Hindawi
Complexity
Volume 2023, Article ID 7310265, 13 pages
https://doi.org/10.1155/2023/7310265

WILEY | Hindawi

Research Article

Design, Analysis, and Control of Biomedical Healthcare Modular Wheelchair with Posture Transformation

Muhammad Zia Ur Rahman,[1] **Imran Ali**,[1] **Asif Ishfaque**,[1] **Muhammad Tanveer Riaz**,[1] **Nasir Ahmad**,[1] **M. M. Sayed Al Mahmud**,[2] **and Rimsha Tanveer**[1]

[1]*Department of Mechanical, Mechatronics and Manufacturing Engineering, University of Engineering and Technology Lahore, Faisalabad Campus, Faisalabad 38000, Pakistan*
[2]*Department of Electrical and Electronic Engineering, Green University of Bangladesh, Dhaka, Bangladesh*

Correspondence should be addressed to Muhammad Zia Ur Rahman; ziaurrahman@uet.edu.pk and M. M. Sayed Al Mahmud; sam_eee.1141@yahoo.com

Received 22 August 2022; Revised 4 May 2023; Accepted 7 June 2023; Published 21 June 2023

Academic Editor: Basil M. Al-Hadithi

The majority of people with disabilities in the world have impairments that affect their lower bodies. In most of these cases, it was found that the affected person's upper body was in good health and capable of carrying out all activities; however, the spinal cord injury results in significant health challenges with body functions like urination, bowel movements, heart rate, and respiratory, cardiovascular, and sexual function, which require prompt medical treatment and mobility aids. This study presents the mechanical layout of a wheelchair that can switch between a sitting and a standing position. The center of gravity must be taken into account when creating an electric standing wheelchair. It is designed specifically for people with disabilities to lessen the need of outside assistance, allowing the disabled person to savour a sense of adoration. In the simulation, the electric standing wheelchair analysis is carried out by loading with a human weight of 40 and 100 kg, and the transformation angle is adjusted between 0 and 90 degrees to compare the center of gravity displacement. SolidWorks and ANSYS are used to design the prototype, assemble the product, and establish the safety factor bounds of the structure and capabilities as required. The research focuses to achieve control of speed deviation and acceleration using a fuzzy control technique. The Arduino oversees the operation of the drive system as a controller, and a linear actuator is utilized for standing and sitting positions. This method is affordable, easily constructed, and highly secure.

1. Introduction

Physical disabilities affect a large portion of the world's population. Serious accidents induce trauma in some persons, the most common of which being spinal cord injuries. According to international occurrence data, between 250 and 500 thousand persons suffer from spinal cord injuries each year, with a large portion of this population suffering from lower body disability. Some people are traumatised by severe accidents, most frequently by spinal cord damage [1, 2]. In most circumstances, the injured person's upper body is regarded as fit and capable of doing all responsibilities. There are more than 70 million people in the group, yet just 15% use wheelchairs [3].

With a modular wheelchair, the user can propel the vehicle from a sitting to a standing position by utilizing just body weight and muscle power. Because of the limited reach of the hands, a person cannot accomplish numerous tasks in a constrained workspace. Many studies have proposed improved designs that increase user accessibility and expand opportunities, making various formerly difficult tasks such as cooking, dishwashing, and accessing the kitchen refrigerator possible [4, 5]. The reduced eye level was a significant barrier to carrying out many daily duties, but this issue can be solved with a standing wheelchair. Traditional wheelchair users also reported improvements in accessibility and confidence due to easier vision. Due to their limited range of motion, paraplegics using wheelchairs are more susceptible to a wide range of health issues [6]. Additionally, severe issues including excretion failure, hematogenous disease, and impairment of bladder functions are among the after-effects of inactivity [7, 8]. Moreover, from a psychological perspective, people who stand have more confidence than those who sit in wheelchairs. People with standing postures have a better sense of confidence than people who are seated in wheelchairs, according to psychological theory [9–11].

A design that allows users to manually adjust their posture utilizing telescopic tubes and generating lift using a cable and pulley system was among the existing work [12–14]. Kim [15] gave wheelchair users safe mobility as they steered the wheelchair in the direction of their destination. The wheelchair recognized a variety of hazards and risky circumstances in actual environments and developed avoidable paths to avoid collisions with them in order to facilitate safe movement. Zhang et al. [16] presented a driver aid and human following control system for smart wheelchairs. When a wheelchair user was manoeuvring through complex environments with unidentified obstacles, driver assistance could prevent the wheelchair from colliding with impediments and going down steps. When a wheelchair user wanted to walk by himself, human following ensured that the wheelchair followed the user at an appropriate distance. However, wheelchair's mechanical design that can switch between a sitting and a standing position was not provided. The authors of this study [17] discussed a wheelchair with standing wheelchair controller (SWC), making it a more economical and cost-effective convertible. To ensure the user's comfort and safety, the experimenters recommended installing an adaptive PID control system in the SWC. A new CAD model of a standing wheelchair with a parallelogram mechanism was created by the author [18]. DOF = 1 was used in the wheelchair design. For sitting to standing or vice versa, they used a linear motor with a minimum load capacity of 2405 N. In the literature, the use of BLDC motors (including Hall sensors), digital signal processor, built-in motion sensors (gyroscope and accelerometer), control strategies including conventional and intelligent approaches, and a joystick to generate intuitive wheelchair locomotion mode was also mentioned for the design of wheelchairs [19–24]. Additionally, discussion on the importance of biomechanical characteristics of wheeled mobility equipment such as propulsion mechanisms, assistive technologies, overuse injuries, pressure ulcer avoidance, and frame design was also provided [25–28]. Yet, a lot of research groups from all over the world are still working on this issue and developing new applications, strategies, and solutions. The majority of references found during searches in the major web databases [19] disregard the marketability of their studies, which necessitates the provision of a suitable mobile platform. We provide an open architecture that makes it easier for manufacturers and academics to create interoperable assistive technology solutions. With the use of this architecture, connectivity is made possible at all levels of abstraction, including hardware and software, encouraging greater field-wide cooperation and innovation.

The proposed modular wheelchair design represents a substantial advancement in wheelchair usability for people with impairments. One essential element that can offer several health advantages is the capacity to alter posture. This can lower the chance of developing pressure sores, improve circulation, and make it easier to breathe. A novel lifting mechanism that is highly effective is incorporated into the standing wheelchair prototype that is suggested in this article. In designing, the frame is a key part of building this electric standing wheelchair. Using several motors and actuators, the frame will move the patient from a sitting to a standing posture. First and foremost, the powered wheelchair with joystick control is the most popularized one, and it can be referred to as a type of electric vehicle driven by a joystick [29–31]. In our wheelchair, we wish to combine mechanical and electrical components in order to improve the existing wheelchairs. The designed wheelchair will help people to stand up while using less electricity, yet it will still be just as convenient as a simple electric wheelchair, where only two DC motors, a joystick, and an Arduino microprocessor make up the wheelchair's drive mechanism. A crucial safety feature that aids in accident prevention and guarantees the user's safety is the installation of an ultrasonic module to detect obstructions in front of the wheelchair. The suggested modular wheelchair design is, all things considered, a very positive advancement that has the potential to completely change how people with disabilities access and utilize mobility equipment. The inclusion of cutting-edge technologies, including novel lifting mechanism and the ultrasonic obstacle detection module, emphasizes the ongoing efforts to make assistive technologies for people with disabilities more usable and accessible.

