Pleated Pneumatic Artificial Muscles for Robotic Applications

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Abstract— **The presented work describes the implementation of Pleated Pneumatic Artificial Muscles (PPAM) into novel robotic applications. These actuators have a very high power to weight ratio and an inherent adaptable compliance. In this presentation two applications for which these characteristics give interesting surplus values will be described.**

Nowadays legged robots are gaining more and more interest. But most of the robots built use heavy electrical drives making these machines heavy and power demanding. An actuator, such as the PPAM lowers the robot weight and the adaptable compliance of the muscles can be exploited to reduce energy consumption. In order to substantiate the benefits of the PPAM, the two-dimensional walking biped "LUCY" has been built.

Manipulators are robots which interact with humans to support them with some heavy-duty tasks. The compliance of the PPAM can assure a "soft-touch" while interacting with the robot. Moreover is it possible to estimate exerted force and torque values by measuring the applied gauge pressures in the different artificial muscles. This provides an important tool to generate manipulator force and torque feedback without expensive and complex sensor devices.

Keywords—**Novel Pneumatic Actuator, Legged Robots, Manipulators**

I. The Pleated Pneumatic Artificial Muscle

A pneumatic artificial muscle is, essentially, a membrane that will expand radially and contract axially when inflated, while generating high pulling forces along the longitudinal axis. Different designs have been developed. The best known is the so called McKibben muscle. This muscle contains a rubber tube which will expand when inflated, while a surrounding netting transfers tension. Hysteresis, due to dry friction between the netting and the rubber tube, makes control of such a device rather complicated. Typical of this type of muscles is a threshold level of pressure before any action can take place. The main goal of the new design was to avoid both friction and hysteresis, thus making control easier while avoiding the threshold. This was achieved by arranging the membrane into radially laid out folds that can unfurl free of radial stress when inflated. Tension is transferred by stiff longitudinal fibres that are positioned at the bottom of each fold. The generated force is non-linear and proportional to the applied gauge pressure in the muscle and the initial length squared. Slenderness of the muscle determines the force characteristic. At a pressure of 3 bar the force can be as high as 4000N for a device with an initial length of 10cm and weighing only 100g.

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II. The PPAM for legged robots

Not so long ago legged robots were exclusive topics for science-fiction movies and the imagined world of children. But recent developments indicate that these machines will become full-fledged robots in near future. One example is the Honda Motor Corporation, that developed the Honda Human Robot followed by its successors P1, P2 and recently ASIMO focusing on the field of domotics. In the leisure industry the Sony company already made one commercially available four legged robot, AIBO, and a humanoid robot SDR-4X will become available soon. But also legged robots for industrial use are increasingly gaining interest, e.g., the Spanish climbing robots for the maritime industry. Since a few years the Japanese government together with most of the leading Japanese manufacturers are investing heavily in the HRP-project. This project tries to create ready-to-use industrial, domotic and health-care applications for humanoid robots.

But in spite of the magnificent models already created a lot of research in many different fields ranging from artificial intelligence to mechanical design is still needed. One of the topics is the implementation of novel actuators, such as the PPAM, replacing the widely spread electrical drives, in order to make lightweight structures and compliant joints. Compliance characteristics can be used to reduce impact and energy consumption.

The Biped "LUCY" is a two dimensional walking robot with two articulated legs and a armless body. This robot has been built at our department to create a test bed for the evaluation of the PPAM implemented in legged robots. This research is focused on the exploitation of the adaptable compliance present in a joint actuated by two artificial muscles. One can show that joint position is determined by pressure differences in both muscles while the stiffness of a joint is characterized by the sum of pressures. This means that stiffness can be changed while still controlling position. The adaptability of compliance is very important regarding energy consumption and control efforts. The strategy is to select appropriate stiffness parameters in the different joints in order to adapt the natural dynamics of the robot to an imposed desired motion. Moving within the natural dynamics of a system would only need energy to overcome friction, while each motion deviating from this situation would require more energy input and control effort.

Presently the robot is in its assembly and debugging phase. With basic implemented control strategies "LUCY" is already able to make her first steps and walk very slowly, which can be seen on our website http://lucy.vub.ac.be/.

III. The PPAM in a Manipulator Application

Repetitive manual handling of heavy loads is common in assembly and is a frequent cause of lower back disorders. This can have a significant impact on the quality of life and has a serious economic cost. Manipulators are robotic systems designed to avoid these problems. They assist people in performing heavy-duty tasks.

Most of the commercially available manipulators use a counterweight, which limits their use to handling loads of a specific mass. Others are electrically or hydraulically actuated. This usually makes them heavy, complex and expensive.

The use of the PPAM actuator allows us to tackle these issues and develop a manipulator that combines ergonomics, operator safety, low cost, low weight and ease of operation.

The goal of our research is to develop a manipulator that will be used in direct contact with an operator, without expensive force or torque sensors and without user interaction through control elements (such as joysticks). We are working towards a system that behaves as follows: when the operator wants to move a load attached to the manipulator, he/she starts moving it as if there were no manipulator. By measuring the muscle gauge pressures, the system can estimate the forces applied by the operator and assist him in accomplishing the desired load movement. Ideally, moving a 30 kg load would feel like moving a 3 kg load. The direct interaction between operator and load (without intermediary control tools) allows for precise positioning.

The main requirement for any mechanical device that is used in the immediate environment of people is safety. The PPAM actuators greatly contribute to the overall safety of the manipulator system: they allow for a lightweight construction, there is no danger of electrocution and, most important of all, the muscles are inherently compliant. The controller will also enhance safety, since there is no fundamental difference between forces generated by a collision and forces applied by an operator. The system will always tend to move away from people or objects it collides with.

At present, the hardware setup of a small-scale manipulator is nearing completion. It consists of two PPAM actuated links in inverse elbow configuration. After initial testing, implementation and evaluation of control strategies will start.