Applied Mechanics and Materials Vol. 598 (2014) pp 141-145
Online available since 2014/Jul/16 at www.scientific.net

doi:10.4028/www.scientific.net/AMM.598.141

Submitted: 29.05.2014
Accepted: 03.06.2014

Mechanical Design of Lower Extremity Exoskeleton Assisting Walking of Load Carrying Human

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Keywords: Lower-extremity, exoskeleton, electro-hydraulic, assisting walking, carrying load.

Abstract. Exoskeletons are used in rehabilitation, military, industrial applications and rescuing, heavy-weight lifting and civil defense applications as well. This paper presents to design of a lower-extremity exoskeleton assisting walking of a load carrying human. Proposed exoskeleton system is designed to be appropriate mechanism with human lower extremity and it operates synchronously with the human realizes. The aim of exoskeleton actuator system is to provide forces against to external load carried by user during walking, sitting, and standing motions. Thus, it supports human walking and significant portion of external load carrying by the user. Also it makes possible to user spend less energy, less stress and fatigue. Proposed work involves the following design steps: kinematic synthesis of the exoskeleton, mechanical and electro-hydraulic system design.

Introduction

Exoskeleton systems are robotic manipulator which are wearable and move with the user synchronously. From past to present various mechanisms for exoskeleton systems are realized and used for human integration applications such as rehabilitation, military, industrial heavy-weight lifting and civil defense [1-14]. Also different actuator and control systems are designed and used in exoskeletons such as hydraulic, pneumatic cylinders, dc servo motors, proportional controller, hybrid controller, posture controller, a power assist controller and neuro-fuzzy logic controller [4-13].

In this paper, a lower extremity exoskeleton mechanism is designed to support human walking, sitting, and standing motions synchronously with human and also it is developed to take significant portion of external load carrying by the user. Design of lower extremity exoskeleton is accomplished in three steps: kinematic synthesis, mechanical and electro-hydraulic system design. Exoskeleton contains two legs powered by two servo hydraulic actuators. Exoskeleton legs are designed almost anthropomorphic to ensure maximum user comfort and harmony between skeleton and user motions. Maximum maneuverability and minimum energy consumption is achieved by designing a lightweight structure. System is actuated by hydraulic cylinders considering their compact and lightweight design advantages and required power. Safety requirements are taken into consideration during mechanical design. This paper focuses on mechanical design and calculation of actuated system emphasizing the critical design criteria. 3D-Cad model of proposed exoskeleton system is given in Figure 1.

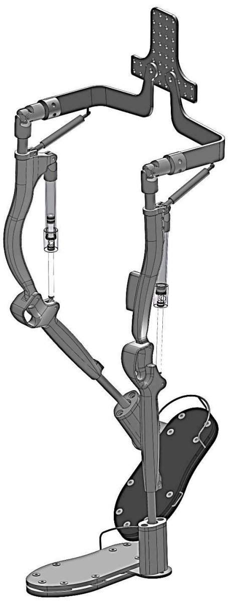

Fig. 1. 3D-Cad model of designed exoskeleton system.

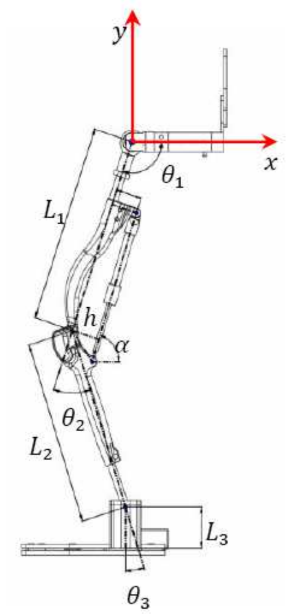

Fig. 2. The schematic picture of exoskeleton mechanism.

