SIMULATION OF SHIFTS IN A WHEELCHAIR WITH LATERAL AND LONGITUDINALSTABILITY CONTROL SYSTEM

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Abstract. *This paper aims at stimulating the development of assistive technology for people with physical disabilities who are entering into a niche research is still relatively unexplored, but promising in practical, economical and social terms, in addition to allowing the nationalization of this technology so effective in transporting people with disabilities. Therefore, the approach taken, though little study is the lateral stability in wheelchairs which is of great importance to reduce injury to people already quite weak and exposed to various correlated diseases, i.e. the wheelchair. It is known that the tipping and falling wheelchairs arise when stability limits are exceeded. These types of accidents can easily occur on banked tracks and are harmed by the action of gravity acceleration when it is on a slope. Due to the benefits of mobility, wheelchairs and electric vehicles have their use in mobility applications, mainly urban. However, the stability study for this kind of vehicle is poorly developed. The control of balance in electric vehicles, with emphasis in wheelchairs presents significant effects with regard to improving the quality of life and safety of wheelchair users, a topic of great relevance today. This paper presents the development of simulation control of balance by controlling semi-active suspension, using sensor like gyroscope. Finally simulations are shown using this system and compared the performance between the position and angular parameters of a wheelchair with the active and disabled system.*

Keywords: Assistive technology, semi-active suspension, wheelchair

1 INTRODUCTION

The traffic on sidewalks of public roads is hindered by the presence of various types of obstacles. For a chairperson these obstacles are increased slopes of streets and sidewalks that compromise posture of these people which are pretty weak. Nowadays, we try to improve the level of performance and independence of people with disabilities to improve their quality of life and provide better working conditions. It is known that the aging population is growing rapidly in many countries, including Brazil. The representation of people over 65 years in countries like Japan, Italy and Germany can vary from 18,8% to 21%. In Brazil there is a difference of representation of people aged over 65 years increased from 4,8% in 1991 to 5,9% in 2000 and reached 7,4% of the population in 2010 (IBGE, 2013; Nakamura & Murakami, 2011). This is important because, associated with aging, disease-causing motor impairment and accidents with severe injuries, is the increased use of wheelchairs by the worsening of the motor resourcefulness.

Wheelchairs are adapted for use by wheelchair users according to their needs and capabilities, so there are many different types and levels of mechanization of these chairs. For people with upper limb mobility, one can use chairs without motorization. However, these people need to adequate physical capacity so that they can move freely on flat surfaces (inside buildings, for example), inclined surfaces (ramps and roads) and displacement on uneven surfaces (reality of most sidewalks in Brazil). According to Li, 1997, to maintain a balanced and upright posture when traveling on a side slope (causing a longitudinal rotation in the wheelchair) can be difficult for someone without adequate body strength in the trunk, as those who use wheelchairs.

The latest developments of wheelchairs are made available with technology controls for gyroscopes and accelerometers and dispense with the type of wheelchair castors. However, these chairs also have a cost prohibitive for the reality of the majority of the Brazilian people and to the exclusion of most wheelchair labor market, it is even more difficult to use. However, the independence of the wheelchair is limited to the displacement on the battery life of your chair, requiring the person planning their daily travels.

The equation and development of lateral and longitudinal stability systems showed an increase of publications during the mid 2000s, with the popularization of development of bipedal robots, quadrupeds and motorcycles. The lateral stability wheelchair joint is usually accomplished by varying the camber angle of the wheelchair, by increasing the turning radius to ensure better stability. The longitudinal stability control in general is done by controlling the torque supplied to the wheels, even on chairs that use castors.

Accidental failures and overturning are the main causes of injury accompanying wheelchair users (Corfman, et al., 2003). Most injuries happen by tipping the chair or wheelchair for the fall of the wheelchair. The wheelchair is more likely to tip over when moving down a slope, across a slope or when it hits an obstacle. The shaft positions, camber angle, the user's position and the position of any mass assist directly affect the angles of inclination of the wheelchair. However, making appropriate adjustments in the wheelchair, can prevent or reduce the possibility of overturning failures and related accidents. However, many accidents occur by an inappropriate design of the wheelchair. The stability of the wheelchair, the frame, the mechanical properties of the materials used, the interaction with the environment and braking performance are important design requirements to develop a wheelchair safe (Cooper, 1993).