The discussion about our methodology is mentioned in Section 2 along with wheelchair design, finite element analysis (FEM), and fuzzy-based control. Section 3 discusses mechanical design and mathematical calculations. Section 4 is about simulation results, discussion, and hardware implementation. Finally, conclusion is provided in Section 5.

2. Proposed Control Methodology

There have been numerous wheelchair operation designs put forth in the past. Here, the presented modular wheelchair with posture transformation is designed to enable paralyzed people to carry out a variety of duties independently. Due to the design's adaptability and the patient's comfort, movements in sitting and standing positions are also cost-effective. In the simulation, the center of gravity displacement is compared by loading the electric standing wheelchair with a human weight between 40 and 100 kg while adjusting the transformation angle between 0 and 90 degrees. The feedback encoders can read position and speed simultaneously. From Figure 1, the encoder provides information to fuzzy speed controller. When encoder reads speed, the fuzzy control is activated. Also, both controls are parallel and decoupled controls, where Figure 1 shows

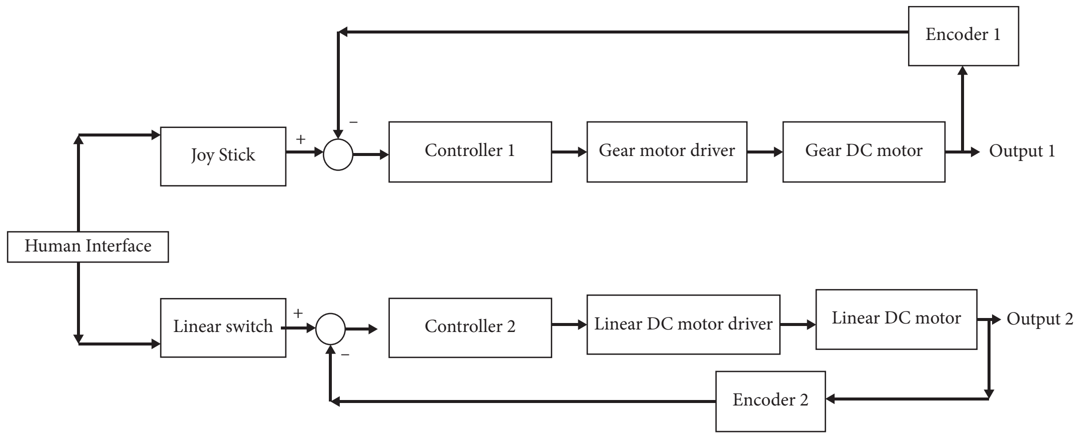

Figure 1: Control methodology of standing wheelchair.

a position control by means of an encoder in the feedback, and the proposed fuzzy regulator provides speed commands to the motors. This approach is more convenient, secure, and inexpensive.

2.1. Software Design on SolidWorks and Stress Analysis

2.1.1. Design on SolidWorks [28]. Firstly, in SolidWorks, we planned all the parts of our standing wheelchair with legitimate measurements agreeing to the height of the Pakistani individuals. After planning the parts of the wheelchair, we collected parts of the outline and parts of the base, and after that we combined the outline and base for the last assembly in SolidWorks. The parts of the wheelchair that are designed in SolidWorks are shown in Figure 2.

After that, we connected the DC straight actuator with the framework assembly to check whether our outline moves from a sitting to a standing position and vice versa. In Figure 3, all the designed components of the wheelchair are assembled.

2.2. FEM Analysis. The following analysis is carried out to check the stretch investigation in a wheelchair. For the push examination, we utilized the ANSYS software. In ANSYS, first, we applied stress analysis to the frame assembly by applying the loads on the frame to check the stability of the frame, and center of gravity was tested at 45, 60, and 90 degrees.

As shown in Figure 4, no breakage point appears during testing, so we conclude that it is within the bearable stress. The ratio of the material allowable stress to the applied stress is known as the factor of safety (FoS). According to the ANSYS results with different loads, an electric standing wheelchair may support a person weighing up to 80 kg as long as the safety factor value is above 2, but anything heavier than 80 kg is unsafe because the safety factor value is below 2. The dynamic load includes the building of the electric standing wheelchair, and hence the safety factor must be 2.

The calculation shows colour levels which represent the degree of stress that happens. The colour levels begin from blue to red. The blue colour demonstrates less stress levels, and the red colour shows the greatest stress. The output will be analyzed so that the maximum and secure stack will be utilized within the electric standing wheelchair.

2.3. Control Algorithm of Joystick and Fuzzy Control

(i) *Joystick Control.* On the joystick, there are two potentiometers. The range of each potentiometer is 10 k ohms. A joystick allows the wheelchair to go forward, backward, left, and right. An analogue sensor, such as a joystick, can read analogue values at pins A0 and A1. To regulate the wheelchair's mobility in any direction, it has two axes: X and Y. As seen, joysticks feature two axes, X and Y, and four quadrants. The wheelchair advances when the joystick detects both positive voltages on the XY pins in the first quadrant. The Joystick reads the X-axis to full voltage and half of the Y-axis value in the second quadrant. The wheelchair thus makes a sharp left turn. The wheelchair moves backward when the joystick is moved in the third quadrant. The fourth sector has a sharp right curve made by wheelchairs.

(ii) *Fuzzy Control.* Control and autonomous systems play an important role in doing daily life tasks [32, 33]. Fuzzy control is achieved based on fuzzy logic. The steps in the algorithm for fuzzy logic-based intelligent systems are as follows: (1) fuzzification; (2) fuzzy logic-based inference rules; and (3) defuzzification, which are extensity discussed in the literature [34]. The most useful and widely used membership functions are those involving triangles represented by equation (1). Table 1 defines the MIN fuzzy inference rule, used in the current paper, for three variables x, y, and z.

