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Research paper

Design of a novel walking assistance device for people with walking disabilities

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Abstract

Moving independently is very important for people with walking disability, thus, in this paper the novel walking assistance device is designed based on strategies derived from optimization of available walking assistance devices for the people with walking disabilities. Available walking assistance device like ReWalk has high price and heavy weight disadvantages. Therefore, the main aim of this study is optimization of available devices by new design and analyses to make them cheaper and lighter. The presented device is a simulator of a human body motion in lower limb which consists of hip, shank and knee. All parts were designed and assembled in software module and after manufacturing, it could be used as a rehabilitation device for the people with walking disability to support their sitting, standing and walking. As a result, regarding to aforementioned issues, in this study the new walking assistance device was designed which is inexpensive and light weight.

Keywords: *Design; Finite Element Analysis; Rehabilitation; Walking assistance device; Walking impaired person.*

1. Introduction

In recent years, the field of medical devices has grown rapidly and has been divided into various branches. Fabricating assistance devices for people with walking disabilities is one of the important aspects in this field. Walking disability is a disability which limits a person's ability to walk. The people with walking disabilities cannot keep a standing posture, and they use a wheelchair for mobility. Such people cannot walk without the use of a cane, a wheelchair, or another assistive device.

There are differences among people with various disabilities [1, 2]. Therefore, many walking support systems have been made for people with various walking disabilities, especially for the elderly [3-5]. Wheelchair is one of these devices and Honda's walking assistance device is another example. Furthermore, many devices have been developed to be used in rehabilitation [6, 7].

Walking can be enjoyable for almost everyone, especially for people with walking disabilities. Robots make life easier and more comfortable and used for many different purposes. Some researchers have focused on wearable robots for people with walking disability [8, 9]. They could be helpful in providing the disabled person with a balance and support their walking, sitting, and standing [10].

Having reviewed many studies on walking assistance robots, wearable robot concept was chosen for this study. Several wearable robot systems for walking support have been developed so far [11-13]. Many of that devices are often expensive and heavy because they use specific actuators and controller. One of them is ReWalk, duo to high price and heavy weight its optimization has yet to be made.

The main aim of this study is the optimization of the available devices by new design and analysis to make inexpensive and lighter device that is expected to be effective and simple to use by disabled people [14]. This project was carried out to compensate for the shortcomings of the existing devices. The proposed walking assistance device will support sitting-to-standing, walking and standing-to-sitting movements of a disabled person. First, all parts of this device were designed; next, they were analyzed, and finally, as a result, a novel and inexpensive walking assistance device was made.

2. The optimized design

This study focused on design and optimization criteria of the walking assistance devices. The design of the walking assistance device was inspired by human lower limb structure. This device consists of three main parts: hip, knee, and shanks. All parts were designed and assembled in the assembly module of the Solidworks software. Virtual step motors were placed in the appropriate joints and the movement of the mechanism was performed in the simulation module of the software. In a nutshell, a novel walking assistance device was designed which is cheaper and lighter than available devices.

2.1. Overview

A perusal of the recent studies has indicated that we should target a practical, simple and functional mechanism. Accordingly, the design, optimization, static and dynamic analyses of all parts were performed. In addition, the weight of the mechanism is one of the most important parameters in this project. In order to allow the convenient use of the device, its weight must be kept as low as possible. The choice of aluminum 1060 alloy as material in motion study module of software is a response to this constraint and, moreover, some holes were made in appropriate places of each part to reduce the total mass of the device. Finally, walking difficulties of a mobility impaired person were examined before designing the device [15]. Then all parts were designed and a virtual prototype was created. This device consists of six parts: waist, waist-hip connector, hip, knee, shank, and coupling elements. This device includes four degrees of freedom (DOF) which two of them taking place in the hip joints, and the other two are in the knee joints. The simplified gait model of the mechanism is shown in Figure 1.