It should be noted that the stability of the wheelchair has a strong subjective character. Equilibrium strategies while driving the wheelchair depend on notions of speed and distribution efforts by wheelchair. Wheelchair mobility with the upper body can adjust his wheelchair with less stability. This can compensate for this instability by moving the body to adjust the center of mass. For driving manual wheelchairs, the wheelchair must control the torques applied to the rims of the wheel to prevent the chair from tipping over or along so you can cram the chair during maneuvers (Cooper, 1993).

An important point to be discussed is that accidents wheelchairs commands can be caused by altered emotional state of the user such as fatigue, irritability, and decreased ability to reflect for whatever reason, among others. The wheelchair with little experience in the operation of the wheelchair can go wrong in driving due to changing characteristics of the sliding surface (Koontz et al., 2010). Also, the wheelchair can lose its stability due to the abrupt changes of slope along the path and the increased speed during driving. The wheelchair tends to turn in the direction of flow of water on sidewalks and speeding excessively when moving downhill or uphill acceleration decreases (Silva, 2009). In cases that the wheelchair is unable to make correct decisions about the speed of the wheelchair is more prone to accidents. However, according to Wang (2009), most accidents involving motorized wheelchairs (Electric Power Wheelchairs, EPW) can be directly attributed to the control system and design features. However, according to Cooper (1998), not all people are able to control the wheelchair when it begins to fall.

Thus, the stability of a chair swirled gives the following factors:

- Design of the wheelchair;
- Parameters set in the chair;
- The ability to control the wheelchair to wheelchair and move its center of mass.

An example of this can be seen in “Fig. 1 "shows that the use of a wheelchair on a sloping driveway.

Figure 1 - A wheelchair user on a sidewalk with inadequate slope (Silva, 2009).

Since most of the outer surfaces are inclined drain so the wheelchair user must control the chain wheels to overcome the rolling resistance to propel the chair (Silva, 2009).

Historically, the control of lateral stability for vehicles is performed by modifying the physical characteristics, such as modification of the width and implementation of appropriate suspensions. Such suspensions are designed with shock absorbers and springs with static characteristics specific to one type of terrain and characteristic direction. This type of suspension design is still widely applied in automobiles, but since the 1980s were developed intelligent systems that change the suspension characteristics to balance vehicles in situations of instability. Examples of these types of modern control stability system are active suspensions, semi active, leveling systems of the bodyshell and the use of steering control. Stability controls through actuators are poorly applied to wheelchairs generally semiactive and active suspensions are adapted for automotive applications, without considering the inherent characteristics of wheelchairs.

Based on the above problems, this paper aims to demonstrate the improvement in performance and driving comfort of a wheelchair system with lateral control and longitudinal stability compared to a chair that does not have this system in operation.

2 THE WHEELCHAIR WITH LATERAL AND LONGITUDINAL BALANCE

The simulated wheelchair is composed of three wheels. Wheels being distributed as follows: two front wheels and two rear wheels as shown in “Fig. 2”. The front wheels are of large diameter (about 22 "or 558,8 mm) fitted to the front of the chair, pivoted while the wheel is mounted on the back of the chair (with approximate diameter 122 mm). The front wheels are equipped with electric motors that make up the wheel hub (motor + wheel structure = m1), eliminating transmission elements. Each wheel support will be riding a linear actuator that will change the quota zi of each wheel, as shown in “Fig 2”.

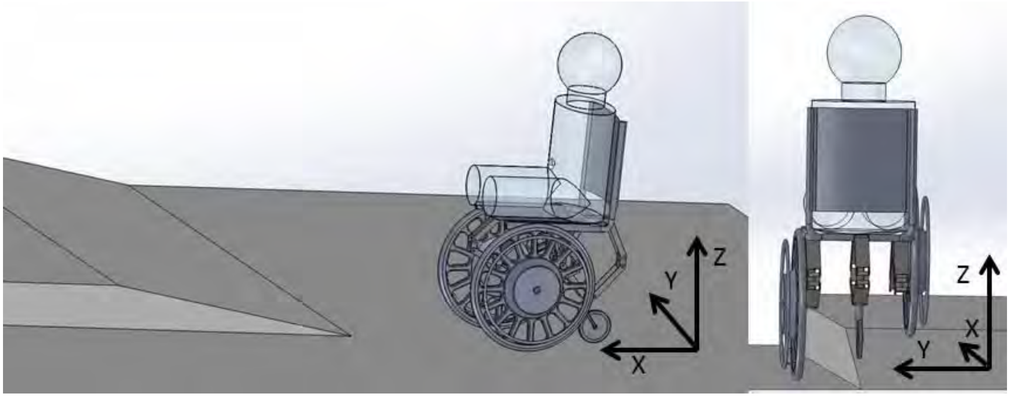

Figure 2 – motion condition for simulation

2.1 WHEELCHAIR CONTROL

To obtain the equations of motion of the wheelchair and the model should consider the following assumptions (Becker, 1997):