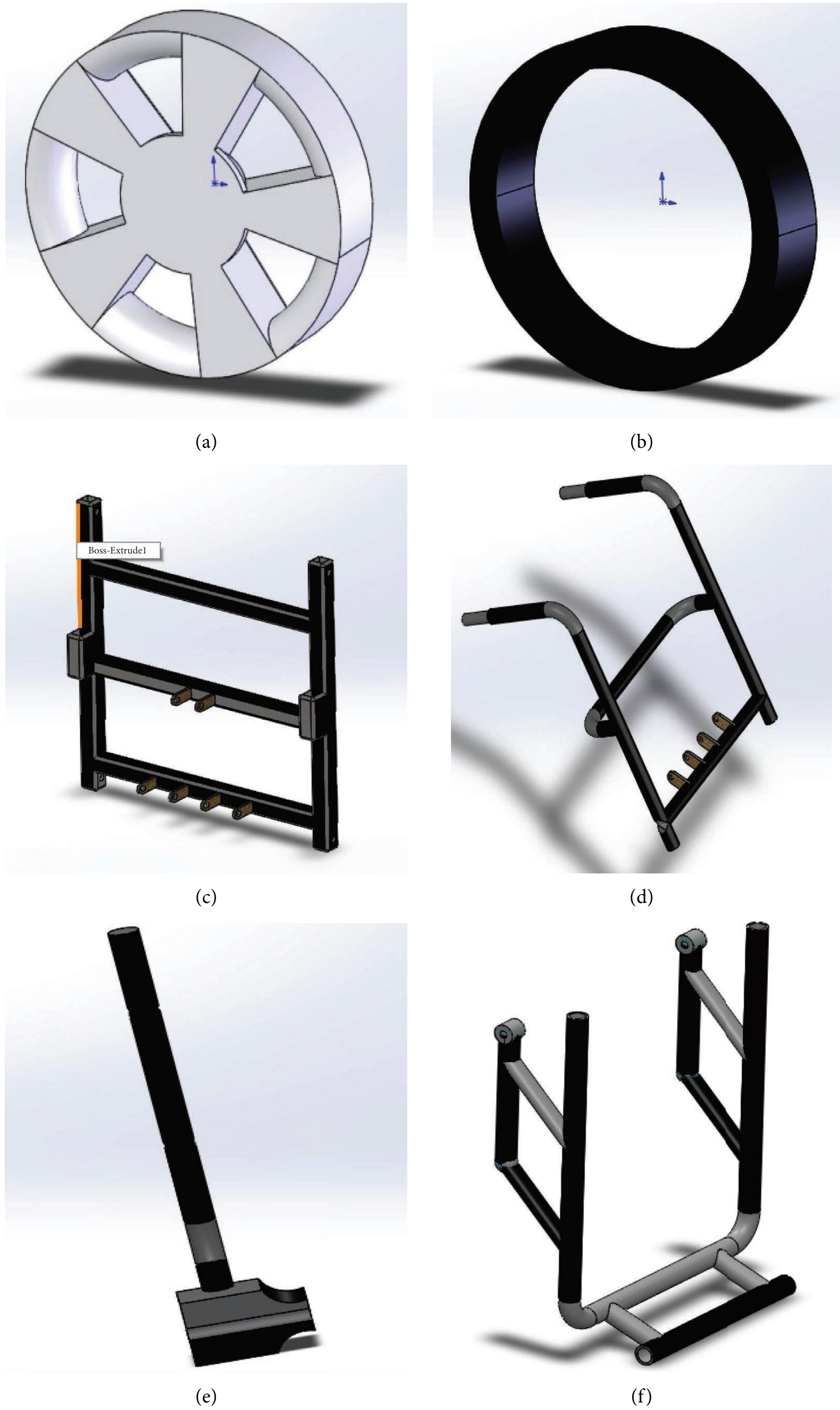

Figure 2: Wheelchair part design in SolidWorks. (a) Wheel rim. (b) Rubber tyre. (c) Wheelchair seat. (d) Back frame. (e) Armrest design. (f) Frame leg support.

FIGURE 3: Frame assembly in SolidWorks.

$$u_A(x) = \begin{cases} \dfrac{x-a}{m-a} & a < x \leq m, \\ \dfrac{b-x}{b-m} & m < x \leq b, \\ 0 & if\ x \leq a, x \geq a. \end{cases} \quad (1)$$

Figure 5 shows that our fuzzy logic toolbox will operate in which we have three inputs: front obstacle distance (FOD), left obstacle distance (LOD), and right obstacle distance (ROD), while the outputs are left and right motor speed. The rules implemented during this logic are shown in Figure 6. The controller for the system was created using the fuzzy logic toolkit. The wheelchair model's motor and the fuzzy controller were then added to the Simulink environment to test the planned system's viability.

The rules are applied to operate the wheelchair for obstacle avoidance. The front, right, and left obstacle distances are in close, medium, and far mode. Then, outputs are in low, fast, and medium-speed mode. For checking the rule implementation, Figure 7 is also shown. The following outputs are obtained as shown in Figure 8, when an output is LMS (left motor speed) and RMS (right motor speed).

3. Mechanical Design and Calculations

One actuator, a DC geared motor, and a linear DC motor are used to create the standing wheelchair. For the stand-to-sit or vice versa transformation, linear DC motors are employed, whereas DC geared motors are used for forward, backward, and turn. Each side of the patient seat has a linear DC motor. The wheelchair is designed in such a way that a linear DC motor pushes the wheelchair seat up, allowing the user to transition from sitting to standing. The linear DC motor has a maximum length of 255 mm. The linear DC motor's speed response should not be so fast that it endangers the patient's safety. We created our wheelchair in such a way that it can assist individuals with spinal cord injuries in overcoming the health issues associated with prolonged usage of a wheelchair. In Figure 9, we represent our wheelchair hardware which shows how the frame looks in sitting and standing positions.

In the process of posture change from sitting to standing, the linear motor expansion is locked as a linkage. The linear motor for standing is the driving link and the whole structure can be seen as composed of 8 moving parts, 9 lower pairs, and 2 higher pairs as shown in Figure 10. e, i, f, and g are fixed points on the wheelchair frame, h, a, c, and d constitute a parallelogram mechanism, and b is the lifting point of the linear actuator shown in Figure 11.

For the degree of freedom determination, we used the number of links, number of lower pair joints, and number of higher pair joints. DOF can be calculated from the following equation:

$$\text{DOF} = 3(n-1) - 2 * l - h. \quad (2)$$

By putting the variable values, the calculated DOF is 1. Parameters used for the maximum distance of linear motor are the angle of actuator and distance from the actuator to wheelchair endpoint.

$$\Delta s = \Delta\theta * r, \quad (3)$$

where $\Delta\theta$ =angle actuator in radian and r = distance from the actuator to the wheelchair endpoint.

$$\begin{aligned} \Delta s &= 1.396 * 180 \\ &= 251.2mm. \end{aligned} \quad (4)$$

The maximum distance achieved by the motor while expanding ranges from 180 mm to 255 mm with an angle of 80° from equation (3).

