Design and Development of an Exoskeleton for Paraplegic Patients using FEA

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Abstract - **Paraplegia and Gait Impairment in persons with Multiple Sclerosis (MS) are associated with weakened muscle control, poor coordination, high metabolic demands and fatigue. Robotic exoskeletons may facilitate them walking and induce better control during walking leading to coordinated muscle activity, reducing metabolic demands and cognitive demands. The purpose of this study is to create a robotic exoskeleton for paraplegic patients who cannot afford expensive rehabilitation or high end walking aids. The project focuses on providing a product which can be afforded by common people. The project lays down the foundation for further studies in the sector, as well as provides important data which will be necessary for the development of an actual model.**

keywords - **Mechanical engineering, robotic exoskeleton, paraplegia, ansys, solidworks, FEA**

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1. INTRODUCTION

A.PARAPLEGIA

1.1 Definition:- Paraplegia is a form of paralysis that mostly affects the movement of the lower body. People with paraplegia may be unable to voluntarily move their legs, feet, and sometimes their abdomen.

1.2 Symptoms:- There are many symptoms that can occur in paraplegia. Sometimes, these symptoms will change over time, or even from day to day.
Symptoms might include:

- a loss of sensation in the lower body
- impaired mobility
- weight gain
- depression
- phantom bouts of pain or sensation in the lower body
- chronic pain
- sexual dysfunction
- difficulty with bladder and bowel function
- secondary infections, such as bedsores and skin problems
- autonomic dysreflexia

1.3 Causes:- People with paraplegia usually have an injury to the brain or spinal cord that prevents signaling to the lower body. The loss of signaling causes paralysis of the lower body.

B. ROBOTICS IN MEDICAL SCIENCE

Robotic surgery can accomplish what doctors cannot because of precision and repeatability of robotic systems. Besides, robots are able to operate in a contained space inside the human body. All these make robots especially suitable for non- invasive or minimally invasive surgery and for better outcomes of surgery.

C. APPLICATIONS OF EXOSKELETON

Medical Uses: The first exoskeletons were focused on enabling paraplegics, amputees, and others to walk. Innovations in this segment continue to make huge differences in patients' lives. The FDA recently approved a new exoskeleton from Ekso Bionics, one of the main players in this field. This new exoskeleton gets stroke and spinal cord injury sufferers back on their feet sooner

2. PROBLEM STATEMENT

- Design an exoskeleton from using AutoCAD and SOLIDWORKS.
- Selection of motors, sensors and actuators for the exoskeleton to perform a GAIT cycle.
- Analyse the design using FEA and FEM approach.
- Design and analyse an Arduino code for the exoskeleton to perform a GAIT cycle.
- Analyse the design as whole using a 3D simulation software.

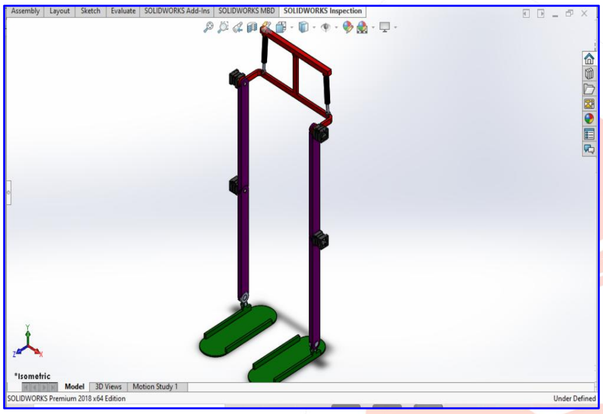
3.OBJECTIVES

3.1. Following steps are involved in the methodology:-

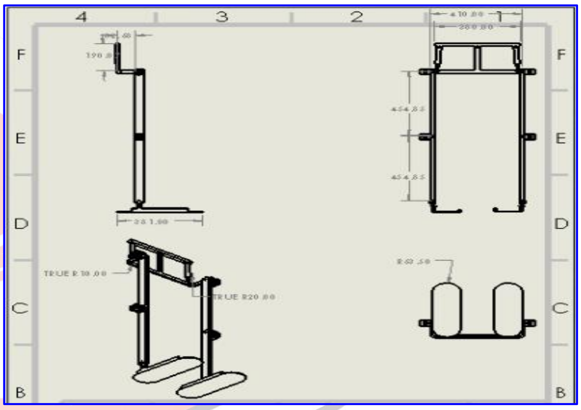
1. A design of the exoskeleton with proper placement of the motors, sensors, and actuators with different variations will be made using AutoCAD and SOLIDWORKS.
2. The final design will then be analysed using FEA and FEM approach.
3. An Arduino code was made for the exoskeleton to perform a GAIT cycle.
4. Selection of motors, sensors and actuators for the exoskeleton to perform a GAIT cycle.

