DESIGN PROCESS AND DEVELOPMENT OF A PROTOTYPE ELECTRIC WHEELCHAIR

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ABSTRACT: *Nowadays, there are many people suffering of temporary or permanent disabilities due to illnesses or accidents. In many of those cases, the result is related to the difficulty of walking, something which means that the continuously refinement of the wheelchairs is becoming crucial. For this reason, there is a massive research and development in the field of wheelchairs. A basic problem in the majority of wheelchairs and trolleys is the boarding and disembarking process. Disabled people face this problem on a daily basis, especially those who has been in bed for many years. The current research presents the design process and development of a prototype electric wheelchair, which has as main target to solve problems encountered by the person with disability on a daily basis. The whole process accomplished according to the current trend of wheelchair design, which is the development of easy to use and reliable low cost devices.*

KEYWORDS: *Product design, design for all, electric wheelchair*

1 INTRODUCTION

The wheelchair development process is a growing research area generated around the world, with a great deal of articles published in the last few years. Although their majority is related to wheelchair usage and clinical assessment, there are an increasing number of articles related to the design of new wheelchair technologies. For some disabled people, wheelchairs are the primary means of mobility, activity and participation in life.

A motorized wheelchair or electric-powered wheelchair is based on the operation by means of electric motors rather than manual power. Motorized wheelchairs are useful for those who are not able to impel a manual wheelchair or those who may need to use a wheelchair for long distances, which would be strenuous in a manual wheelchair. Moving around with the wheelchair is an important factor to study, but it is not the only one related to mobility. It is also important to be able to move to and from the wheelchair as the handicap person has to use the toilet, shower, bed etc. All those actions must be taken also into consideration to make a worthy user-friendly model.

2 LITERATURE SURVEY

Extensive work has been implemented in order to increase the safety of electric powered wheelchairs, while reducing the level of human intervention. In the past decade, a great effort has been reported in research and development (R&D) of an assistive technology for people with disabilities. There have been many reported achievements, like innovative autonomous smart wheelchairs (Gao, at al., 2008; Gao, at al., 2010). Li et al. proposed the use of multi-layered maps for navigation and interaction of an intelligent wheelchair. Its autonomous navigation and human-robot interaction was the major challenge. The extension of the capability of task planning for the wheelchair and the efficiency of path planning and navigation improved from the semantic information. Mori and Nakada examined the patient lifting capacity. They developed a portable small and light patient lift, appropriate to be carried using a wheelchair in a folded state. Its operation was simple and a small user force was required because this lift has a sliding mechanism that brings the fulcrum closer to the patient's center of mass. The positive experimental results showed the effectiveness of the proposed patient lift.

Al Sibai and Manap reviewed the recent studies on smart wheelchair system in order to evaluate the current available technologies and to deliberate new future directions for the ongoing research projects. Medola et al. reviewed and analyzed the most important aspects of wheelchair configuration that affect the users' actions and mobility in terms of the kinetics and kinematics of the manual propulsion, the inertial properties of different wheelchair configurations, the importance of hand in a wheelchair assembly, as the interface through which the user drives the chair. Furthermore, a number of researchers have used mobile robot technologies to develop smart wheelchairs (Yayan, et al., 2014; Jain, and Argall, 2014; Leishman, et al., 2014). Different computer systems, a number of sensors and a mobile robot base to which a seat has been attached, have been added. Sinyukov, et al. presented both experimental and simulation results of a developed hardware and software control framework for a semi-autonomous wheelchair. They developed an assisted control framework that augments the user inputs by providing functionalities and a semi-autonomous navigation, which takes higher level destination goals and executes a SLAM algorithm. Leaman and La provided a complete state-of-the-art overview of a smart wheelchair research trends. They introduced the power wheelchairs, the communities they serve and discussed in detail the associated technological innovations with an emphasis on the most researched areas, generating the most interest for future research and development. Finally they analyzed their vision for the future research and how to serve people with all types of disabilities.

3 WHEELCHAIR DESIGN

The aim of this project is the design and creation of an economic and user-friendly wheelchair that is capable of moving indoors and outdoors. It has to be flexible enough to move inside houses, narrow spaces with different difficulties and be able to get around on outdoor places. The main target of the concept design is the solution of the patient movement difficulties such as the transfer from the chair to bed and vice versa and the elevation to different layers. The user should feel free in different activities in order to be more independent in everyday life. In addition, the wheelchair has to be as economic as possible in order to be available for all.