The factor of safety (FoS) of any mechanical model is the ratio of ultimate stress to allowable stress which can be determined using the following equation.

$$\text{Factor of safety} = \frac{\text{ultimate stress}}{\text{allowable stress}}. \quad (5)$$

The ultimate stress of carbon steel of 6 mm thickness is 415 MPa.

$$\text{Factor of safety} = \frac{415\text{Mpa}}{195\text{Mpa}} = 2.1. \quad (6)$$

For finding the mass of the frame, we use the following equation:

$$\begin{aligned} \text{M} &= \text{Psteel} * \text{V} \\ &= 7.84 * 3765.53\text{cm}^3 \\ &= 29521.75\text{g} = 29.5\text{kg} = 30\text{kg}. \end{aligned} \quad (7)$$

4. Results and Discussion

4.1. Design Simulation and Calculations. Within the proposed mechanical plan, the fundamental structure has been decided by building and tackling numerical models on the kinematics mechanism. The DOF is characterized by keeping in mind that the linear actuator makes the standing

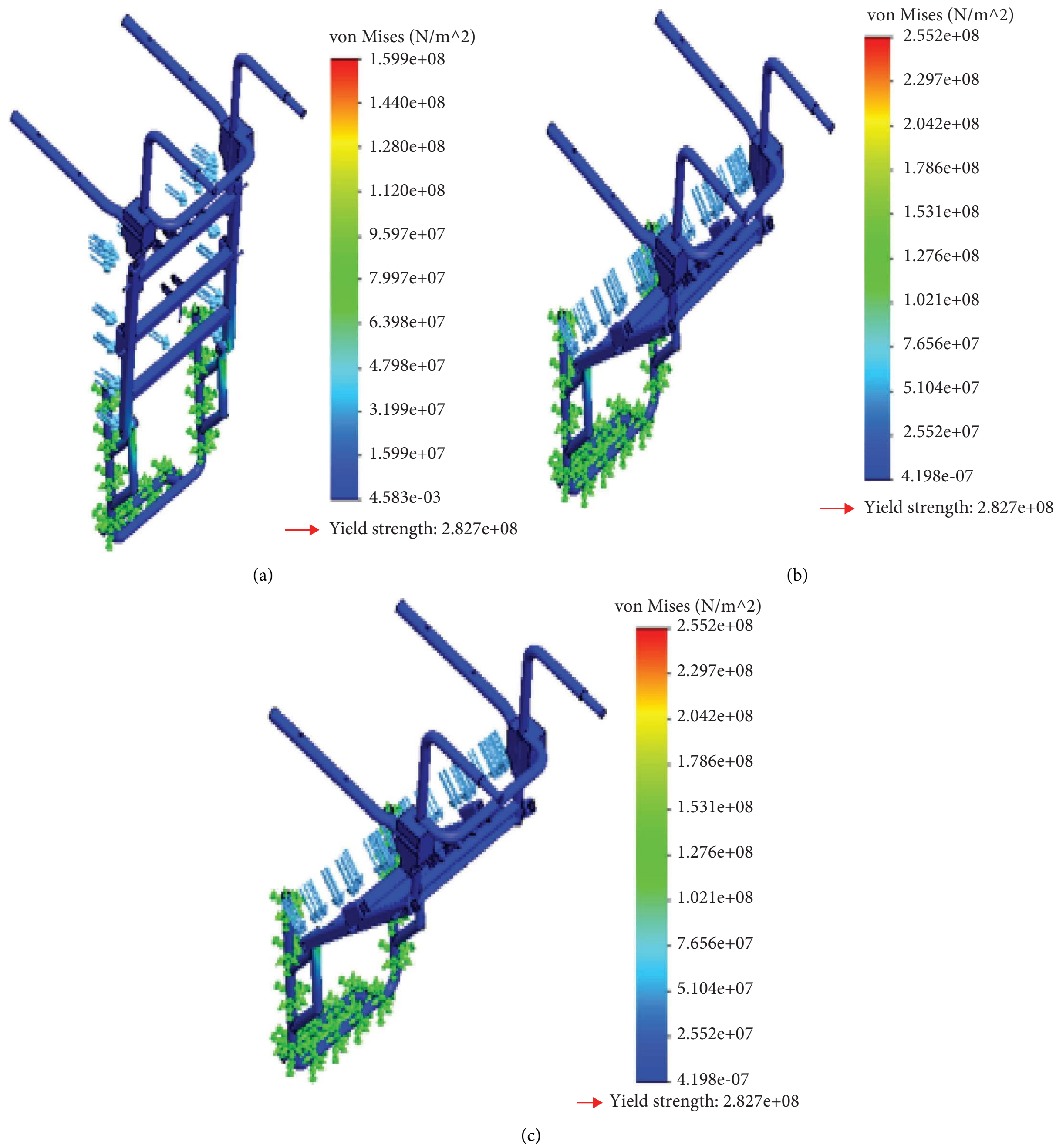

Figure 4: Stress analysis on frame with different angles using ANSYS. (a) With 90°. (b) With 60°. (c) With 45°.

positon reasonable. The maximum extension to make the standing position is 255 mm with a starting point of 80° from the base line. This extension is an ideal one for the attached linear motor to maintain a steady center of gravity while guaranteeing the safety and stability of the structure. The plan preparation was carried out utilizing the CAD computer program SolidWorks as shown in Figure 12.

With a human load of 40 and 100 kg, the simulation's output is von Mises stress, safety factor, and displacement. Figures 13 and 14 are the free body diagrams of the

Table 1: MIN inference rules.

Rules	**Input (x)**	**Input (y)**	**Output (z)**
Rule 1	if x = low	if y = high	then z = low
Rule 2	if x = low	if y = low	then z = low
Rule 3	if x = high	if y = high	then z = high
Rule 4	if x = high	if y = low	then z = low

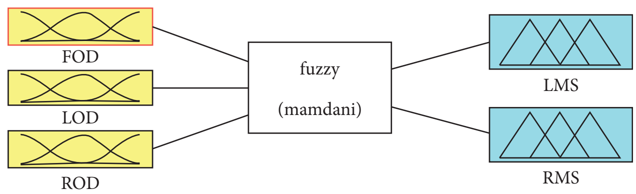

Figure 5: Obstacle avoidance environment in fuzzy tool.

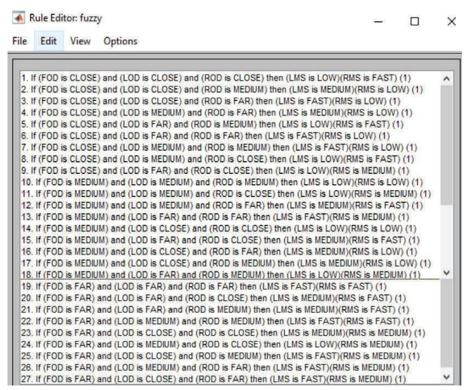

Figure 6: Rules implemented during the logic.