- The system can be treated as a rigid body and symmetrically along the longitudinal axis (X, “Fig. 2”);
- The resulting lateral force exerted by the ground is perpendicular to the plane of the wheel and acts directly on the projection of the center of the wheel;
- The side slip angles are small and assume a linear relationship between them and the friction force.

The “Fig3." shows the flow chart wheelchair flux control, which simulates the system behavior. For this case, a wheelchair with three wheels, to each suspension is added a system that controls the displacement of the actuator that is coupled to chassis, as “Fig. 4". The gyroscope signal is converted into a travel command for each actuator, in order to correct the seat level wheelchair.

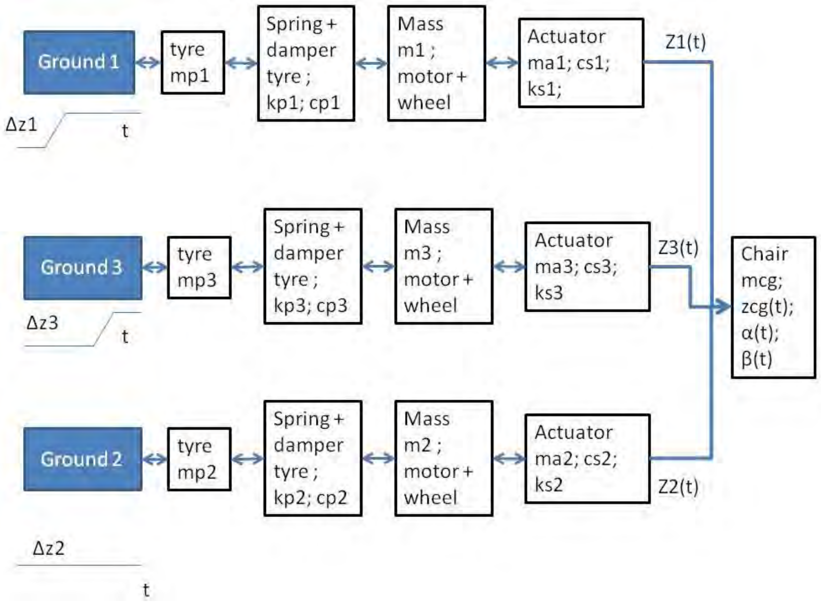

Figure 3 – Flow flux chart wheelchair control.

These assumptions enable the differential equation of motion is linear and its simplification allows not lost a lot of information. “Figure 4” shows a scheme that simplifies the front and side view of a chassis of a vehicle self-leveling. This illustration is intended to identify the key parameters and reference solution for the control equation. However, in “Fig. 3” the wheelchair is presented to identify the mathematical entities for calculating static and dynamic wheelchair.

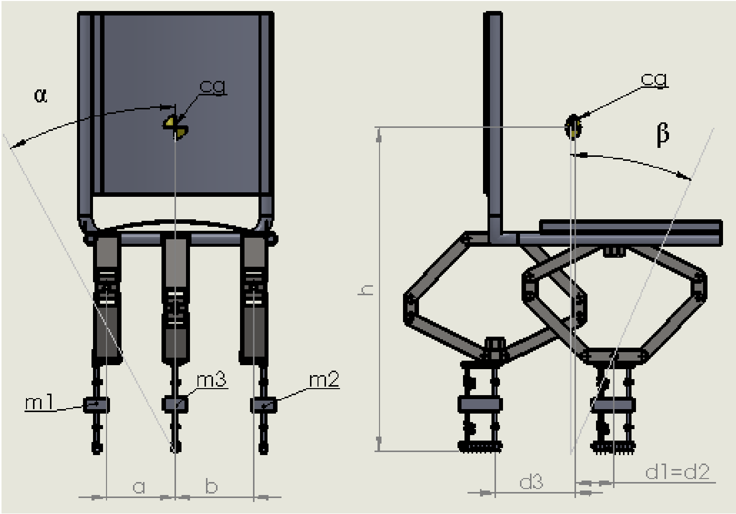

Figure 4 - Parameters and references for force distribution, m1 and m2 are masses from left and right wheels, and d3, d2, d1, and distance from the center wheels to the center mass seat.

