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Design and Simulation of an Automated Wheelchair with Vertically Adjustable Seat

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ABSTRACT
The motivation of this research work is to design an automated wheelchair for the physically disabled people of both developed and developing countries. This design also facilitates the users to adjust the wheelchair seat vertically according to their needs. Though many designs of automatic wheelchairs are published in different research works, those are not so available in present market that common people can buy and use it for their personal purpose. Beside this, the high price restricts most of the disabled people of developing countries like Bangladesh from using the automated wheelchair for their maneuvering. For this reason, A microcontroller based embedded system is designed to control the wheelchair motion comfortably along with the vertical movements of the seat. On the contrary, the price of the wheelchair will not exceed the economic range of general people. The feasibility of this design is also verified through simulation works.

Keywords: Automatic Wheelchair, Embedded system, vertically adjustable seat, Belt and pulley

1. Introduction

The number of physically impaired people is increasing rapidly in recent years. Recent statistics shows that around 15% people (700 million) of total world population are physically and mentally disabled. Among them 100 million people are physically challenged. One study presents that the number of physically challenged people in Bangladesh is around 5.6% (8.4 million) of total population (Fig.1) [1], whereas, the actual scenario is much more acute. The majority of physically challenged persons of countries like Bangladesh either use crutches or manual wheelchairs for their maneuvering. Because of physical weakness, many wheelchair users cannot control the wheelchairs properly by using their hands. Moreover automated wheelchairs are not available everywhere in developing countries and the cost is high with respect to the economic status of the common people.

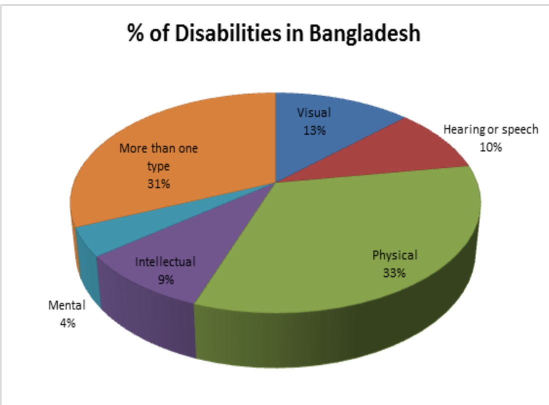

Fig.1 Percentage of disable people in Bangladesh

User uses the traditional automatic wheelchairs need help from others and cannot move the wheelchair seat for their necessary purposes (shown in Fig.2). Moreover physically weak users also face problems to grip joystick for moving the automated wheelchairs. In this circumstance, this research aims to design an automatic wheelchair with a vertically moveable seat to enhance its facilities for the users.

Fig.2 Hindrance of Wheelchair users during work

2. Background

The main purpose of scientific research is to facilitate every human being through the scientific inventions. Though automated wheelchair is the gift of modern science, most of the common people of developing countries do not have its access because of its high price and less availability. From the last decades of 19th century, researchers had been working on this purpose. In 1994, MITRE Corporation published their research on low cost automated wheelchair which was a theoretical modification of manual wheelchair [6]. Their practical implementation was found in 1995 [12]. Later, in the research of Taslima reza, 2012 [4], EMG signal was used for controlling the wheelchair, but its practical implementation is still a long way to go. The smart wheelchair showed by Trivedi (2013) [5] is a laptop assembled wheelchair and such kinds of wheelchair is too expensive for the common people of developing countries. NavChair and other joystick controlled wheelchairs [10, 13] are difficult for those users having wrist weakness. Vision based EOG system for wheelchair [7], voice operated wheelchair [8], voice enabled device [9], and gesture recognition based

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wheelchair [11] are not feasible yet for the application in developing countries. The signal processing system of these wheelchairs are still in research level and the user interaction of these wheelchairs are not easy to adapt. The design and implementation of wheelchair by Humaira salmin [2] is as same as “Tin man” by MITRE Corporation [12]. As the manual wheelchair is disassembled and then converted into automated wheelchair, it is nothing but a power car and there is no option for adjusting the seat height. From above analysis it is seen that no one still feel the necessity of vertical movement of wheelchair seat for facilitating users need. Because of these technical limitations and economic perspective of developing countries, we present a new design of automatic wheelchair.