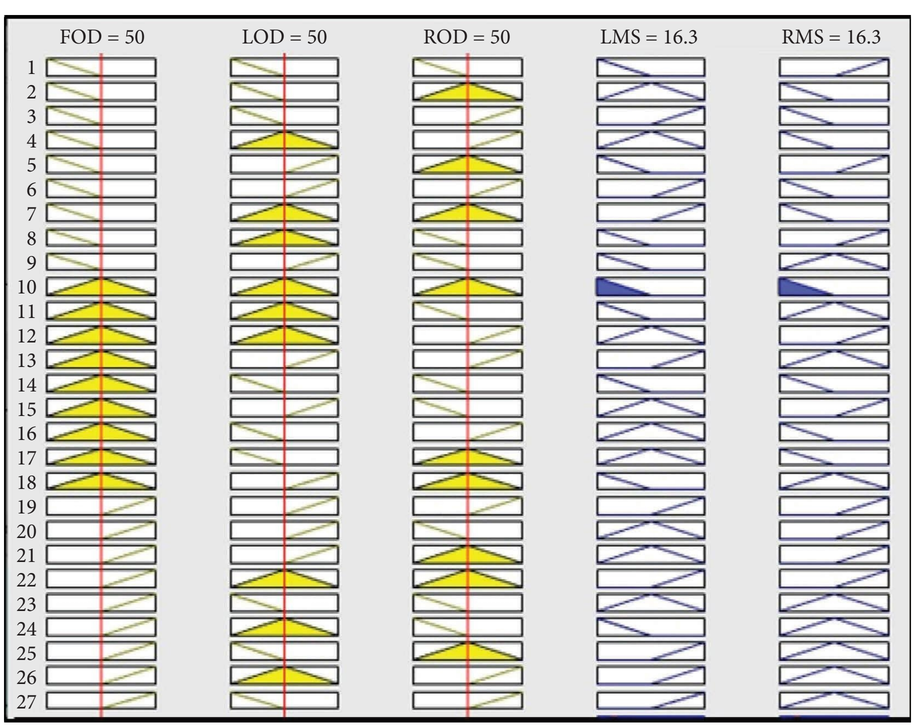

Figure 7: Rules checker.

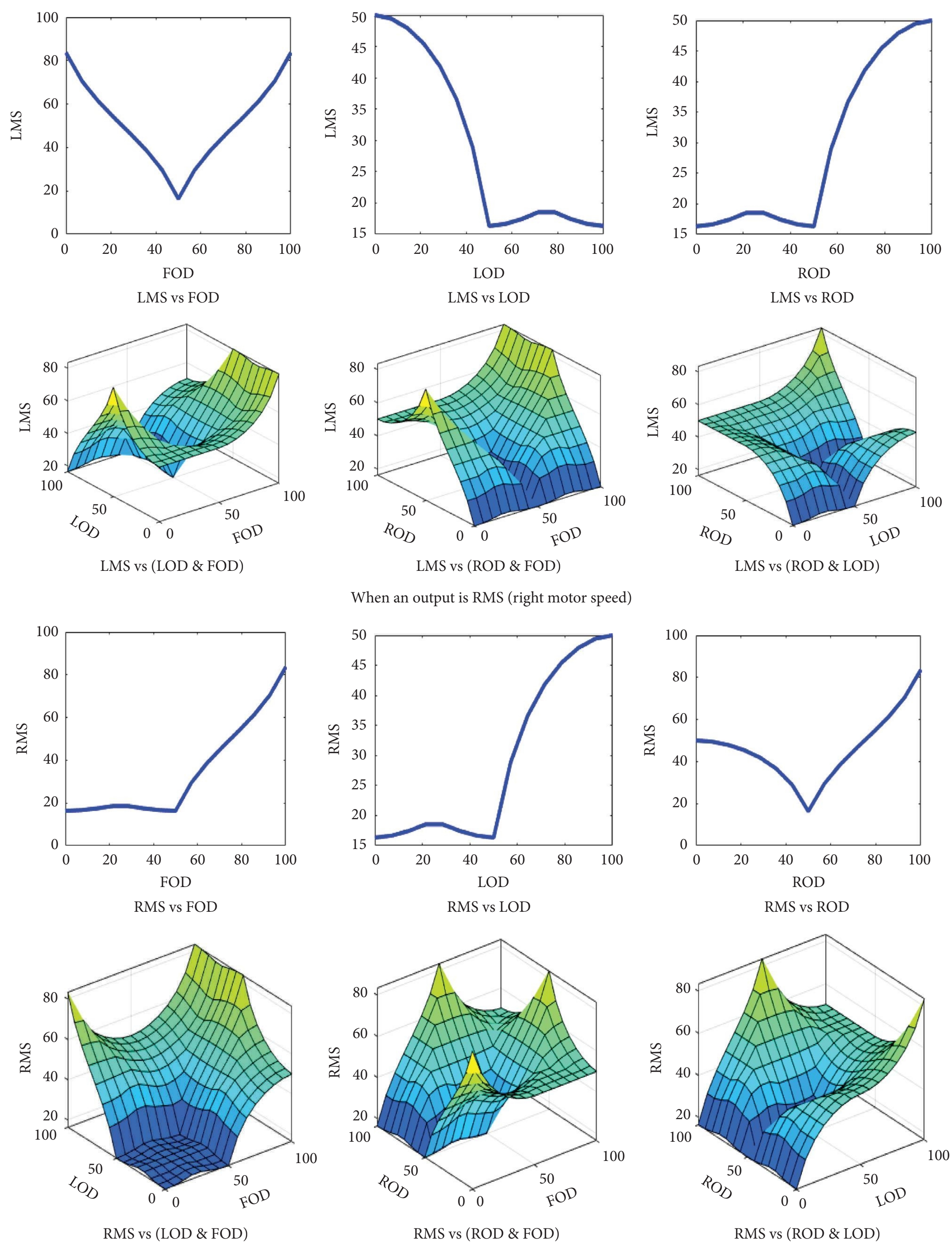

Figure 8: Observed outputs for LMS and RMS.

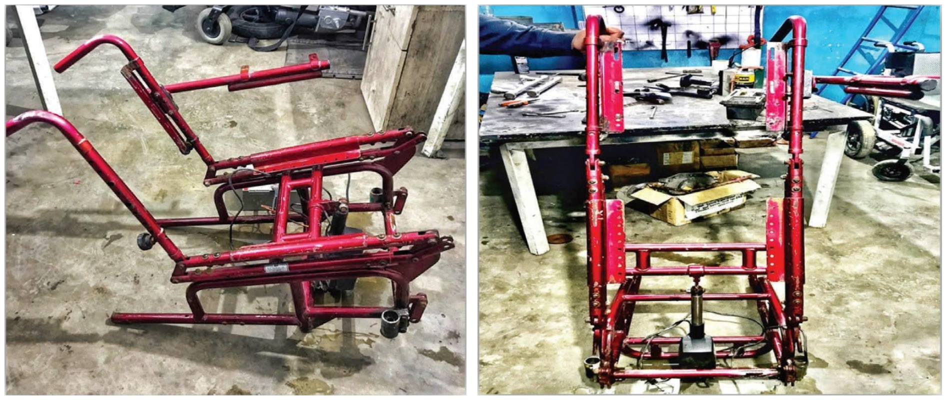

Figure 9: Frame in sitting and standing posture.

