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DESIGN OF VEHICLES FOR THE DISABLED

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Abstract. *The objective of this article is to study the constructive forms more viable to build an autonomous vehicle for people with some deficiency. This vehicle will be called as mobile robot,because the vehicle's results can be applied to this type of robots. Initially an introduction of many advances in wheeled mobility for disabled people are present. Comparisons are made between a three whelled vechicle with two wheels on the rear axle and a standar four wheeled vehicle. Each vehicle's lateral stability, rollover stability during lateral acceleration and rollover stability while accelerating in a turn are determined.*

Keywords*: dynamics, mobile robots, disabled people, rehabilitation.*

1. Introduction

Technologies or know how derived from robotic researches can contribute to the restoration of some functions lost by disabled people.

Robot applications or more generally technologies derived from robotic researches have quickly evolved during the last decade to realistic products for medical applications. However the spreading of those products to general public is very limited for a great part due to the prohibitive cost and performances less than those hoped by users. For example, the rehabilitation market proposes manipulator arms such as MANUS (Oderud, Overboom and van Woerden, 1997), but no smart wheelchairs. If it considers the contribution of robotics only concerns autonomous functions integrated to assistance devices. The over-cost must be related to the price of the usual product. It is one of the major brakes on smart wheelchair spread. An important research effort is needed to propose technological components which are a correct compromise between cost, reliability and security.

Another major constraint of assistance robotics is human factors. An adequate cooperation between human and machine contributes to the improvement of the use of such sophisticated assistance. An appropriate cooperation gives several advantages and firstly a reduction of the robot complexity by using human skills for perception and decision making. The system must allow the adaptation to the particularity of the handicap but also to other conditions for example, the fatigability or the learning level of the user. However the more complex a machine is the more difficult the system control, especially in case of handicapped people. Before and during the design process of an assistive device it is important to be sure that it will be "controllable" Hoppenot, Rybarczyk and Colle, 2002).

The paper presents ML (Módulo Libero) (Fig.1) which aims at assisting a wheelchair user in up, down ramps and travel long distances. The environment is supposed partially known, the floor plan and heavy furniture are modeled. The assistance device is composed of a mobile robot easily mounted on a wheelchair by occupant.

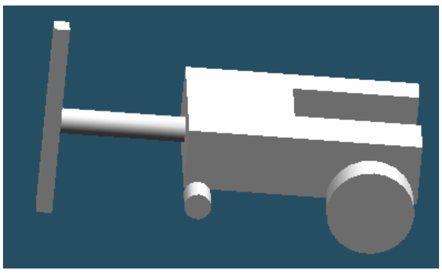

Figure 1. Firstly prototype conception.

A proof of concept prototype ML for the motor disabled is proposed with the objective of demonstrating the feasibility of a completely new approach to mobility.

2. Advances in Wheeled Mobility Technologies for disabled people

Rehabilitation robots are assistive devices designed for use by people with severe disability in order to gain independence in tasks of daily living. The purpose of this item is to describe emerging technologies and trends in wheeled mobility approach disabled person.

2.1 Robotic Manipulators

For carrying out simple daily activities, like eating, drinking, opening a door or combing hair, the disabled people rely totally on the help of carers or relatives. Robotic manipulators can be of assistance in these situations. These devices can compensate for arm and hand function, and can be controlled by any of the remaining body functions of the disabled person (Driessen, Evers and Woerden, 2001).

Different robotic approaches for people assistance have been presented in (Kawamura and Iskarous, 1994). HANDY1 (Topping and Smith, 1998) is a table-mounted manipulators, which work in a known environment. Wheelchair-mounted manipulators, such as MANUS (Oderud, Overboom and van Woerden, 1997), allow operations in indoor and outdoor environments. MANUS is a wheelchair-mounted (designed for permanent attachment to a Wheelchair) general purpose manipulator now in use with over 100 people in their homes in the Netherlands, in France and in other countries (Driessen, Evers and Woerden, 2001). Mobile robot mounted manipulators, such as MOVAID (Kawamura et al., 1994) is the most complex but the most versatile configurations.

