MECHATRONIC DESIGN OF A CHAIR FOR DISABLED WITH LOCOMOTION BY LEGS

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Abstract. *Wheelchairs have severe limitations in the buildings and urban roads, so there is a need for new concepts of chairs for the disabled. In this paper the design of a chair with legs for locomotion is presented. The designs of the various systems are discussed. A system based on closed cinematic chain was developed to reduce the complexity of the mechanical and control system. Thus, a control system as simple as the used in motorized wheelchairs can be used.*

***Keywords**: legs locomotion; mechatronic design; mechanism*

1. INTRODUCTION

The wheelchair to the disabled mobility collides with the lack of adaptation of existing buildings and roads according to Brazilian technical standard NBR 9050. Thus, a simple gap is a barrier to wheelchair person. The conventional wheelchair employs the transportation means more efficient and simpler, the wheel, however this does not allow to cross the simple gaps in sidewalks. Therefore, many solutions have been developed, some focusing on specific obstacles, using locomotion provided since mats until legs. In Lawn and Ishimatsu (2003) a wheelchair with a bar mechanism was developed focusing on the mobility of disabled people to climb stairs. In Chun-Ta Chen and Pham Hoang-Vuong (2009) a wheelchair robot is also proposed with wheels and bars to climb the stairs

Figure 1. WL-16 Robot (Gizmodo, 2010).

Figure 2. Hubo chairbot fx-1(Hubolab, 2010).

In 2003 in Japan, was presented the chair robot WL-16 with two legs (Fig. 1), each one with a parallel mechanism kinematics chain, composed of six linear actuators, allowing 6 degrees of freedom for each leg (Sugahara et , 2007). In Korea a robotic chair Hubo FX-1 was developed (Fig. 2) with two legs, each one composed of an open kinematic chain, where each leg has six degrees of freedom, two degrees at the ankle, one degree at knee and three degrees at joins the leg at the hip, moving at a speed of 1.25 km / h (Jung-Yup et al, 2007).

Legged locomotion systems for wheelchair is not a new concept, but the solutions become complex systems and therefore costly. The solutions using legs of robotic systems present a challenge to control an unstable dynamic system, thus requiring heavy computational resource, servomotors and inertial sensors (Sugahara et, 2007;Jung-Yup et al, 2007). The aim of this study is to develop a solution with static stability, ie, the center of gravity is always within the area formed by the contact points of the legs with the ground.

2. DESIGN METHODOLOGY

The design of a mechatronic system is characterized by the integration of knowledge from three areas of engineering: mechanical, electronics and computing. Each of these areas applies a systematic design adapted to its context. However it's possible to prescind the context and verify that the systematic basically has the initial problem determination, a development stage of a concept, details and validation.

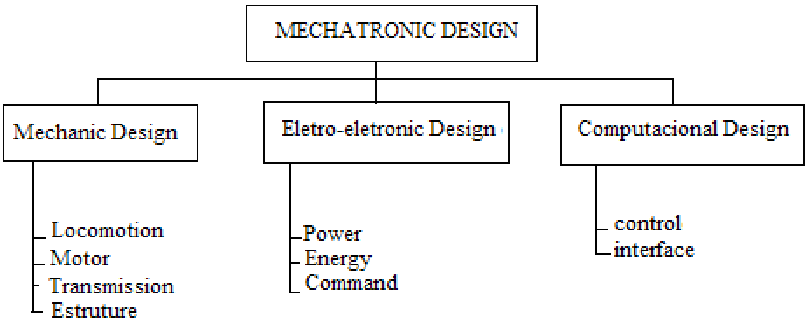

Figure 3. Mechatronic design subsystems.

The process of project developing adopted is systemic, top-down, where the project is divided into systems and in each of several subsystems (Fig. 3) can be sequential or concurrent.

2.1. Problem definition

It begins by analyzing the motivational needs and converting them into requirements and design constraints. The main guideline is to develop a system for locomotion by legs. The systematic for requirements determination begins by literature review, where the dimensions of this chair are chased according to NBR 9050, because it allows access to the buildings, thus, should occupy a maximum rectangle area of 1.15 x0,7 m. The speed requirement may be obtained by analyzing the chairs robotic locomotion by legs already developed. It was observed that the speed of this system is below the conventional motorized wheelchairs. The ability to transpose gaps of sidewalks and stair climbing is another requirement.

