# Development of the heavy load transferring task oriented exoskeleton adapted by lower extremity using qausi - active joints

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**Abstract:** Herein, this study proposes that the exoskeleton has not full of active DOF (Degree of Freedom) joint, but partial active DOF joint which is so called the quasi-active joint system. It consists of 4 quasi-active joints and 2 active joints 3 passive joint and 1 active joint. So as to verify the efficiency of the quasi-active exoskeleton, muscle activation results are compared by before and after the wearing exoskeleton results.

**Keywords:** Lower Extremity Exoskeleton, Quasi active, Intent signal, Support weight, MSS(Muscle stiffness sensor)

## 1. INTRODUCTION

There are many studies in recent years to apply the wearable robot to muscular strength assistants for the elderly, soldiers wearing battle equipment, workers carrying heavy loads in work sites, surgical or medical patients undergoing long-term hospitalization; various wearable robots usually worn around the hip, knee, and ankle joint of a user have been developed to assist the muscular strength of degenerative muscular disease patients or the elderly. General exoskeletons have been introduced that all joint parts of the system are active joints including drive units as in a leg of a general robot. Tsukuba University in Japan developed an exoskeleton called the ‘Hybrid Assistive Leg’ (HAL-3). The exoskeleton employed harmonic drive motors at the hip, knee, and ankle joints. According to the publication, the EMG based control strategy was not fully solved, and the wearer experienced discomforts due to controller errors and its mass - 17kg [1]. In case of BLEEX - Berkeley Lower Extremity Exoskeleton used linear hydraulic actuators to power the hip, knee, and ankle in the sagital plane. Complex control algorithm was implemented using only measurements from the exoskeleton and not from the human or the human-machine interface [2]. Sarcos created an exoskeleton similar to that of Berkeley. Rotary hydraulic actuators were located at each joint. One drawback for both the Berkeley and Sarcos exoskeletons is that an internal combustion engine may be undesirable for military applications, because of the noise and harshness from the engine may give away the position of soldiers in a covert operation [3]. A full of DOF powered exoskeleton may be more complex than necessary to achieve a metabolic reduction for load carrying for level ground walking. The more active joints set into the system, the more excessive increase in weight of the exoskeleton and complicate the configuration thereof, thereby causing frequent malfunction. In order to keep away from these kinds of defects, underactuated exoskeleton adapted by the lower extremity can effectively transmit payload to the ground during the one cycle of the gait. These efforts have been followed up to investigate the energy based control approach to controlling underactuated mechanical systems [4], [5]. They have several edges on that the quasi-active joints make for mechanical simplicity and relatively high efficiency, and control of speed and direction as well. When it comes to assisting the lower limbs, the specific resistance of machine is somewhat better than 0.002 in a comfortable stride [6].

Herein, this study proposes that the exoskeleton has not full of active DOF (Degree of Freedom) joint, but partial active DOF joint which is so called the quasi-active joint system. It consists of 4 quasi-active joints and 2 active joints 3 passive joint and 1 active joint. Human feels reduce the load weight that was support the heavy load by the 4 bar linkage. And the knee joint of the exoskeleton is activated from intent signal that determine the muscle activity relationship to gait. So as to verify the efficiency of the quasi-active exoskeleton, muscle activation results are compared by before and after the wearing exoskeleton results through gathered EMG signal analysis.