Otmane et al. (2000) have developed an assistance system ARPH (Assistance Robot for People with physical Handicap) which is composed of a control-command station for the disabled person and a manipulator arm mounted on a mobile robot. The mission consists in carrying and manipulating an object in a partially known environment such as a flat. The flat plan is known but table; chairs are not modeled and are considered as obstacles.

2.2 Advances in wheelchair technologies

Powered wheelchairs are can be grouped into several classes or categories (Cooper et al., 2003). The most common groupings are based upon the functions provided by the wheelchair and the intended use. Indoor wheelchairs have a small footprint (i.e., area connecting the wheels). This allows them to be maneuverable in confined spaces. However, they may not have the stability or power to negotiate obstacles outdoors. Indoor/outdoor powered wheelchairs are used by people who wish to have mobility at home, school, work, and in the community, but who stay on finished surfaces (e.g., sidewalks, driveways, flooring). Both indoor and indoor/outdoor wheelchairs conserve weight by using smaller batteries, which in turn reduces the range for travel. Some wheelchair users want to travel long distances, and to move fast (Cooper et al., 2003).

Scooters are designed for people with limited walking ability and substantial body control (Cooper et al., 2003). Reclining wheelchairs allow the user to change sitting posture through the use of a simple interface (Cooper et al., 2003). Stand-up wheelchairs offer a variety of advantages over standard wheelchairs. They provide easy access to cabinets, shelves, counters, sinks, and windows. Many activities around the home are easier to accomplish by using a stand-up wheelchair, for example, cooking, washing dishes, and ironing clothes. In many cases stand-up wheelchairs allow people to perform activities without significant architectural modifications. This has tremendous potential for overcoming both physical and social barriers which have prevented wheelchair users from gaining greater access to employment, education and community services. However stand-up wheelchairs are more complex and more expensive than most manual or electric powered wheelchairs.

Wada and Asada (1998) have designed and manufactured an omni-directional robotic wheelchair. Four balls, actuated independently by DC-motors, enable for moving the wheelchair along any direction in the plane and rotating it around its center while having the ability to change the angle between the beams holding the balls. This novel feature facilitates for varying the footprint configuration to augment stability and change the gear ratio as desired (see Fig.2).

Several robotic wheelchair prototypes are produced in different research facilities in the world (Tzafestas, 1998). As control architecture, supervisory control (skill-, rule-, knowledge-based behaviors) is suggested in Bourhis and Agostini (1998).

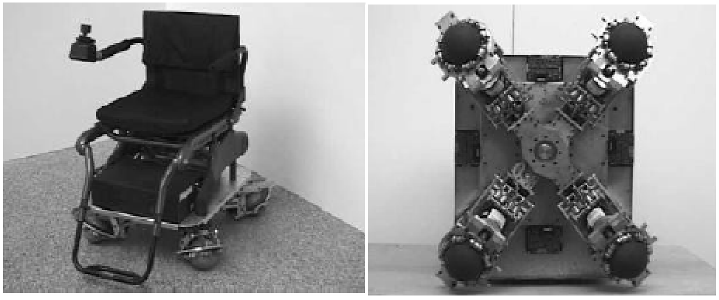

Figure 2. Prototype of the wheelchair.

The NavChair assistive navigation system is being developed to meet the needs of multiply handicapped people who are unable to operate available wheelchair systems. The NavChair Project was conceived as an application of mobile robot obstacle avoidance to a power wheelchair. The NavChair assistive navigation system is being designed to improve the mobility and safety of people who have impairments that limit their ability to operate a power wheelchair. The NavChair control system is being built to avoid obstacles, follow walls, and travel safely in cluttered environments (Borenstein, J., Levine, S. and Koren, Y., 1990).

Wellman et al. (1995) developed a prototype system that consist of a equipped with wheels and legs and is capable of walking uneven terrain and circumventing obstacles. The chair consists of a conventional wheelchair which has been fitted with two 2 degree of freedom manipulators/legs. See Fig. 3. A legged vehicle allows locomotion in environments cluttered with obstacles where wheeled or tracked vehicles cannot be used. The legs also give the chair versatility and allow it to be re-configured. When stationary, one of the legs can be used as a manipulator in order to perform simple tasks such as reaching for objects or pushing open doors.