2.2. Mechanical system design

Analyzing the locomotion system, it is observed that a system needs robotic legs with 5 to 6 degrees of freedom and a complex control. The idea of employing chains with closed kinematic mechanism bar can simplify the locomotion system by reducing the amount of degrees of freedom.

The requirement is to generate kinematic trajectories of the legs ends parallel to the ground, which produces a smooth motion of the chair both in the plan, uphill or downhill, such as stairs and ramps. This indicates attribute of Jansen and Klann bar mechanisms (Norton, 1992 ; Dought, 2001; Giesbrecht,Wu and Sepehri, 2009), which are based on a kinematic chain with one degree of freedom (Fig. 4).

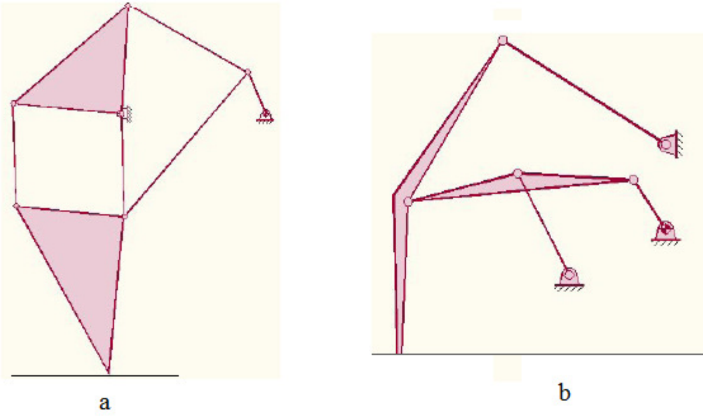
a
b

Figure 4. Jansen (a) and Klann (b) mechanisms.

The transverse stability of the chair requires that these mechanisms are mounted in symmetrical pairs with the entrance of the movement made by a single handle for both plans kinematic (Fig. 5). Analyzing these mechanisms, it was chosen Klann, since it needs only 6 bars and allows smooth movement of the center of gravity, with only two kinematic plans. Jansen's model requires 3 planes.

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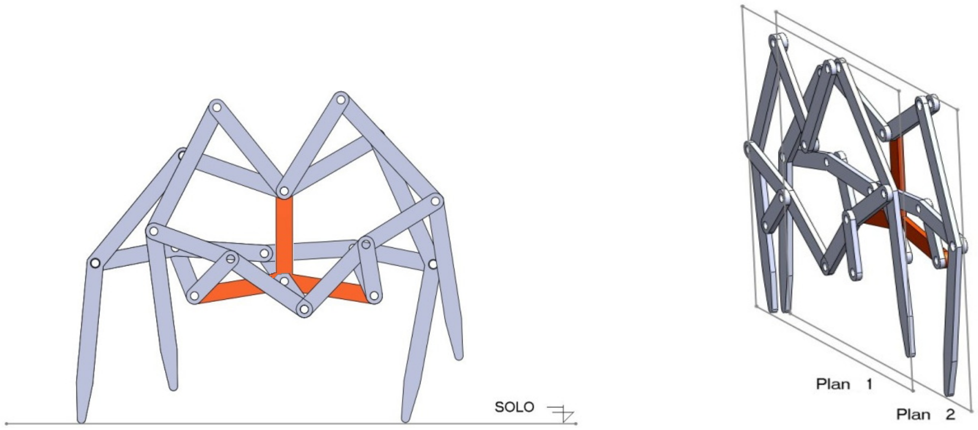

Figure 5. Kinematic plans.

Thus the two kinematics chain in each plane are connected to the same handle 180 degrees out of phase, so that always have two legs in contact with the ground at all times (Fig. 5). It required two kinematic planes on each side of the chair to allow static stability. This system requires a single motor for each kinematics pair. From the choice of mechanism, synthesis variables are the dimensions of the chair and the stairs geometry, the distance and height of each month and location of the center of mass.

