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MOTION STUDY OF A WHEELCHAIR PROTOTYPE FOR DISABLED PEOPLE

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***Abstract*—** In this paper is presented the design and experimental prototype of a wheelchair for disabled people. Design solution proposed to be implemented uses two reduction gears motors and a mechanical transmission with chains. The motion controller developed uses PWM technology (pulse wave modulation). The wheelchair has the ability of forward – backward motion and steering. The design solution is developed in Solid Works, and it's implemented to a wheelchair prototype model. Wheelchair design and motion makes him suitable especially for indoor use. It is made a study of the wheelchair kinematics, first using a kinematic simulation in Adams. Are presented the wheelchair motion trajectory and kinematics parameters. The experimental prototype is tested with a motion analysis system based on ultra high speed video recording. The obtained results from simulation and experimentally tests, demonstrate the efficiency of wheelchair proposed solution.

***Keywords*—**Wheelchair, kinematics, prototype, motion study.

I. INTRODUCTION

THIS paper is structured in three sections. The introduction section presents a literature review of existing wheelchairs design solutions. The second part presents the design solution of experimental prototype and motion controller implemented to the wheelchair. In the last part is presented the kinematical characterization of the wheelchair, by motion simulation in Adams and experimental motion analysis. The experimental motion analysis is based on high speed cameras motion capture and analysis equipment.

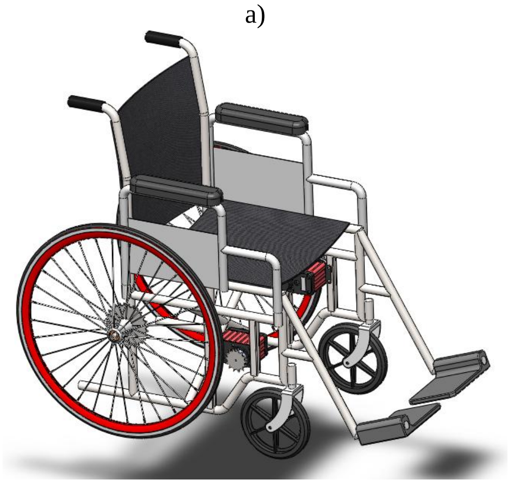
To assist mobility of disabled persons, several electrical powered wheelchairs are available on the market [1]-[4]. In last decades, there have been great's improvements in power wheelchairs design and manufacture. Wheelchairs available on the market, for disabled patients, are much diversified as features and facilities, allowing the user to adjust their sitting position. Power wheelchairs are used predominantly by people with both lower and upper extremity impairment resulting from cerebral palsy, high-level spinal cord injury, or muscular dystrophy [5]. The propulsion system of powered wheelchairs typically consists of a pair of motors, one for each drive wheel, and a drive train consisting of gears, belts and other mechanical elements that couples the motor's shaft to the drive wheel shaft. Speed and torque generated by each motor is controlled by modulating the pulse width. Solid state relays are generally used to switch supply voltage polarity to change the running direction of PM (permanent magnet) motors [6]-[7]. The wheelchair's control module converts positional information from the joystick into power signals to the motors. Control modules are microprocessor based and have many adjustable parameters. Many control modules utilize feedback to sense whether the motor is responding properly to the joystick position. Such control systems adjust motor torque so as to maintain near constant speed while the load varies in response to changes in the terrain (incline, bumps) and surface (linoleum, carpeting, concrete, grass, sand) [8]-[12].

Proposed solution uses an indirect drive transfer system, the motor is coupled to the drive wheel shaft through a system of gear train and flexible machine element (chains). The gear train and chain serve to reduce the motor speed while proportionately increasing motor torque [13]. Incorporating a transmission mechanism into the drive train would allow the PM motor to run efficiently for all speeds and torques and extend the serviceable lifetime of PM motor [14]-[17].