Kinematic Analysis of the Exoskeleton

The schematic picture of exoskeleton mechanism is shown in Figure 2. In this scheme, independent and dependent variables are defined as $\boldsymbol{\theta_1}, \boldsymbol{\theta_2}, \boldsymbol{\theta_3}$ and $\boldsymbol{h}, \boldsymbol{\alpha}$ respectively. Kinematic equation is written in Eq. 1 by using independent variables. Using this equation, position of foot is obtained according to generalized coordinate plane. Also Matlab/SimMechanics software is used to calculate independent variables of exo-mechanism during simulations.

$$ {}_3^0T = \begin{bmatrix} \cos(\theta_1+\theta_2+\theta_3) & -\sin(\theta_1+\theta_2+\theta_3) & 0 & \cos(\theta_1+\theta_2)L_2+\cos\theta_1 L_1 \\ \sin(\theta_1+\theta_2+\theta_3) & \cos(\theta_1+\theta_2+\theta_3) & 0 & \sin(\theta_1+\theta_2)L_2+\sin\theta_1 L_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

Mechanical Design and Results

The main part of a lower-extremity exoskeleton is skeleton body which interacts with the user. Successfully designed a exo-body directly transmits weight acting on the user legs to ground by creating a force path between connection points with the user and ground. Thus, it recovers the user from the effects of gravity. Exo-body is a manipulator which consists of rigid parts connected together via joints. The most important feature of this manipulator from the others is that its' kinematic structure is fully compatible with the anatomical structure of the human. A lower-extremity exoskeleton body consists of joints and main parts such as waist, upper legs, lower legs and feet. Also these main components must have some basic characteristics such as comfort, adjustability, robustness and lightness.

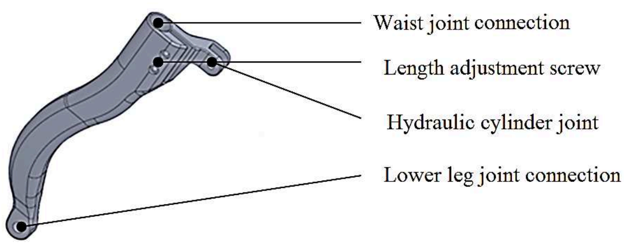

Fig. 3. Upper leg Cad model.

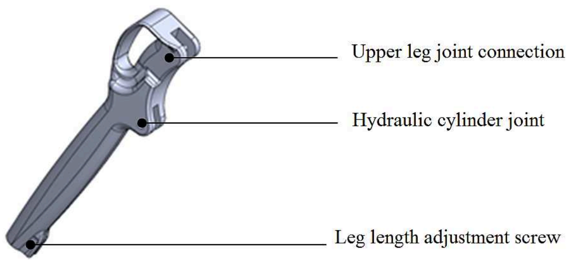

Fig. 4. Lower leg Cad model.

In the design of exoskeleton system, waist mechanism consists of two links which are capable of moving individually. Thereby waist part of user body remains parallel to ground during different height positions of feet. In addition, this mechanism provides that exoskeleton system can be wearable without adjustment for users who have different waist width. Waist joint is universal joint and it has three degree of freedom.

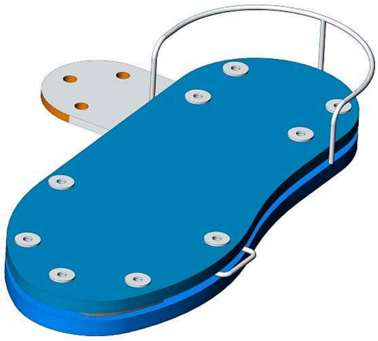

Fig. 5. Exo-shoe Cad model.

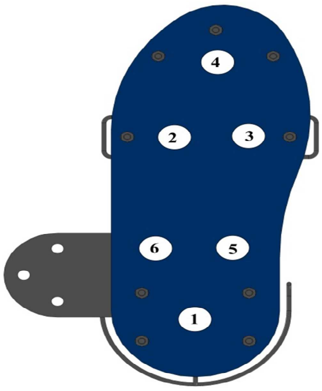

Fig. 6. Force sensor layout.