## 2. DEFINITION OF TARGET TASK

For the purpose of deriving the target task in this paper, dominant works in the site and daily life on fair way and steps are classified and defined. General workers or laborers have their own established work custom instinctively, since human evolved for the environment through many centuries without much energy consumption and avoiding injuries. For the sake of minimizing the energy loss, workers decrease their moment arm, it means that they commonly fold their arm when they carry or handle heavy stuffs. In this case, they can get the effect of making small value of joint torque and energy when they lift heavy things. On the other hand, for the lower extremity, there are a few ways that minimize the energy consumption and fatal injuries. From that reason in this paper, we chose several main works adapted by the lower extremity – walking with heavy stuffs and carrying and lifting heavy materials on a fair way and stair way conditions like in the figure

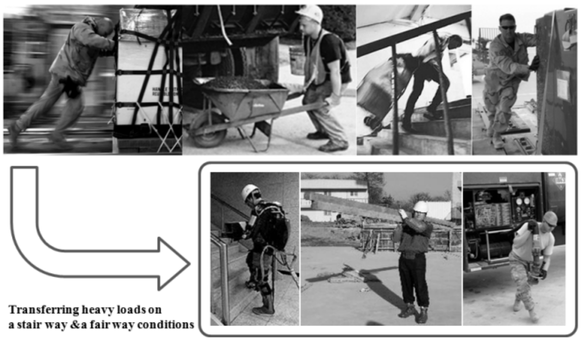

Fig. 1 Frequently conducted working pattern and target task

below. The chart book from U.S. Bureau of Labor Statistics general laborers in the construction site have exposure to the fatal occupational injuries, so the work of carrying and lifting heavy materials are finally picked out by the target task in this research (Fig. 1).

## 3. PROPOSAL OF THE PROTOTYPE USING QUASI-ACTIVE JOINTS

Figure 2 shows that the exoskeleton adapted by lower extremity is planned for transferring the heavy load, and it is designed by 2 quasi – active joints and 1 active joint at each side. First, quasi-active joints are on the hip and ankle joints and an active joint is located in the knee joint. Second, a backpack which is connected with hip joint is composed of main controller and connector for equipping the heavy loads. Third, an exoskeleton is connected with human body through the orthotics and harness such as ankle braces and shoes. Proposed system takes 4DOF, and there are share of the role with each joint; quasi - active joints move along the hip joint of human body, role of supporting heavy loads by the 4-bar linkage through with reducing its weight during the gait. Rotary actuators are implemented on the knee joints for the extension/flexion movement. Motor drivers are set aside the each links and the main controller which is for analyzing the intent signal and squaring up the phase are attached on the backpack module as shown in the figure 1. It determines the intent signal stages based on the gait analysis of the human-

Fig. 2 Exoskeleton architecture and major component

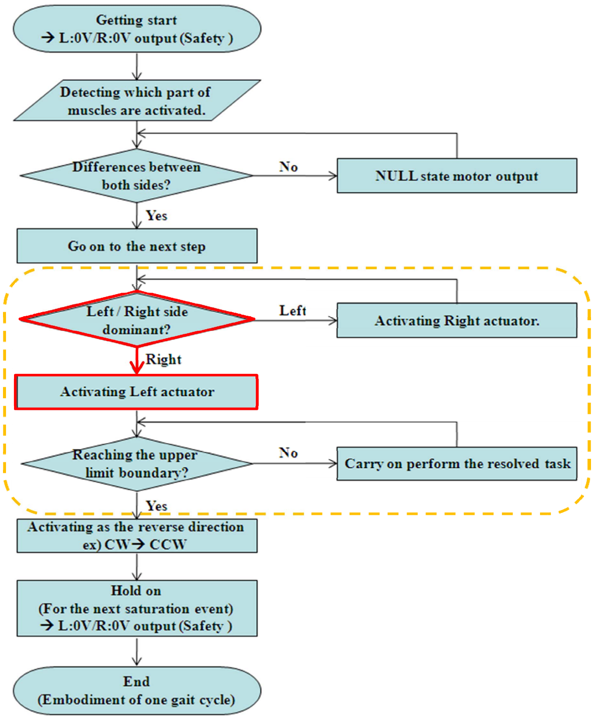

Fig. 3 Control algorithm

body using by MSS (Muscle stiffness sensor) which measure muscle activity and the walking pattern. So, if muscles of the lower limb are activated on the left side, main controller decides that the intent signal of the right side turns on and the same of knee joint onto the exoskeleton is activated by the specific angle displacement. So does the left side in the same pattern. Figure 3 depicts the schematic of the main control algorithm for the behavior.