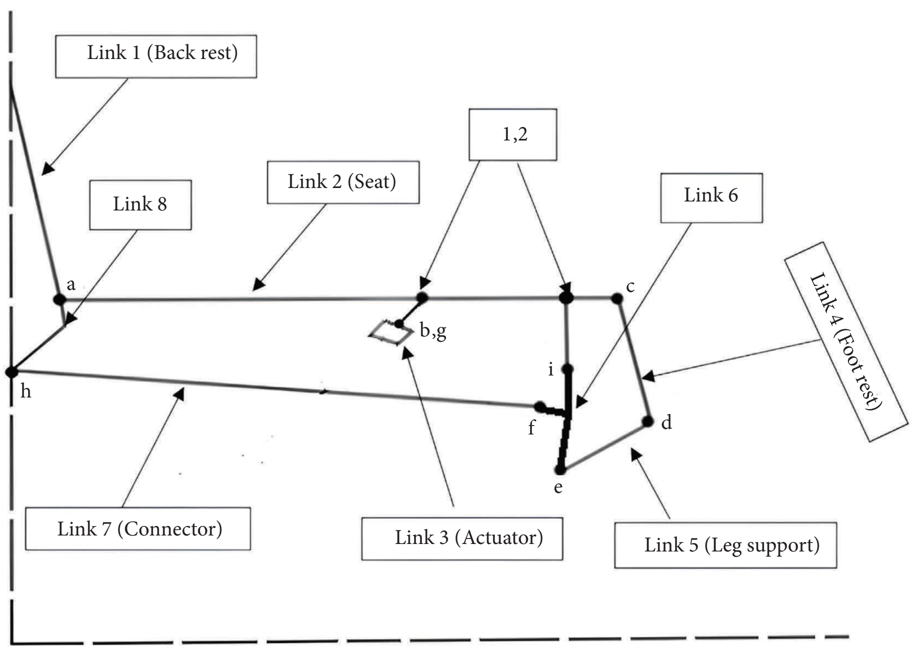

Figure 10: Kinematics of wheelchair in sitting position.

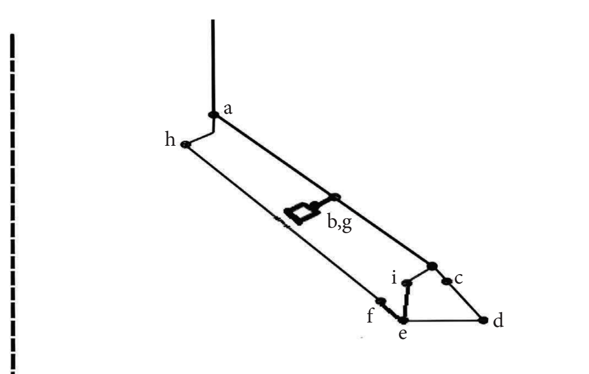

Figure 11: Kinematics of wheelchair in a standing position.

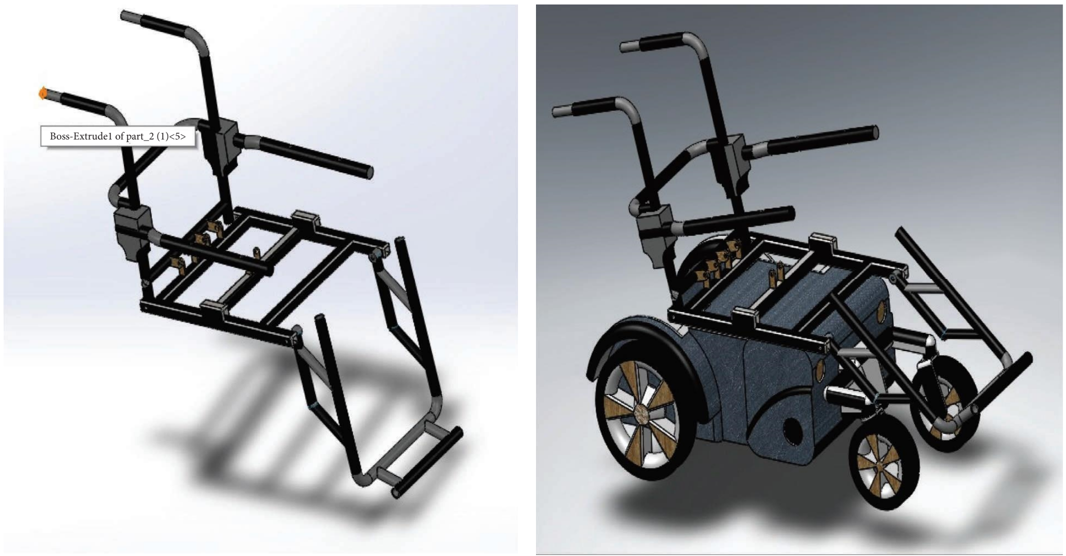

Figure 12: CAD model of standing wheelchair.

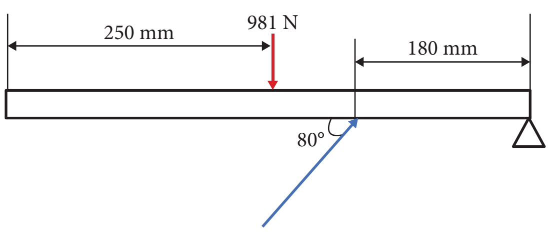

Figure 13: Minimum strength of the linear motor.

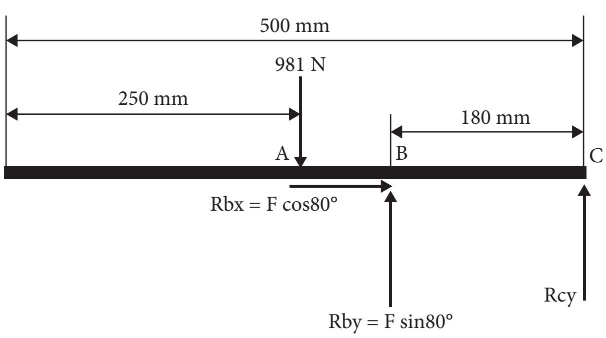

Figure 14: Minimum strength of the linear motor with force components.

wheelchair which show how much force was applied at each point.

The minimum load capacity of a wheelchair can be found through equations (8) and (9):

$$\begin{aligned} \sum \mathrm{Fy} &= 0, \\ \sum \mathrm{Fy} &= \mathrm{Rby} - \mathrm{Rcy} - 981, \\ 981 &= Rby + Rcy, \end{aligned} \tag{8}$$

$$\begin{aligned} \sum \mathrm{Mc} &= 0, \\ 0 &= Rby\left(18 * 10^{-2}\right) - 981\left(25 * 10^{-2}\right), \\ 0 &= 0.18 * Rby - 245.25, \\ Rby &= \frac{245.25}{0.18} \\ Rby &= F \sin 80, \\ 1362.5 &= F * 0.866, \\ F &\geq 1338.51, \\ 981 &= 1338.51 + Rcy, \\ Rcy &= -402.51N. \end{aligned} \tag{9}$$

Based on the calculation above using equations (8) and (9), the minimum strength of the linear motor to perform an ideal standing position with a 981 N load and an initial angle of 80 is 1338.51 N.

Stress occurs because the weight of the seat on the frame is equal to 80 N-m.

Calculation of allowable frame stress can be done using the following equation:

$$\tau = \frac{M * C}{I}, \tag{10}$$

where C = point of action = 0.0267/2 = 0.01335 and I = moment of inertia.