II. PROPOSED DESIGN AND CONTROL SOLUTION OF WHEELCHAIR

Design solution of the wheelchair is developed in Solid Works. Based on wheelchair dynamics calculated parameters is established the necessary torque and speed of propulsion motors. There are used two servo motors from Pololu, with reduction gears. The i00600 Torxis is an ultra-high-torque servo that can deliver a continuous duty torque of up to 115 (kg·cm) at 12 (V). The servo is powered by 12 (V) and draws approximately 3 (A) at full load. All of its gears are metal for increased durability and the hardened output shaft has 9.5 (mm) diameter and is supported by two ball bearings. It is pre-configured for a 90(degree) range of motion, but this can be modified by reconfiguring the embedded controller [18]. Designed train drive solution uses chain wheels with reduction ratio by 2. The model of the wheelchair, designed in Solid Works is presented in Fig. 1.

a)



b)

Fig. 1. Wheelchair CAD model developed in Solid Works.

The obtained 3D virtual prototype is important because it will be used to simulate in Adams the wheelchair motion trajectory and study of motion dynamics. Also the virtual prototype is useful in further design studies, to optimize the construction (minimize weight, ergonomics).

Fig. 2.Aspect of the wheelchair chain transmissions.

The experimental model of the wheelchair, assembled at Faculty of Mechanics, Craiova, is shown in Fig. 2, 3.

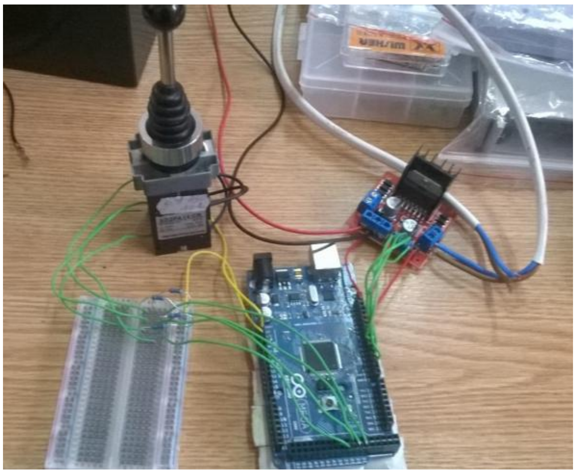
The wheelchair proposed solution uses two gears motors. The motion transmission to wheels is made with chain transmissions. Chain transmission multiplies two times the motor torque, and reduces the angular velocity.

a)

b)

Fig. 3. Front a), and side view b) of the wheelchair prototype.

Controller implemented is based on a L298N Dual H-Bridge Motor Controller module. H-Bridge's are typically used in controlling motors speed and direction. An H-Bridge is a circuit that can drive a current in either polarity and be controlled by Pulse Width Modulation - PWM. Pulse Width Modulation is a means in controlling the duration of an electronic pulse. The longer the pulses the faster the wheel will turn, the shorter the pulses, the slower the wheel will turn. Motors will last much longer and be more reliable if controlled through PWM [19]. The microcontroller is based on Arduiono Mega 2560 board. The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 (MHz) crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button [20]-[21], see Fig. 4.



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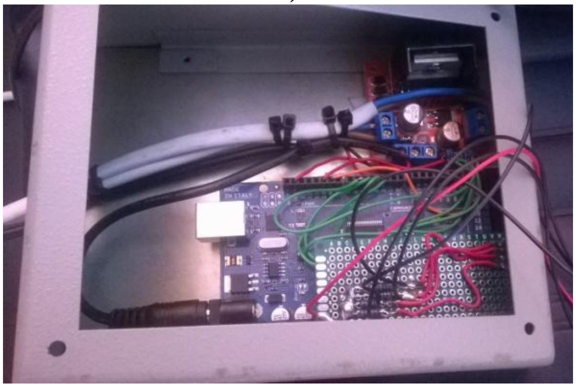


b)

Fig. 4. Aspects of PWM controller and joystick.

Mechanical design solution is innovative from aspect of wheelchair folding for easy transportation. As is presented in Fig. 5 the motorized wheelchair keeps the folding capability. This is very useful in the situation when the person with disabilities is going to another location (a visit for example) and needs to move the wheelchair with a transportation vehicle. This can be done with a family vehicle.

