Conceptual Design and FEM Analysis of an Exoskeleton Suit for Post-stroke Patient: A Lower Limbs Exo Suit

Muhamad Fikhri bin Abdul Hamid[1], Mohd Hanif bin Mohd Ramli[1(✉)], Noor Ayuni Che Zakaria[2], and Zulkifli Mohamed[1]

[1] Sport Engineering and Artificial Intelligence Centre, Faculty of Mechanical Engineeing, UiTM, Shah Alam, Malaysia
`haniframli@uitm.edu.my`
[2] Neoteric Rehabilitation Sciences Research Group, Faculty of Mechanical Engineeing, UiTM, Shah Alam, Malaysia

Abstract. This paper presents a study on the conceptual design of an exoskeleton suit for post-stroke rehabilitation. A lower-limb exoskeleton suit is proposed to facilitate the post-stroke patients in the restoration of their gait motion. The aim of this study is to design and analyze the mechanical properties and strength via the finite element method (FEM). The exoskeleton suit is capable to assist the victims of post-stroke patients from sitting to stand-up positions and vice versa. The design aspect takes the basis of the human anatomy of Asian people with an average mass of 80 kg. The most effective and optimum design of the exo-suit model is evaluated through FEM static stress analysis using CATIA and ANSYS. Results proved that the proposed design is able to fully support the aforementioned average mass with the maximum Von-Mises stress of 9.5887e7 N/m^2 (Standing Position) and 160.16e6 N/m^2 (Bent Knee Position) of which did not exceed the yield strength of 180e6 N/m^2

Keywords: Post-stroke · Exoskeleton · Lower limb · Finite element method

1 Introduction

Generally, post stroke is an emotional disturbance and sometimes give rise to personality change due to physical effects, which caused by brain damage. In addition, the stroke may cause paralysis of one part of the body and the patient might find it difficult to moves. Stroke is known to be a significant global health problem and stroke was ranked as the second commonest cause of death and the third most common cause of disability-adjusted life-years (DALYs) [1]. Most stroke survivors tend to have emotional disorder and affect their self-confidence. A mixed feeling of fear, apprehension, and uncertainty are the norm amongst the stroke patients. One of the main problems that post stroke survivors face is they are trying to be independent. Often survivors feel like a burden to those around them and become depressed. These feelings may lead to more difficult of

Y. Shiraishi et al. (Eds.): APCMBE 2020, IFMBE Proceedings 82, pp. 126–134, 2021.
https://doi.org/10.1007/978-3-030-66169-4_17

a recovery where post stroke patient having limited movement issue that make such as to stand up and walk.

In the recent Stroke Registry Report (2009–2016), Malaysia's National Stroke Registry (NSR) captured over 11000 patients from sixteen participating source data providers (SDP). Stroke predominantly affected men (56%). Slightly over than 40% of the total cohort sustained stroke below the age of 60 years. Hypertension remained the major risk factor (70%), followed by diabetes (41%) and hyperlipidemia (24%) [2]. There are several alternatives to regain the confidence and back on normal life after a stroke. The most common approach is through a rehabilitation program. However, not all rehabilitation (rehab) centers are close to patients. Commuting back and forth to the rehab is sometimes very challenging for patients living far from the centers. According to statistics, only 68.9% of the patients had been referred for neurorehabilitation [3]. Post stroke care at public primary care health centers showed benefits in stroke risk factors control (i.e. hypertension and dyslipidaemia). However, the lack of knowledge and awareness on post stroke rehabilitation services are identified as causes which prevent delivery of comprehensive post stroke care for patients residing at home in the community. A more structured coordination is needed to optimize post stroke care beyond acute phase management for patients who reside at home in the community [3]. In this regard, one of the effective ways is to adopt a robotic technology in the loop. For this purpose, an exoskeleton based robotic system is proposed to assist post stroke patients in gaining their ability to stand up and walk again.

