WHOLE BODY ACTIVE EXOSKELETON FOR HUMAN EMBODIMENT IN VIRTUAL ENVIRONMENT

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Abstract: In this work, the development of a human whole body active exoskeleton is presented. Exoskeleton system is designed for embodiment in immersive virtual reality (IVR) where it is allowing human to perceive forces at different body parts or the weight of lifted objects. The choice of a mechanical structure is shown equivalent to the structure of the human body. A drive system is described based on braided pneumatic muscle actuators and antagonistic drive scheme for each joint. A control algorithm is presented as a distributed control scheme.

Keywords: Exoskeleton, haptic device, embodiment, virtual reality.

1. Introduction

Exoskeleton is outside wearable robot with joints and limbs corresponding to those in the human body. Exoskeleton transmits torques to human joints by actuators. Exoskeletons are used for four basic functions according to the control algorithms [1]: a) rehabilitation – fit closely to body, fulfils tasks of physical therapy in an active or passive working mode; b) Haptic device – the subject physically interacts with virtual objects, as the interaction forces are applied by the exoskeleton actuators; c) Master device – for tele-communication robot control „master-slave” as the interaction forces are applied to the slave exoskeleton from moving the master; d) Assistive device - human body amplifier, operator feels lighter the loadings, accepted by the exoskeleton.

Haptic devices allow to perceive and transmit motion and forces to real or virtual entities stimulating the somatosensory system, and indeed the participation of the user in the immersive virtual reality.

The role of the haptic feedback component is to provide the physical interaction. Several elements are identified [2] that contribute to the overall haptic feedback:

- proprioceptive feedback: information about the position of our body parts and their movements;
- kinesthetic feedback: information about the forces applied to the body;
- tactile feedback: information covering the touch with surfaces;
- vestibular feedback: perception of the gravity vector.

In scenario when the participant is moving, most important is the kinesthetic feedback. Kinesthetic feedback enters into action during the exchange of forces between the user and the virtual environment. For the purpose of embodiment the haptic interface should be capable of affecting the whole body allowing to perceive
forces at different body parts, simulate different terrains, or the weight of lifted objects.

For providing a higher level of embodiment by means of multiple points of interactions researchers have investigated haptic exoskeletons, applied to hands, arms and legs. Arm exoskeletons can simulate large forces at the hand or arm, like the weight of an object that is held [3]. Lower-limb exoskeletons are also currently being developed in addition to the usual military and medical applications. The fundamental purpose of this type of exoskeleton is to compensate the lack of force in the joints and to support the user’s body weight [4]. The exoskeletons described above can be combined to more complex total systems as full body exoskeletons like Japanese Exoskeleton "Robot Suit HAL" [5].

The objective of the work is to presents a new human body force-feedback exoskeleton system with a wearable structure and anthropomorphic workspace that can cover the full range of motion of the human body. The exoskeleton system is designed for application where both motion tracking and force feedback are required, such as human interaction with virtual environments.

2. Exoskeleton of human body as haptic device for embodiment in virtual environment

The exoskeleton of human whole body have to include an exoskeleton for upper limbs as a haptic device providing force feedback of the limbs at interaction in a virtual reality; an exoskeleton for the torso and lower limbs that will support the upper limbs and sets of the virtual avatar movements as well as change of the position in the space. A general view of virtual embodiment system is shown on Fig.1.

![Fig. 1 Virtual embodiment system- general view](image)
In immersive virtual reality (IVR) [6] the system will give the people the illusion that they have a different body. They will wear a head-tracked head-mounted display (HMD), and when they look down towards themselves they will see a virtual body that is spatially coincident with their real body. Through real time motion capture when the person moves their real body they will see the virtual body move correspondingly. They can also see this in a virtual mirror reflection (Fig.2) of their body as well as looking directly towards it.

A IVR system has two critical components. The first is a display device (HMD), that delivers surrounding high-resolution stereovision. The second is the use of Head Tracker (with six degrees of freedom) in real time. There is a third critical system, which is a full body motion capture device [6], used to drive in real time the virtual body. The role of motion capture device is performed by human body exoskeleton through exo optical tracking constellation or through body parts position sensors.