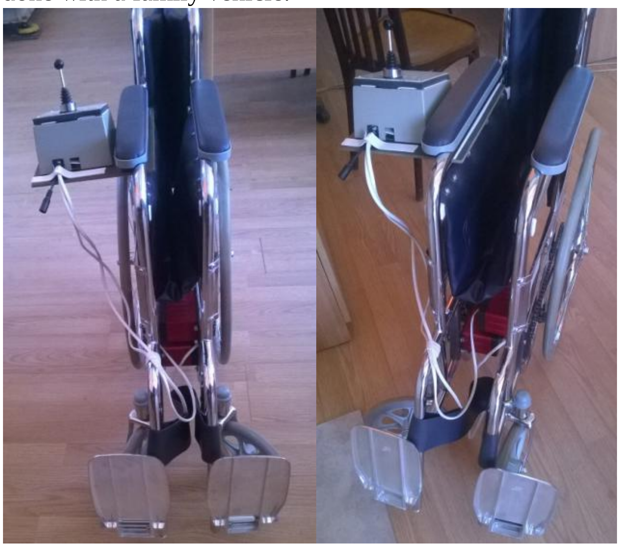


Fig. 5. Wheelchair in folded position.

III. Motion Analysis of the Wheelchair

For beginning the motion analysis of the wheelchair is studied in Adams software. For that purpose the CAD model of the wheelchair is imported into Adams software database. Trough a suitable Adams developed procedure is analyzed the wheelchair motion trajectory and motion parameters. First are defined the components materials type, upon the programs calculates the inertia properties of elements. Upon this step are defined the rotation joints of the wheels. The front wheels are self directionally, and they are mounted on the wheelchair structure with axial-radial bearings. The kinematic model of the wheelchair constructed in Adams is presented in Fig. 6.

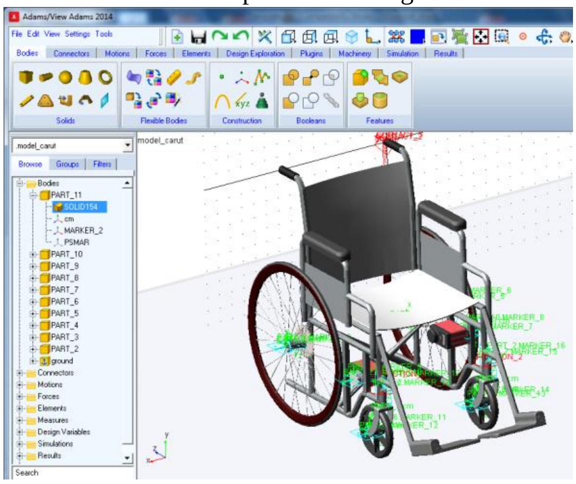


Fig. 6. Wheelchair kinematic model in Adams.

Very important to complete the kinematic model of the wheelchair represents the stage of defining the chains transmissions. For that purpose it is used Adams Machinery, to define the sprocket set of the chain system and chain sprocket actuation input. Aspect of chain system modeled in Adams is shown in Fig. 7.

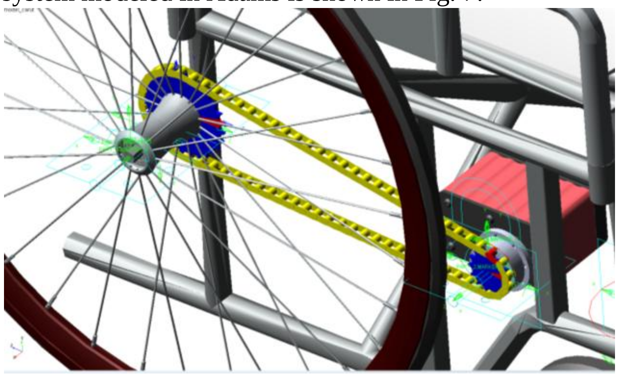


Fig. 7. Chain system in Adams Machinery.

The contact forces from wheels and ground are described by a contact mechanics model which is determined by parameters such as stiffness, force exponent, damping and friction coefficients and penetration depth. These parameters are defined by studying the literature [22]-[24].

