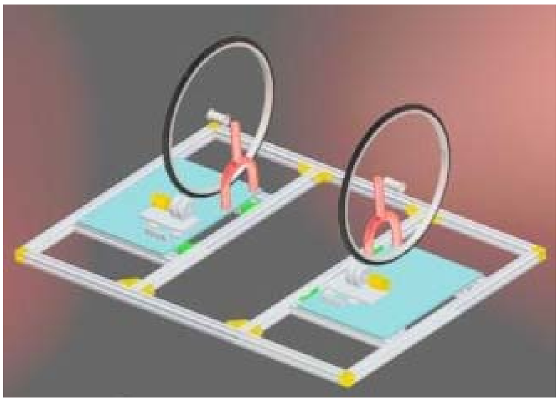

Fig. 2. Design of the structure to adapt the user's wheelchair with adaptable sizes of wheels.

B. Sensors

The instrumentation consists of 3D force and torque transducers measuring three components of the forces and torques applied on the handrims and also 3D force transducers applied on the seat and the backseat. Encoders are placed to measure the instantaneous velocity and acceleration of each wheel. Inertial sensors are fixed on the wheelchairs frame to calculate tilt, based on accelerometer data. Useful force exerted by the user in order to accelerate the wheels is calculated based on the torque transducers. Also, we need torque and velocity obtained from the encoder in order to measure useful power.

C. Actuators

Actuation is provided by motors controlled by a master computer with a data-acquisition system for all incoming signals. Two motors of 250 W are used with and effective output torque at each of 30 N.m.

D. Control electronics and DAQ

The acquisition system enables capturing of additional systems, e.g. electromyography (EMG), pressure socket, heart rate, etc. A software application in the master computer is developed for control and measurement purposes. The control system is designed in order to

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simulate for rolling resistance, air drag and slopes, controlling the wheels.

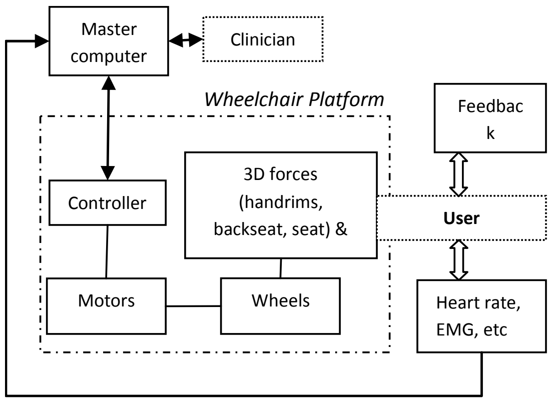

Fig. 1. Configuration of the system components.

E. *Modes of simulation*

A maximum velocity of 10 m/s is considered. The simulated propulsion might be isokinetic, isoinertial or static which are the main methods we have to measure force, power and other muscles features [5]. The overall inertia of the human-machine system will also be simulated. A biofeedback monitor is presented to the user to control performance and effort. Also, different types of floor textures can be simulated. The following modes of simulation are provided:

- Isoinertial simulation
- Isokinetic simulation
- Isometric (static) simulation
- Constant power

Isoinertial mode simulates real behavior of a wheelchair where inertia keeps wheels rotating among time-interval user impulses. In this mode, we can simulate slopes, ground friction, air friction and different types of ground textures.

Isokinetic mode adjusts motor torque in order to let the user maintain a constant speed. This implies to reduce motor opposite torque as user gets tired along time.

Isometric mode allows clinicians to determine the maximum force the patient can exercise in static conditions. The motor actuates with the same torque as the one exerted by the user but in opposite direction. As a result speed is zero and we can measure user´s torque with torque sensors.

To control *constant power* mode is necessary to keep constant the product of torque by velocity.

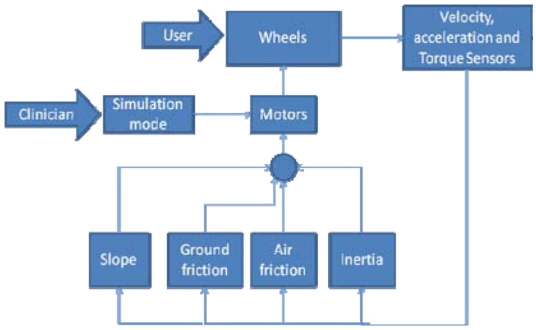

Fig. 3. General control system specification

F. *Solving handrim 3D-force applied and force point application (PFA) on the handrim*

Classical methods of 3D force measurement require lots of complex [6] [7] and very expensive instrumentation which needs to be constantly maintained. Thus, a simpler and cheaper solution has been developed which will allow many specialized centers to afford this ergometer.

Most difficult problem to come over in an inexpensive way is to measure handrim 3D-force and point force application. We we will use the information of an encoder, a 3D force transducer fixed in the rotational axis near the center of the wheel and also information provided from a torque sensor placed in the roller axis. The range of the 3D force transducer is 200-200-1000 N and 50 N.m for the torque sensor. Although the 1000 N force component is oversized it has been considered as it will ensure the transducer will keep on good conditions although an accidental extremely big force applied on it could damage the sensor.

The point force application (PFA) is obtained by the combination of the angular position obtained by the encoder and the calculation of the direction of the resultant force formed only by the Fz and the Fy components. Measuring 3d force applied by the user on the handrim is a complex trigonometrical problem as we have to consider the camber of the wheel and the placement of our force sensor which is not placed exactly on the center of rotation. We will need also the torque transducer in order to obtain the tangential force exerted by the hand on the handrim. This force is the most important as it is the only one which really contributes to the wheel rotation. Although torque sensor is placed in the roller and not in the wheel axis there is a known reduction relationship between the wheel and the roller which will help us to calculate real torque.

The key of the success in the measurement is the correct calibration of the instrumentation required as roller is applying a normal force to the wheel which we can not measure at all. Therefore, an automated calibration algorithm has been design in order to maintain the high quality measurements required.

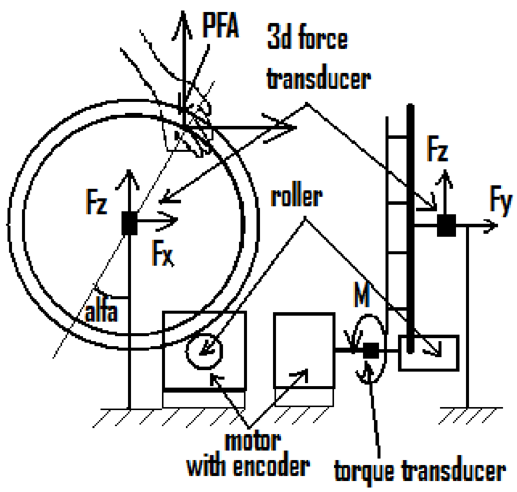

Fig. 4. Instrumentation placement needed for measuring 3D force exerted on the handrim

III. RESULTS AND CONCLUSIONS

A novel design of a wheelchair ergometer is presented. The minimized set of transducers integrated in the structure allows for the quantification of the most relevant kinesiological parameters, in a relatively low cost solution. The control system permits the simulation of the varying conditions of propulsion at the wheels, adjusting the inputs to the motors. The remote master computer implements the real-time monitoring and control applications. The presented design has considered ease of accessibility to the user, with a fully static device that provides confidence. A preliminary study with manual wheelchair users in combination with a marker-based 3D motion analysis system will be the next step in order to examine the strategies adopted by the users for each simulated condition.

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