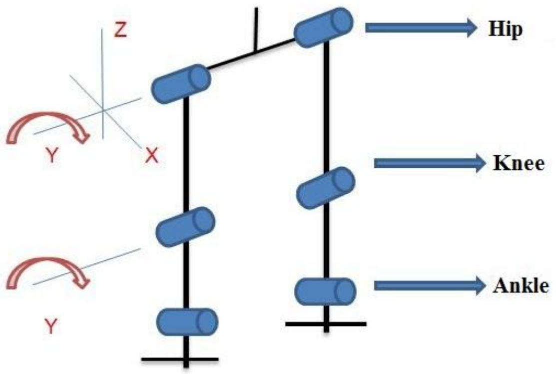

Fig. 1: The gait model of mechanism

2.2. Designing the walking assistance device

2.2.1. Waist

The waist was designed symmetrically and this component was assumed as a fixed part in the assembly module. The inner side of the waist was covered with soft pillow to make this part more comfortable for the disabled person. 3D model of this component is shown in Figure 2.

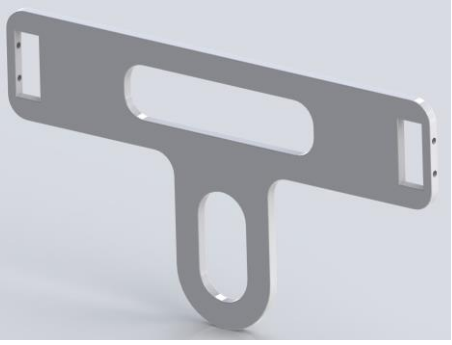

Fig. 2: 3D model of waist

2.2.2. Hip

This part was installed to the waist through the waist-hip connector. The length, width and depth of hip are 460, 100 and 25 (mm), respectively. Figure 3 shows the hip, that five rectangular pockets were machined in one side of it to hold the batteries and to lighten the device weight.

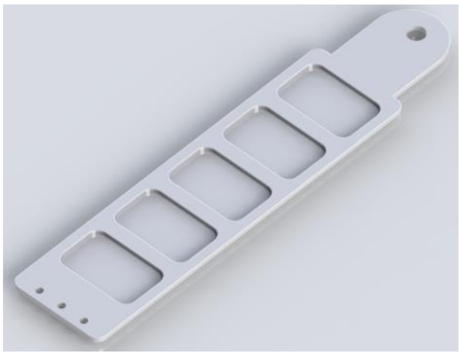

Fig. 3: 3D model of hip

2.2.3. Waist-hip connector

The waist-hip connector was split into two separate pieces for the ease of manufacturing. These two parts were assembled together through nuts and bolts and behave as a single piece. The waist-hip connector is connected to the waist from specific points. This part is connected to the hip through bearings and pins, as shown in Figure 4.

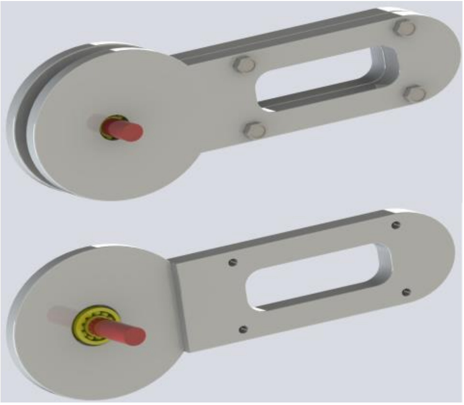

Fig. 4: 3D model of waist-hip connector

2.2.4. Shank

Designing the shank is similar to that of the hip; however, it is mandatory to use knee connector to interconnect the hip and the shank. The upper and the lower sides of the shank are connected to the knee and user's shoes, respectively. 3D model of this component is shown in Figure 5.

Fig. 5: 3D model of shank

2.2.5. Knee

The hip is connected to the shank through the knee. As the same method with the waist-hip connector, the knee is also made by two separate parts. The flat side of this part is connected to the hip through nuts and bolts and the semi-circle side is connected to the shank through bearings and pins. There are two knee parts in each leg assembled by coupling elements and play a role as a single piece. 3D model of this component is shown in Figure 6.

Fig. 6: 3D model of knee

2.3. The assembly of walking assistance device

The assembly of the walking assistance device was made after designing all parts. Nuts, bolts, and coupling elements were used for connecting the related parts. This mechanism was designed by using the measurement of a disabled person. The structure of the walking assistance device is simple which can easily be fastened on a person with walking disability. The walking assistance device prototype is shown in Figure 7.