Exoskeleton suit (exo-suit) is a wearable device that is powered by a system of electric motors, pneumatics, levers, hydraulics, or a combination of technologies to assist limb movements especially lower limb with increased strength and endurance [4]. Typically, its design aims to provide back support, sense the user's motion, and send a signal to motors which manage the gears. There are variants of exo-suits that support the shoulder, waist and thigh, and assists movement for lifting and holding heavy items, while lowering back stress. Recently, there is a number of of exo-suits produced to facilitate stroke patients, for example; The Robotic Orthosis Lokomat developed by Hocoma (Zurich, Switzerland), Active Leg Exoskeleton (ALEX) from University of Delaware (Newark, DE, USA), and Hybrid Assistive Limb (HAL) by Japan's Tsukuba University [5–7].

In this paper, the fundamental challenge in realizing exo-suit is addressed in terms of conceptual design and analysis. The design aspect takes the basis of human anatomy of Asian people with an average mass of eighty (80) kilograms. The most effective and optimum design of the exo-suit model is then evaluated through FEM of static stress analysis using dedicated software packages (CATIA and ANSYS). The analysis considers three major joints, i.e., hips, knee and ankle joints.

2 Modelling

2.1 Pre-processing Stage: Geometry Modeling

Figure 1 shows a reference mannequin used in getting the size of geometrical design of the exo-suit. The total length from hip to the ground is approximately 1000 mm and width 320 mm. The average body mass is set to 80kg, and due to gravitational effect, the body weight acting on the exo-suit will be around 784.8N. The expected outcome for structural design is to ensure that the load of patient body weight is fully supported without structure failure.

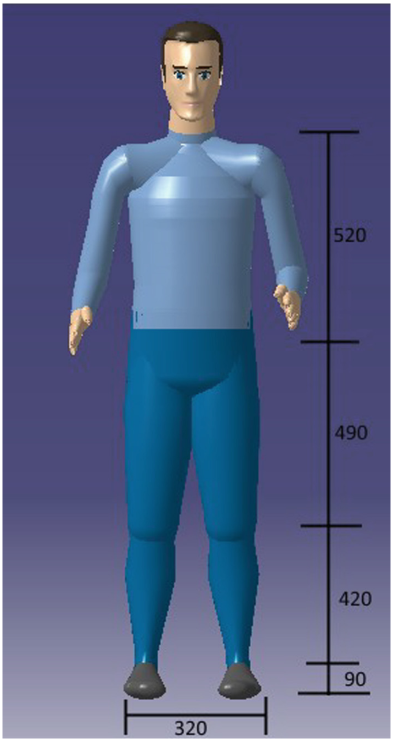

Fig. 1. Reference body dimension in unit mm

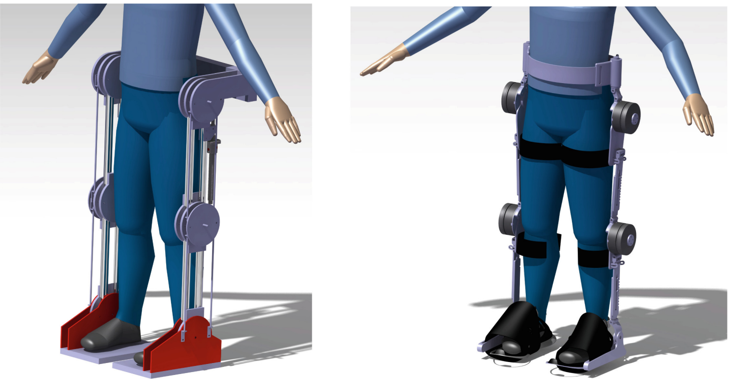

Fig. 2. (right) Preliminary structure design and (left) Finalized structure design.

Figure 2 shows the initial and finalized design in 3D environment. The overall mass of the final design is 10 Kg including the four motors integrated to the structure. The structural design is also incorporated with a height adjustable mechanism as shown in Fig. 3. In addition, a planetary gear system is properly designed and fitted to model of brushless motor GBM110-150T of which capable of producing 49.03 Nm to 78.45 Nm of torque (see Fig. 3). A strapping mechanism is integrated to ergonomically increase user's comfortability.