The “Fig. 5” and “Fig. 4” show the wheelchair geometry, composed by three wheels, with two large-diameter front wheel and one rear wheel of the castor type. This decision is based on the advantage of this assembly type in improving the ability to overcome obstacles and improve the comfort during wheelchair journeys on rough terrain.

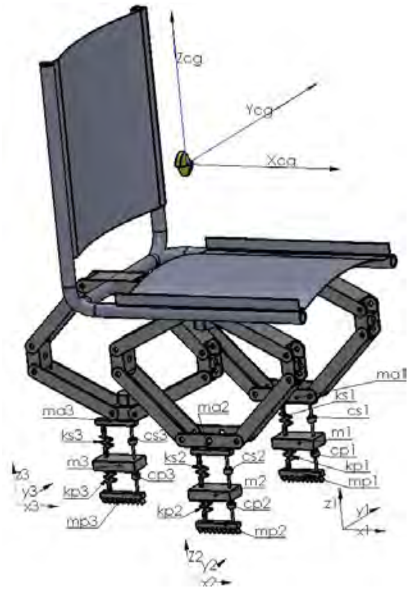

Figure 5 - simplify reference to mathematical systems wheelchair.

2.2 Wheelchair equations

For equationing the model, the quotas $z_1(t)$; $z_2(t)$ are α (t) responsible variation, since $z_3(t)$ quota along with the average $z_1(t)$ and $z_2(t)$ will be responsible for the variation $\beta\ (t)$, and:

$$\alpha(t) = \arcsin\left(\frac{z\ (t) - z_1(t)}{2.b} \right. \tag{1.1}$$

$$\beta(t) = \arcsin\left(\frac{\frac{(z_2(t) - z\ (t)}{2} - z_3(t)}{d_4} \right. \tag{1.2}$$

$$d_4 = d_1 + d_3 \tag{1.3}$$

$$z_1(t) = z_{01}(t) + \mathrm{z}_{\mathrm{p}1}(t) + z_{m1}(t) + z\ _1(t) \tag{1.4}$$

$$z_2(t) = z_{02}(t) + \mathrm{z}_{\mathrm{p}2}(t) + z_{m2}(t) + z\ _2(t) \tag{1.5}$$

$$z_3(t) = z_{03}(t) + \mathrm{z}_{\mathrm{p}3}(t) + z_{m3}(t) + z\ _3(t) \tag{1.6}$$

$z_{03}(t)$, $z_{02}(t)$, $z_{01}(t)$ are the coordinates of the point of contact between the tires and floor, respectively. z_{p1} (t), z_{m1}(t), z_{a1}(t), z_{p2}(t), z_{m2}(t), z_{a2}(t), z_{p3}(t) z_{m3}(t), z_{a3}(t) are the displacements of the wheel assembly and structure of the wheelchair.

If the control system is switched off, $z_{ai} = 0$. When the system is connected:

$$z\ _1(t) = a_a(t).a\ .\frac{t^2}{2} \tag{1.7}$$

$$z_{a2}(t) = a_a(t).a\ .\frac{t^2}{2} \tag{1.8}$$

$$z\ _3(t) = a_a(t).a\ .\frac{t^2}{2} \tag{1.9}$$

Where and a_a (t) the acceleration of the actuator.

The control logic follows the following algorithm:

$$\begin{aligned}
&\text{if}, \alpha + \\
&\text{then}, a1 = 1;\quad 2 = -1 \\
&\text{if}, \alpha - \\
&\text{then}, a1 = -1;\quad 2 = 1 \\
&\text{if}, \alpha = 0 \\
&\text{then}, a1 = 0; a2 = 0 \\
&\text{if}, \beta + \\
&\text{then}, a3 = -1 \\
&\text{if}, \beta - \\
&\text{then}, a3 = 1 \\
&\text{if}, \beta = 0 \\
&\text{then}, a3 = 0
\end{aligned} \tag{1.10}$$

The control logic was selected with the intention of indicating the action and the displacement of the actuators. Being there in the positive gaining of the respective share z_i and a_i being negative in the positive sense of gain in its share z_i and a_i negative regression of the respective a_a actuator. In case the angle in which actuator modifies the a_i is zero, the value ai also will be zero and there will be no changes in the share due to the leveling system. In "Fig. 6" it is possible to see the a_i actuators sign variation in relation to the angle value it modifies.

