A System and Method of Maneuvering Powered Exoskeleton Using Mechanical and Hydraulic Feedback

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***Abstract*—This paper describes how to control a powered exoskeleton with motion amplification using mechanical systems, actuators, micro controllers and force sensors and it also explains a method which can be used for sensation and position feedback in exoskeletons. The exoskeleton described in this paper is powered by hydraulics, also this paper describes how we can use this method in a pneumatic powered exoskeleton with least modification. The various majour issues of existing exoskeleton technology and how this method solves those issues are also described in this paper.**

***Index Terms*—powered exoskeleton, mechanical feedback, hydraulic feedback, weight lifting exoskeleton, pressure sensors in exoskeleton, maneuvering mechanism**

I. Introduction

At present there are a wide variety of methods and systems to drive or to control exoskeleton. The main disadvantages of existing exoskeleton technology are power inputting way, accurate and fast feedback of position, feedback of sensation, and cost of production etc. [1]. An aspect of this paper is to address at least the above-mentioned problems and or disadvantages and to provide at least the advantages described below.

Another aspect of this paper is that it describes a design which requires small pressure from the body parts and it uses pneumatic or hydraulics for full body actuation with motion amplification.

In this technique the micro controller unit only controls the motion of exoskeleton, and it doesn't require any position feedback rather the position can be felt directly by user with sensation and the user can control it simply by actuating sensors. This method doesn't use a separate mechanism for feedback of sensation, and the system has a mechanical and electrical connection with actuators and the sensors. Each body part of user produces control signals for corresponding parts in exoskeleton.

Apart from mechanical feedback panto-graph amplification is used for motion amplification. Panto-graph amplification is very common for motion amplification but here this mechanism is used to give position and sensation feedback.

Thus this paper is focusing on motion control, motion and power amplification and feedback of position and sensation for a powered exoskeleton works by pneumatics or hydraulics.

II. Existing Exoskeleton Technology

There are many developers working in the field of exoskeleton. Major researches are going on in the field of Defense, Medical, Industrial and gaming etc. focusing on developing an exoskeleton which can be used to enhance user's existing abilities, rehabilitation etc. The application of exoskeleton is limitless but there are many problems to this development and these are finding a suitable power source for exoskeleton, i.e. the existing battery powered exoskeleton can't run for long time and there are developments going for engine powered exoskeleton but the space limitation and weight are the major issues in the acceptance of these types.

And other issues are flexibility of the design, safety, accurate and fast feedback of position and sensation for real experience for the user etc. Mainly exoskeletons are controlled by electromyography technology [2]. The electric pulses produced by our muscles are detected this will be varying according to the output conditions like load on the body ,speed of motion etc., according to the variations in the pulses, controllers produce controlling signals for exoskeleton to make a synchronized motion with the muscles and it will be almost a linear one

The examples for most advanced exoskeletons aiming to supercharge our lives in the near future are as follows Lockheed Martin H.U.L.C, Cyberdyne H.A.L-5, Muscle Suit by Kobalab, Argo ReWalk NASA X-1 etc. [3].

Manuscript received July 22, 2015; revised February 26, 2016.

doi: 10.18178/ijmerr.5.3.234-238

III. Detailed Explanation of Presenting Method

The following description with reference to the accompanying drawings is provided to assist in a comprehensive understanding of exemplary embodiment's of the method. The exoskeleton design described in this paper is provided with sockets in upper and lower torso, which is used to connect the arms, legs, body of user with exoskeleton each sockets [4] is provided with minimum 4 pressure or force sensors for sensing the attempt of users body to move [5] (Fig. 1 shows the sensors attached to the arm socket) this is when the user tries to move, the sensors produce a signal according to force or pressure developed in the socket connecting users body and exoskeleton.

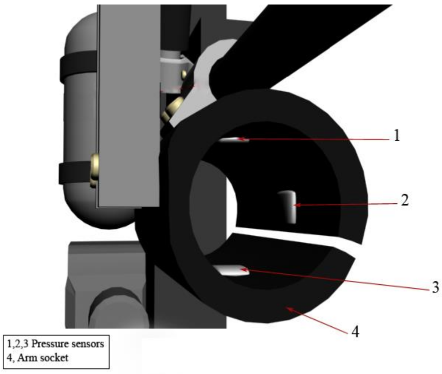

Figure 1. Sensors placed inside the arm socket

The smoothness of system can be increased by providing more sensors in each socket. The sockets and exoskeleton are controlled by respective actuators work by hydraulic principles these actuators can be pneumatic also, which means socket can be only moved by actuators not by user's power, user is only providing a force very small to active actuators through sensors, micro controller, actuators. This will produce a powered motion of exoskeleton according to the user’s movements [6].