Figure 3. Prototype of chair with legs and wheels and crossing obstacles impeding the course of locomotion.

Until recently, people who were unable to effectively propel a manual wheelchair would be presented with the options of using an electric powered wheelchair, using a scooter, or being pushed by an assistant in their manual wheelchair. Many systems of alternatives motorization for conventional wheelchairs have been designed (Alvarenga and Dedini, 2001). This devices improve the daily activities rely in a wheelchair.

Trough researches about wheelchairs, habits of wheelchair users, it was made a questionnaire concerning that how the wheelchair users expect from their wheelchair and what kind of device could facilitate or improve their life (Alvarenga, 2002). During the research, many configurations were explored (Alvarenga and Dedini, 2003) and discarded because it was not sufficiently versatile or not achieve the user’s needs. A lot of quality tools methods have applied and a conception of a product were found to assist wheelchair users. The prototype ML (Module Libber) consists of a power base equipped with motors, drive wheels, castors, controllers, sensors and batteries and is capable up, down ramps, travel long distances and circumventing obstacles. ML is a separate mobile robot and can be mounted on all manual wheelchairs.

For the definition of the ML behavior is important to study some concepts about mobile robots.

3. Mobile robot moviment

A displacement of a mobile robot requires three functions: planning, navigation and localization. Planning determines the best path to go from one point to another. Navigation ensures the robot follows the planned path avoiding obstacles. Localization gives the position and the orientation of the robot in the flat at any time. The description of control modes has shown that some tasks can be performed by using both different skills of user and robot. It is important the person understands robot behaviors in those cases (Otmane et al., 2000). A natural approach is to give human-like behaviors to robot functions needed for the robot move.

3.1. Planning

The problem is to reach a goal. For a far destination a plan is used to find a way to go from one point to another. If the destination is within sight the person reaches the interest point following the direction he looks at. In a classical robotic approach the robot computes a path through the flat to reach the goal using the known flat plan. The second way to plan a trajectory is to use the camera in auto tracking mode. The person points out a goal with the camera. The goal must be within sight of the camera. The camera tracks the goal, for example object, automatically. The robot moves in the direction pointed out by the camera. This is a human like behavior. The object is considered as a target which can be mobile. The remaining issue is only to avoid obstacles on the path. This is a navigation problem (Otmane et al., 2000).

3.2. Navigation

The problem is to follow the planned trajectory. A person divides navigation into two behaviors: goal-seeking and obstacle avoidance. A fusion of the two behaviors is performed during the displacement. The orientation of the head defines the direction for goal seeking. If an obstacle is on the way, the trajectory is deviated locally to avoid it. Usually people try to walk as far as possible from obstacles, for example in the middle of corridors. Automatic navigation imitates the human behavior making the fusion of goal-seeking and obstacle avoidance. For goal-seeking direction is defined by relative positions of the robot and the goal. If a non modeled obstacle stands on the robot path, it must be avoided. Ultrasonic sensors detect these obstacles and fuzzy logic manages obstacle avoidance. As human like behavior, the robot goes in the middle of the free space. The fusion of two behaviors takes into account only obstacle avoidance when an obstacle is nears the robot. When the distance between obstacles and the robot grows up, goal-seeking behavior takes more importance in the robot command.

3.3 Localization

Cost effective constraint due to the field of application implies the use of a poor perception system as seen before. Three levels of behavior are used in the localization function. They are well suited to possible situations. Each level uses specific algorithms, little sensitive to high rate of wrong measurements and to presence of obstacles. In the first level, the robot knows approximately its position and orientation. They are updated on-line by the odometer under the control of the ultrasonic sensors. When the robot notice it is lost (the decision can be taken in collaboration with the human operator), the off-line localization level is activated. The third behavior level corresponds to the human intervention. The supervisor analyses the situation thanks to two kinds of information: sensor measurements displayed on a 2D plan of the environment and an indicator of the quality of the position given by the algorithm running on the mobile base (Hoppenot, P. et al., 1996). The person builds strategies to succeed a mission. A strategy can be seen as a succession of control modes which are of three types: automatic, manual and “mixed” mode.