3. Mechanical Design

The design of the wheelchair is done by using Solidworks 2013 software and the outlook view is generated with Keyshot4 software. Solidworks 2013 software is further used for stress and displacement analysis. AISI 1020 steel is used as material for simulation purposes. The material properties of AISI 1020 are given at Table 1.

Table 1 Material property of AISI 1020

Property	Value	Units
Elastic Modulus	2e+011	N/m^2
Poisson Ratio	0.29	N/A
Shear Modulus	7.7e+010	N/m^2
Density	7900	Kg/m^3
Tensile Strength	420507000	N/m^2
Specific Heat	420	J/(Kg.K)
Yield Strength	351571000	N/m^2
Thermal Expansion Coefficient	1.5e-005	/k
Thermal Conductivity	47	W/(m.K)

The design of the wheelchair is done by considering the maximum weight of the person is 100kg. So, the structure of the wheelchair has to be capable of carrying 980N load. Von Mises stress analysis and URES displacements indicate the validation of structure strength, using AISI 1020 steel under 980N load. Designed structure of the wheelchair is given below

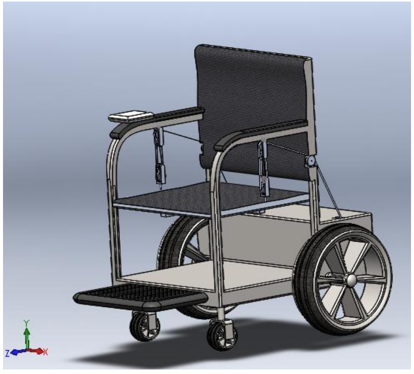

Fig.3 Isometric view of designed wheelchair

3.1 Von Mises stress analysis

Von Mises stress analysis is used to find the yielding criteria of isotropic or ductile materials under complex load. According to Von Mises yield criterion, it is independent of first stress invariant. But the ductile materials will exceed yield point when the second deviatory stress invariant will reach a critical value. The stress analysis of wheelchair frame, seat and pulley are given in the Fig.4, Fig.5 and Fig.6 respectively.

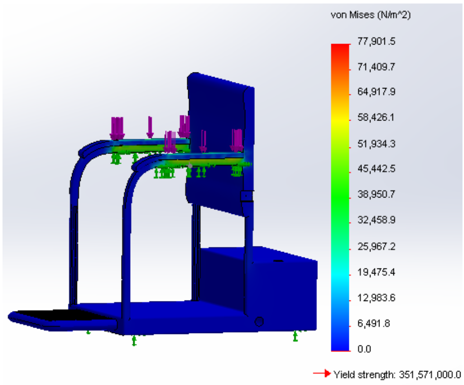

Fig.4 Von Mises stress analysis of frame

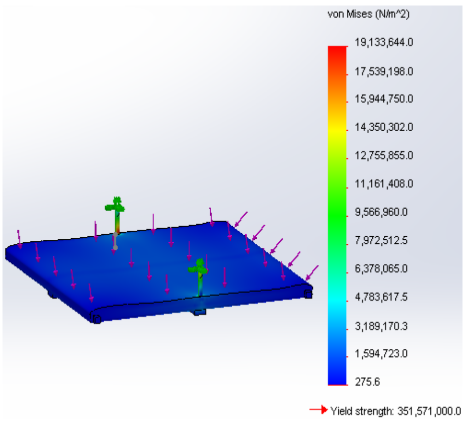

Fig.5 Von Mises stress analysis of seat

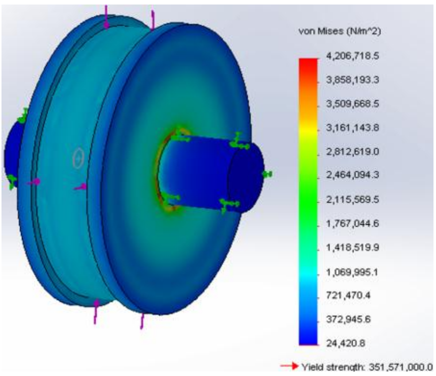

Fig.6 Von Mises stress analysis of pulley

From the stress analysis of the wheelchair frame, seat and pulley, it is found that the structures will sustain under the applied load.