## 4. DESIGN ARCHITECTURE OF LOWER EXOSKELETON SYSTEM

### 4.1 The Human-Robot Interface Design for Lower Extremities

For use in work sites, the wearable robot for assisting the lower extremity must be used along with a robot for assisting muscular strength of a user's upper body, or must overcome problems relating to load exerted on the lower extremity of the user since a high load is generally exerted on the user and the robot when the user wearing the wearable robot carries the high load. Further, when all joint parts of the wearable robot are active joints including drive units as in a leg of a general robot, the driver units cause an excessive increase in weight of the wearable robot and complicate the configuration thereof, thereby causing frequent malfunction. In this thesis, new type of mechanical system is proposed to solve the problems as described above, and an aspect of the present study is to provide a wearable robot for assisting muscular strength of the lower extremity, which has a reduced weight and a simple structure, and allows a user wearing the robot to experience a reduced load when carrying a high load.

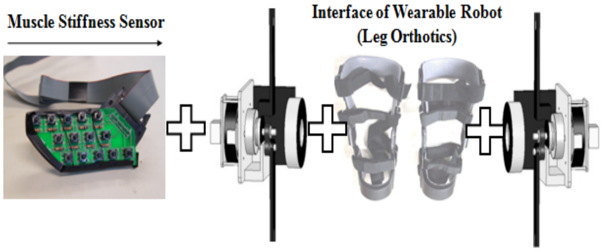


Fig. 4 System Integration for Lower Exoskeleton and HRI System

An appropriate exoskeleton design must take into account comfort considerations for the human-robot interface. Comfort is defined to a very great extent by the biomechanical interaction between user and robot. In addition, the biomechanical interaction will be defined by the combined interaction between the compliant, soft body tissues and the support surface through which forces are transmitted. The factor is an important one to consider in the development of any device that is in contact with the human body. Bodily response to loads is still not fully understood. Pressure is important factor to consider in the development of any device that is in contact with the human body. Fig.4 shows the interface design of lower exoskeleton for lower extremities. Designed muscle stiffness sensor (MSS) is to acquire the signal for the degree of expansion of the muscle and this sensing unit is used to measure the human intense signal to operate the proposed lower exoskeleton system

Fig.5 and 6 shows the attachment position of MSS while wearer and lower exoskeleton is combined. Two units of MSS are used per each leg and considered anatomical meaning of attachment position

### 4.2 Kinematical Structure of Lower Exoskeleton System

Fig.7 is a view of a wearable robot for assisting muscular strength of the lower extremities. In the wearable robot of this embodiment shown in Fig.7, a drive unit is provided only to a knee joint part to rotate an upper-side outer frame and a lower-side outer frame, and thus, a hip joint part is constituted by a passive joint to which such a drive unit is not provided. In Fig.24, the wearable robot includes a central torso harness part (Part (a) + Part (b) of Fig.7), the hip joint part (Part (c) of Fig.24), a femur part (Part (d) of Fig.7), a knee part (Part (e) of Fig.7), and an ankle part (Part (f) of Fig.7).

The torso harness part serves to bridge right and left parts of the wearable robot to each other such that the right and left parts of the wearable robot can be integrally put on the legs of a user, respectively. In order to allow load to be exerted not on the user's body but on the wearable robot for assisting the muscular strength of the lower extremity when the wearable robot is fastened to a robot component for assisting muscular strength of an upper body of the user or is used to carry a freight of a heavy weight, the wearable robot is configured to allow the load to be exerted on the torso harness part.