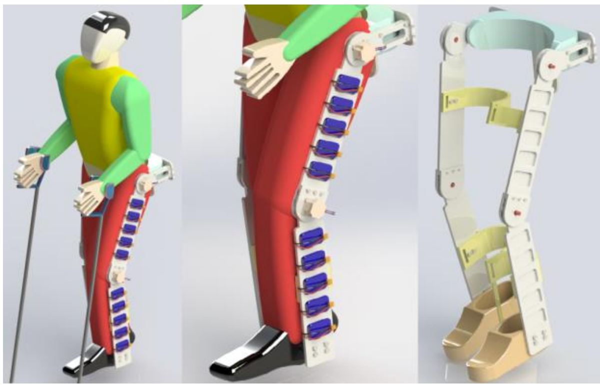

Fig. 7: Walking assistance device

2.4. Finite Element Analysis

2.4.1. Static analysis

Many factors are important in static analysis; stress and displacement are the most important ones due to the weight of mechanism. Static analysis was needed for most parts; however, only the hip component analysis was described in this section, having in mind that all other components have the same method of analysis. The hip was connected to the waist from specific points and total of 200 N forces were applied to each leg which is due to the combination of body mass and the weight of the equipment. However, the reason for the low force is that the user uses the canes simultaneously. First, the stress analysis was conducted, and the maximum amount of stress for the hip was 13 MPa, but this value is lower than aluminum yield strength and does not impose any defects in mentioned place, as shown in Figure 8. Therefore, a big amount of force was applied on the canes. If the stress value was more than 27.57 (MPa) "yield strength point of aluminum alloy 1060'' the probability of refraction would be high in the specific sections. Thus, factor of safety (FOS= Yield stress/Maximum working stress) for the hip is 2.12.

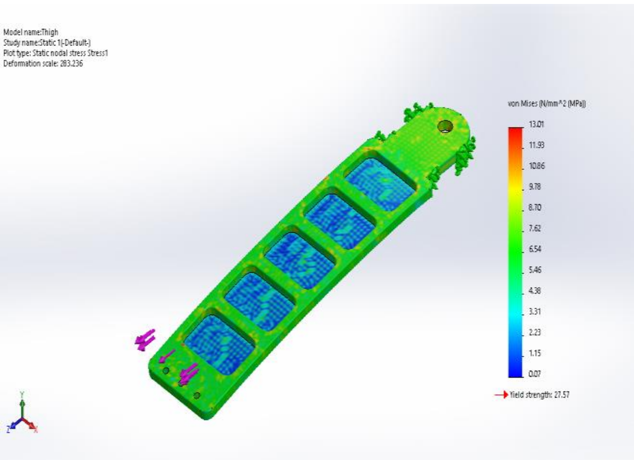

Fig. 8: Stress analysis of hip

Second, the displacement analysis was performed for the hip. In the fixed points of the hip, the amount of displacement was so low that it could be assumed as zero. The maximum amount of displacement occurred in a place where the forces were applied and is equal to 0.163 mm, as shown in Figure 9.

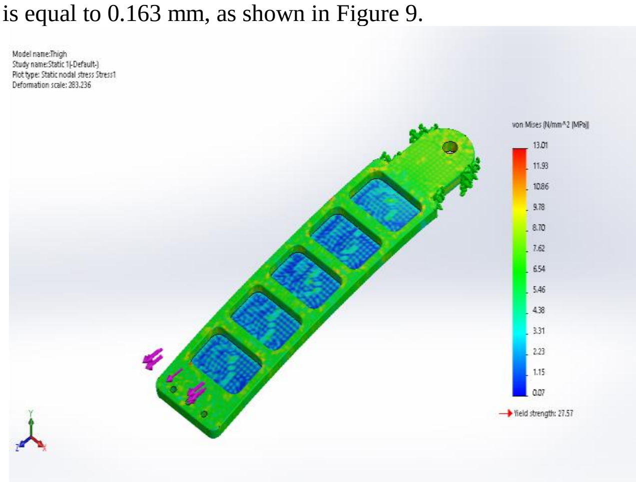

Fig. 9: Displacement analysis of hip

2.4.2. Dynamic analysis

Figure 10 shows the total angular displacement of the hip related to the waist in the first period (1 sec.). Therefore, the hip had a total of 60° angular movements varying between (-30, +30) degrees. This limitation was due to the normal motion of the human body in the lower limb while walking.