Getting off and on the wheelchair is one of the biggest problems that most users face every day on different occasions. Movements such as getting to the bed or getting on the car are daily routine problems for those people.

Another problem that disabled persons have is the seat height. The position of the seat affects every day life of the user, i.e. if the user wants to grab something from a higher level or if something is dropped on the floor. Most wheelchairs do not have an elevation system for the seat and those that have such systems are way too expensive to own. For many wheelchair users, the decision to venture into public places is something difficult. The desire for autonomy was the driven parameter during the wheelchair design process.

3.1 Concept Development

The first concept was an electric wheelchair in which the axle distance varies (Figure 1a). Moreover, this distance varies with the chair position, lowering the center of gravity as the axle distance grows, when going faster, to avoid turning over the wheelchair. In this wheelchair, a single scissors mechanism was selected for the lift of the seat. The elevation is obtained with a linear electric motor mounted on the frame. Two electric motors and two castor wheels were selected also for the movement of the vehicle. The scissors mechanism is mounted on the top frame in front and at a sliding bearing at the back. For achieving the lift of the seat and movement of the vehicle, a rotating mechanism for the castor wheels mounted on the beam was necessary. Finally, the batteries of the wheelchair are placed inside the beams for space saving.

The second concept (Figure 1b) is a wheelchair with a stable framework with two electric motors and two castor wheels with stable axle. A double scissors mechanism was selected in order to achieve the elevation of the seating position with two linear electric motors. The double scissor mechanism is giving the ability for higher elevation than a single type scissor. Two linear bearings are mounted to the upper frame and two at the main frame, giving the mechanism more stability and fixed connection to the framework.

The third concept mechanism (Figure 1c) was a double scissor with four fixed points on the frame. It was very similar to the previous mechanism but with more stability, because of the connected arms to the scissor beams. There was no need for linear bearings connected to the framework because of the added linkages. All four joints are connected to the framework with joints.

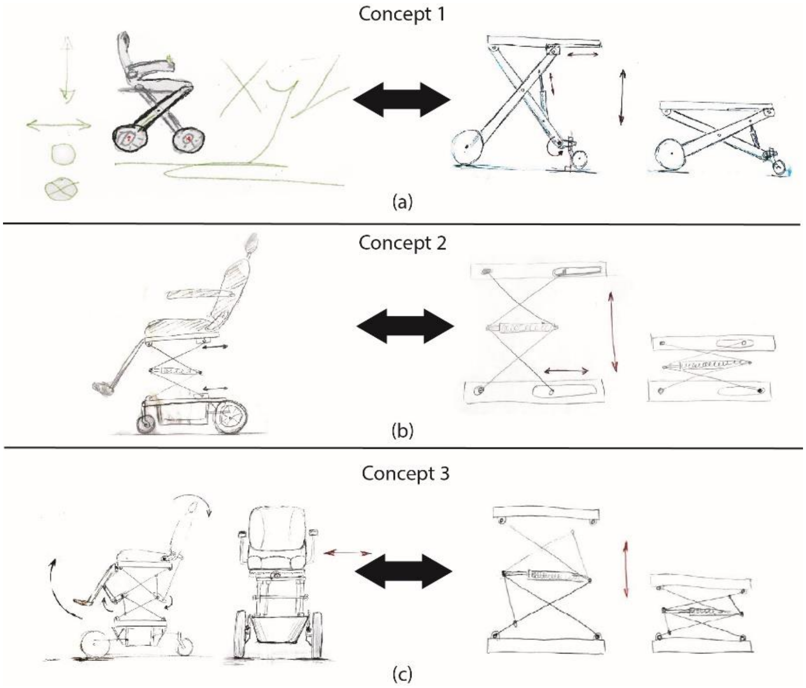

Fig. 1 The developed concepts in the concept design phase.

