STRUCTURAL ANALYSIS OF LOWER LIMB EXOSKELETON WITH EVALUATION OF HUMAN STABILITY AND DEVELOPMENT OF JOINT ANGLE MEASUREMENT SYSTEM

A SYNOPSIS

Submitted by

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in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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OCTOBER 2022

1. ABSTRACT

In the Socio-Psychological context of humans, locomotion plays a crucial role, which is not only required for survival, but also for the numerous day to day activities of a person. The ability of locomotion is directly related to a person's quality of life but the importance of it is somehow recognized only when the mobility is either hindered or absent at some point of time. For a human being, there are several reasons for mobility dysfunctions that stretch from genetic disorders to trauma. The effect of mobility dysfunction can sometimes notably recognize even at the time of child birth or at any point in a life time.

The disorders like Ataxia and Parkinsonism originate as a result of brain problems but the reason for Dystonia and Myoclonus are much related to muscles in the body. There are several disorders originate as a result of nervous dysfunctions, which includes multiple system atrophy, progressive supra nuclear palsy, Tardive dyskinesia, Tourette syndrome etc. Apart from all these classes of mobility issues, there is a bigger population who are born with mobility but lost its function due to trauma. The accidents accounts for more number of mobility dysfunctions than all the collective disorders explained above.

The mobility aids are structures or devices that support a person in their walking. Its usage is also necessary when a patient has increased risk of falling. Canes, crutches, wheelchairs, three wheeled scooters or even guiding dogs are employed as walking aids by many individuals. These solutions have one feature in common and that is distribution of load thereby reducing the effort of limbs.

Cranes and crutches appear to be primitive in design but they are advised to patients considering their loss of mobility and requirement. The

majority of load is transferred directly from the upper body to the ground using the structures. But when considering the balance of the user, the crutches are far better recommended than canes.

Wheelchairs offer better mobility support for the patients when they are unable to walk. Irrespective of the fact that, whether the device is powered or not, there are several cons for the wheel chairs. One issue is related to the inability to make stair ascend and descend which is a common construct in building framework. Another challenge is that, even though this device can enhance the mobility to a larger extent than the previously mentioned support systems, the device will not enhance, train or rehabilitate the bipedal walking of a patient. As a result, the user diminishes the ability to walk for in an extended period of usage and become more dependent on the wheel chairs.

2. MOTIVATION

The National Crime Records Bureau (NCRB) an agency of India Government responsible for gathering and analyzing the data pertaining to crime as referred in the Indian Penal code (IPC) and Special and Local Laws (SLL). NCRB release three annual reports on Crime in India, Accidental deaths and suicides & Prison statistics. As per the latest annual report published in 2021, there were 4.22 lakhs traffic accidents recorded and 1.73 lakh people died in India.

The accidents are serious issues in our country. The injuries are ranged from mild to serious and its affects from brain to fingers. There are 20,000 new cases of spinal cord injury added every year due to trauma which is an alarming data. Spinal cord injuries induce the victim with physiological, psychological and socioeconomic disorders. These disorders can develop as an acute or chronic. The major symptoms of spinal cord injuries are muscle dysfunction, loss of sensation and loss of autonomic function below the level of injury.

One serious issue associated with the spinal cord injury is the inability to walk. Even though the limbs are musculo-skeletally intact, the spinal cord injured patients cant able to walk as normal and it will restrict the patient's locomotion and their ability to interact freely with the society. The aftermath of spinal cord injury is the psychological and emotional trauma, which are more evident and dangerous than the physical trauma that created the hindrance of mobility.

3. OBJECTIVE OF THE RESEARCH

The objective of the proposed research work is listed below:

- To develop a lower limb exoskeleton structure to support a patient and analyze the performance during sit-to-stand transition
- To explore the possibilities of designing exoskeleton structure that can enhance load distribution, improve the degree of freedom and torque enhancement.
- To examine whether lateral, medial or combined support is beneficial in design perspective and introduce the ergonomic factors in design.
- To establish a machine learning algorithm for assessing the stability of a patient.
- To develop a joint angle measurement system for providing feedback to the exoskeleton controller and investigate the Gait-pattern generator system

4. OVERVIEW OF ROBOTIC MOBILITY SYSTEM

Robotic mobility support system, can also be called as powered lower limb exoskeleton robot, are wearable devices consisting of frame of support, actuators, drivers, controllers, sensors, joystick, software and a battery, primarily developed with the intention to support a patient to walk. Since all the robotic exoskeletons are deployed with microprocessor, the system can adjust its performance in accordance with the patients and also with the environment. Most of the exoskeleton imitates the bipedal walking of humans but there are certain exceptions of motorized wheels for movement. The exoskeletons are designed for the patient with movement difficulty that has a non-injurious physical limb and an existence of intact neural conduct between brain and muscles. Exoskeletons cannot be used for fully paralyzed patients since their issue is somewhere in the conduction between brain and the muscles.