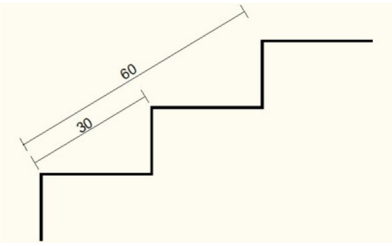

Figure 6. Minimum and maximum stride.

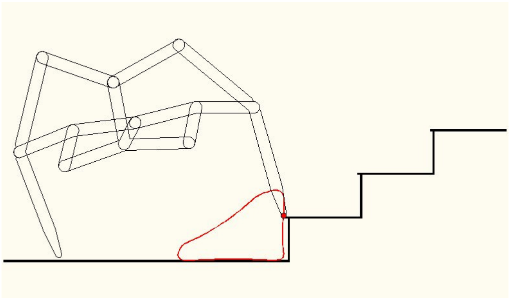

Figure 7. Klann's Classical curve.

The step dimensions is 15x25 cm to standard stair (Provenza, 1996), thus the distance between each step should be between 30 cm and 60 cm for each leg up one step at a time. Choosing the length 35 cm can the curve to base of the step edge in Figure 6, or to have interference of step in Figure 8. To avoid this is necessary a smooth curve, as disposed in Figure 9.

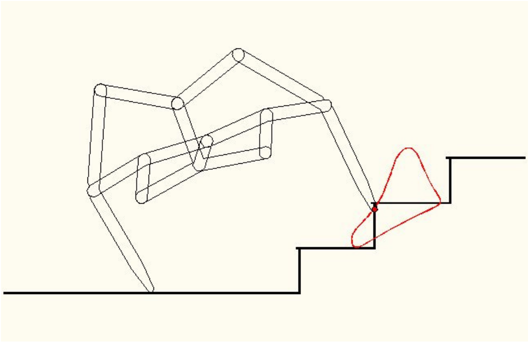

Figure 8. Step interference.

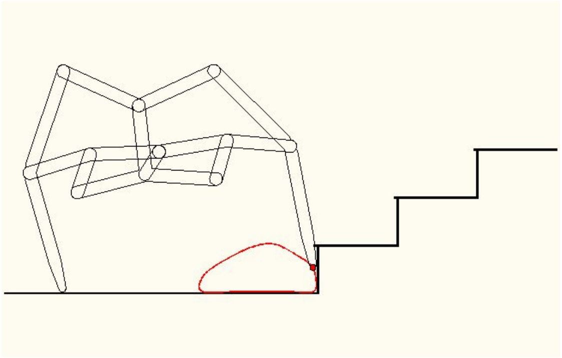

Figure 9. Shift of the curve and adjust the leg.

The curve demonstrated in figure 7 is exempt from the possibility of an accident or slip at the start of the climb from the first step due to the fact that its input is less than the height of the step, causing a landslide and vertical repositioning of the leg to secure an early rise.

2.2.1. Kinematics modeling

For determining the motor speed is necessary to get the speed of the leg. Based on measurements of the various bars involved in the mechanism, using a simplified drawing (Fig. 10), it was calculated the displacement equation (2) and speeds Equation (3) of all the bars involved (Dought, 2001; Shigley and Uicker, 1980). Get the speed of the leg (bar "BPA") as a function of the angular velocity of the handle bar ("FC") and therefore from this, calculate the velocity of point P, also a function of the angular velocity of the handle. This defines our curve and also the linear speed of the chair.

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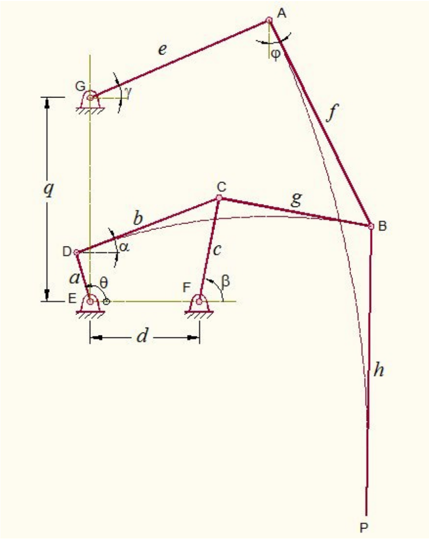

Figure 10. Mechanism schematic drawing for analysis.

