A Review on Design and Development of Complete Wearable Exoskeletons

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ABSTRACT

Exoskeleton find application in various fields like medical, rehabilitations, military, workshops. The human body is an extreme piece of engineering, but it has got several limitations. With the help of robotics these limitations can be eliminated. Exoskeletons or orthosis are external devices which assist humans for their day today work. In case of military, soldiers get chronic back problems due to constant heavy load they carry similarly for that population who face any kind of disability, exoskeletons can be used to prevent and cure their discomforts. In this review, design of upper and lower limb exoskeleton is been discussed. Also various types of exoskeletons and power sources is also reviewed. Lastly the future scope and applications have been discussed.

Keywords*- Exoskeletons, Orthosis, Robotics suits.*

1. INTRODUCTION

Exoskeletons are robots then can be used on, in day today life that will provide user extra strength. It is actually true integration of man and machine. A average soldier carries 100 pounds equipment on his back, 30% of them face chronic back injuries. There are 68 million people estimated to be in wheelchairs worldwide, this is about 1% population which even people at age of 20s which face spinal cord injuries due to accidents. 25% workers face Musculoskeletal disorders (MSDs) constitute the most common work-related health problem. Intelligent Assist Devices (IADs) are mechatronic devices whose aim is to help the user carry out daily tasks that require a certain effort. These efforts may not be too great, but if they are carried out frequently (either in a repetitive or a habitual manner in the workplace or in a domestic environment), they can cause serious health problems.

IADs are machines designed not to replace the human but to help carry out the work more safely and efficiently. The following review discusses about some of the revolutionary IADs that were developed to help human sustain work more efficiently. The exoskeleton design is mainly categorised as upper limb and lower limb exoskeletons.eg.

IKerlan's Orthosis (IKO) is a wearable upper limb exoskeleton invented for helping the user performs a routine activity at the workplace. The main purpose of a exoskeleton can be stated in 3 points.

1.1 Restoring human functions (orthosis)
1.2 Enhancing human capabilities
1.3 Substituting human functions (prosthesis)

2. MODELLING

Modelling of upper and lower limb exoskeleton is discussed separately as follows.

2.1 Upper Limb Exoskeleton

The kinematic analysis of motion of hand like in Figure 1.(a) is carried by considering suitable degrees of freedom (DOF) at the joints through theoretical and experimental ways.

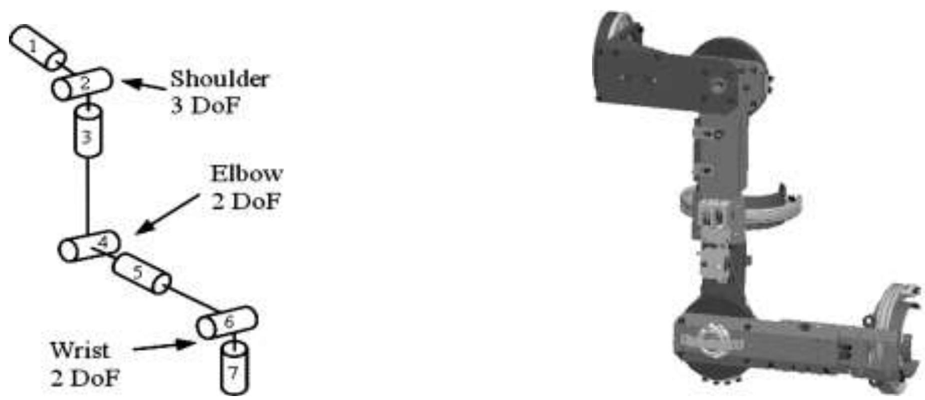

Figure 1. (a)Human Arm Kinematics. (b) Proposal of redesigned mechanism.

From those many cases it was concluded that the most optimal possible kinematic chain with 3 DOF for shoulder and 2 DOF at elbow. Wrist is not included in this case as it is considered that user uses his wrist to carry the operation, where all the forces are transmitted to exoskeleton and not his arm. Figure 1.(b) shows final designed exoskeleton arm.