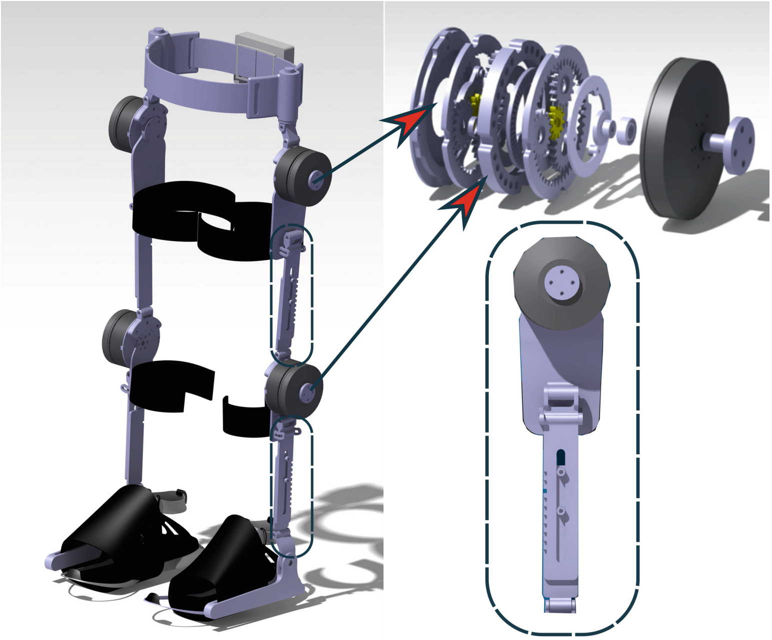

Fig. 3. (left) Isometric view of the finished exo-suit (right) Exploded view of planetary gears and Dc Motor.

2.2 Post-processing Stage

Once the final design is completely modelled in CAD, next is to carry out static or dynamic analysis on the structure. First is to consider the material of the structure, and then export the 3D model into static/dynamic analysis software package, ANSYS and establish the meshing, loads and boundary conditions.

Table 1. Material properties of steel and aluminum.

Properties	Steel	Aluminum
Young Modulus (GPa)	200	71
Yield Strength (MPa)	280	180
Poisson's ratio	0.3	0.33
Density (kg/m^3)	7850	2770

Table 1 shows the mechanical properties of steel and aluminum. For this project, aluminum is chosen due to its density which is much smaller than the steel (Aluminum: - 2770kg/m^3; steel: - 7850kg/m^3). Low density give rise to lower overall mass of the structure. Meanwhile, the maximum yield strength of aluminum is 180 MPa and Steel 280 Mpa. The simple rule of thumb, the designed structure must not exceed the tensile yield strength while supporting the load of the patient. In this case, only two conditions are analyzed, the stress distributions during knee bend and standing position as illustrated in Fig. 4. While the patient is in sitting position, the stress concentrations/distributions is not significant at all as all the load is distributed to the sitting object.

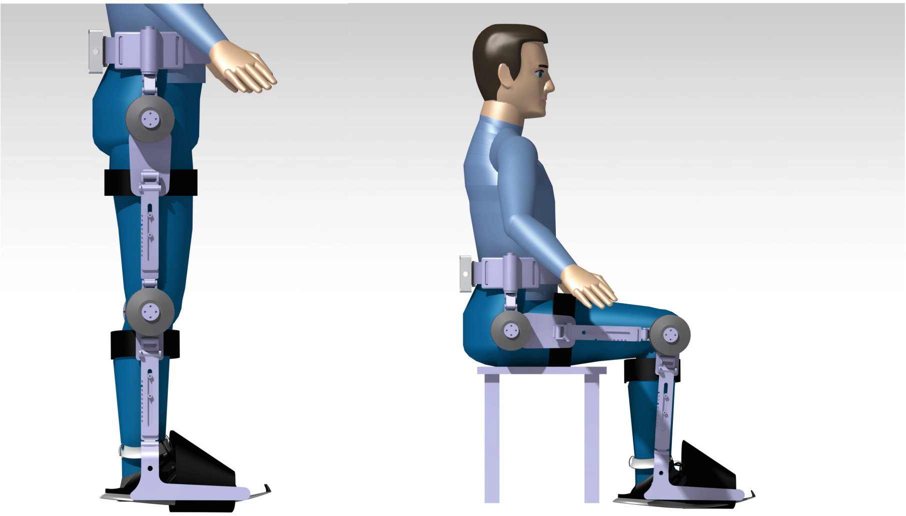

Fig. 4. The movements that exo-suit to assist/actuate: - sitting to standing positions.