With this system the center of gravity of the chair remains at the center of the vehicle at all heights. The possible change of the center of gravity during elevation of the seat or driving the wheelchair may be dangerous and turn over the vehicle. Two linear electric actuators are connected to all four main beams of the scissor mechanism to a main linkage. The main linkage is composed from sheet metal welded parts and is the basic part of this mechanism. Two linkages are placed, one at the back and one in the front connection point of the scissor. The basic function of the linkage is to connect the scissor to the actuators in order to lift the chair and at the same time, it is connected to the footrest and to the back of the seat. In this way, it is possible to change the angle of the back and the legs of the user, while adjusting the seat height. Furthermore, at the top frame two slider mechanisms and a rack & pinion gear are connected with a 12V DC motor for the vertical movement of the chair, in order to be easier for the user to disembark from the vehicle.

3.2 Concept selection

Although the three concepts explained above, suited the requirements of the project, the concept that adapted best was selected based on the strengths and weaknesses evaluation presented in Table 1. Each concept was tested in a series of aspects. Those aspects were valued on a scale from 0 to 5 (choosing 0 for the lowest value and 5 for the highest). The ratings were given according to how the characteristics were fulfilled by an existing wheelchair. Furthermore, for each aspect a weight importance was introduced, as some aspects were more crucial than the others. The concept with the highest overall value was approved for the next phase.

	Importance Value %	Concept 1	Concept 2	Concept 3
Outdoor Capability	15	5	4	4
Indoor Capability	15	2	4	4
Max Height	5	4	5	5
Min Height	5	3	5	5
Disembark	30	3	3	5
Autonomy	5	3	4	4
Stability	20	2	4	5
Storage	5	3	4	4
Overall	100	3	3.8	4.6

Table 1. Concept Selection

All concepts were evaluated and according to the results, the final decision was taken. Concepts 2 and 3 were very similar in outdoor and indoor capability and also at max – min height that wheelchair can operate. Concept 1 is performing the best outdoor solution but is not performing as well as in the other aspects, so it is out of the competition. Concept 3 (Figure 2) is the only one that can fit a sliding mechanism for the disembark of the user from the vehicle, which is the most important aspect as the aim of this project, So, Concept 3 got the highest overall score and was selected for further development.

Fig. 2 The proposed concept

4 TECHNICAL SPECIFICATIONS

During the movement of a wheelchair, there are some resistances that appear. These resistances are variable and depend on various parameters as described below:

- Rolling resistance
- Aerodynamic resistance
- Anode resistance
- Inertial resistance

In the wheelchair, aerodynamic resistance and inertia resistance are considered insignificant because the accelerations and speeds which are developed on the vehicle are kept to a minimum.

4.1 Rolling Resistance

When an unformulated wheel is wrapped in unformed ground or, respectively, a fully resilient wheel is wound on a fully developed ground, there is no resistance to the movement. These are the ideal cases, as in reality both the ground and the wheel suffer from deformations. The developed torque which is created equals to:

$$T_r = N*\alpha \quad (1)$$

where N is the maximum vertical force in newtons and a is distance from a theoretical axial line of the wheel in meters. To balance this torque, it is necessary to develop a torque opposite to this. This torque equals the product of the pulling force Fr and the dynamic radius of the wheel. The vertical force (F_z) which expresses the mass of a body in strength equals to:

$$F_z = m*G \quad (2)$$

where m is the body mass and G is the acceleration of gravity.

The rolling resistance F_r is described by the following formula:

$$F_r = F_z * \mu_r \quad (3)$$

Where μ_r is the rolling resistance coefficient which is estimated for the wheelchairs with non-pneumatic wheels on concrete, with the value of

$\mu_r = 0.015$.

For the calculation of the wheelchair rolling resistance is taken into account the mass of the vehicle appr. 27 kg plus the mass of a 90Kg user.

$$F_z = (m1+m2)*G => F_z = 1147\ N \quad (4)$$

m1 is the vehicle mass in kg and m2 is the user mass in kg.

$$F_r = F_z * \mu_r => F_r = 1147*0.015 = 17.2\ N \quad (5)$$

When climbing a vehicle due to road inclination, a resulting force from the weight of the vehicle appears (Figure 3). This force opposes the movement of the vehicle when it is on the hill.