4. Stability Study

In order to establish the ML configuration it is necessary a study about stability. Comparisons are made between a standard four wheeled and three wheeled vehicle with two wheels on the rear axle.

4.1 Lateral Stability

The first problem is determining the lateral stability of each configuration. The models used for the four wheeled vehicle and the three wheeled vehicle with two wheels on the rear axle are shown in Fig. (4).

A zero width vehicle, commonly referred to as the bicycle model, with the appropriate number of wheels per axle is assumed for each configuration. The wheels are located on the center line of the vehicle with the front axle located a distance l_1 in front of the center of mass and the rear axle located a distance l_2 behind the center of mass. The resultant lateral force exerted on the tire by the road is assumed to act perpendicularly to the plane of the wheel directly below the wheel center.

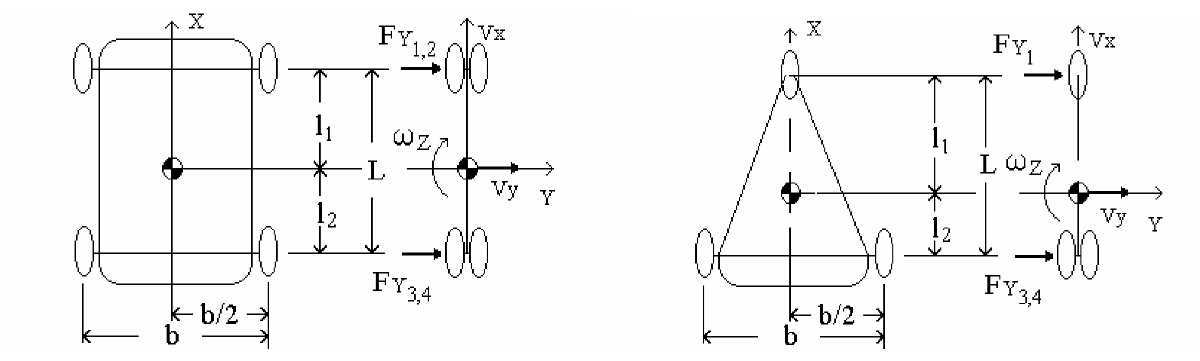

Figure. 4 Four wheeled vehicle model and three wheeled vehicle model with two wheels on rear axle.

For the specific case of constant speed straight line motion, the following assumptions can be made: a) the steer angle is zero; b) there are no tractive, braking, or rolling resistances forces. c) the speed in the x direction is constant (V_x= constant).

Given the assumption listed above, the equations of motion governing the behavior of four wheeled vehicle (Fig. 4) can be written:

$$m\dot{V}_y + \left(mV_x + \frac{2l_1 C_{\psi F} - 2l_2 C_{\psi T}}{V_x} \right) \cdot \omega_z + \left(\frac{2C_{\psi F} + 2C_{\psi T}}{V_x} \right) \cdot V_y = 0 \tag{1}$$

$$I_z \dot{\omega}_z + \left(\frac{2{l_1}^2 C_{\psi F} + 2{l_2}^2 C_{\psi T}}{V_x} \right) \cdot \omega_z + \left(\frac{2l_1 C_{\psi F} - 2l_2 C_{\psi T}}{V_x} \right) \cdot V_y = 0 \tag{2}$$

where:

I_z - the moment of inertia of the vehicle with respect to a vertical axis through the mass center;

V_x - the speed of vehicle in the X direction;

V_y - the speed of vehicle in the Y direction;

ω_z - the rotational (yaw) speed of the vehicle about the vertical axis;

$C_{\psi F}, C_{\psi T}$ - the cornering stiffness of each tire associated with front and rear axles, respectively.

To ensure lateral stability for the four wheeled vehicle, the roots of the characteristic equation of above differential equations must be negative. One way to check stability of a system without actually solving for the roots of the characteristic equation is to use the Routh- Hurwitz criterion ((Huston, Graves and Johnson 1982). By means of algebraic manipulation, this equation may be written:

$$L + \frac{V^2{}_x}{g}\left(\frac{W_F}{C_{\Psi F}} - \frac{W_T}{C_{\Psi T}}\right) > 0 \tag{3}$$

where:

L - the total distance between the front and rear axles (l1 + l_2); g - the gravitational constant;

W_F, W_T - the weight on each tire associated with the front and rear axles, respectively.