There are three types of actuators commonly implemented in an exoskeleton they are electric, hydraulic and pneumatic. There are several pros and cons for these actuators, but the selection of a particular type is based on the operating conditions of the exoskeleton and requirement. Military exoskeletons need to carry more weight and as a result, hydraulics and pneumatic can be implement and system becomes bulky. But most of the medical exoskeletons are electric motor driver as they are compact and less weight.

The cost of the lower limb exoskeleton ranges from Rs.8 lakh for ankle exoskeleton to Rs.78 Lakhs for below hip exoskeleton. The value represented is a conversion of its price in dollars outside India. The expenditure incurred for the users are higher than the figures if added with the import duty when importing from the origin country, as there are no manufacturers in India.

5. PROPOSED METHODOLOGY

5.1 Modeling and Simulation of Lower limb Exoskeleton Structures

Exoskeletons are external hardware that can assist a person in walking or to perform basic activity using the upper limb. Exoskeleton can be used to assist the upper limb or to support lower limb. The upper limb exoskeleton is intended to provide more range of motion and facilitate to perform the basic activity of a human hand. The lower limb exoskeleton is a structure that enables a person to balance, distribute the force and assists to perform basic actions of locomotion. Exoskeleton can be designed along with an actuator or without any form of driving system. The former case is called as a powered exoskeleton and the latter case is called as a passive exoskeleton.

Three exoskeleton models are being proposed in this research work and are simulated for its mechanical behavior.

5.2 Analysis of Lower limb exoskeleton for Sit-To-Stand Transition

The module 1 exoskeleton consists of components for foot, lower leg, upper leg and hip. These components assembled together to form the exoskeleton. For this design, the methodology is shown in figure 1. The anthropometric parameters of an individual are considered for the dimensions in the design. This is because, the exoskeleton cannot be used for mass production, and in turn it should have to be fit exactly for one user. The model of the exoskeleton parts is developed using the Solidworks software. The Von-Mises stress for the models has been performed for continuum postures of Sit-to-stand transition. Three materials are selected to evaluate for the performance of the exoskeleton, they are Alloy steel. 1060 Aluminium and Titanium.

Analysis has proven the 1060 Aluminium is best suitable for the selection of the material when comparing the mechanical performance and the cost. Also from the finite element analysis performed upon the developed model, it is evident that the maximum stress developed during the analysis is within the limit of the failure point of the material and the design.