Fig.5 MSS Attachment Position on the Wearer

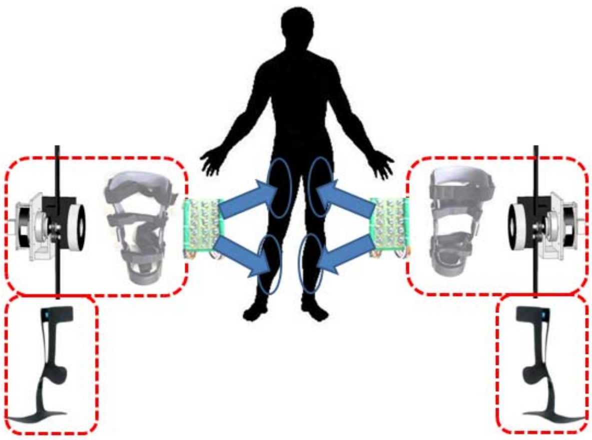

Fig.6 System Integration for Lower Exoskeleton and HRI System

The torso harness part may have various configurations. For example, it may include an upper body wearing portion and coupling members (Part (a) of Fig.7). The upper body wearing portion is provided with a shoulder strap which allows the upper body wearing portion to be carried on the user's upper body like a backpack and further include a belt to improve stability of the robot. Although it is not desirable to fabricate the upper body wearing portion with a rigid material, the coupling members made of a rigid material are fastened to the upper body wearing portion since the torso harness part requires a rigid portion for its application. Each of the coupling members is made of a steel plate in an elongated shape for load distribution, and is longitudinally fastened to the rear side of the upper body wearing portion.

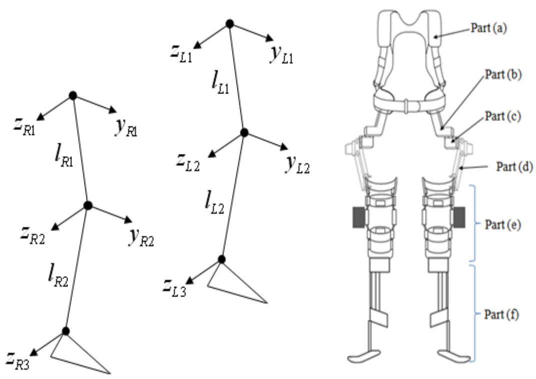


Fig.7 Structure of Lower Exoskeleton System

The hip joint part is a hinge connector disposed between the torso harness part and the femur part, and acts like a human hip joint. The hip joint part is provided to either side of a lower end of the torso harness part and is also fastened to the femur part. The hip joint part is provided to each lower end of the coupling members, which are made of the elongated steel plate.

The femur part connects the hip joint part to the knee part and has sufficient rigidity to allow the femur part to endure load exerted on the torso harness part. In the wearable robot according to this embodiment, since the hip joint part is constituted by a passive joint, the femur part with elasticity is connected to the hip joint part to assist motion of the hip joint part, which is not provided with the drive unit, through the elasticity of the femur part. Further, the load applied to the torso harness part is distributed by the elasticity of the femur part, thereby relieving impact that can be imposed on the robot when a user wearing the robot walks. The femur part can be realized in various forms. For example, it is a four-bar linkage that includes a suitable adjusted spring damper. In this case, the femur part has a suitable rigidity and exhibits superior effect in distribution of load while assisting hinge operation of the hip joint part.

The knee part includes orthotics for human knee interface and an outer frame integrated with a drive unit. The orthotics is directly placed on the user's body and is configured to be located over upper and lower parts of the knee of the user. It is provided with wearing members to secure the orthotics to the user's body. The outer frame of knee part is fastened to the knee orthotics, and is located outside the user's leg. The knee joint part includes a gear. Advantageously, a reduction gear may be provided to the knee joint part in order to reduce backlash of a general gear. To this end, harmonic drive is used for the knee joint part due to superior efficiency.