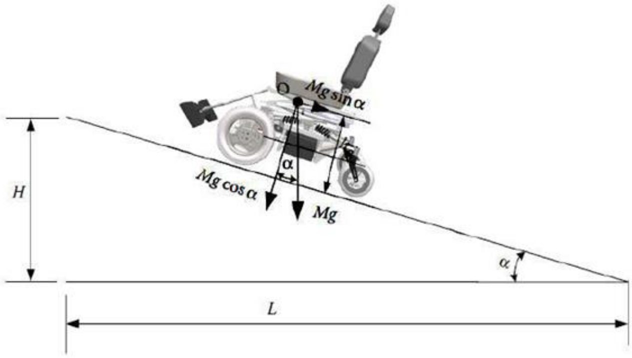

Fig. 3 Forces in road inclinations

The ascent resistance F_B is calculated from the following formula:

$$F_B=F_z*Sin\alpha \quad (6)$$

Where F_z is vertical force in newtons and α is the angle of the road inclination. As it is known, the tilt of the road is the ratio of the height H to the distance L (Figure 3) and expresses the height to be developed at a distance of 100 km:

$$I = H/L = tan\alpha \approx sin\alpha \quad (7)$$

To find the angle α, in order to calculate the ascent resistance, the right formula is the following:

$$A=tan^{-1}(i) \quad (8)$$

Thus, for a pavement slope of 10° the vehicle has an ascent resistance equals to:

$$F_B = F_z * sin\alpha => F_B = 205N \quad (9)$$

Since the forces are opposing to the movement of the vehicle, it is accurate to be summed in order to find the required driving force (traction force) to be applied to the wheels in order to move it.

$$Ft_{otal} = F_r + F_B = 205+17.2 = 222.2\ N \quad (10)$$

Where F_{total} is the total traction force which is the sum of ascent resistance F_B and the rolling resistance F_r

The torque needed on the wheel to overcome these resistors is calculated by the formula:

$$F_t = Mk * i_{tot}/r_t => M_k = F_t*r_t / i_{tot} \quad (11)$$

Where M_k is the torque on the wheel in *Nm*

The r_t the radius of the wheel and i_{tot} its gear transmission ratio from the motor to the wheel.

Four electric motors specially designed for power wheelchairs were selected for the wheelchair, and they also feature a release lever to allow the wheel to move freely, when the user's helper is required to operate the vehicle.

The motors have a diameter of 12inch (308mm) with a working voltage of 24V, 250Watt and a fixed gear transmission ratio of 23: 1.

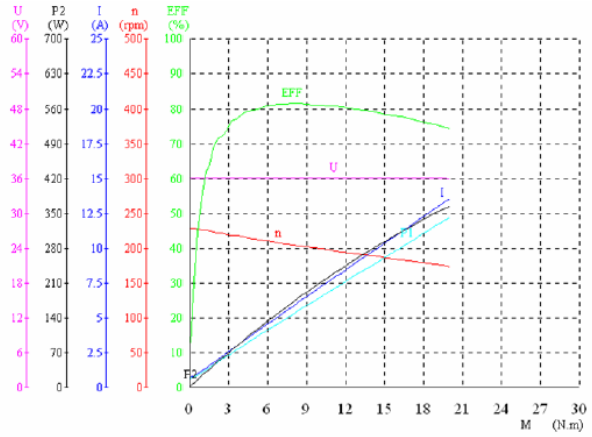

Fig. 4 The motor diagram

The maximum torque that can be produced by the motor according to its operating diagram (Figure 4) is 20Nm and is enough to overcome the climb and roll resistors.

$$F_t = M_k*i_{tot} / r_t => M_k = F_t * r_t / i_{tot} =>$$

$$M_k = 22*0.154 / 23 => M_k = 1.5\ Nm \quad (12)$$

According to the motor diagram (Figure 5) its maximum speed is 220 rpm and the maximum speed that the wheelchair can develop is 12Km/h. This is calculated by the following formula:

$$N = V* 60/2*\pi*r => V = n*2*\pi*r / 60$$

$$= 222* 2 * \pi * 0.154/60$$

$$V = 3.54\ m/s => V = 12.7\ Km/h \quad (13)$$

Where V is the maximum speed that wheelchair can achieve in *Km/h*
n is motors speed in rpm and r is wheelchair's wheel radius in *m.*