A. Wheelchair motion analysis in Adams

In this paragraph is presented the wheel ground contact parameters necessary to specify, to obtain a proper contact model from wheel and ground. Considering the computational efficiency and accuracy, is adopted the impact method to define wheels and ground contact. Necessary parameters for this method are explained below [22]-[23]. The friction coefficient between ground and wheels is specified according to the literature: Ψ_a =0.5-0.6 for old asphalt road, old concrete.

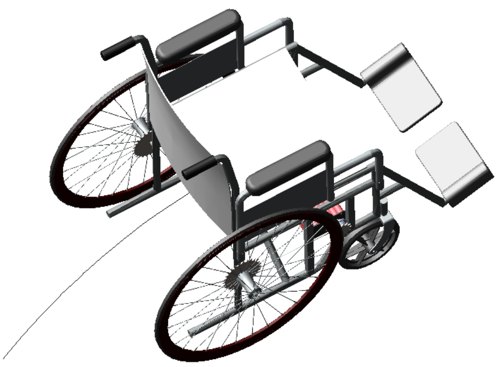
1) Stiffness K: The details of the contact bodies are specified from literature, typical values for Poisson ratio and the Young's modulus are: for ground $\upsilon = 0.16$ *and* $E = 2.2 \cdot 10^{10} (N/m^2)$, *for wheel* $\upsilon = 0.28$ *and* $E = 8.3 \cdot 10^9 (N/m^2)$.

2) Force exponent e: Considering numerical convergence and computation speed, a force exponent e=1.2 is determined [22]-[24].

3) Damping coefficient C. For this simulation the damping coefficient is set to C=100 (Ns/mm).

4) Penetration depth: In most cases, a reasonable value for penetration depth is 0.01(mm). We used d=0.1(mm), considering the numerical convergence in Adams.

5) Dynamic and static friction coefficient and viscous velocity. Typical values found in books are: $\mu_s = 0.2$; $v_s = 10(mm/s)$, $\mu_d = 0.18$, $v_d = 100(mm/s)$ *[22].*



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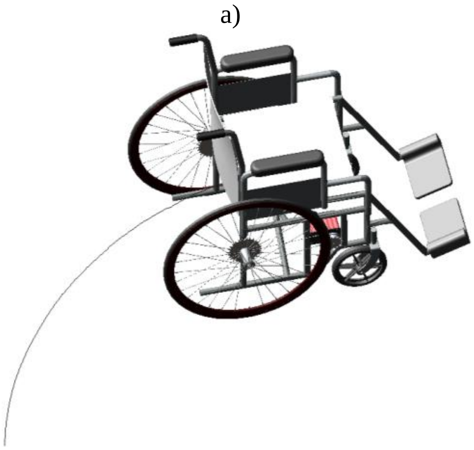


b)

Fig. 8. Wheelchair motion trajectory computed in Adams.

It is made robotic wheelchair motion analysis in Adams, in first case for a straight line displacement, when both motors run with same angular velocity. For this simulation the both motors run with 9.55 (rot/min), the wheelchair motion trajectory is shown in Fig. 8. a, and the propulsion torque is shown in Fig. 9. The wheelchair propulsion speed is constant and is shown in Fig. 10.

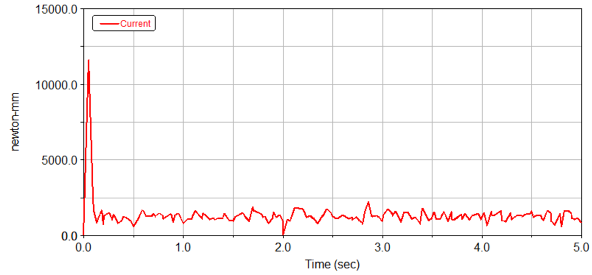


Fig. 9. Propulsion torque for straight line motion.