The ankle part is put on the user's ankle and has an upper end fastened to the lower end of the lower-side outer frame. The part is provided with a bottom flexible part contacting a user's foot sole and the ground. The load of the robot and the load exerted on the torso harness part are distributed through the femur part, the outer frame of knee part and the ankle part while being transferred to the ground through the bottom flexible part, so that a significantly reduced load can be applied to the user's lower extremity. Although an articulation is also located in the ankle on which the ankle part is placed, the ankle part is not provided with the drive unit and is connected to the bottom flexible part through an elastic ankle support of ankle part. When pressure of the foot sole applied to the bottom flexible part is varied by bending the ankle articulation, the elastic ankle support is elastically deformed so as to act as an ankle articulation part. Particularly, the elastic ankle support helps a user wearing the wearable robot to walk by storing and releasing elastic energy through elastic deformation. The wearable robot according to this embodiment also includes a sensor and a controller to operate the drive unit of knee part.

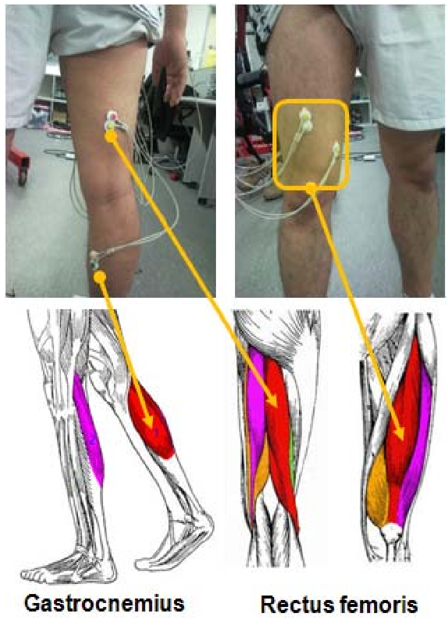


Fig. 8 EMG Electrode Attachment Position to Test the Level Walking Performance

## 5. EXPERIMENT AND RESULT

EMG is typically combined with stride or angular kinematic analysis to provide information on phasic muscle activation patterns. EMG helps explain the motor performance underlying the kinematic and kinetic characteristics of gaits. The experiment is preceded as following steps. First, we obtained the EMG signal of healthy subjects while they walked on a step and a step by carrying the 20kg weight. After that, we asked them to wear the exoskeleton system we developed. The subject then repeated the procedure with the same walking speed. Finally, we gathered the EMG signal history and verified its feasibility.


Fig. 9 Step Walking Test while Wearing the Lower Exoskeleton System with payload

Experiments are set up by four main topics: □ walking on flat with payloads (20kg) and lower exoskeleton, □ walking on flat with payloads (20Kg) and without lower exoskeleton, □ walking on stair with payloads (20Kg) and lower exoskeleton, and □ walking on stair with payloads (20Kg) and without lower exoskeleton (Fig.9). At each experiments EMG signals are gathered by four channels and its sampling frequency and gain value was 1024Hz and 1126.7uV. Those are attached on rectus femoris, vastus medialis, biceps femoris and gastrocnesmius muscle group. Every RMS(Root Mean Square) calculated by EMG signal has tendency to be assisted as shown at the figure below. the signal strength of simultaneous contraction area of Gastrocnemius muscle is reduced. Magnitude of EMG signal have 50% larger value using lower exoskeleton than before. Though system mass is approximately 10kg, muscle activation gets the effects of assisting (Fig.10,11).

## 6. CONCLUSION AND FUTURE WORK

Previously on the experimental result, the feasibility of transferring task oriented exoskeleton is evaluated through the EMG signal analysis – the experiments are arranged by muscle activities with and without lower exoskeleton – soldier on a fair way and a stair way conditions. Although, the proposed mechanism which is contracted by the terminology: quasi – active joints is proper to the exoskeleton in specific objective and purpose, other muscles belong to the gait could be imposed another loads upon wearer's gait. It is from the limitation of the real-time control architecture which is little bit behind the human intent signal, heavy loads which influence different way of weights to the wearer, and having just few parts of locomotion – not full of gait pattern realization.