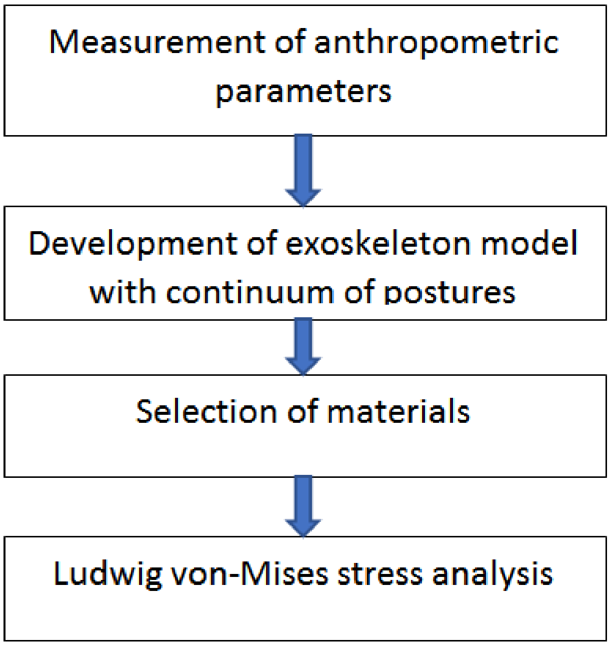

Figure 1 Methodology of module 1 exoskeleton

5.3 Exoskeleton With modified ankle and Hip Joints

A module 2 exoskeleton was developed with a modification performed on the hip and the ankle joint. The main motive for this modification is that, the adduction and abduction movement of the hip is not possible in the first model. But the proposed second model has the ability to move both in frontal and sagittal plane. The second modification implemented was on the ankle joint. From the beginning of the research work, it is taken in to the account that the direct coupled DC electric motor is used as the powering source for the development of the exoskeleton. The torque generated by the actuators to perform an action on the exoskeleton joint can be minimized, if we increase the moment arm of the exoskeleton joint segment. With this in view, an additional element is inserted in the ankle joint to reduce the torque requirement off that joint. As in the first case the Finite element analysis was performed to this model and verified the acceptance of the model. Apart from the sit-to-stand analysis, several other analyses were also performed in the model which include; standing, walking, stair ascend, stair descent and failure. The average and maximum Von-Mises stress for various activities is shown in table 1.

Table 1 Maximum and average stress during different phases of stair descent

GAIT PATTERN	MAXIMUM VON-MISES STRESS (MPa)	AVERAGE VON-MISES STRESS (MPa)
Weight acceptance	7.1212	0.73288
Forward continuance	483.11	22.539
Controlled lowering	365.69	16.651
Leg pull through	470.22	22.063
Foot placement	449.91	21.428

5.4 Exoskeleton with Enhanced Stability and Ergonomics

A third model of exoskeleton was developed as shown as module 3 in the figure 2. In this model, the ergonomic factors were considered along with all the design aspects that lead to the development of module 1 and 2. In module 2, the transfer of force from the body to the ground is through the lateral support provided in the exoskeleton. But in this model, both lateral and medial support is provided for the ankle and the knee joint. Also the linear actuators are preferred in the development of the ankle joint.

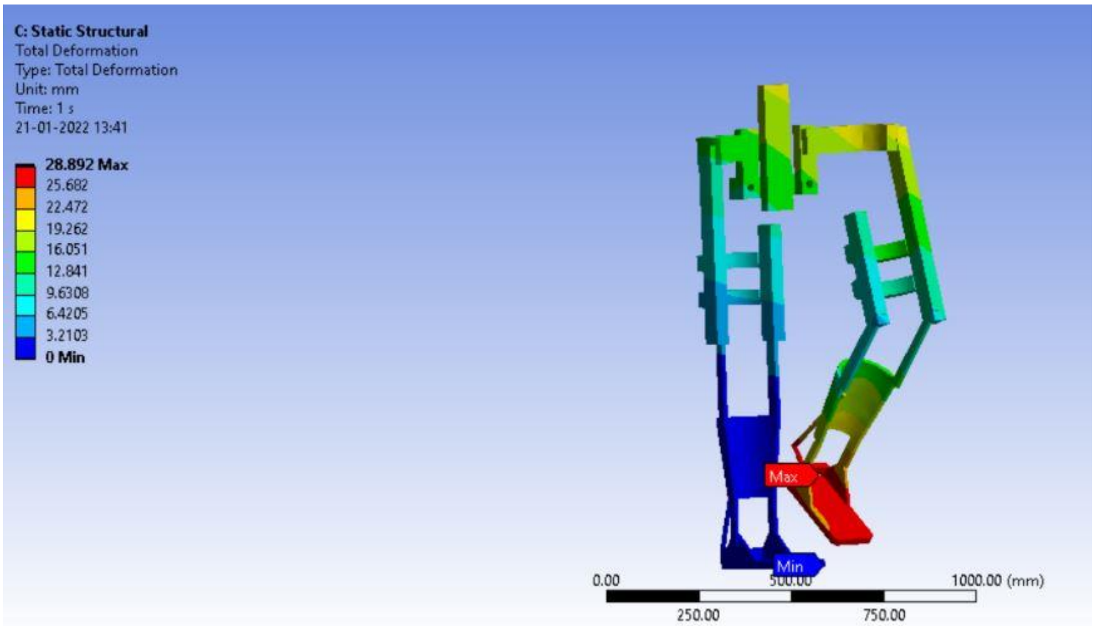

Figure 2 Deformation analysis of mid stance for walking for module 3

The methodology for the module 3 is same as shown in the figure 1. The finite element analysis was performed for the various loading conditions of the exoskeleton and tested for its performance.