The speed at which four wheeled becomes instable can be determined by setting Eq. (3) equal to zero. This speed, called the critical speed, can be expressed as:

$$V_{CRIT} = \sqrt{\frac{-gL}{K_{us}}} \tag{4}$$

where: K_{us} is the under steer coefficient which is equal to:

$$K_{us} = \left(\frac{W_F}{C_{\Psi F}} - \frac{W_T}{C_{\Psi T}}\right) \tag{5}$$

The equations of motion governing the behavior of the three wheeled vehicle with two wheels on the rear axle (Fig. 4) can be written as:

$$m\dot{V}_y + mV_x + \left(\frac{l_1 C_{\psi F} - 2l_2 C_{\psi T}}{V_x}\right)\cdot\omega_z + \left(\frac{C_{\psi F} + 2C_{\psi T}}{V_x}\right)\cdot V_y = 0 \tag{6}$$

$$I_z\dot{\omega}_z + \left(\frac{l_1{}^2 C_{\psi F} + 2l_2{}^2 C_{\psi T}}{V_x}\right)\cdot\omega_z + \left(\frac{l_1 C_{\psi F} - 2l_2 C_{\psi T}}{V_x}\right)\cdot V_y = 0 \tag{7}$$

In order to for the three wheeled vehicle with two wheels on the rear axle to be stable, the zeroth order term of the characteristic equation must be positive. By means of a few algebraic manipulations it can be shown that this condition becomes:

$$L + \frac{V^2{}_x}{g}\left(\frac{W_F}{C_{\Psi F}} - \frac{W_T}{C_{\Psi T}}\right) > 0 \tag{8}$$

The relationships governing the lateral stability of the two vehicles configuration are found in Eq. (3) and (8).

It is readily apparent that these equations are identical. However, the weight distribution for each vehicle is different. For the four wheeled vehicle, the load on each of the front and rear tires, respectively, is:

$$W_F = \frac{Wl_2}{2L} \quad \text{and} \quad W_T = \frac{Wl_1}{2L} \tag{9}$$

For the three wheeled vehicle with two wheels on the rear axle, the load on each of the front and rear tires is:

$$W_F = \frac{Wl_2}{L} \quad \text{and} \quad W_T = \frac{Wl_1}{2L} \tag{10}$$

Equations (3) and (8), in combination with Eq. (9) and (10), respectively, can be used to establish fundamental design conditions that must be satisfied to ensure stability. To develop these conditions, assume that the cornering can be expressed in the following analytical form (Huston, Graves and Johnson 1982):

$$C_\psi = (A - BC_n)C_n \tag{11}$$

where:

C_ψ - the cornering stiffness per tire;

C_n - the normal load on that tire;

A, B - positive constants dependent upon the tire's properties.

The design condition for the four wheeled vehicle can be found by combining Eq. (11), (9) and (5). Thus,

$$K_{us} = \frac{W_F}{C_{\psi F}} - \frac{W_T}{C_{\psi T}} = \frac{BW(l_2 - l_1)}{2L(A - BW_F)(A - BW_T)} \geq 0 \tag{12}$$

Because the cornering stiffness is always positive, Equation (12) leads to the well known condition for lateral stability of four wheeled vehicle: $l_2 \geq l_1$ or $l_2 \geq L/2$. Consequently, lateral stability is ensured if the vehicle's mass center is located in the front half of the vehicle.

Finally, the design condition associated with the three wheeled vehicle with two wheels on the rear axle can be found by combining Eq. (11), (10) and (7). Thus,

$$K_{us} = \frac{BW(2l_2 - l_1)}{2L(A - BW_F)(A - BW_T)} \geq 0 \tag{13}$$

Which leads to the condition that $l_2 \geq 1/2\, l_1$ or $l_2 \geq 1/3\, L$. Consequently, lateral stability is ensured provided that the mass center is located in the front two thirds of the vehicle. The lateral stability conditions developed in the preceding analysis are summarized in Table 1.

Table 1. Center of mass requirements for lateral stability.