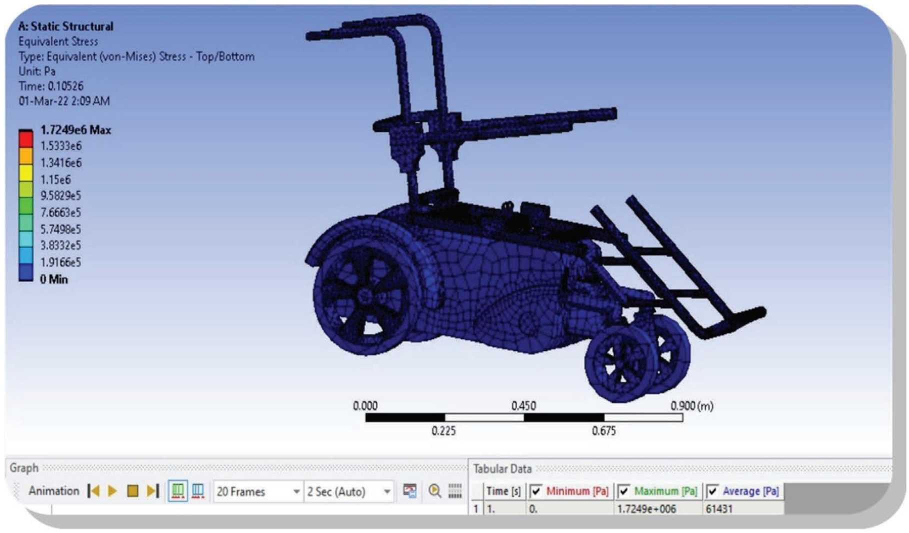

Figure 15: The maximum stress occurs on the bottom frame.

Figure 16: The final structure of wheelchair in sitting position.

Figure 17: The structure of wheelchair in raised position.

I can be found using the following formula:

$$I = \frac{\pi}{64}\left((0.0267)^4 - \left(0.0267 - \frac{0.0267}{16}\right)^4 \right) = 5.67 * 10^{-9},$$

$$\text{Ʊ} = \frac{80 * 0.01335}{5,67 * 10^{-9}} = 189\text{Mpa}. \tag{11}$$

The method of calculation of von Mises push is done with the ANSYS program, and the colour degree indicates the level of push that happens. The gradation of colours runs from blue to red. Blue denotes minimal stress, while the red colour denotes moderate to high stress. Figure 15 displays the findings of von Mises stress with a load of 100 kg. The results will be studied so that the maximum and safe load will be employed in the electric standing wheelchair. The bottom frame experiences the most stress. This high stress is a result of the component restricting the linear DC motor's force, which lifts people from a sitting to a standing position.

4.2. Implementation of Hardware Model. The value of the outside inactive stack that we utilized in SolidWorks FEA is 981 N. For DOF characterization, it was made sure that the liner actuator makes the standing positon fair one. To make the standing position, maximum extension is 255 mm with a starting point of 80° from the flat line. Typically, the ideal position of the direct engine to preserve a steady center of gravity guaranteeing the security and steadiness of the pose alters the structure. The least required direct engine value to lift the stack is 1338.5 N. Figures 16 and 17 show the wheelchair while operating in sitting and standing positions, respectively. Three components are used to create the standing wheelchair: a single actuator, a linear DC motor, and a DC geared motor. For the stand-to-sit or vice versa transformation, linear DC motors are employed, while DC geared motors are used for forward, backward, and turn. A linear DC motor is present on each side of the patient seat. By pushing the seat up with a linear DC motor, the wheelchair's design enables the user to go from sitting to standing.

5. Conclusion

Based on the investigation carried out for the electric standing wheelchair design, it can be concluded that the electric-powered standing wheelchair plan is driven by a control source (DOF = 1) to attain basic lifting and standing movement capacities with a least direct engine stack capacity of 1338.5 N. The plan and calculation for the electric standing wheelchair match well with the FEM. The basic point of the structure has been demonstrated to be secure based on the FoS value. The improvements in the current proposed electric standing wheelchair design as compared to the existing ones can be summarized as,

(i) The perfect structure position, integrated robust fuzzy speed control, and actual linear motor position determination for pose alteration.

(ii) The most extreme extension of the direct engine when extending ranges from 180 mm to 255 mm with an introductory point of 80° from the base line.

(iii) It utilized simple measurements for the structure and instrument, so it will be easy to build in a little workshop.

The electric standing wheelchair plan can withstand a persistent weight of up to 80 kg and is not suggested for utilization in patients who weigh over 80 kg. At a weight of 80 kg, the FoS figure is 2.08, while at a weight of 85 kg, the estimation of the FoS is 1.96. The development of an electric standing wheelchair is included within the active stack, so the least value of the FoS must be equal to 2. In addition, the electric standing wheelchair encompasses a fuzzy-based speed control scheme for FOD, LOD, and ROD by controlling LMS and RMS. Also, linear controller provides the sitting and standing positon control. The proposed electric standing wheelchair is anticipated to assist patients with spinal wounds to decrease a few of the well-being issues caused by sitting for long periods in a wheelchair.

6. Recommendations and Future Works

In the proposed wheelchair design, the inadequacies and possible steps to further strengthen this work in future are listed below:

(i) Characterizing the programmed control framework based on the result of the structure mechanism.

(ii) Making a model of the electric-powered standing wheelchair agree with the plan that has been suggested along with inclusion of Internet of things-(IoT-) based control and monitoring.

Future research/design can be made for multi-pose work such as lying position or altering the framework to be more appropriate and comfortable for impaired individuals. Since there are numerous existing electric-powered standing wheelchair plans, this research is a fair one among them.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] C. Schofield, K. Evans, H. Young et al., "The development of a consensus statement for the prescription of powered wheelchair standing devices in Duchenne muscular dystrophy," *Disability and Rehabilitation*, vol. 44, no. 10, pp. 1889–1897, 2022.

[2] A. Harvey and A. Lisa, "Physiotherapy rehabilitation for people with spinal cord injuries," *Journal of Physiotherapy*, vol. 62, no. 1, pp. 4–11, 2016.

[3] World Health Organization, *Wheelchair Publication an Overview World Health Organization*, World Health Organization, Geneva, Switzerland, 2018.

[4] L. K. Kenyon, K. L. Harrison, M. K. Huettner, S. B. Johnson, and W. C. Miller, "Stakeholder perspectives of pediatric powered wheelchair standing devices: a qualitative study," *Developmental Medicine and Child Neurology*, vol. 63, no. 8, pp. 969–975, 2021.

[5] M. T. Riaz, A. A. AlSanad, S. Ahmad et al., "A wireless controlled intelligent healthcare system for diplegia patients," *Mathematical Biosciences and Engineering*, vol. 19, no. 1, pp. 456–472, 2022.

[6] R. K. Shields and S. Dudley-Javoroski, "Monitoring standing wheelchair use after spinal cord injury: a case report," *Disability and Rehabilitation*, vol. 27, no. 3, pp. 142–146, 2005.