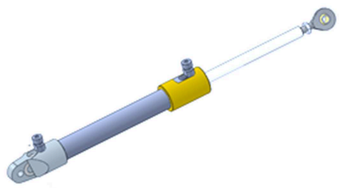

Fig. 7. Force sensor layout.

Upper leg shown in Figure 3 is produced to be adjustable for different lengths of the users. With screws located on side, waist joint is fixed by adjusting according to the location of the person. As seen in Figure 4, lower leg length is adjusted via adjustment screw in order to be used in different sized people. Piston rod connection joint of hydraulic actuator shown in Figure 4 is over the lower leg. This joint has two degrees of freedom. Also force sensor is used to force feedback for control action and it is placed between this joint and the end of the piston rod to sense actuated hydraulic force to lower leg. Moreover upper leg connection joint shown in Figure 4 and lower leg is designed to prevent further opening of the human leg as safety requirements. Shoe design of proposed exoskeleton is given in Figure 5. In Figure 6, six flexible force sensors are placed and compressed among two plates which are between base and upper parts of shoe like a sandwich style and also these parts are fixed by screws. These sensors are used to measure ground reaction forces for control methodology of exo-system. Also prediction of walking cycles can be realized by using these force sensors. Hydraulic cylinder is shown in Figure 7 and it is manufactured according to force requirements and velocity parameter.

Fig. 8. Actual appearance of exo-shoe.

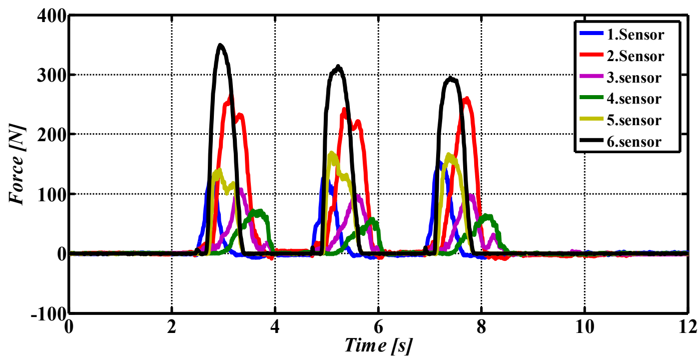

Fig. 9. Measured data from shoe sensors along a walking cycle.

Actual shoe of the proposed exoskeleton is given Figure 8. The belt system is designed on shoe to fasten the user's shoe. This belt system allows the user to use the exoskeleton system comfortably with their shoes. Measured data from shoe sensors along a walking cycle are given in Figure 9. By using these data, control software of exo-system observes how much force is comprised at any point of shoe and walking stage. Cad model based Matlab/SimMechanics first and second generation simulation models for kinematic and dynamic synthesis are given in Figure 10.