Required condition	Four wheeled vehicle	Three wheeled vehicle 2 wheels rear
for: $K_{us} \geq 0$	$l_2 \geq \frac{L}{2}$	$l_2 \geq \frac{L}{3}$

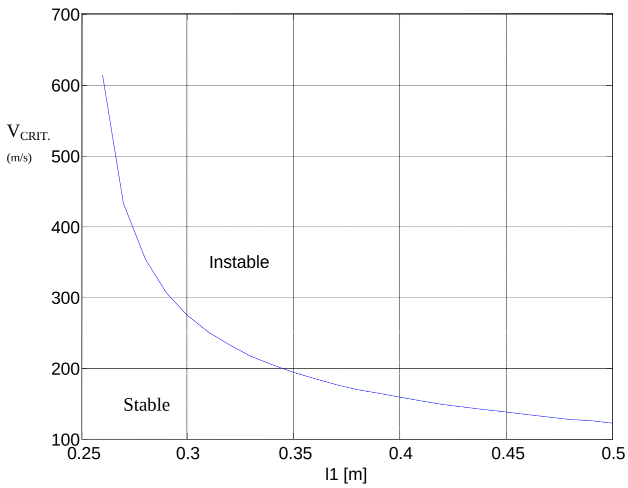

Figure 5. CG position in relation to limit velocity for the lateral stability.

It is observed (Fig. (5)) that how much bigger the value of l_1, or either the more next the CG will be rear axle, lesser is the critical speed so that if it initiates slipping.

4.2 Rollover stability during lateral acceleration

In this section geometrical relationships governing the rollover stability during a lateral acceleration are derived for both the four and the three wheeled vehicle. This lateral acceleration, which may be caused by such occurrences as a wind gust or a steady turn maneuver, is assumed to act perpendicular to the center line of the vehicle.

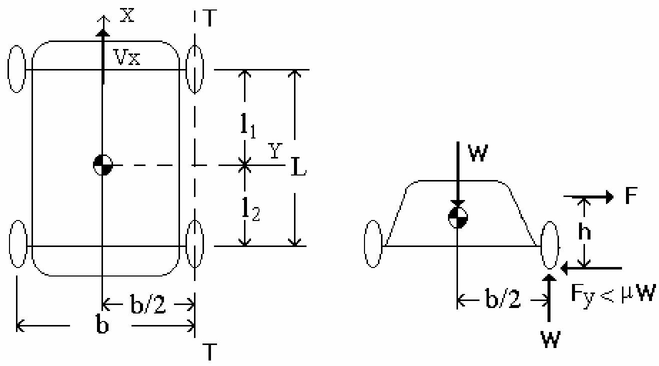

Figure 6. Four wheeled vehicle model, lateral acceleration.

Figures (6) and (7) illustrate the top and rear views of the four wheeled vehicle. In all figures, the TT axis represents the axis of tipping. To ensure rollover stability, a negative clockwise moment about the TT axis, as viewed from the rear of the vehicle, must exist.

Consider the four wheeled vehicle model in Fig. 6. Summing moments about the TT axis:

$$\sum M_{TT} = -W\frac{b}{2} + Fh < 0 \tag{14}$$

this can be rewritten as:

$$F < \frac{b}{2h}W \quad \text{or} \quad \frac{a}{g} < \frac{b}{2h} \tag{15}$$

Summing forces in lateral direction reveals that:

$$F = F_Y < \mu W \tag{16}$$

where μ is the coefficient of friction that exists between the tire and road surface. As long as the coefficient of friction, μ has a value less than $b/2h$,the vehicle will slide laterally before it overturns. For most four wheeled vehicles, the term $b/2h$ is greater than μ , is always less than one. Therefore, most four wheeled vehicles are ensuring rollover stability. However, this does not mean that vehicle rollover can never occur. For instance, if the vehicle hits a curb while sliding laterally, the lateral force then becomes infinite, causing the vehicle to overturn.

Next consider the three wheeled vehicle model with two wheels on the rear axle shown in Fig. 7.