The complexity of the structure design reduces the number of nodes to establish on the structure. The highest number of nodes found to be optimal is 91,968 nodes with 54,445 elements networked on the structure. Mesh networks of exo-suit is illustrated in Fig. 5.

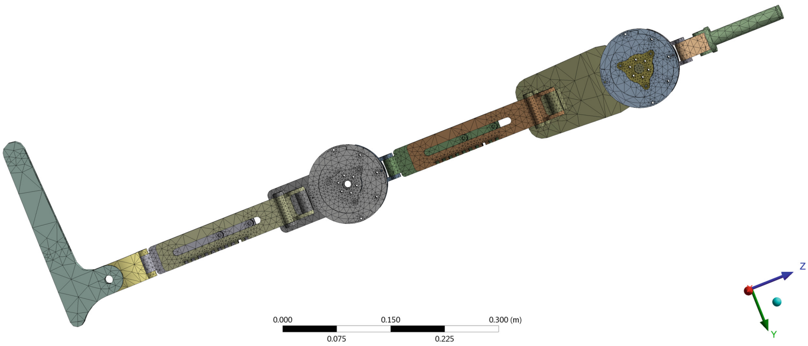

Fig. 5. Mesh networks on the exo-suit structure.

Meanwhile, Fig. 6 shows boundary conditions and applied load on the exo-suit structure. Force of 784.8N exerted in vertical axis (negative Z-axis) on top hip joint and fixed support boundary condition is applied on the bottom of the foot surface.

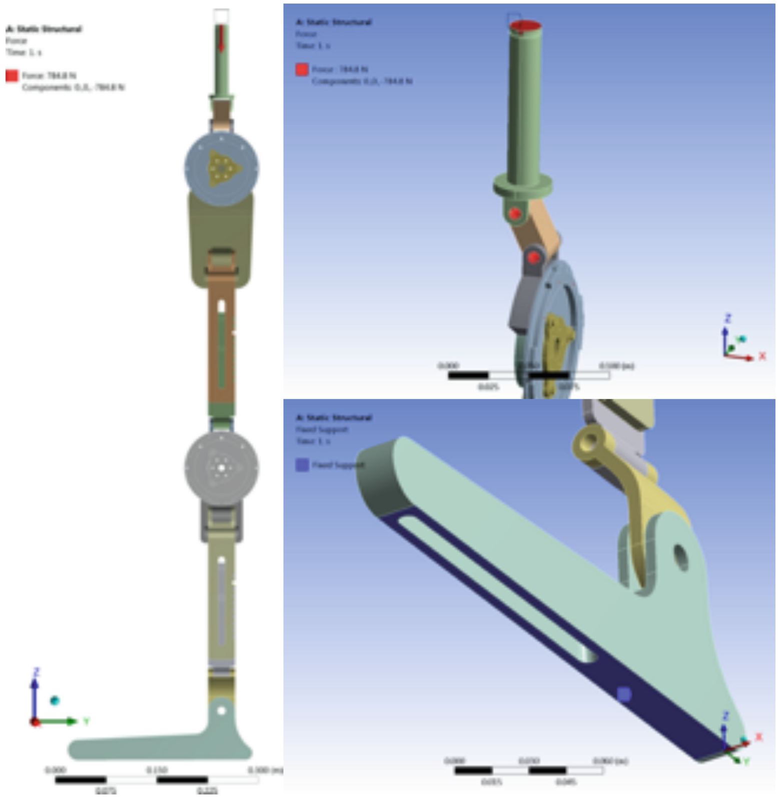

Fig. 6. Force exert in vertical axis (negative Z-axis) on top hip joint, fixed support boundary condition is applied on the bottom of the foot surface.

3 Results and Discussions

This section discusses the findings of the simulated stress distributions on exo structure by comparing their maximum and minimum stress (Von-Mises) to validate the yield strength of the aluminum characteristics. For this model, static analysis is produced using the structural ANSYS. The geometry is imported with IGS file from CATIA CAD to ANSYS to execute static analysis (focus only on static analysis).