3.2. **Build the CAD model**

The lower extremity exoskeleton have two mechanical legs, each mechanical leg has three rotational degrees of freedom. Each joint has one degree of freedom. owing to two mechanical legs are completely symmetrical, so the single leg is modeled and analyzed. In this article, the primary parts of the lower extremity exoskeleton are modeled and assembled by using the powerful 3D modeling software PRO/E. Due to analyze the bulk structure, taking into account a number of small features which have little effect on the performance of the overall structure. Therefore, based on the Saint-Venant principle, it properly simplifies the part's local features, such as the thread, the chamfer, screw holes and so on . At the same time, in order to balance the calculation accuracy and the computational time of AWE, the paper omits the connecting accessories (screws, nuts) which have little effect of the overall rigidity and the vibration frequency. After utilizing the dedicated seamless interface with AWE, the whole lower extremity exoskeleton is imported into AWE, paying particularly attention to the consistency of units. This method utilizes the specialized interface to combine with PRO/E and AWE, which achieves the seamless connection. Therefore elements are not basically lost in the model transferring process.



3.2a- CAD model of the exoskeleton



3.2b- mechanical drawing of the exoskeleton

3.3. **Finite element modeling (FEM) using ANSYS WORKBENCH (AWE)**

After the model of lower extremity exoskeleton is imported into AWE, taking into account the consistency of the actual model materials finite element analysis, ANSYS Workbench (hereinafter referred to as AWE) is used to create the finite element model of the lower extremity exoskeleton and calculate the intensity and rigidity of key parts of the lower extremity exoskeleton, the maximum stress and the total deformation displacement are obtained, in order to check the intensity and rigidity of the key parts; The rigidity of bulk structure of the lower extremity exoskeleton is analyzed, and the integral rigidity characteristic is obtained; The natural frequencies and mode shapes of the lower extremity exoskeleton are obtained by modal analysis, in order to avoid resonance; finite element analysis, ANSYS Workbench (hereinafter referred to as AWE) is used to create the finite element model of the lower extremity exoskeleton and calculate the intensity and rigidity of key parts of the lower extremity exoskeleton, the maximum stress and the total deformation displacement are obtained, in order to check the intensity and rigidity of the key parts; The rigidity of bulk structure of the lower extremity exoskeleton is analyzed, and the integral rigidity characteristic is obtained; The natural frequencies and mode shapes of the lower extremity exoskeleton are obtained by modal analysis, in order to avoid resonance.

STEPS INVOVED IN STATIC ANAYLYSIS USING (AWE)

1. Select the pose of exoskeleton for static analysis
2. The exoskeleton linear static structural analysis
   - Select the material
   - Meshing
   - Applied the constraint and load
   - Simulation and analysis

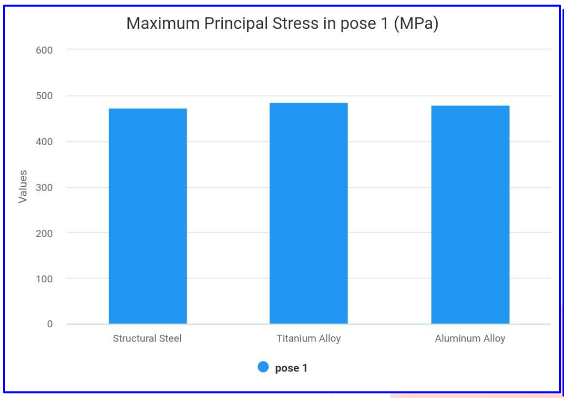
Stress and Deformation analysis

- As our design is based on GAIT cycle we will start working from there.
- A GAIT cycle has four crucial steps of completion
- So we set the design in four different position as shown above. Now the all the analyzation of the design will be done on these for poses only.

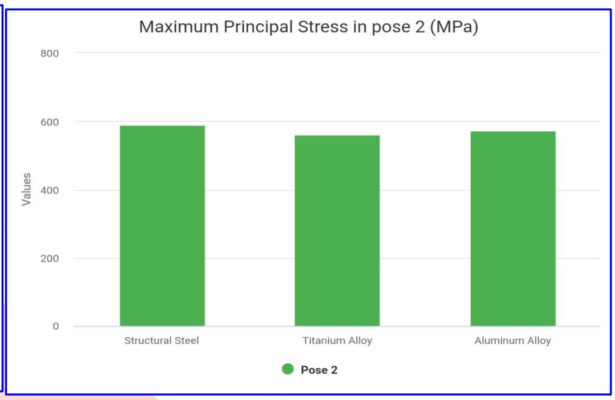
- The design is supposed to support a grown up man from its waist down, so its going experience high force at the waist section.
- So we add a distributed force of 1200N on its waist section so as to imitate a man's weight.
- We also add two fixed support at the base of the design so the analysis is genuine.
- The three materials used would be;

properties	Density (kg/m3)	Young's modulus(Pa)	Tensile yield strength (Pa)	Tensile ultimate strength (Pa)
STRUCTURAL STEEL	7850	2xe^11	2.5xe^8	4.6xe^8
TITANIUM ALLOY	4620	9.6xe^10	9.3xe^8	1.07xe^9
ALUMINIUM ALLOY	2770	7.1xe^10	2.8xe^8	3.1xe^8