4.2 Calculation of required power

In physics, power is the amount of energy transferred per unit time.

$$P= d_w/d_t \quad (14)$$

Where P is the power in *watts* and it is defined as a derived unit of d_w1 joule per d_t second

Work results when a force acts upon an object to cause a displacement (or a motion) or, in some instances, to hinder a motion. Three variables are of importance in this definition - force, displacement, and the extent to which the force causes or hinders the displacement. Each of these three variables find their way into the equation for work. That equation is:

$$W=F*\chi \quad (15)$$

Where W is the work in *Joules*, F is force in N and χ is the displacement in *meters.*

Considering the above mathematical formulas and knowing the velocity it follows that:

$$P = F_t*V_t \quad (16)$$

Where P is the power in *watts* F_t is the traction force in N and V_t is the velocity in *m/s.* Theoretically, the power given to the vehicle, when it moves at the maximum speed (3.54m/s) it can develop (considering only the rolling resistance):

$$P = F_t*V_t = 17.7N * 3.54\ m/s = 62\ Watt \quad (17)$$

The needed energy to drive the vehicle for one hour is calculated by the formula:

$$E= P*t => E = 0.062Kwh \quad (18)$$

Fig. 5 The wheelchair design and development

Where *E* is the energy in *Kwh*, *P* is power in *watt* and *t* is the time in *hours*

According to the formula below, the vehicle needs 2.58Ah to move one hour at maximum speed.

$$E = Q_x*V/1000 \Rightarrow Q_x=0.062*1000/24 \Rightarrow 0.062*1000/24 = 2.58Ah \quad (19)$$

Where E is the energy needed in Ah, Q_x is the capacity of the battery in Ah and V is the voltage of the battery used in the experiment equal to 24v.

4.3 Autonomy

Autonomy expresses the ability of a vehicle to travel a distance under strictly driving conditions. Autonomy is usually expressed in km but can also be expressed in energy consumed. To calculate the autonomy of an electric vehicle properly, it is necessary to take into account operating cycles and experimental measurements. However, for wheelchairs, there are no operating cycles. In the previous calculations, the results were derived solely by considering the resistances of the motion. In a realistic scenario, the vehicle was assumed to be moving steadily with a mean required torque of 7Nm. Based on this, traffic autonomy was going to be calculated. This torque leads to the two engines. Thus, each one corresponds to a torque equal to 3.5Nm. According to the operating diagram of the motor, each drive produces about 100 watts of energy and has a performance level of about 73%. Therefore, the required power is calculated from the following formula:

$$P_m=P_t/0.73$$

$$P_t=P_m*2 \Rightarrow P_t=169W \quad (20)$$

where P_m is the power produced in mechanical energy with losses from motor efficiency.

So, the energy consumed by the battery is:

$$E = Q_x * v/1000 \Rightarrow Q_x = 0.169*1000/36 \Rightarrow Q_x = 7.05Ah \quad (21)$$

According to the above calculations, the wheelchair runs 12Km in one hour and consumes 7.05Ah of the battery, so the vehicle can travel about 43Km at a constant speed of 12Km / h with the 26Ah battery.

The final result was the development of a new wheelchair (Figure 5), in order people to overcome difficulties that they currently cannot independently manage. It has been embodied in a prototype, which can be treated as a fully functional wheelchair and be both ridden and evaluated.

5 CONCLUSIONS

During the last years, computer systems and sensors have been faster and smaller, while software has become smarter than ever before. Many researchers have developed prototypes in order to be able to accommodate people with all disability types by utilizing computer vision, touch, voice, even artificial intelligence. During the design process, the human factors should be taken into account, so wheelchairs made customizable to the individual user's preferences, giving people with disabilities the appropriate quality of life. Motivated by the need to set up usability, safety and reliability of an autonomous wheelchair, this research represents a paradigm to empower the mobility of individuals with disabilities. Furthermore, provides information that could be used for further development of current and future products for disabled people. The new technology implemented through the development of this wheelchair offers a differentiation from currently offered solutions on the market, which means that there is a competitive advantage. Of course, even though this project has given a satisfactory result, there is still a need for further discussion before this technology could be fully introduced to the intended user group.

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