2.2 Lower Limb Exoskeleton

Design of leg structure is complex due to multi degrees of freedom required at hip and ankle joints. Figure 2. Shows various joints and their kinematic analysis. The knee joint which is specially designed using regeneration technique is also discussed in brief in later part of this review.

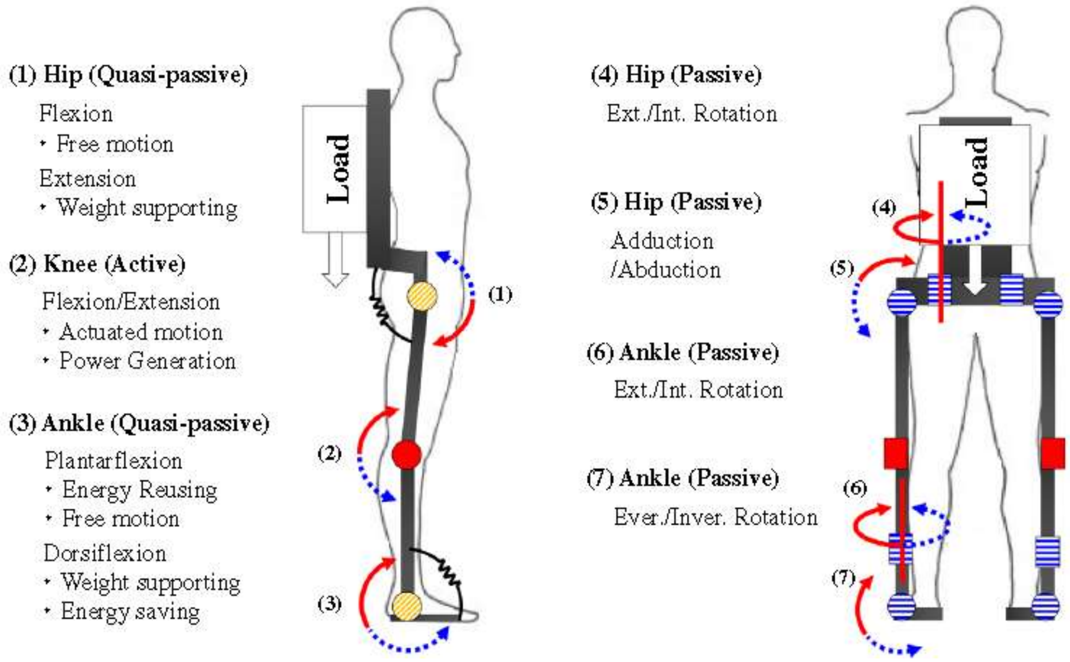

Figure 2. Human Leg kinematics (solid circle indicate active joints and stripped circle indicates passive joints)

2.3 Design of Knee Joint

The Figure 3. (a) and (b) shows the design of the quasi-passive joint for hip extension/flexion motions of the exoskeleton. Under this mechanism, the location of the supporting spring changes according to the phase of the gait. During the stance phase, when the legs of the exoskeleton are making contact with the ground, one head (A) of the supporting spring moves along the slider (AB), creating a moment arm (A´B), and enabling the generation of a counter moment by the spring force. Conversely, during the swing phase, the force from the supporting spring is removed by moving the head (A) of the supporting spring and returning the spring (ksp2) to the rotation centre of the hip mechanism in extension/flexion motions.

With the backpack weight, and the length of the moment arm between the backpack and the hip joint, the torque caused by the external load can be calculated and the same torque should be generated by the supporting springs of (ksp1). In this review, the moment arm length (AB), sliding rail angle (α), inclination angle of supporting spring (β), and spring length variation (A´A) were designed specifically according to authors calculations. Consequently, the spring constants of the supporting spring (ksp1) to support a backpack load of 30 kg.