3.2 Resultant displacement

The resultant URES displacement of Solidwork shows the average displacement of the wheelchair structure. It includes the resultant deformation in X, Y, and Z direction. It is found from the analysis that the highest deformation of the wheelchair frame is 0.00000815mm under the applied load. The URES displacement of the wheelchair frame, seat and pulley are shown in Fig.7, Fig.8, and Fig.9 respectively.

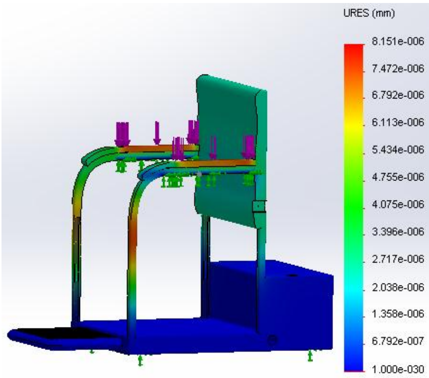

Fig.7 URES displacement of wheelchair frame

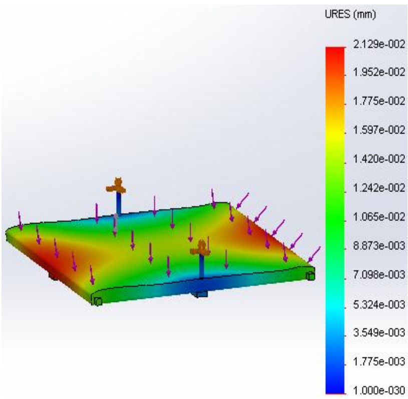

Fig.8 URES displacement of wheelchair seat

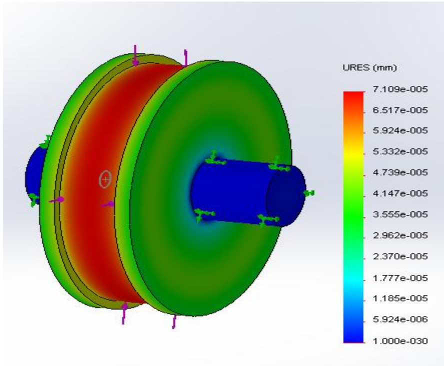

Fig.9 URES displacement of wheelchair pulley

3.3 Suitable wire for load

To hold 980N, 3/8 inches (9.5mm) diameter steel wire is well enough which is justified by Engineering Toolbox-wire-rope-strength table [4].

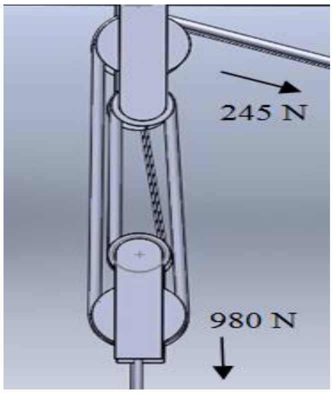

Fig.10 Wire rope and pulley

The safe load of this wire is 10.9 KN. So the maximum safe mass, M for 3/8 inches wire, can be calculated as

$$M = F/g \qquad (1)$$

The maximum weight limit of the wire is 1111kg. So the factor of safety of our design is more than 10.

4. Electrical Components

In order to drive and control the wheelchair two DC motors, one DC gear motor, rechargeable battery, ATMEGA 32 micro- controller, and L293D motor driver are used as the electrical components.