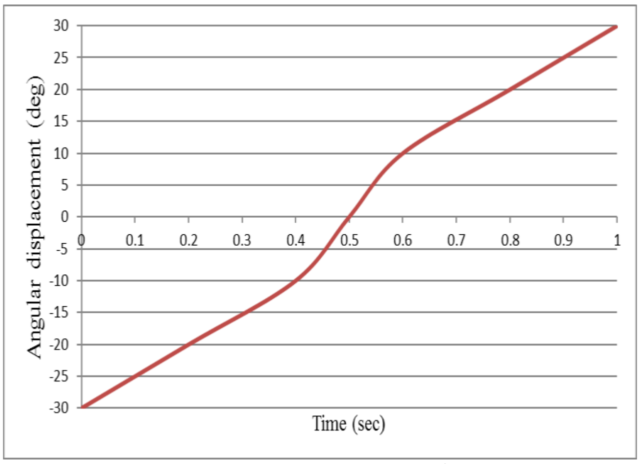

Fig. 10: Angular displacement of hip

The dynamic analysis of the shank shows that the rotation of the shank was limited to a total of 45° related to the hip, as shown in Figure 11. The rotation of the shank was limited until the knee axis. There are not any movements after this position due to the limitation of the human body movement.

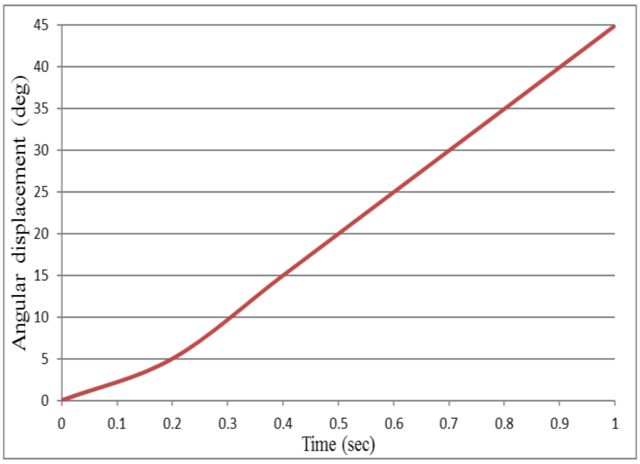

Fig. 11: Angular displacement of Shank

3. Result and discussion

Nowadays, the price of available walking assistance devices for the disabled people is between $ 69.000-85.000. The main aim of this study was to produce an economical assistance device for the people with walking disability. Thus, the walking assistance device will be offered to the market at a low price when it is manufactured.

Another aim of this study was to reduce the mass of the mechanisms by new design and optimization. The mass of the available devices for the disabled people varies between 20 and 25 kg. Aluminum 1060 alloy was used (simulation module) in the fabrication of this device. Thus, the mass of the mechanical parts of designed device is approximately 5.500 kg. In addition, electrical-electronic equipment will be installed on this mechanism to providing movement. The total weight of designed device will be reduced by almost half compared with the existing devices. As result, the total weight of the walking assistance device will be approximately 11.500 kg.

Lithium batteries will be used as a power supply in this device. The number of lithium batteries could vary from 3 to 5. These batteries will be mounted on appropriate places designed on the legs. The advantages of the holes on each leg are to reduce the weight of the backpack of the patient's and to balance the center of gravity of the device by distributing the batteries evenly between the right and left legs.

Dimension, shape, and weight play an important role when the device is designed. All dimensions used to manufacture this device are the same as in human body. Aluminum 1060 alloy was used as a material for the reduction of the mechanism’s weight. The walking assistance device is a wearable robot that disabled person can carry this device easily.

4. Conclusion

In conclusion, if durable but lightweight materials such as magnesium or fiber carbon are to be used in this device, the weight of mechanism will be reduced more and the target users would carry this mechanism more easily. Due to the budget limitation, aluminum 1060 alloy was used in this mechanism and made the total weight of the mechanism approximately 11.500 kg. Therefore, it is possible to use lightweight material to decrease the total mass of mechanism. In the next spot of this project, electrical-electronic control of this device will be performed. Therefore, each leg will actuate by step motor and an encoder. Step motors will be placed in appropriate joints and provide the rotation of the shank and the hip. PLC, step motors, encoders, sensors, lithium batteries and related parts will be used to control this mechanism.

As a disadvantage of the designed device and available devices, we can mention using canes by the users to keep their stability. Prospective studies should concentrate on the stability of walking assistance devices.

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