Three models are developed and the finite element analysis is performed for the same set of experiments. By this way, it is possible to compare the performance of the developed models. The third model outweighs the performance when comparing to the other two. This is because of the fact that, most the movement capabilities of the joint is incorporated for the exoskeleton design, the modifications are performed to the support structure and also due to the introduction of the linear actuators in the ankle joint.

5.5 Human Stability Evaluation

As of now, there is no common standard procedure to evaluate the stability of the person. The current techniques are based on several forms of questionnaire prepared by the physician and evaluated from the user's choice of answers. This technique is purely subjective as it does not involve any kind of sensors or algorithms. The person's stability analysis is essential to understand the acceptance towards the usage of the exoskeleton. The chance of fall is one such parameter in the stability analysis that needs to be quantified. In this research work a machine learning model has been proposed which takes the input from the force sensors and evaluates the chance of fall from the patient data.

Three questionnaire test named BESTest, FES Test and IPAQ Test are generally performed in various countries to evaluate the stability. Either one of them mentioned here are employed by any physician. But in the proposed methodology, the model has been developed from these three test result and in combination with the force sensor output. The major advantage of the developed model is that, no more questionnaire is needed for evaluating the chance of fall and also by using simple force sensor data and the developed machine learning model, it is possible to evaluate the stability of the person. The metrics of various tests when implemented in the model are evaluated.

5.6 Joint Ankle Measurement system and Gait Pattern Generator

The exoskeleton system should have to work in accordance with the gait pattern of the user. Along with that, the real time measurement of angle is essential for providing the feedback for the processor employed in the exoskeleton. In this proposed methodology, a gait pattern generator system has been developed which incorporates the kinematic gait analysis of the user and thereafter the development of control circuitry for the exoskeleton. The developed Gait pattern generator will be useful for the patient during the period of fully assisted walking mode of the exoskeleton. The MEMS based real time angle measurement system for measuring the angle variations of hip, knee and ankle joint is also proposed in this work.

The results of the proposed angle measurement sensor are compared with the existing techniques such as video analysis and manual measurement of angle. It is proven from the analysis that the proposed technique is accurate with the mean absolute error of 0.5.

6. CONCLUSION

In this research work, three analyses have been performed with the exoskeleton as the central subject. The first is the development of exoskeleton models with advancements and the finite element analysis upon the developed models. The second work is on the development of machine learning model to evaluate the stability of the patient. This model quantifies the patient for their necessity of powered exoskeleton. The third work is on the development of Gait-Pattern generator system and the joint angle measurement system for powering the exoskeleton.

From the finite element analysis performed for the three developed models, it can be concluded that, the 1060 aluminium can be the best suited material for making a cost effective exoskeleton design. From the analysis, the maximum stress area is visualized and those affected area can be built within the lower level when the cross sectional area is increased. All the three models sustained the testing conditions and proved their fit for use. Since the third model is incorporated with the lateral and medial support and along with the ergonomic factors, its performance is better when compared with the other two models.

The machine learning model developed in the proposed research work is the first of the kind of that uses machine learning concept to evaluate the person's stability. Even though there are several ways to quantify the stability, the ultimate aim for the stability analysis is that the person will fall down in a given condition or not. With the proposed model, the chance of fall of an individual can be quantified and proven to have reliable output. The output of the machine learning model can be used for decision making of whether the person needs any kind of assistance for their locomotion.

Angle measurements system proposed in this research work is developed using the MEMS sensor. Electrogoniometer based angle measurement sensors are available in the market which are very costlier. But the proposed measurement system can be implemented within few hundreds of rupees. For developing a cost effective exoskeleton, the indigenous development of associated technology is essential. In this way the Gait Pattern generator system and the developed MEMS based angle measurement system are applicable to all kind of the exoskeleton design and have a better performance when comparing to the other existing technique.

The mechanical analysis, stability evaluation and the angle measurement system are developed and are used to evaluate the performance for the defined intended operation.

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International Journal

1. **Umesh K** & Vidhyapriya R 2021, 'Finite element analysis of lower limb exoskeleton during sit-to-stand transition', Computer Methods in Biomechanics and Biomedical Engineering, vol.24, Issue 13, pp 1419-1425. ISSN: 1025-5842, IF: 1.669