The forces to be analyzed are at the hip, knee and ankle main joint. Besides that, the analysis is also simulated at the joints where the motor case is located and focused only on one side of the structure.

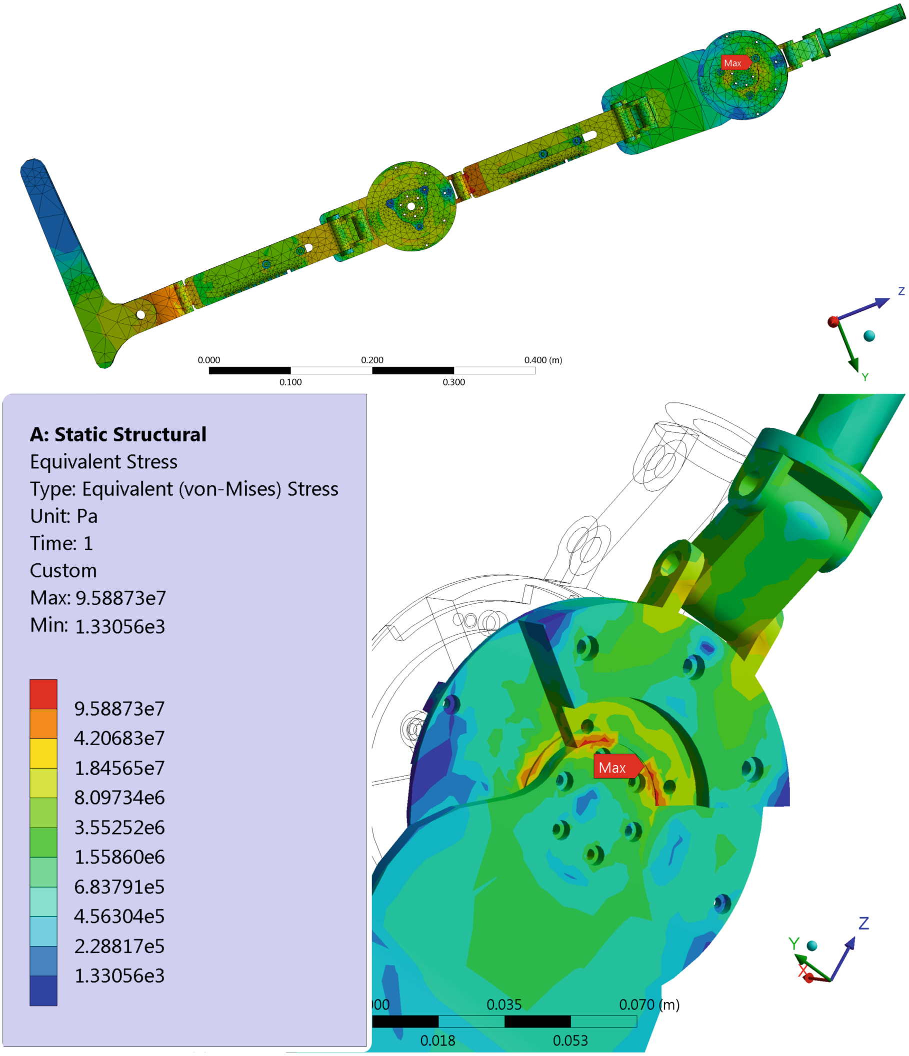

Fig. 7. Stress contour and maximum static stress (von-Mises) on the structure and motor hub during standing position.

3.1 Standing Position

Static stress analysis is conducted by applying fixed support boundary condition on bottom part of the structure i.e., foot surface and exert the force of 784.8N in Z-direction downward to determine the maximum stress. The results stress contour is depicted in Fig. 7 with maximum of 95.88 MPa and the minimum stress on the structure is 1.33 kPa. The maximum stress concentration is located around the motor hub.