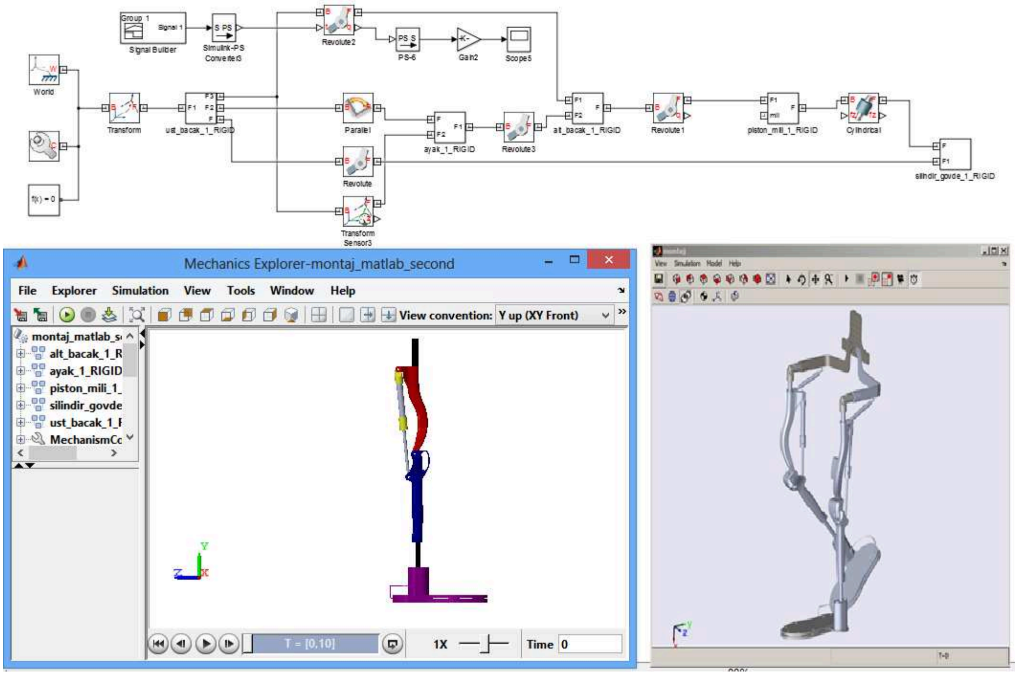

Fig. 10. Cad model based simulation model of exo-system.

Conclusion

In this study, mechanical design of a lower-extremity exoskeleton assisting walking of a load carrying human is realized according to design criteria and objectives of desired system successfully. This work is implemented both experimentally and simulations and it's supported by a scientific project. Mechanical design of proposed exoskeleton system is created as to a human lower extremity to be worked synchronously with the user and it is provided forces against to external load carried by user during walking, sitting, and standing motions. Mechanical and hydraulic actuator system are designed to support human walking and significant portion of external load carrying by the user and it makes possible to user spend less energy, less stress and fatigue. According to achieved theoretical and simulation works, real proposed lower extremity exoskeleton is manufactured and initial experimental tests are realized to obtain measured data from shoe sensors along a walking cycle of the user. The suitability of the mechanical design according to design criteria's is verified by walking tests of actual exo-system shown in Figure 11. Also sufficiency and accuracy of selection of hydraulic circuit elements and founded hydraulic system are determined and used hydraulic circuit of exo-system is given in Figure 12.

Fig. 11. Real proposed lower extremity exoskeleton system.

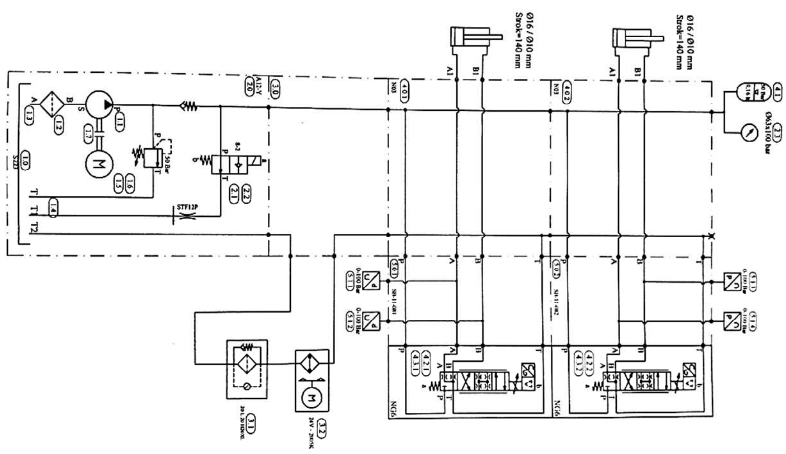

Fig. 12. Hydraulic circuit of exoskeleton system

Acknowledge

This work is supported by The Scientific and Technological Research Council of Turkey (Project No: 108M289), The Scientific Research Projects Coordinatorship of Necmettin Erbakan University.