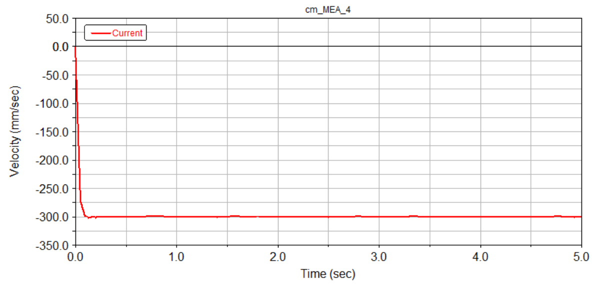


Fig. 10. Wheelchair mass center marker velocity.

For the second simulation case, the right motor runs with 1.9 (rot/min) and left motor runs with 9.55(rot/min), the wheelchair obtained trajectory is shown in Fig. 8, b. The wheelchair motors torque, measured in Adams simulation is shown in Fig. 11, for right motor, and in Fig. 12 for left motor. Is observed that is needed a greater torque for right wheel, because it's spins with a lower angular speed.

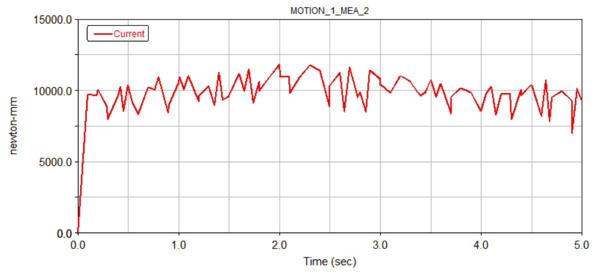


Fig. 11. Propulsion torque for wheelchair right wheel.

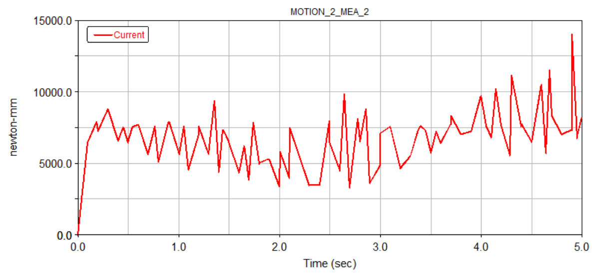


Fig. 12. Propulsion torque for wheelchair left wheel.

Wheelchair displacement, upon transversal axis, and longitudinal axis are shown in Fig. 13 and 14. For that simulation case the wheelchair velocity magnitude is shown in Fig. 15.

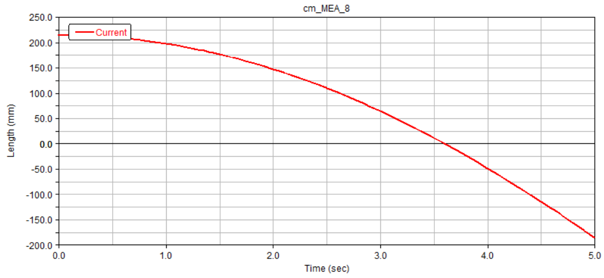


Fig.13. Wheelchair displacement, upon transversal axis.

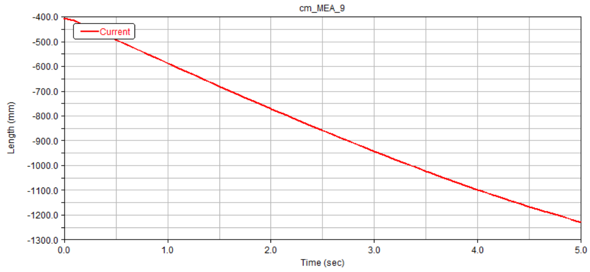


Fig.14. Wheelchair displacement, upon longitudinal axis.

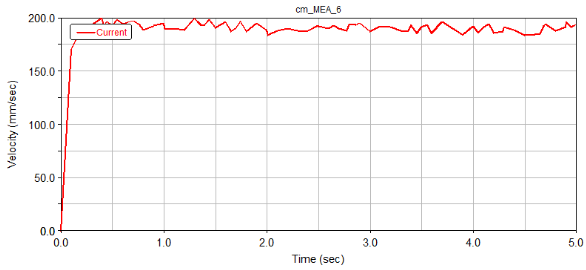


Fig.15. Wheelchair velocity magnitude.