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The independent variable is **θ**□ (fig. 10) which corresponds to motor speed, being known at all instant, the dependents variables are **α**, **β**, **γ** e **φ**.

The aim is to calculate these secondary variables for their displacement. This can be done by solving the system of nonlinear equation (2), four equations in four unknowns. This is done very easily by numerical methods.

$$\begin{cases} a \cdot \cos\theta + b \cdot \cos\alpha - c \cdot \cos\beta - d = 0 \\ a \cdot \sin\theta + b \cdot \sin\alpha - c \cdot \sin\beta = 0 \\ e \cdot \cos\gamma + f \cdot \sin\varphi - g \cdot \cos(\varepsilon - \alpha) - b \cdot \cos\alpha = 0 \\ e \cdot \sin\gamma + f \cdot \cos\varphi - g \cdot \sin(\varepsilon - \alpha) + b \cdot \sin\alpha - q = 0 \end{cases} \tag{2}$$

The variable **ε** is a constant that depends exclusively from geometry of the bar "BCD". With various angular displacements obtained by solving Equation (2) it is possible to obtain the various speeds for these dependent variables ($\dot{\alpha}, \dot{\beta}, \dot{\gamma} e \dot{\varphi}$) as a function of the angular velocity of the handle bar ("ED") obtained from the solution of equation (3). The solution depends only on the inversion of a 4x4 matrix composed of values already known. This inversion is perfectly feasible by analytical methods, or through symbolic program.

$$\begin{bmatrix} -b\cdot\sin\alpha & c\cdot\sin\beta & 0 & 0 \\ b\cdot\cos\alpha & -c\cdot\cos\beta & 0 & 0 \\ (\varepsilon-1)g\cdot\sin(\varepsilon-\alpha)+b\cdot\sin\alpha & 0 & -e\cdot\sin\gamma & f\cdot\cos\varphi \\ (\varepsilon-1)g\cdot\sin(\varepsilon-\alpha)+b\cdot\sin\alpha & 0 & e\cdot\cos\gamma & -f\cdot\sin\varphi \end{bmatrix}\cdot\begin{Bmatrix}\dot\alpha\\ \dot\beta\\ \dot\gamma\\ \dot\varphi\end{Bmatrix}=\dot\theta\cdot\begin{Bmatrix}-a\cdot\sin\theta\\ a\cdot\cos\theta\\ 0\\ 0\end{Bmatrix} \tag{3}$$

For displacements of point "P ", final extremity of the leg, treated as a point of the coupler, and with various angular displacements obtained from Eq (2), together with the dimensions of all the bars, it is possible to build a system uxv, place on the point "A" demonstrated at Fig (11). In this system, the point "P" would have constant coordinates (u, v) been possible to determine its movement through the solution of equation (4).

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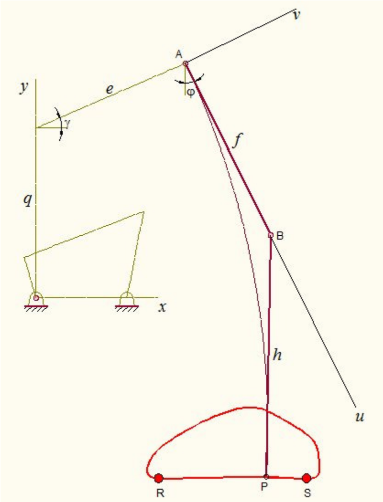

Figure 11. Local system for calculating the displacements and velocities of point P.