The rollover stability condition after summing moments about TT axis is:

$$F < \frac{bl_1}{2hL}W \quad \text{or} \quad \frac{a}{g} < \frac{bl_1}{2hL} \tag{17}$$

This condition results in a less stable condition than that found for the corresponding four wheeled vehicle. To obtain some physical feeling for the conditions that might cause overturning, consider that each of the above vehicles is negotiating a curve of radius R. The corresponding lateral acceleration for this case can be expressed in terms of the vehicle forward speed, V, and the turning radius, R, as:

$$a = \frac{V^2}{R} \tag{18}$$

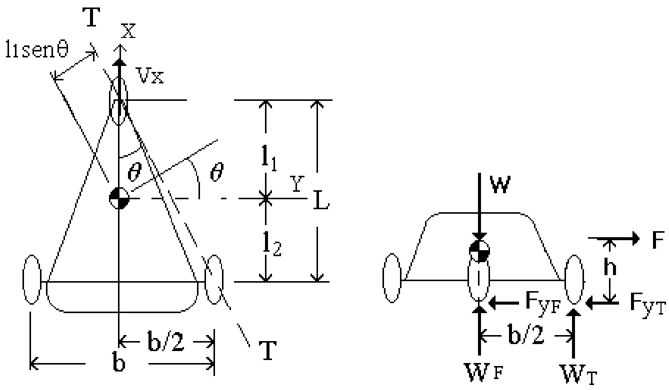

Figure 7.Three wheeled vehicle model with two wheels on the rear axle, lateral acceleration.

Substituting Eq.(18) into the rollover stability equations for the four wheeled vehicle (Eq. (15), and the three wheeled vehicle with two rear wheels (Eq. (17)) yields an equation for the vehicles' forward speed at which rollover occurs. These rollover speed equations are represented by:

$$Vro = \sqrt{\frac{gRb}{2h}} \tag{19}$$

for the four wheeled vehicle, by:

$$Vro = \sqrt{\frac{gRl_1}{2hL}} \tag{20}$$

for the three wheeled vehicle with two rear wheels. Notice that l_1 is always less than L, the speed at which rollover occurs for the three wheeled vehicles will always be lower than those for corresponding four wheeled.

4.3 Rollover stability while accelerating in a turn

Next consider the rollover stability case when each vehicle is accelerating while negotiating a steady turn. Figure (8) shows the four and three wheeled vehicle respectively. In each figure the symbol $\vec{A}$ represents the inertia force vector caused by the longitudinal acceleration, the symbol $\vec{E}$ represents the inertia force vector caused by the lateral acceleration resulting from the steady turn, and the symbol $\vec{Z}$ represents the resultant vectors $\vec{A}$ and $\vec{E}$. The magnitudes of the inertia force vectors $\vec{A}$ and $\vec{E}$ can be written:

$$A = \left|\vec{A}\right| = \frac{W}{g}a \tag{21}$$

and

$$E = \left|\vec{E}\right| = \frac{WV^2}{gR} \tag{22}$$

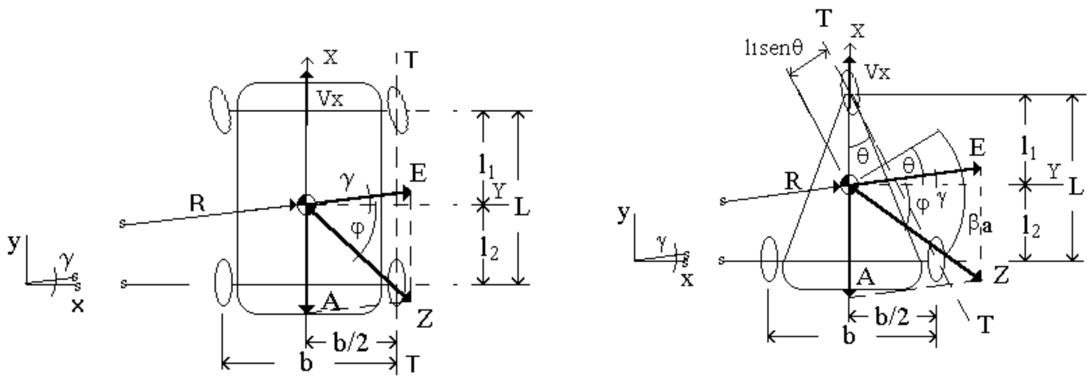

Figure 8. Four wheeled vehicle model and three wheeled vehicle model with two wheels on rear axle, accelerating in a turn.