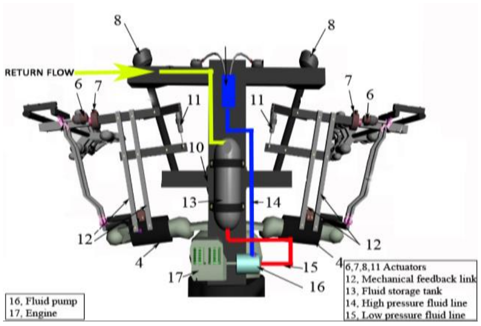

Figure 2. Hydraulic system

There is an internal combustion engine shown in Fig. 2 part 17 coupled with a pump or compressor part 16 to provide high pressure fluids for actuators [7]. The internal combustion engine is provided with adequate cooling mechanism, fuel system etc., for its smooth and efficient running (it’s not shown in Fig. 2). There is lot of space available for these systems since the exoskeleton is bigger than human user and its size can be varied to larger scales. This is achieved by a simple panto-graph mechanism and mechanical links. The user is attached with exoskeleton using links and sockets, initially the exoskeleton parts including sockets are loaded on hydraulic actuators which means the only possible way of moving the exoskeleton is to run the actuators. The overall weight of the exoskeleton is taken by respective actuators and which is directed towards ground through exoskeleton body. The sensors in exoskeleton socket are tightly coupled with user’s body to measure the pressure produced accurately when user tries to move his body parts. These sensors are connected to a micro controller which produce control signals and operate the solenoid valves [8], For the voltage to the solenoid valve, we have a separate ac generator (not shown in Fig. 2) coupled with engine. The controlling of solenoid valve is done by controlling the AC voltage or current going in to solenoid valves by using switching devices such as Opto coupler, MOSFET, thyristor etc. (power electronic devices) by micro controller. Here the flow of fluid is controlled by controlling on and off time of solenoid valves according to the sensor inputs.

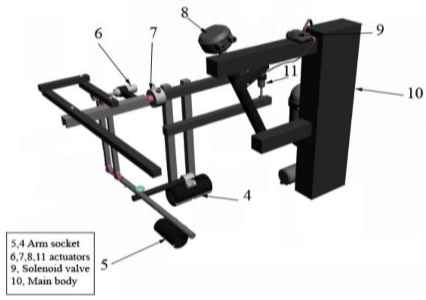

Figure 3. Arm skeleton and actuators

A. *Working of Upper Torso*

The Fig. 3 shows the working of upper torso arm skeleton structure the user wear the arm sockets [4] and [5], these sockets contain sensors to measure the pressure produced by user's hand while user tries to move his arm. At least 4 sensors required to measure the pressure and direction.

Let’s now consider only the part 4 upper arm socket (Fig. 1 shows the upper arm socket and sensors) used to control the motion of the upper arm. The socket and exoskeleton body will be always loaded on actuators so the user doesn’t feel any pressure at the beginning of motion. When he tries to move his upper arm for example when user tries to move his upper arm downward (other possible motions upward, towards front, towards back and combination of these. this is not pure transitional rather rotational about shoulder point. According to pressure sensors, this seems to be always normal to it (since the pressure sensors always remain in parallel to the human body) the pressure sensor [3] (it can be force sensor also), the one which is used to check the downward pressure produce corresponding signal since it was a pure downward movement about shoulder point all other sensors read nothing. This signal is fed to a micro controller which operates the switching circuit that controls the actuator 1 used for up and down motion of exoskeleton and move the exoskeleton arm. When we stop our motion, the pressure sensor read zero this reading will make micro controller to stop the fluid flow to actuator by cutting down the voltage supply to solenoid valve and there by closing the flow. When we go in to details consider the pure upward motion let the exoskeleton arm carrying a load W kg now the user tries to move his arm upward there develop a pressure in the upward sensor 1 in Fig. 1, sensor produces a signal according to the pressure which makes micro controller to trigger the switching circuit and start a controlled flow to the actuator 1 by switching the solenoid valve on and off accordingly. But due to the weight, there won’t be an acceptable speed for exoskeleton arm rather the process become slow this also slows down the socket movement but as the user tries to move the socket up at a desired speed, makes the user to push the socket at comparatively higher pressure this would further increase the pressure input to socket which results in a small increase in load acting on users body according to the output load, this new input to micro controller will produce corresponding signal in output which will increase the flow of pressurized fluid there by making the actuator to take W load and makes a synchronized movement of exoskeleton arm with users arm movement. This synchronous movement provides a constant output from the force sensors and which make a constant output flow or pressure. If user tries to slow down the motion of his hand the initial pressure sensor reads zero and its opposite direction sensor reads a value corresponding to the retardation of users arm. Corresponding output of micro controller cause fluid to flow according to the input pressure to reverse the motion of exoskeleton.