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Note that **u** is a constant from the length of the bar "AB" plus the length of the bar "BP" multiplied by the angle cosine formed between these two bars and **v** will be also constant equal to the length of the bar "BP" by the angle sine. The differential expression obtained, Equation (5), in time, will provide the speeds $\dot{x}_P$ e $\dot{y}_P$ that can be compounded vectorially to give the tangential velocity of point "P" along curve described by the end of the leg.

$$\begin{Bmatrix}x_P\\ y_P\end{Bmatrix}=\begin{Bmatrix}e\cdot\cos\gamma\\ q+e\cdot\sin\gamma\end{Bmatrix}+\begin{bmatrix}\cos\varphi & -\sin\varphi\\ \sin\varphi & \cos\varphi\end{bmatrix}\cdot\begin{Bmatrix}u\\ v\end{Bmatrix} \tag{4}$$

$$\begin{Bmatrix}\dot{x}_P\\ \dot{y}_P\end{Bmatrix}=\dot\gamma\cdot\begin{Bmatrix}-e\cdot\sin\gamma\\ e\cdot\cos\gamma\end{Bmatrix}+\dot\varphi\cdot\begin{bmatrix}-\sin\varphi & -\cos\varphi\\ \cos\varphi & -\sin\varphi\end{bmatrix}\cdot\begin{Bmatrix}u\\ v\end{Bmatrix} \tag{5}$$

The graph in Figure (12) shows exactly the velocity curve of point "P " for a complete cycle of the handle and the curve shifts, so it is possible focus this analysis on the range where the R-S point P would be in touch with floor.

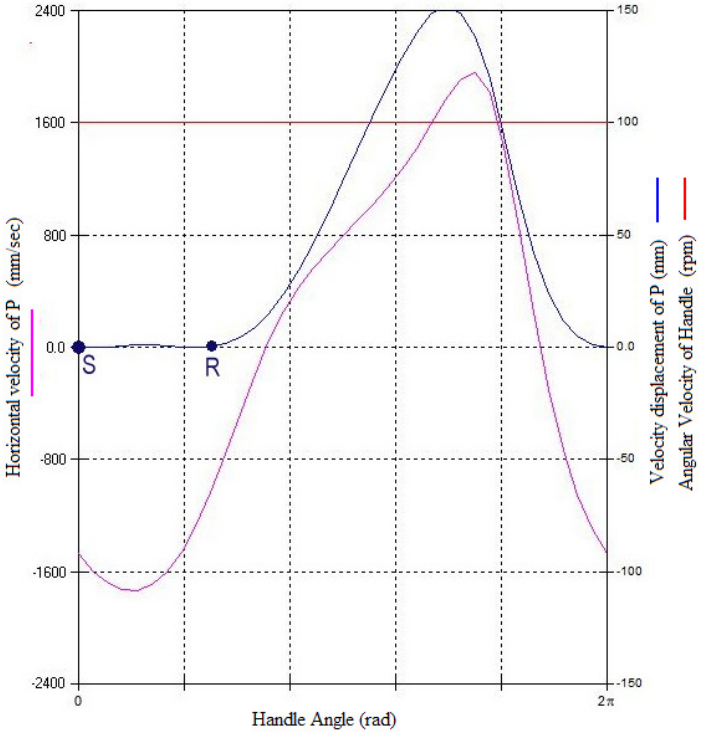

Figure 12. Displacement and velocity of point P.

In the graph disposed at figure 12 its is possible to see that for a constant 100 rpm speed of the handle, the point "P" of the leg reaches a maximum speed of horizontal 1.7 m /sec. with the leg on the floor and reaches 2.4 m/sec. upon the return of this, making clear that they have a quick return to the next step, permitting to maintain a leg in contact with the floor when it was put two legs 180 degrees out of phase on the same side.

The mechanical system designed was modeled on CAD software for analysis and verification of the theory, where it was possible to see movements and interference curves with the stairs, as well as stability.

Figure 13. Final design.

2.3. Eletro-eletronic system design

The electro-electronic systems include electronic power and digital control electronics board. Dividing the drive and control system facilitates maintenance because it separates the control of the power that has higher risk of fault. The requirements for the design of the power part are: engine power, voltage and current. The power board can use the technology of H bridge of transistors, driven by PWM, allowing less energy lost. In the project could be employed two potted H bridge IC, as the L298, or using discrete components. The communication of the control and power cards employs opto-couplers to separate them in case of short power overload.