4.1 DC motors

Two DC motors are used for independent rotation of rear wheels. The output power, torque and voltage of this DC motor are 200W, 20Nm and 24V respectively. High torque of DC motor ensures the smooth movement of the wheelchair. The torque of DC gear motor is 50Kg-cm which is used to pull 980N load of a wheelchair user smoothly.

Fig.11 DC Motor for rear wheel and DC gear Motor for lifting seat

4.2 Wheelchair Battery

NiMH battery is a kind of rechargeable battery. The specific energy of large NiMH cells is about 270 KJ/Kg. This battery is very robust and shows the current charge status by pressing a button. It's charging time is 2 hours and volumetric energy density is 1,080 MJ/m^3. The voltage and current of one set of battery is 24V and 2200mAh.

Fig.12 Rechargeable NiMH Battery

4.3 ATMEGA 32 microcontroller

This microcontroller have 32 Kbytes self - programmable Flash program memory, 1024 Bytes EEPROM, 2 Kbytes internal SRAM, 8 channel-10 bit ADC and 32 programmable I/O lines. Operating voltage of this microcontroller ranges between 4.5V-5.5V. This is helpful for multifunctional automated system with low cost and low power consumption.

Fig.13 ATMEGA 32 microcontroller

4.4 L293D motor driver

L293D is quadruple high-current half-H drivers. It provides bidirectional drive currents up to 600mA at voltages from 4.5 V to 36 V. It is designed to drive inductive, high current/high voltage loads such as relays, solenoids, DC motors etc. in positive supply applications.

Fig.14 L293D motor driver

5. Control Algorithm

Functions of wheelchair motor are controlled by ATMEGA32 microcontroller, L293D motor driver by using PWM (Pulse Width Modulation) and measuring duty cycle of motor. When the PWM is initialized, motors are individually rotated according to the user's purposes. If the user desires to move forward or backward, then the both rear wheel motors will rotate in forward or backward direction. This command is sent to the register of microcontroller by switch1 and switch2 respectively. Similarly, the wheelchair will turn left when the right motor will rotate in forward direction and left motor will be in reverse direction by pressing switch4. On the other hand, switch3 will set signal to microcontroller register to enable the rotation of wheelchair to turn right. The DC gear motor is controlled by pressing switch6 or switch7 to move the seat vertically up and down. The flowchart of control algorithm and the circuit diagram are given in Fig.15 and Fig.16 respectively.