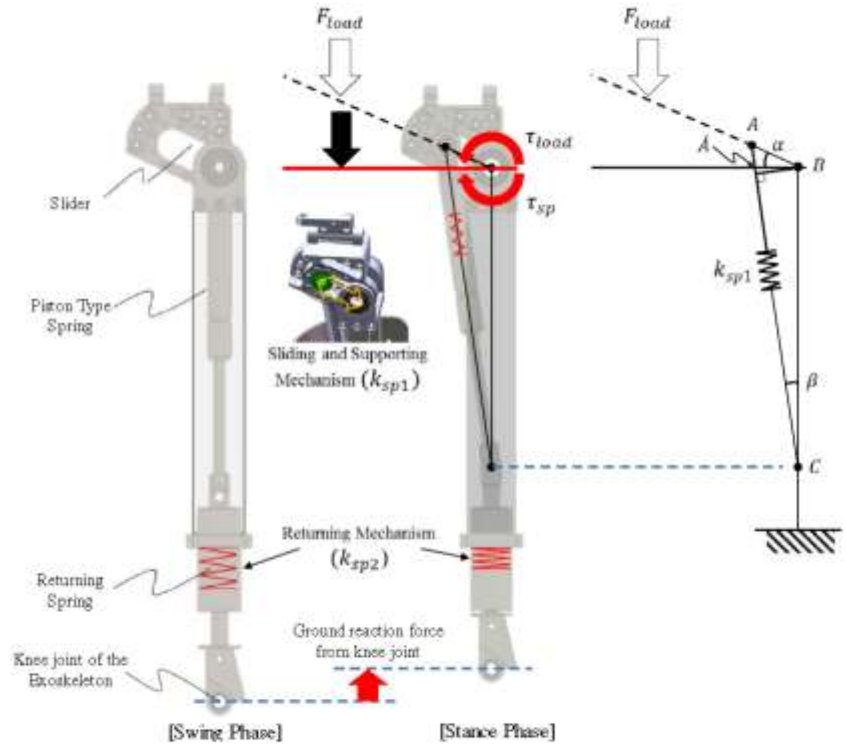

Figure 3. Mechanism for hip joint in (a) swing phase (b) stance phase

2.4 Actuator Selection

Selection of actuators is based on type of load to be carried, amount of force and how precise positioning is required. Thus, servo motors serves good precision but less load capacity, pneumatics and hydraulics actuators can lift heavy load but system is bulky and precise positioning cannot be maintained. Thus for various joints actuators are selected according to cases.

- For hip joints 90W, 24 V DC motor torque 390 mNm with strain wave gear with gear ratio of 100:1 with output torque 39 Nm is selected.

- For knee and ankle joints joint 70W, 24 V DC motor torque 130 mNm with strain wave gear with gear ratio of 160:1 with output torque 20.8Nm selected.

- For the shoulder flexion and abduction DC motor(MaxonGP42C). Both the motors, (Maxon EPOSP 24/5) positioning controllers are used.

- For elbow rotation is powered by two (DMSP-20200N) pneumatic muscles manufactured by Festo, length 200mm working with (MPYE-5-1/8HF) pneumatic servo valve with a working pressure of six bar.

3. EXPERIMENTATION AND SIMULATION RESULTS

The experiments performed on prototypes and their results monitored using software and sensors are mentioned below according to upper and lower limb part of exoskeleton.

3.1 For Upper Limb Exoskeleton

Experimental results are given to show the dynamic features of the actuated DOF. Initially, in order to perform the movements, a dummy wore the exoskeleton as shown in Figure 4. (a) To see the influence of a mass grasped by the hand, a weight of 2 kg was fixed to the dummy’s hand. Figure 4. shows the response of the elbow flexion to a 60◦ upward jump followed by a downward jump, first of all with no weight in the hand and then with a 2-kg weight. Firstly, despite the action of gravity, which is not expressly compensated, the upward and downward dynamics are seen to be identical .Furthermore, there is absolutely no difference when the weight is placed in the hand. The time required for movement is around 3.5 s due to the motor that is used and the resulting reduction factor.