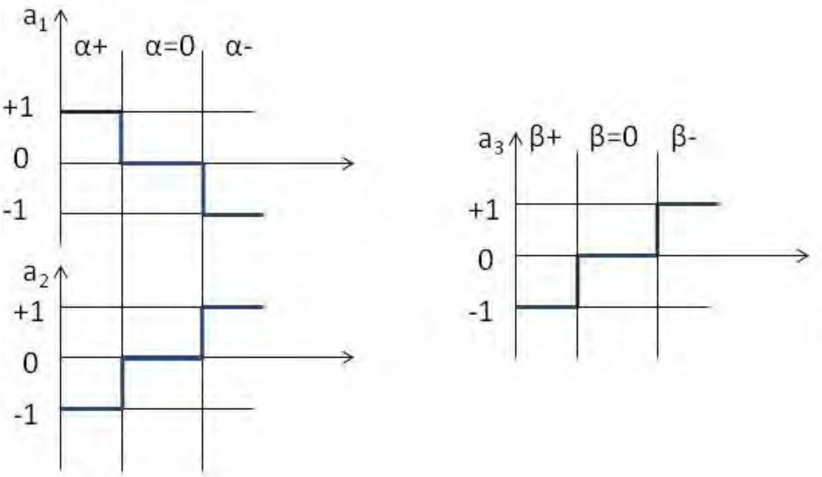

Figure 6 - a_i variation folowing the control logic.

2.3 TRAVEL SIMULATION

The development of this work was done with the simulation of the dynamic behavior of a structure of a wheelchair. This simulation was performed with the implementation of a simplified system to idealize the operation of a wheelchair in an upward movement of two of the three wheels on a step. The displacements were divided in two parts:

- Displacement of the wheelchair without the influence of the linear actuators of the suspension;

- The control system and semiactive suspension actuators.

With the intention of implementing the equations and the wheelchair logic simulation control, a MATLAB technical programming software and its sub routine Simulink and Simmechanics was chosen. In this software, the (1,1) and (1,2), which used the displacement results and iterations of the SimMechanics elements shown in "Fig. 3" were implemented. The Eq. (1,1) e Eq. (1,2) results were implemented in the logical control [Eq. (1,10)], making possible the visualization of angles α and β results concerning time from "Fig.10".

The tests were conducted simulating a displacement constant speed of 1,71 m/s in the x-axis direction, with the wheels 1 and 3 climbing a curb of 0,2 m in a relegation sidewalk with slope of $\pi/36$ rad. The initial parameters for the simulation of the dynamic behavior of the wheelchair can be found in Table 1.

Table 1. Experimental parameters for wheelchair simulation.

Parameter	Value	Units
d1	0,095	m
d2	0,095	m
d3	0,855	m
a	0,35	m
b	0,35	m
m1	8,2	kg
m2	8,2	kg
m3	1,5	kg
ma1	3,9	kg
ma2	3,9	kg
ma3	1	kg
mcg	90	kg
mp1	2	kg
mp2	2	kg
mp3	2	kg
z01	0,5588	m
z02	0,5588	m
z03	0,5588	m
zcg	0,725	m
zma1	0,5588	m
zma2	0,5588	m
zma3	0,5588	m
ks1	36496350	N/m
ks2	36496350	N/m
ks3	36496350	N/m
cs1	0,001	Ns/m
cs2	0,001	Ns/m
cs3	0,001	Ns/m
cp1	0,1	Ns/m
cp2	0,1	Ns/m
cp3	0,08	Ns/m
kp1	190000	N/m
kp2	190000	N/m
kp3	190000	N/m

2.4 RESULTS AND DISCUSSION

The “Fig. 6" shows the variation of angle α as a function of time, with the leveling system off, when in the equations from 1,3 a 1,5 Zai(t) is steady “Fig. 8” shows the variation with angle of the same system on, remaining from the equations 1,1 and 1,2. Notice that this introduces sudden variations in angle, and α (system off) has values between 0° and approximately 16.6°. However, α (system on) have values between 0 and 0.2°. This difference in behavior for side slope shows values that can cause discomfort to the wheelchair and can modify their sitting posture, with the connected system can better comfort in the displacement of a wheelchair user.

