Hydraulic actuation of exoskeletons - state of the art and prospects

Abstract

Exoskeleton technology appreciates rising sales and rumors are circulating about more use of hydraulic actuation in future. This paper gives general requirements on exoskeleton actuation technologies and concludes that only new hydraulic principles have a chance to fulfill the extremely challenging requirements. The digital hydraulic cylinder and its control by a hydraulic binary counter are briefly presented as one promising principle.

Keywords: exoskeleton, hydraulic actuation, digital hydraulics

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Introduction

Exoskeletons[1] are defined as devices worn outside of human limbs, to enhance power, force, durability, or load carrying capacity of a person or to regain lost or weak limb functionality. A complete exoskeleton has structural elements, joints, actuators creating support for the human motion and movement intention recognition devices. Market is expected to increase substantially; for medical exoskeletons[2] gives a growth expectation of $16.5 million in 2014 to $36.5 million in 2015 and $2.1 billion by 2021. High wearing comfort is the key requirement for all types of use, currently hardly being met by any exoskeleton. Efficiency of the actuation systems is crucial for that comfort to make size and weight of energy sources and prime movers low and operating time high. Therefore, light weight and compact actuators and power supply system are essential. In[3] acceptable weights are seen in the ranges of portable consumer electronic devices for the hand, or of a backpack for the spine or hip. A major behavioral property is to emulate the natural human motion. Human walking, for instance, has a strong passive portion. Power is transferred from the ankle joint to other body segments.[4] The free swing of the shank should be facilitated by releasing the knee joint actuator, thus, back-drivability and low inertia of the actuation system are important.

Discussion

In a literature survey on exoskeletons in summer 2016 from approx. a thousand papers only 63 were dealing with hydraulic drives and 151 with electro-mechanical drives. Hydraulic actuation was quite prominent in the beginnings of exoskeleton development; examples are BLEEX,[5,6] and XOS 2.[7] Both use resistance control by servo valves for control which keeps peripheral masses low at the cost of low efficiency. Hydraulic actuation concepts discussed in[8,9] employ displacement control principles which have lower losses but are dynamically less preforment. The system described in[8] uses a variable speed electrical motor in combination with a constant displacement pump for the actuation of ankle prosthesis, the ELBOT lower limb exoskeleton,[9] instead, a switching concept in combination with displacement control. In[10–12] switched inheritance type hydraulic control for a quadruped robot is investigated.

For fast human walking a peak power of 760 watts for the knee joint is found in,[13] proper electrical motors weigh approx. 1 kg.[14,15] Electromechanical concepts require a gear and one drive per joint. The average power of a joint is small; one motor could supply several joints if, e.g., a hydraulic system controls each joint; that gives considerably lower total weight. Hydraulic valves overall size and weight is dominated by its electric valve actuators (solenoids).[13] In[13,16] a digital cylinder actuator with four active chambers for the knee joint is studied for a squat and for fast walking. To minimize weight, the four on-off valves for the chambers are controlled hydraulically by a so called binary counter, originally presented in.[17] Simulation studies show an excellent energetic performance including also energy recuperation. This keeps overall energy consumption low and saves weight of battery and electric motor. The actuator weighs about 400 grams with a prospect of weight reduction using high strength plastics for some structural parts. It can generate knee torques for fast walking as well as full back-drivability, both impossible with electromechanical drives even having a multiple weight.

Conclusion

In view of the most demanding requirements for exoskeletons – low weight and distal space – the high force and power density give hydraulic actuators a great prospect to become the prevailing actuation technology. This, however, requires new concepts and components. They must have high energy efficiency and the ability to recuperate and store small amounts of energy. Digital cylinder drives are one option since they provide lossless actuation. New hydraulic components for the sub-kilowatts power range, extremely light and compact, have to be developed. Innovative methods of valve actuation to reduce weight of electric actuators have to be found.

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Conflict of Interest

The authors declare there is no conflict of interest.

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