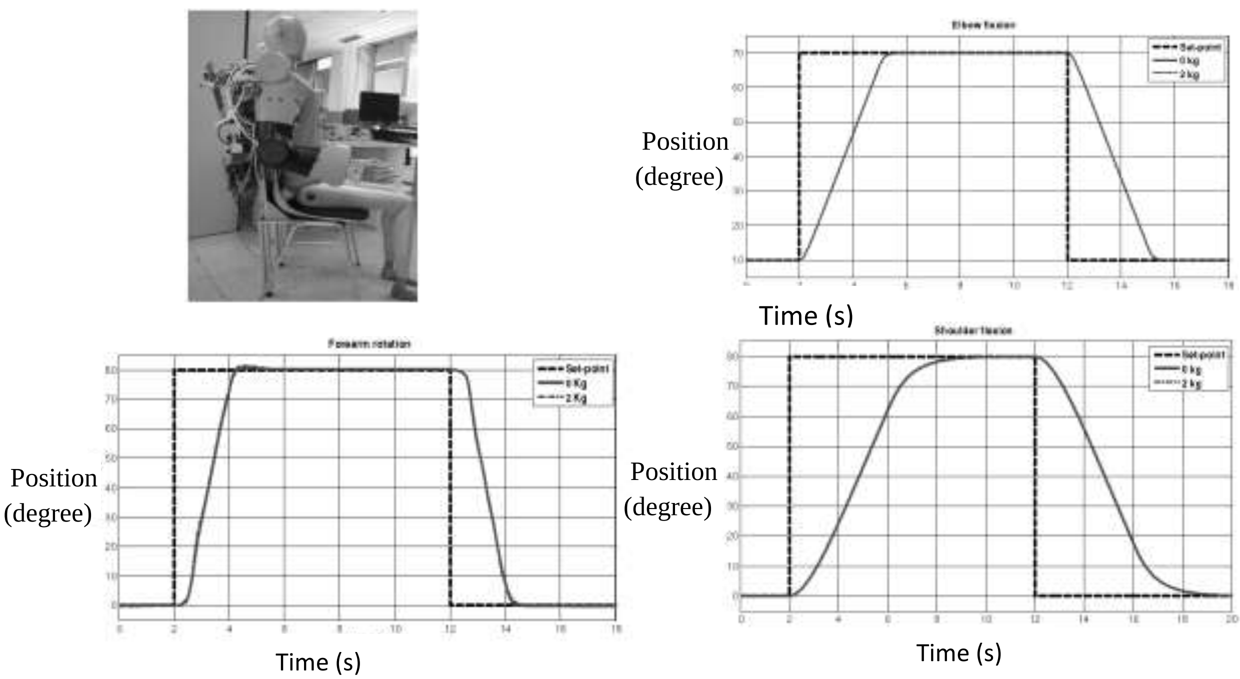

Figure 4. (a) Exoskeleton IKO worn by a dummy. Experimental results for:(b)elbow flexion. (c)forearm rotation. (d)shoulder flexion

3.2 For Lower Limb Exoskeleton

Figure 5. and 6. Shows graphs of experimental results which were carried on a male asset, the results show considerable decrease in EMG readings (ie. Muscle strength required to carry out work) on muscles Rectus Femoris and Gastrocnemius, which proves effectiveness of exoskeleton.