[7] R. B. Dunn, J. S. Walter, Y. Lucero et al., "Follow-up assessment of standing mobility device users," *Assistive Technology*, vol. 10, no. 2, pp. 84–93, 1998.

[8] K. M. Goher, "Modelling and simulation of a reconfigurable wheelchair with a sit-to-stand facility for a disabled child," in *Proceedings of the 2013 18th International Conference on Methods and Models in Automation and Robotics (MMAR)*, pp. 430–434, Miedzyzdroje, Poland, August 2013.

[9] J. P. Mankowski, "Stand-up wheelchair," FPO, Secundrabad, India, United States Patent US5096008A, 1992.

[10] B. Nordström, A. Näslund, M. Eriksson, L. Nyberg, and L. Ekenberg, "The impact of supported standing on well-being and quality of life," *Physiotherapie Canada*, vol. 65, no. 4, pp. 344–352, 2013.

[11] G. Dawar, "Report on the prototype testing with hospital patients and their feedback," Technical report, Thapar Institute of Engineering and Technology, Patiala, India, 2017.

[12] T. A. Kuiken, "Inventor, Rehabilitation Institute of Chicago, Assignee. Manually Operable Standing Wheelchair," FPO, Secundrabad, India, United States Patent US7165778B2, 2007.

[13] J. A. Johnson, "Assignee. Motorized Standing Wheelchair," Inventors; FENA Design Inc, Plymouth, Mi, USA, United States Patent US6231067B1, 2001.

[14] M. A. Lizama-Troncoso, "Inventors; University of Puerto Rico, assignee. Mechanically assisted standing wheelchair," University of puerto rico, San Juan, PR, USA, United States Patent US6533304B2, 2003.

[15] E. Y. Kim, "Wheelchair navigation system for disabled and elderly people," *Sensors*, vol. 16, no. 11, p. 1806, 2016.

[16] J. Zhang, J. Wang, and W. Chen, "A control system of driver assistance and human following for smart wheelchair," in *Proceedings of the IEEE International Conference on Robotics and Biomimetics*, Bali, Indonesia, December 2014.

[17] G. W. Rahman Ahmad, H. Renaldo, D. S. Purnomo, and E. S. Ningrum, "Electric standing wheelchair controller to provide user safety and comfortness," in *Proceedings of the International Medical Device and Technology Conference*, pp. 6-7, Johor Bahru, Malaysia, September 2017.

[18] S. Alhadi, "Design optimization and structural analysis of electric powered standing wheelchair using linear motor movement systems for disabled people in indonesia," 2018, https://dspace.uii.ac.id/handle/123456789/11818.

[19] J. Leaman and H. M. La, "A comprehensive review of smart wheelchairs: past, present, and future," *IEEE Transactions on Human-Machine Systems*, vol. 47, no. 4, pp. 486–499, 2017.

[20] M. Callejas-Cuervo, A. X. González-Cely, T. Bastos-Filho, and T. Control, "Control systems and electronic instrumentation applied to autonomy in wheelchair mobility: the state of the art," *Sensors*, vol. 20, no. 21, p. 6326, 2020.

[21] J. H. Choi, Y. Chung, and S. Oh, "Motion control of joystick interfaced electric wheelchair for improvement of safety and riding comfort," *Mechatronics*, vol. 59, pp. 104–114, 2019.

[22] A. Ebrahimi, A. Kazemi, and A. Ebrahimi, "Review paper: wheelchair design and its influence on physical activity and quality of life among disabled individuals," *Iranian Rehabilitation Journal*, vol. 14, no. 2, pp. 85–92, 2016.

[23] D. Gautam, A. Kejariwal, and D. Kumar, "Design of a modular wheelchair with posture transformation capabilities from sitting to standing," *Disability and Rehabilitation: Assistive Technology*, vol. 15, no. 6, pp. 670–683, 2019.

[24] M. M. Abdulghani, K. M. Al-Aubidy, M. M. Ali, and Q. J. Hamarsheh, "Wheelchair neuro fuzzy control and tracking system based on voice recognition," *Sensors*, vol. 20, no. 10, p. 2872, 2020.

[25] N. Singkhleewon, "A development of adjustable standing and automatic stop electric wheelchair prototype operated with a smartphone," *Systematic Reviews in Pharmacy*, vol. 11, no. 11, pp. 564–570, 2020.

[26] R. Yassine, M. Mrabet, and F. Fnaiech, "Intelligent control wheelchair using a new visual joystick," *Journal of healthcare engineering*, vol. 2018, Article ID 6083565, 20 pages, 2018.

[27] X. Huang, X. Xue, and Z. Yuan, "A simulation platform for the brain-computer interface (BCI) based smart wheelchair," in *Proceedings of the Artificial Intelligence and Security: 6th International Conference, ICAIS 2020*, pp. 257–266, Springer International Publishing, Hohhot, China, July 2020.

[28] W. Amos and R. Hotchkiss, *Mechanical Principles of Wheelchair Design*, Massachusetts Institute of Technology, Massachusetts, MA, USA, 2010.

[29] R. A. Cooper, D. M. Spaeth, D. K. Jones, M. L. Boninger, S. G. Fitzgerald, and S. Guo, "Comparison of virtual and real electric powered wheelchair driving using a position sensing joystick and an isometric joystick," *Medical Engineering and Physics*, vol. 24, no. 10, pp. 703–708, 2002.

[30] R. Thomas, C. Mandel, and Tim Laue, "Controlling an automated wheelchair via joystick/head-joystick supported by smart driving assistance," in *Proceeding of the 2009 IEEE International Conference on Rehabilitation Robotics*, pp. 743–748, IEEE, Kyoto, Japan, June 2009.

[31] S. P. Levine, D. A. Bell, L. A. Jaros, R. C. Simpson, Y. Koren, and J. Borenstein, "The NavChair assistive wheelchair navigation system," *IEEE Transactions on Rehabilitation Engineering*, vol. 7, no. 4, pp. 443–451, Dec. 1999.

[32] M. Z. Ur Rahman, M. T. Riaz, M. M. S. Al Mahmud, M. Rizwan, and M. A. Choudhry, "The prescribed fixed structure intelligent robust control of an electrohydraulic servo system," *Mathematical Problems in Engineering*, vol. 2022, Article ID 5144602, 12 pages, 2022.

[33] M. Zia Ur Rahman, M. Usman, A. Farea, N. Ahmad, I. Mahmood, and M. Imran, "Vision-based mobile manipulator for handling and transportation of supermarket products," *Mathematical Problems in Engineering*, vol. 2022, Article ID 3883845, 10 pages, 2022.

[34] M. Z. Rahman, M. A. Akbar, V. Leiva, A. Tahir, M. T. Riaz, and C. Martin-Barreiro, "An intelligent health monitoring and diagnosis system based on the internet of things and fuzzy logic for cardiac arrhythmia COVID-19 patients," *Computers in Biology and Medicine*, vol. 154, Article ID 106583, 2023.