By controlling the flow, we are actually controlling the pressure. This pressure is actually used to lift the output load. Since the fluid pressure or flow is controlled by the pressure sensor attached to the arm sockets and the pressure in socket is increased or decreased according to the output load condition on exoskeleton arm because of direct links attached to the exoskeleton and sockets, the user experiences a feel of sensation of loads acting on the exoskeleton arm. This feel of sensation can be varied according to the micro controller programming. If microprocessor is programmed such a way that a large increasing in output flow according to a small pressure variation in pressure sensors, will produce small sensational changes according to increase in output load. This is called mechanical feedback of sensation, without any separate mechanism for sensation feedback.

Now the direct mechanical connection between the exoskeleton arm and user arm also provide a physical experience to user about the exoskeleton arm position. This will help the system to work without a position feedback. Rather the system will stop automatically when it reaches the required position.

The other two sensors for forward and backward motion used to control the forward, backward motion of exoskeleton about shoulder point using the actuator [8]. There is a body socket with pressure sensors which is wrap around users chest is used to balance the exoskeleton by driving the actuator's 34, 35, 36, which control the upper torso's inclination there by the center of gravity of the body. The forearm of the exoskeleton is also controlled by the same manner as mentioned above therefore it is connected to the forearm socket [5] with four pressure sensors for its actuation.

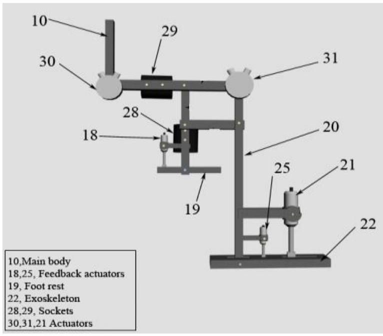

Figure 4. Foot mechanism

B. *Working of Lower Torso*

Fig. 4 shows main parts used in the lower torso, sockets 28, 29 are used to connect the user's lower leg and thigh to the exoskeleton. This socket contains sensors minimum number of 4 to read the pressure and direction of users movement. The sensors inside the socket are loaded on exoskeleton body. The user leg is not loaded by the weight of exoskeleton rather it is absorbed by the exoskeleton itself. When the user tries to move his leg, the sockets provide resistance to the motion where by this combined effect produce an increase in pressure in the socket area. This is sensed by pressure sensors inside the sockets which provide corresponding signals regarding the amount of pressure and the direction. The four sensors (minimum) placed in such a way that to measure the direction in a two dimensional, like two are used to measure up and down and two are used to measure left or right and the combination of pressure sensor readings indicate a combined directional motion. According to this input micro controller produce controlling signals which triggers the switching circuit and controls the ac voltage to the solenoid valve which controls the flow or pressure delivering the actuators. When motion stops the pressure sensors read a zero value which stop the flow by micro controller and stay loaded on actuator until user again tries to move. And if the exoskeleton got weight more than usual the user need to provide comparatively higher pressure to the sensors for moving since normally no load pressure and corresponding micro controller output is not enough to move the exoskeleton leg in desired speed. The decrease in motion velocity produces higher pressure in sockets and in pressure sensors. This higher pressure produce higher output flow by micro controller and take the load since the user tries to move at a desired speed, which move the exoskeleton leg in desired speed.