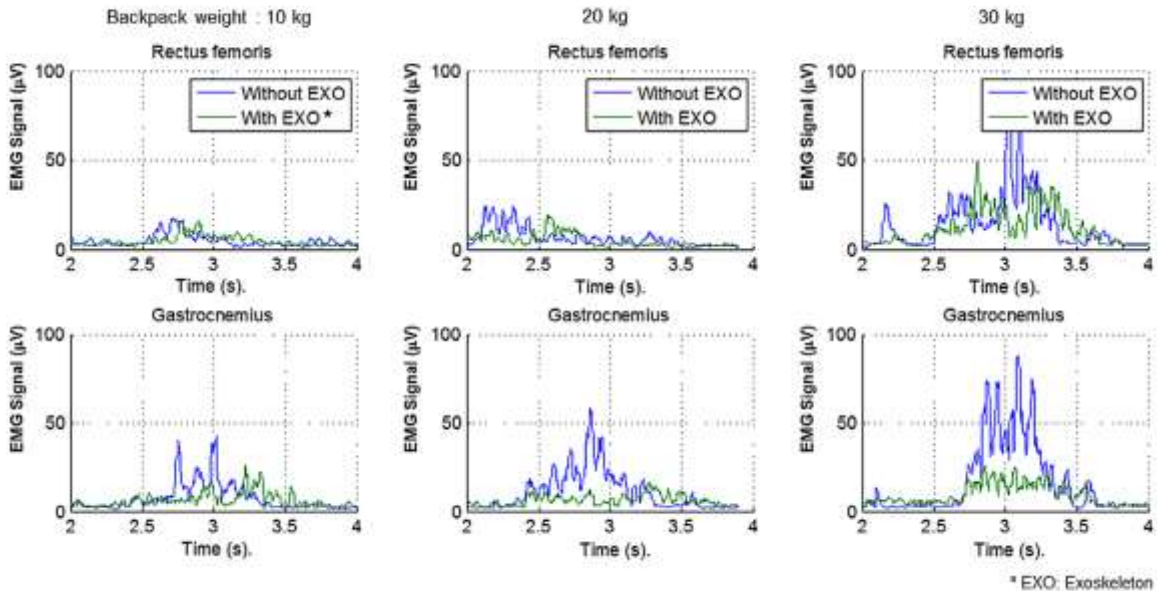

Figure 5. Measured EMG data for the level walking experiment with/without the exoskeleton

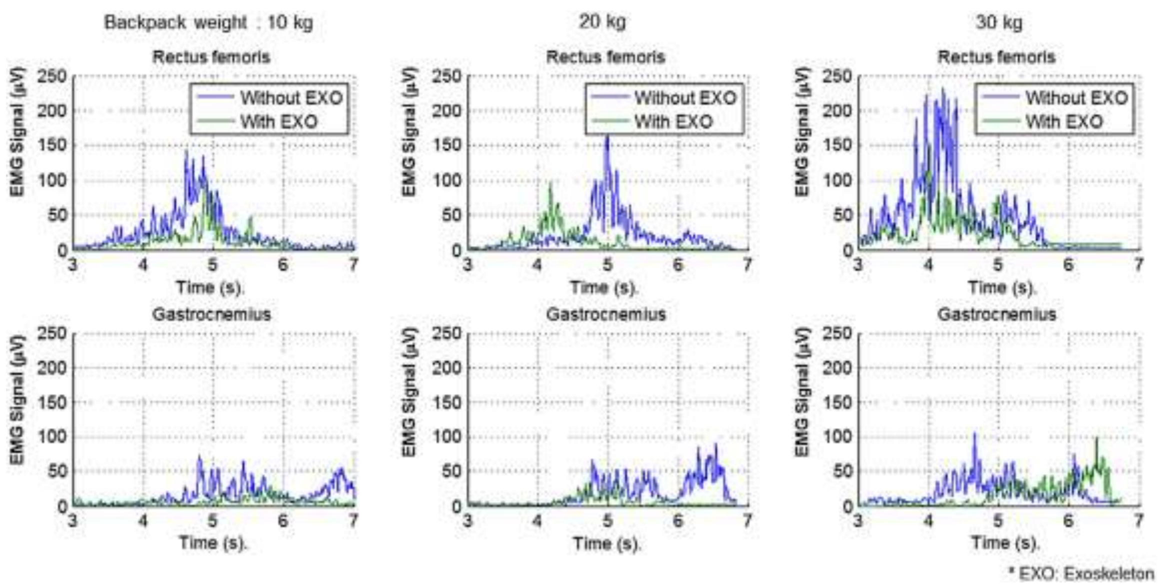

Figure 6. Measured EMG data for the stairs ascension experiment with/without the exoskeleton