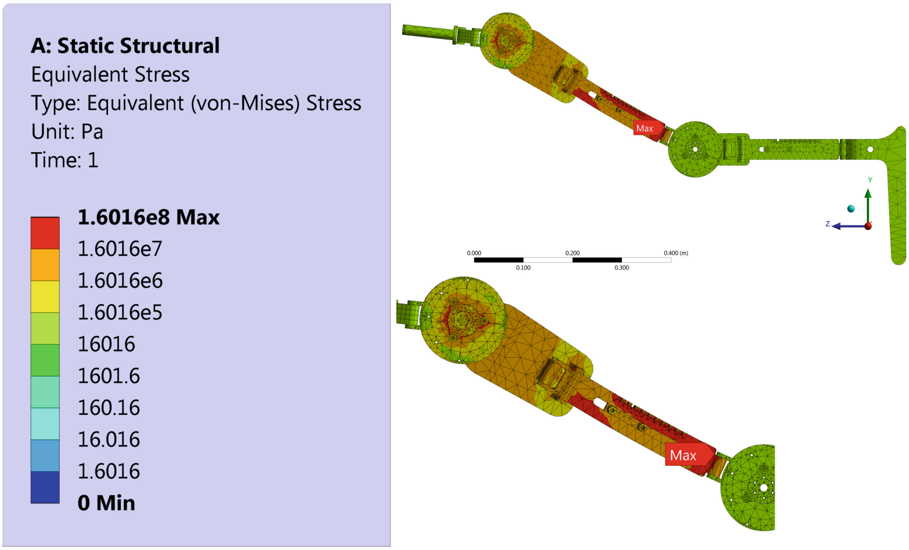

Fig. 8. Stress contour and maximum static stress (von-Mises) on the structure during knee-bent position.

3.2 Knee-Bent Position

The static stress continues by applying force to the structure while the knee part of the structure is bent and force is also applied downwards in component z-direction as the standing position, but the knee joint is set as rigid where the knee position set to bent and the result of maximum stress is 160.16 MPa as shown in Fig. 8. It can be seen that the maximum stress concentration is around the thigh section. However, the maximum stress is less than the aluminum yield strength of 180 MPa.

4 Conclusions

The aim of this project is to model a conceptual mechanical exoskeleton for the lower limb that can assist the recovery ability of the post-stroke patient. The choice of material i.e., aluminum is sufficient for this project due to the lower density compared to steel. The area of analysis is very critical because the area is exposed to higher loads such as each bolt and nut joint will easily deform and collapse if the material properties beyond the elastic region. Result of the analysis are obtained by conducting finite element analysis by comparing the maximum Von-Mises stress for standing position and bent-knee positions. The maximum stress for both positions 9.5887e7 N/m^2 (standing position) and 160.16e6 N/m^2 (knee-bent position) does not exceed the yield strength of the material (180 MPa). For future research, the dynamic analysis could be done to the next level due to this conceptual design such that optimized geometry design could be achieved to increase ergonomics and comfortability to the post stroke patient.

References

1. Kooi, C.W., Peng, H.C., Aziz, Z.A., Looi, I.: A review of stroke research in Malaysia from 2000–2014. Med. J. Malaysia **71**, 58–59 (2016)
2. National Stroke Report, 2009–2016
3. Aziz, A.A., Ali, F., Yusof, M., Che'Man, Z., Sulung, S., Aljunid, S.: Profile and outcome of post stroke patients managed at selected public primary care health centres in Peninsular Malaysia: a retrospective observational study. Sci. Rep. **8** (2018). https://doi.org/10.1038/s41598-018-36154-0
4. Li, R.M., Ng, P.L.: Wearable robotics, industrial robots and construction worker's safety and health. In: Advances in Human Factors in Robots and Unmanned Systems. Advances in Intelligent Systems and Computing, vol. 595, pp. 31–36 (2018). https://doi.org/10.1007/978-3-319-60384-1_4. ISBN 9783319603834
5. Chen, B., Ma, H., Qin, L.Y., Gao, F., Chan, K.M., Law, S.W., Qin, L., Liao, W.H.: Recent developments and challenges of lower extremity exoskeletons. Orthop. Transl. **5**, 26–37 (2016)
6. Sankai, Y.: HAL: hybrid assistive limb based on cybernics. University of Tsukuba, p. 10 2019
7. Aguilar-Sierra, H.: Hybrid actuation. A Lower Limb Exoskeleton, pp. 696–967 (2014)