Since this also works in similar to the upper torso the mechanical connection between the user and exoskeleton provide the user a sense of position and sensation of the exoskeleton body. So this system doesn't require a separate system for position, sensation feedback.

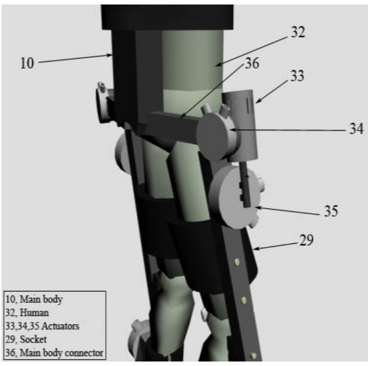

Figure 5. Thigh boosting mechanism

C. Working of Thigh Boosting Mechanism

Fig. 5 shows thigh boosting mechanism. This mechanism is used for the thigh joint for its 3 degree of rotational motion [9] there are three separate motion generator (actuator's 33, 34, 36) for each degree of motion, which runs according to the micro controller that controls the solenoid valves to each actuator's according to the sensor inputs from different sockets attached to the user. These actuator's control the inclination of the upper torso relative to lower torso. This inclination is the main factor for the position of center of gravity of exoskeleton, which balance the exoskeleton. The sensational feedback from each sockets which control the thigh boosting actuator's will produce a feel of balance to the user and user can balance the exoskeleton by his own body movements according to the unbalance occurs in normal motion just like how human being balance his own body.

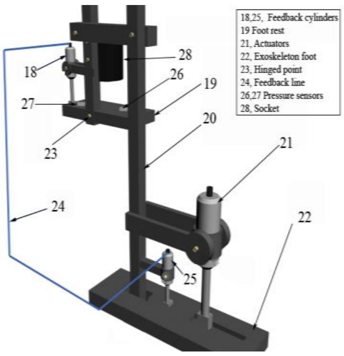

Figure 6. Hydraulic feedback system

D. Hydraulic Feedback and Boosting System Used in the Foot

Fig. 6 shows the hydraulic feedback system. The feedback system works as follows refer Fig. 6 the piston cylinder assembly 18 and 25 are connected through a hydraulic fluid line shown as Part 24. There must be a minimum of two sensors required [10] to be used in foot rest [1], [9] where user sets his foot, one for clockwise motion detection about the point [2], [3] and the other for anti-clockwise motion. This motions are necessary for walking. In anticlockwise motion the sensor 27 shown in Fig. 6 reads a pressure according to user's requirement of motion according to this pressure the micro controller will produce a corresponding output flow to the actuator 21, and this produces a movement of piston to move the exoskeleton foot in clockwise direction about point where its hinged (not shown in Fig. 6). The piston inside the actuator 25 goes down produces a vacuum in hydraulic feedback line 24 which is connected with actuator 18 this makes the piston of this actuator to move up there by moving the foot rest in the desired direction of user which decrease the pressure in the sensor and decrease the flow, the process occurs almost in synchronization with the user's movement if there is no higher loads in the exoskeleton foot. If it is loaded the foot rest won't move at desired speed with normal pressure used to move at no load. Due to the hydraulic feedback with the loaded exoskeleton foot, it requires more flow and pressure than no load. So the user has to increase the pressure applied for desired speed which produce a high flow and pressure to actuator which move the foot faster, so this hydraulic feedback between exoskeleton foot and user foot rest provide a physical connection to user regarding the exoskeleton foot position and the load is applied on the exoskeleton .So we don't require an additional system for the position ,sensation feedback ,when user move his foot in anti-clock wise direction the sensor 27 read comparatively high pressure according to this reading the micro controller operates the corresponding switching circuit and solenoid valves (including the return flow solenoid valve) for the motion of actuator piston to move up. This produce a anti clock wise motion of exoskeleton foot. If the system is loaded the hydraulic feedback helps to increase the flow or pressure at the output accordingly.

Figure 7. Prototype of the exoskeleton works by the mechanical feedback

E. Results after Fabrication

We succeeded in developing a prototype according to the method explained above and its shown in Fig. 7. From the prototype we understood that the system is stable, we doesn't require a separate gyroscopic mechanism for stabilizing the exoskeleton for walking on two feet, and there is a large space available for placing an on-board engine and its different subsystems such as cooling system, fuel system etc., without losing the center of gravity point.

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