4. CONCLUSION

The upper limb exoskeleton reviewed presents IKO, a wearable five-DOF upper limb exoskeleton for increasing performance levels during daily tasks, especially at the workplace. The selection of the five actuated DOF and certain auxiliary passive DOF was based on both ergonomic considerations and maximum reachable workspace. Conventional electrical motors and pneumatic muscles are used for actuation purposes. Bowden cable-drive transmission appears to be a good solution for reducing moving mass and actuator and structural part size. After the first prototype was built, a redesign process was carried out by the author, where materials and, in particular, aesthetic issues were analysed in detail. For the next stages, an inverse kinematic model is being set up and tested in simulation before it is integrated in IKO, together with a generator of position set-point values.

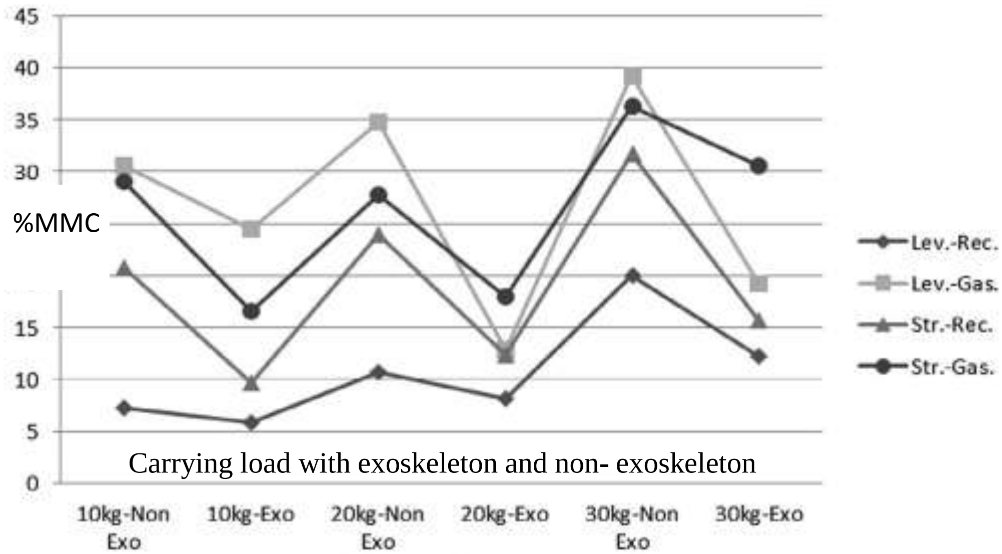

Figure 7. Comparison of the %MVIC of Rectus Femoris and Gastrocnemius muscles for the walking conditions.

As shown in Figure 7. for lower limb exoskeleton reviewed, the most notable effect of the exoskeleton system can be found in the gastrocnemius during level walking and the Rectus Femoris during stair ascension with a relatively heavy load. The force reduction of the gastrocnemius in level walking is considered to be as a result of the exoskeleton system supporting the external weight of the backpack and walking propulsion.

The maximum carrying weight considered in this article, as assumed in the section 3.2, can be handled by a normal person even without the exoskeleton system. From this point of view, if the user’s torso is not significantly inclined forward while wearing the exoskeleton with the backpack, the major portion of the vertical weight can always be supported by the exoskeleton and the user can be assisted continuously during the walking cycle by the exoskeleton system. However, this system can partially assist with that load. Consequently, gait posture change could occur while the user is wearing the developed exoskeleton system as a result of the underactuated leg mechanism and uncomfortable interface design. Therefore, we have reviewed the design for comfort fitting to the wearer to minimize the unexpected extra burden and fatigue caused by exoskeleton system. Further, development for inexpensive exoskeletons for Indian market is currently in development by using standard available actuators, and efficient design systems.

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