Even though it was in specific confined condition, minimizing system weights and solving independent electrical power system, the lower exoskeleton system is going to be useful powered harness for individual users. In this study, as compared with normal walking of non-wearing system, the effect of wearing exoskeleton for the loaded walking is verified to be helpful to human.


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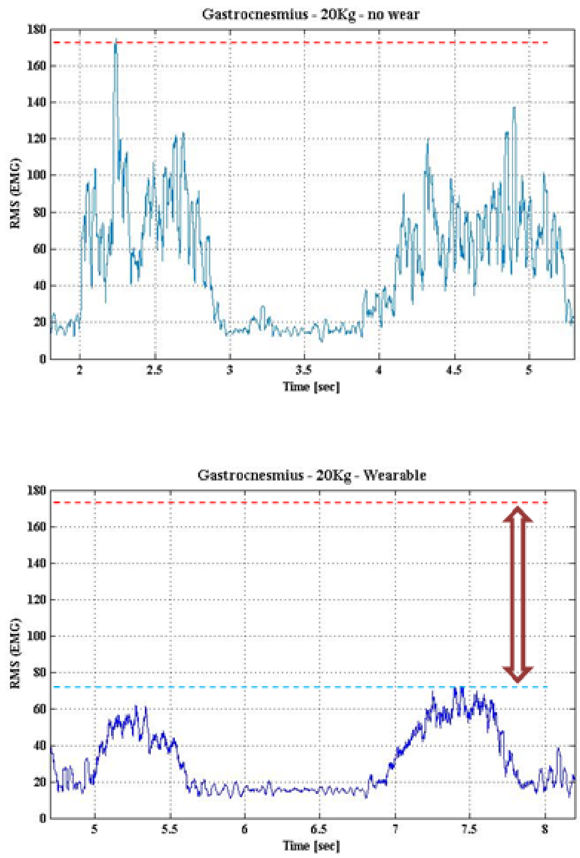


Fig. 10 Difference of EMG(RMS) signal with and without exoskeleton on a fair way condition

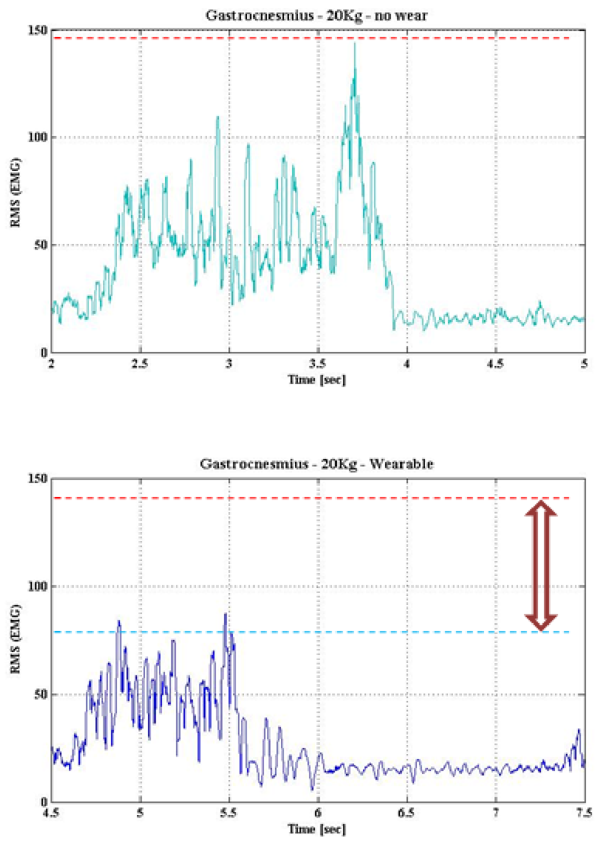


Fig. 11 Difference of EMG(RMS) signal with and without exoskeleton on a stair way condition

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