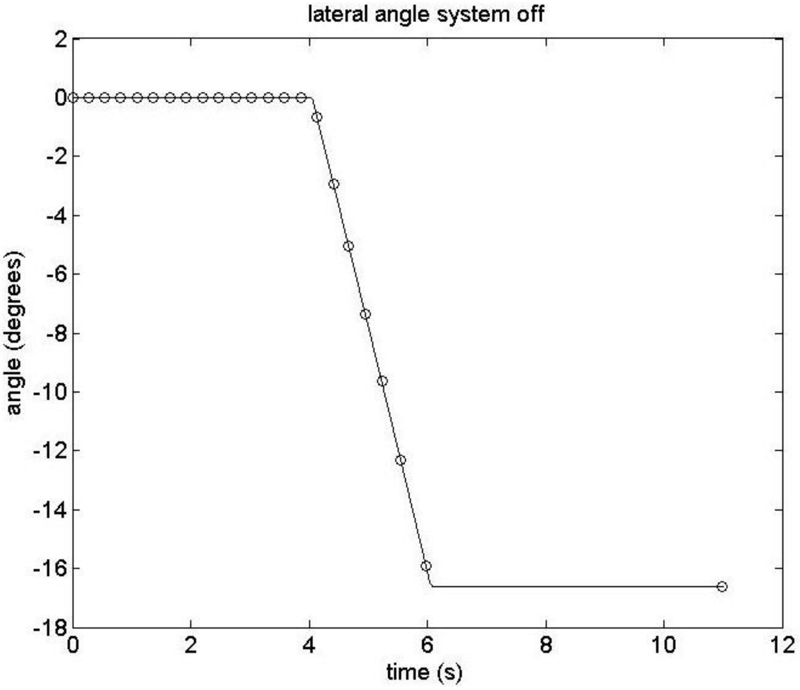

Figure 7 - simulation of bank angle α with actuators off.

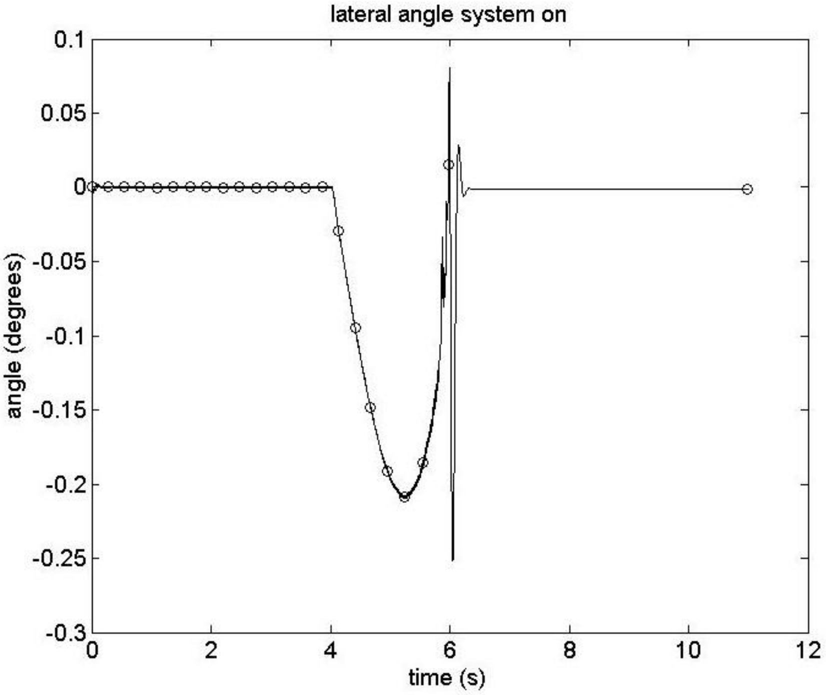

Figure 8 - simulation of bank angle α, with actuators system on.

Figure 9 shows β (system off) reveals an important front tilt the wheelchair while traveling on the ramp. Such forward tilt is softened ("Fig. 10") by the action of the grading system of the wheelchair, decreasing the slope of a maximum of 8.5°, with system off for about 3°.