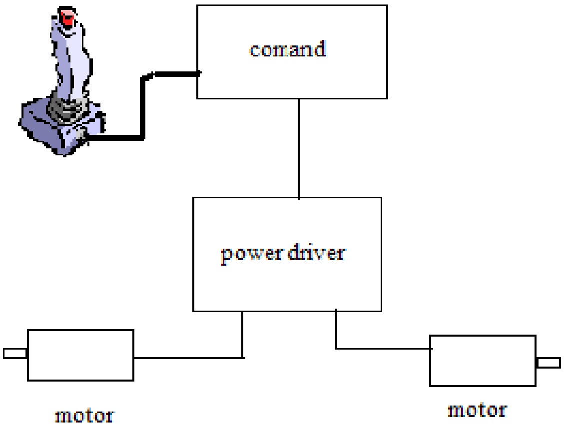

Figure 14. Electro-eletronic system.

The control system is simpler than those used in the control of robotic legs, since there is no need for position or equilibrium control. The user closes the control loop using a joystick, controlling the speed of the motors on each side of the chair, like in the conventional motorized wheelchair (Vidal Filho, 2010). The control card can employ a microcontroller, where two analog signals are read from a joystick potentiometers and converted into PWM signal for the motors.

2.4. Computacional systems design

The design of the control software starts with the choice of program language level. The control program can be made directly in assembler, but can be used the C language and converted to machine language by an appropriate compiler. Program requirements are to read two signals analog from the joystick, converting the voltage signal value to speed value and generating a PWM for each motor respectively (Fig. 15).

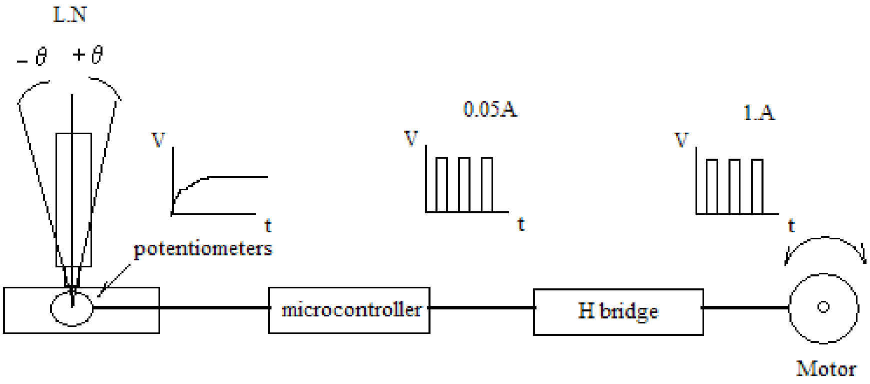

Figure 15. Motor control

The joystick serves the user as a means of selecting the speed of the chair in a certain direction in the horizontal plan. Thus, the speed of the chair should be proportional to the angle formed by the lever of the joystick with the vertical neutral line (Fig.15). In the horizontal plane the chair can move forward, backward, curves forward and backward or rotate about a central axis (Fig. 16). These movements can be determined by the position of the joystick. In Vidal Filho (2010) can be understood as the eight positions of the joystick lever determines the movements of each motor.

The program should obtain eight movements options from two analog signals and switch the motor in the direction and speed for the desired motion.

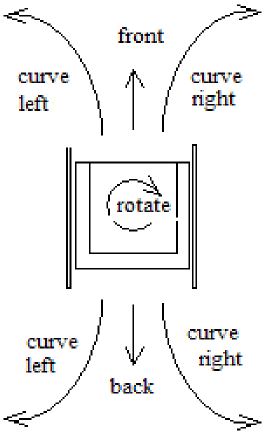

Figure 16. Direction of movements.

3. CONCLUSIONS

This paper presented the design of a chair with legs for locomotion of desabled person. Although this idea is not new, the solutions developed (Sugahara et, 2007, Jung-Yup et al, 2007) presents a complexity of control and construction that hinder the viability of the idea. A project like developed in Jung-Yup et al (2007) need to control six degrees of freedom in each leg and a balance control. The concept developed in this paper reduces the need for a complex control system by the use of bar mechanism. The control system may be the same used in a motorized conventional wheelchair like developed in Vidal Filho (2010). The systematic design used in each sub-project was presented. A mechanical system configuration and concepts of electronics and computer system was developed. The analysis and design of all subsystems to demonstrate the technical feasibility for building a prototype was presented.

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