References

[1] B. J. Makinson, "*Research and development prototype for machine augmentation of human strength endurance, Hardiman I project,"* General Electric Co., Schenectady, NY, USA, Tech. Rep. (1971), S-71-1056.

[2] M. Vukobratovic, D. Hristic, and Z. Stojiljkovic, "Development of active anthropomorphic exoskeletons," *Med. Biol. Eng.*, vol. 12, no. 1, (1974), pp. 66–80.

[3] H. Kawamoto, S. Kanbe, and Y. Sankai, "Power assist method for HAL-3 estimating operator's intention based on motion information," in *Proc. IEEE Int. Workshop on Robot and Human Interactive Communication*, Millbrae, CA, USA, Oct. 31–Nov. 2, (2003), pp. 67–72.

[4] H. Kawamoto and Y. Sankai, "Power assist method based on phase sequence driven by interaction between human and robot suit," in *Proc. IEEE Int. Workshop on Robot and Human Interactive Communication*, Okayama, Japan, Sep. 20–22, (2004), pp. 491–496.

[5] H.Kawamoto andY. Sankai, "Power assist system HAL-3 for gait disorder person," in *Lecture Notes Computer Science, vol 2398: Proc. 8th Int.Conf. Computers Helping People with Special Needs*. Berlin, Germany: Springer-Verlag, (2002).

[6] K.Yamamoto, K. Hyodo, M. Ishii, and T.Matsuo, "Development of power assisting suit for assisting nurse labor," *JSME Int. J. Series C.*, vol. 45, no. 3, (2002), pp. 703–711.

[7] A. Chu, H. Kazerooni, and A. B. Zoss, "On the biomimetic design of the Berkeley lower extremity exoskeleton (BLEEX)," in *Proc. IEEE Int. Conf. Robot Autom. ICRA*, Barcelona, Spain, Apr. 18–22, (2005), pp. 4345–4352.

[8] J. Ghan and H. Kazerooni, "System identification for the Berkeley lower extremity exoskeleton (BLEEX)," in *Proc. Int. Conf. Robot Autom.*, Orlando, FL, USA, May 15–19, (2006), pp. 3477–3484.

[9] H. Kazerooni, R. Steger, and L. Huang, "Hybrid control of the Berkeley lower extremity exoskeleton (BLEEX)," *Int. J. Rob. Res.*, vol. 25, no. 5-6, (2006), pp. 561–573.

[10] H. Kazerooni, A. Chu, and R. Steger, "That which does not stabilize, will only make us stronger," *Int. J. Robot Res.*, vol. 26, no. 1, (2007), pp. 75–89,

[11] R. Steger, S. H. Kim, and H. Kazerooni, "Control scheme and networked control architecture for the Berkeley lower extremity exoskeleton (BLEEX)," in *Proc. IEEE Int. Conf. Robot Autom.*, Orlando, FL, USA, May 15–19, (2006), pp. 3469–3476.

[12] A. B. Zoss, H. Kazerooni, and A. Chu, "Biomechanical design of the Berkeley lower extremity exoskeleton (BLEEX)," *IEEE/ASME Trans. Mechatronics*, vol. 11, no. 2, (2006), pp. 128–138.

[13] Ü. Önen, F. M. Botsalı, M. Kalyoncu, M. Tınkır, N. Yılmaz, and Y. Şahin "Design and Actuator Selection of a Lower Extremity Exoskeleton," *IEEE/ASME Trans. Mechatronics*, vol. 19, no. 2, (2014), pp. 623–632.

[14] J. Chen, X. Zhang and L. Zhu, "Kinematics analysis and three-dimensional simulation of the rehabilitation lower extremity exoskeleton robot" The International Journal of Soft Computing and Software Engineering [JSCSE], Vol. 3, No. 3, (2013), pp. 342–345.

Advanced Materials, Mechanics and Industrial Engineering
10.4028/www.scientific.net/AMM.598

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