B. Experimental evaluation of wheelchair motion

For wheelchair experimental motion evaluation it is used motion analysis equipment – Contemplas, based on ultra speed cameras [25]. Reflective markers have been attached to the wheelchair frame and wheel. The marker motion is captured and processed with TempoloMotion software in order to establish wheelchair wheels rotation and displacement variation in time. Positioning of reflective marker is shown in Fig. 16 and motion tracking results are indicated in Fig. 17.

The notations used are following:

1) back attached reflective marker.
2) front attached reflective marker.
3) wheel center attached marker.
4) wheel circumference attached marker.

With Contemplas motion analysis equipment, the wheelchair is analyzed during a straight line displacement. Obtained results for markers trajectories and kinematic parameters are presented in the Fig. 18. The graphic of the angular variation of wheel is presented in Fig. 19.

Fig.16. Positioning of reflective markers on the wheelchair.

Processing the motion capture, it is obtained markers trajectories, presented in Fig. 17.

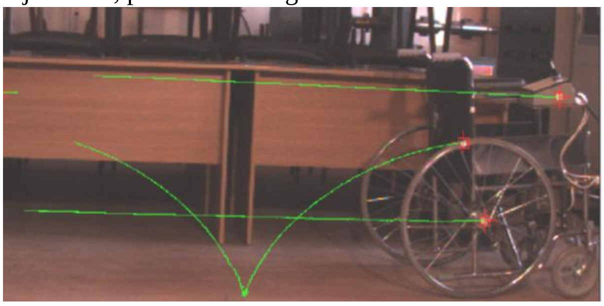
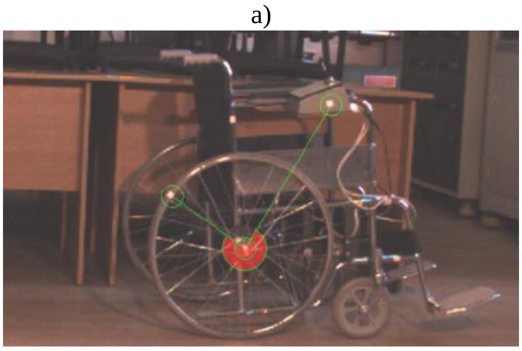


Fig. 17. Markers obtained trajectories.

Is observed that the wheel circumference marker describes a cycloid curve, and markers attached to the frame are describing a straight line. Motion tracking allow establishing the wheel angular position, and also angular velocity.

a)



b)

Fig. 18. Motion tracking for wheel angular position establish.

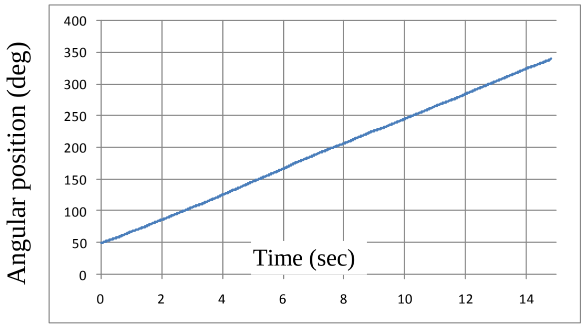


Fig. 19. Time variation of wheel angular position.

IV. CONCLUSION

This paper proposes to develop a kinematic analysis model of a robotic wheelchair, which will be used for further dynamic studies. In order to increase efficiency propulsion motors must run at a high angular speed. For that are implemented motors with reduction gears and chain drive trains, in order to change the motor speed to a lower speed and increase the available torque to wheels. The virtual model of the wheelchair is designed in Solid Works and upon this model is developed the experimental model. Proposed solution uses two motors, controlled by a joystick module, based on a PWM controller. Kinematic analysis reveals motion trajectories of wheelchair, kinematic parameters of the system: wheel angular displacement and speed, running speed. Further studies concerns the motion study for steering situation, and establish of dynamic parameters of the wheelchair: electric DC motors propulsion and steering torque.

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