These differences in behavior to the slope side and front with the power switched off and the system shows values that can cause discomfort to the wheelchair and can modify their sitting posture. However, the system is on, and the possibility of better comfort at offset, can be avoided in some cases tipping the chair of a wheelchair user.

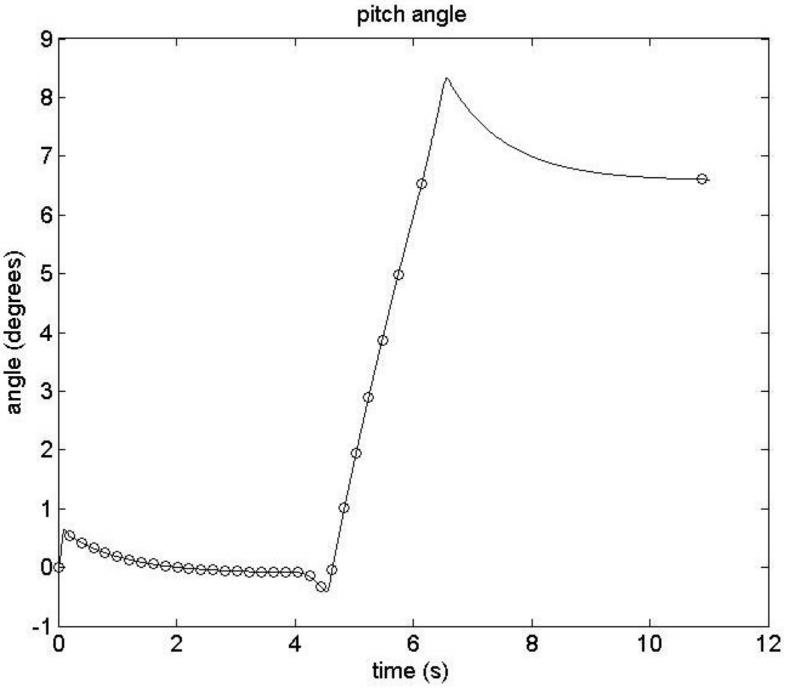

Figure 9 - simulation of the pitch angle β with actuators system off.

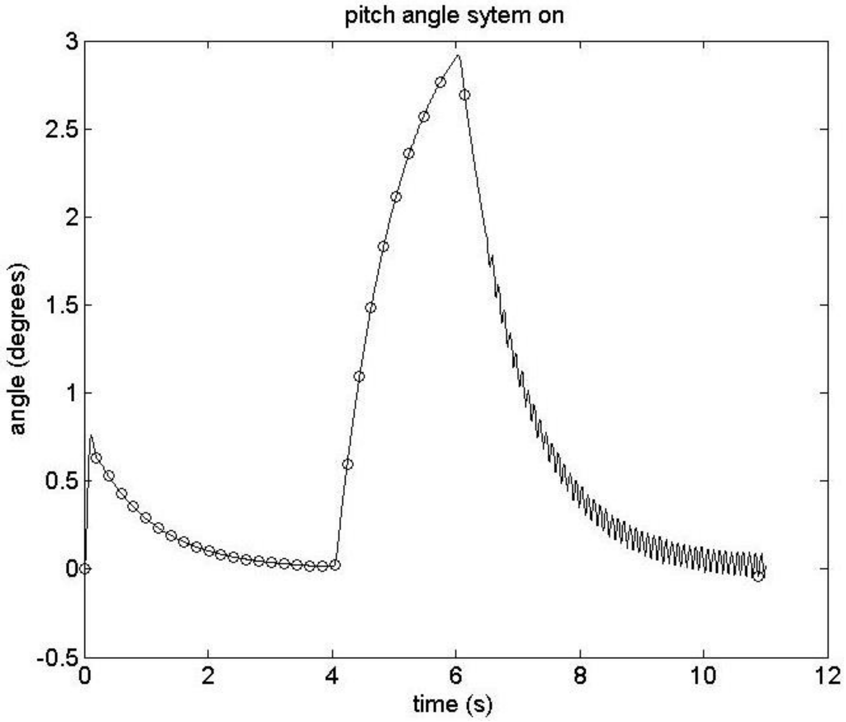

Figure 10 - simulation of the pitch angle β, with actuators system on.

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