Where a virtual body is spatially coincident with a real body, human see through the eyes of that virtual body. The term ‘embodiment’ is used to refer this setup. In an embodiment system we can identify two key roles: the participant and the avatar. The participant is the human subject that is going to experience the avatar world by means of the body of the avatar. The avatar is a virtual body that interacts in a totally virtual environment generating perceptual stimuli from the virtual model. Human virtual body (avatar) as a component of the virtual word is a product of computer graphics as it is shown in Fig. 2.

Fig. 2 Virtual human body (avatar)
3. Mechanical structure and actuation system

The exoskeleton is build-up of a branched serial kinematics structure consisting of rotational joints kinematics equivalent to the structure of the human body. The choice of a solution of mechanical structure kinematics equivalent to the structure of the human body with sufficient dof is done as it is shown in Fig. 3 a). It includes three basic segments: left and right upper limb, left and right lower limb and exoskeleton structure corresponding to human torso and waist. The exoskeleton structure is constructed primarily from aluminium and plastic materials, with high stress joint sections from steel. Based the structure scheme shown in Fig.3 a), a CAD solution of the whole body exoskeleton is created using Solid Work software package (Fig.3 b).

The actuation system uses braided pneumatic muscle actuators (PMA). These actuators provide a low cost actuation source with a high safety due to the inherent compliance. Self-made actuators are used since it permits greater control over the dimensions, forces and general performance. Joint motion/torques on the exoskeleton joints are achieved by antagonistic torques through cables and pulleys driven by pairs of pneumatic muscle actuators. All actuators are mounted on the body brace behind the operator’s back through force measurement loading cells.

![Fig. 3 Whole body exoskeleton:](image)
a) mechanical structure; b) CAD solution.
4. Control of the exoskeleton system

Control of the exoskeleton system is built as a Distributed Control Scheme (Fig. 4). The exoskeleton contains multiple Micro-controller units (MCUs) which communicate with the Master controller through standard Two Wire Interface (i2c) communication protocol and perform the following tasks for each joint: actuation, sensing, signal processing and control.

MCU are connected to sensors and actuators by a set point control loop consisting of a force sensor, controller, and control valve. Positional and force measurements are transmitted to the controller, through the aid of a signal conditioning input/output (I/O) device. The MCU sends discrete output signals to the pneumatic valves which are 2 state either on or off. Control algorithm perform the following steps:

a) the position sensors of the prototype joints provide information for the joint angles rotation in real-time and sends it to Exoskeleton C++program. This program transfer the data through the internet by UDP protocol in order to mapping the Avatar in the virtual reality; b) the avatar in the virtual reality may perform an action or movement and thereby activate the corresponding limb sending new information about forces applied to the end effector; c) the control algorithm analyses the motion and received information and decides on appropriate action - corrections of the joint position or new orientation of the body; d) the tactile and force sensors detect the actuators forces (joint torque) and send the appropriate signals to the control system realising joint torque control implemented on each joint.

![Fig. 4 Distributed control scheme of the exoskeleton](image-url)
5. Conclusions and future work

In this work, the development of a human whole body exoskeleton is presented. Exoskeleton system is designed for embodiment in immersive virtual reality (IVR) where it is allowing human to perceive forces at different body parts or the weight of lifted objects. The choice of a mechanical structure is shown equivalent to the structure of the human arm. A drive system is described based on braided pneumatic muscle actuators and antagonistic drive scheme for each joint. A control algorithm is presented, which allows the use of two alternative control strategies for the execution of robot-in-charge and patient-in-charge exercises. As a future work, the control algorithm to be completed, the integration for the embodiment and control of exoskeleton through the virtual reality to be finished.

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References:

ЕКЗОСКЕЛЕТОН НА ЧОВЕШКОТО ТЯЛО ЗА ОЧУСТВЯВАНЕ ПРИ РАБОТА ВЪВ ВИРТУАЛНА СРЕДА

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Резюме: В настоящата статия е разгледано създаването на активен екзоскелетон на човешко тяло. Той е предназначен за очувствяване при задачи с пълно потапяне във виртуалната реалност (IVR), където човека възприема въздействията на виртуалните обекти върху различни части от тялото. Механичната структура е избрана да е еквивалентна на структурата на човешкото тяло. Задвижващата система е с изкуствени пневматични мускули и въжени предавки в антагонистична схема за всяка става.

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