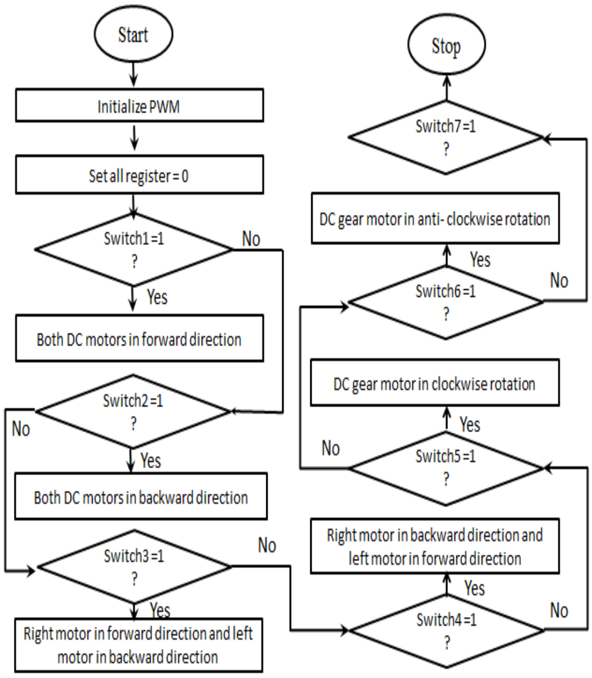

Fig.15 Flowchart of control mechanism

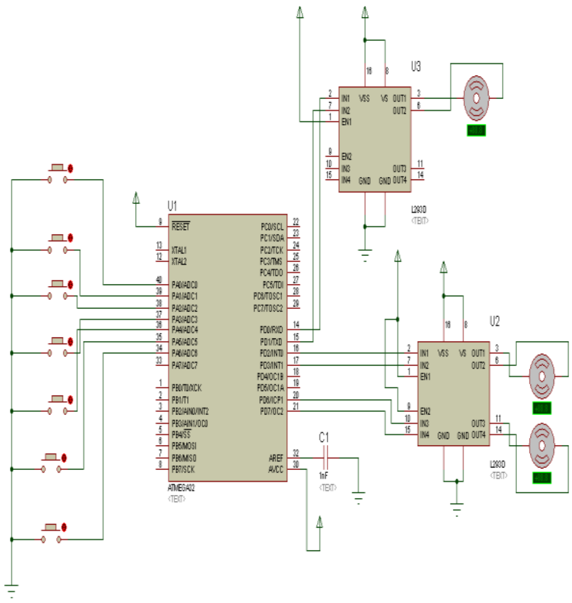

Fig.16 Circuit arrangement by Proteus software

Wheelchair seat movements are shown in the Fig.17

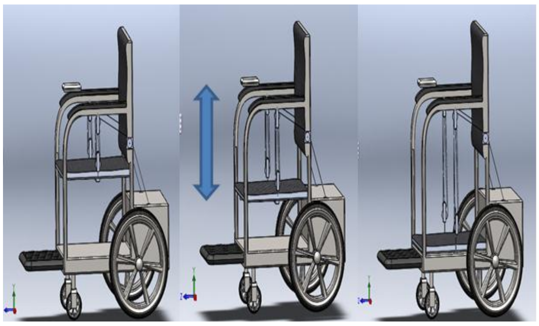

Fig.17 Downward motion of wheelchair seat

6. Final rendering of wheelchair

The final rendering is presented by Keyshot4 software.

Fig.18 Final design

6. Economic analysis

The necessary components of the proposed wheelchair are available in the electronics market of Bangladesh, TechshopBD and eBay. From the market price of these components, the estimated price of this wheelchair is given in Table 2.

Table 2 Estimated price of Wheelchair

Parts name	Price in BDT	Price in $
Wheelchair frame	10,000	128.2
Electrical component(microcontroller chip, mosfet, buttons)	1200	15.38
Dc wheel motor	4988	62.35
Dc gear motor	2494	31.18
Mechanical equipment	3000	37.5
Battery	6392	79.9
Total -	28,074	354.51

7. Result and Discussion

The main focus of this research work is to design an automatic wheelchair with vertically adjustable under the economic production feasibility. The load carrying capacity of the seat depends on the structure and the material stability of related parts of the wheelchair. After designing the wheelchair structure, stress and displacements analysis of the wheelchair frame, seat and pulley are justified. The results of simulation work show the sustainability of the mentioned parts under applied load (980 N). Thus the stability of wheelchair structure is verified. The rope and pulley system is used to minimize the load on DC gear motor. The suggested DC wheel motors and gear motor are able to make the motion and to carry the mentioned load. Thus the structure can bear the load, and the motor can operate synchronously. So the designed structure has passed all the necessary safety criteria. The cost analysis also represents that it is going to be the cheapest wheelchair model with vertically adjustable seat.

8. Conclusion

The recent research works of automated wheelchairs are mostly concerned about control mechanisms. Though some low cost wheelchair projects are done, no new design is proposed for low production cost and multiple function facilities. This research work presents a new multifunctional wheelchair which will diminish the inaccessibility of automated wheelchair for the common people of developing countries. This project develops a new design of wheelchair which can be accessible to every people and a unique concept of wheelchair seat movement is developed with practical feasibility through simulation software. The future work of this research can focus on engaging more sensors and developing sophisticated control system that will add more freedom for the disabled user.

NOMENENCLATURE

M : mass , Kg
F : Force , N
G : Gravitational acceleration , m/
EPW : Electrical Powered Wheelchair
NiMH: Nickel Metal Hydride.

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