Where:

W - the total weight of the vehicle; g - the gravitational constant; a - the longitudinal acceleration; V - the forward speed of vehicle; R - the radius of the turn.

The angles γ, θ, φ, α and β shown in Fig. (8) can be defined as follows:

γ - the angle between the line drawn from the center of curvature of the vehicle's center mass and the line drawn from the center of curvature to the vehicle's rear axle;

θ - the angle between the center line of the vehicle and the tipping axis TT (note that θ is undefined for the four wheeled vehicle since these axes are parallel);

φ - the angle between the resultant vector $\vec{Z}$ and the X axis;

α - the angle between the resultant vector $\vec{Z}$ and the line drawn perpendicular to the tipping axis through the mass center of the three wheeled vehicle with two rear wheels;

β - the angle between the resultant vector $\vec{Z}$ and the line drawn perpendicular to the tipping axis through the mass center of the three wheeled vehicle with two rear wheels.

As in the case of rollover stability for lateral acceleration, the clockwise moment about the tipping axis, TT, as viewed from the rear of the vehicle, must be negative to ensure rollover stability while accelerating in a turn.

For the four wheeled vehicle model, it can be seen from Fig. (8) that the inertia force caused by the longitudinal acceleration, $\vec{A}$ is parallel to the axis of tipping, and therefore does not contribute to the rollover stability equation. Summing the moments about the axis of tip, TT, results in:

$$\sum M_{TT} = Eh\cos\gamma - \frac{Wb}{2} < 0 \tag{23}$$

or the condition that for rollover stability,

$$E < \frac{Wb}{2h\cos\gamma} \tag{24}$$

Substituting Eq. (22) into (24) results in an expression for the speed at which rollover occurs. Thus,

$$V_{ro} = \sqrt{\frac{gRb}{2h\cos\gamma}} \tag{25}$$

The rollover speed expression of Eq. (25) is more accurate than one obtained earlier for steady turning, Eq. (19), since Eq. (25) incorporates the effects of the geometry of the curve as represented by angle γ.

For three wheeled vehicle, it can be shown that the rollover stability equation governing is (Fig. (8)):

$$Z\cos\beta < \frac{Wb}{2h}\frac{l_1}{\sqrt{L^2 + \left(\frac{b}{2}\right)^2}} \tag{26}$$

where:

$\beta = \varphi + \theta$

6. Conclusion

Today's life difficulties of disabled people are more and more taken into account for accessibility, integration into the job market and medical. Assistance systems currently available on the market require heavy adaptation by means of special building design. On the contrary, mobile robots represent an attractive solution as they could minimize the required degree of adaptation. The ML will be one robot mobile that it will go to assist the wheelchair users.

In this paper also presents, lateral and rollover stability relationships governing four wheeled and three wheeled vehicles have been presented and compared. For the lateral stability case, it was shown that the relationship governing the three wheeled vehicles was the same as the classical lateral stability solution for the four wheeled vehicle. This result can be deceiving since the region where each vehicle's mass center must be located to achieve absolute lateral stability is different. For example, the center of mass location for the four wheeled vehicle must be in its front half. Whereas, the three wheeled vehicle with two rear wheels, the mass center may be locate anywhere in the front two thirds of the vehicle. With regard to rollover stability, it was shown that the three wheeled vehicles are more susceptible to rollover than the four wheeled vehicle.

In conclusion, the analysis suggests that three wheeled vehicles offer a safe, efficient alternative to traditional four wheeled vehicles. Ongoing research into the dynamic behavior will furnish additional design recommendations that should further establish the viability of both configurations. From this study, will be possible to study the dynamics of wheelchair with ML and a prototype will be constructed for experimental tests.

The emergence of advanced mobility devices shows promise for the contribution of engineering to the amelioration of mobility impairments for millions of people who have disabilities. The application of advances in power electronics, controls, sensors, and instrumentation have really only just scratched the surface. Advancing mobility technology for people with disabilities represents a significant career and business opportunity for engineers who want to serve the public good in a meaningful and tangible way.

7. Acknowledgements

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9. Responsibility notice