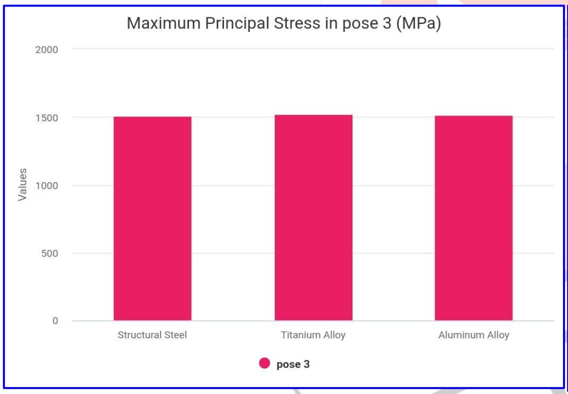
Comparison of the analysis results



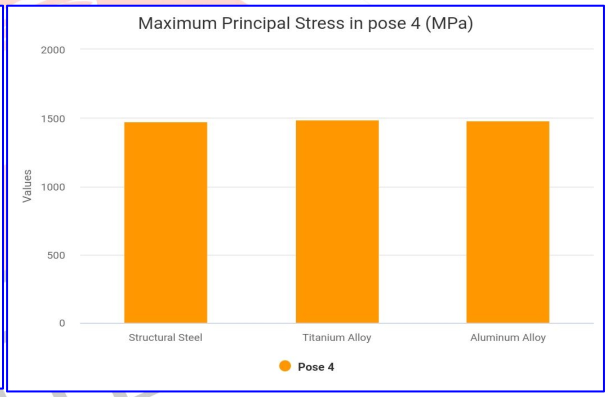
3.3a- max. Principal stress comparison in pose1



3.3b-max. Principal stress comparison in pose2



3.3c- max. Principal stress comparison in pose3



3.3d- max. Principal stress comparison in pose4

Comparison of principal stress in different materials(MPa);

Sr. No.	materials	Pose 1	Pose 2	Pose 3	Pose 4
1	Structural steel	474.03	676.6	1505.6	1474.5
2	Titanium alloy	484.72	645.77	1520.8	1489.6
3	Aluminium alloy	478.72	658.87	1512.8	1482.2

3.4. Gait cycle for exoskeleton

Gait planning is an essential problem for lower limb exoskeletons. The basic gait planning method for paraplegic rehabilitation exoskeleton robots is the predefined joint trajectory; this has been widely adopted in commercialized ambulatory rehabilitation exoskeletons. To adjust walking according to the user's preference, many interesting solutions have been proposed. a methodology is presented to control the walking speed of an exoskeleton using feasibility guaranteed trajectories that are stored in a database. Each trajectory has a different step length, and by estimating the walking speed, a reference trajectory is provided at the double support phase of walking. However, this system relies on the force feedback from a pilot, making it poorly suited for paraplegia patients. it considers a pendulum model and orbital energy. Different stride lengths have been tested to demonstrate the effectiveness of this method. However, in this article, the pilot is responsible to master the ability to transfer weight.a gait planning method that considers walking cadence. They introduce a gait intention estimator in a gait planning loop. The intention estimator computes the swing leg speed and the start of motion based on plantar pressure. In a 10-m walking test, the proposed gait planning method presents a varied walking cadence for each step; the experimental results of the plantar pressure show that the ground reaction force distribution of the proposed gait planning method is similar to healthy people. . The controller not only provides movement coordination but also enables a user to retain the step-to-step motion sequence . This gait planning method provides a swing leg motion similar to healthy people.

4. RESULTS

- After thorough research,FEM analysization,design specs and software algorithms we come to a conclusion that the proposed design can be used for rehabilitation as well as personal use.
- The proposed design is valid.
- The design of the exoskeleton can withstand high forces, high stresses, and deformation without any fatigue or failure.
- The motor and transmission assembly
- The result comparison reveals to us that out of the three materials (structural steel,titanium alloy,and aluminium alloy) titanium alloy is the best for use in real life but due to the high cost of this material we will consider the material closest to it i.e. aluminium alloy.

5. CONCLUSION

- A low cost lower limb hybrid exoskeleton with custom made back-drivable gearbox, as compared to the existing hybrid exoskeletons which are driven by harmonic drive, was designed,developed and tested.
- Based on the Finite Element Analysis of different posture, material, stress value and deformation of each component is obtained, the stress value provided theoretical numerical value for for the optimization design of the wearable lower extremity exoskeleton and set the foundation for the further research on wearable exoskeleton.
- Combined with analysis results and the laterality caused by the incompact physical model structure, the project puts forward the optimization scheme of the lower extrimity exoskeleton which has compact joint structure.
- There are limitations when it is integrated to the paraplegic user such as number of joints and actuator capacity. However, the design was carried with a parametric approach to be able to change the number of active joints depending on the condition of the paraplegic user.

6. FUTURE SCOPES

- The design is based on the gait cycle of walking, but if enough data is provided to the system it can be integrated for jogging and running.
- A few minor adjustments and some data feed can make the exoskeleton to be able to climb stairs.
- The exoskeleton can also be used in defence sector, it would double the walking capability and load carrying capacity of soldiers.
- An exoskeleton can also be designed for other parts of the body which are paralyzed.

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