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Pleated Pneumatic Artificial Muscles for Robotic Applications

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***Abstract*— This work describes the implementation of Pleated Pneumatic Artificial Muscles (PPAM) into innovative robotic applications. These actuators have a very high power to weight ratio and an inherent adaptable compliance. Two applications for which these characteristics give interesting surplus values are described.**

Nowadays legged robots are gaining more and more interest. But most of the robots use electrical drives making these machines heavy and power consuming. 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, a two-dimensional walking biped ”LUCY” has been built.

For robot manipulators, which interact with humans to support them with some heavy-duty tasks, the compliance of the PPAM can assure a ”soft-touch”. Moreover it is 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.

***Index Terms*— Pleated Pneumatic Artificial Muscle, Legged Robots, Manipulators**

I. THE PLEATED PNEUMATIC ARTIFICIAL MUSCLE

A pneumatic artificial muscle is, essentially, a membrane that expands radially and contracts 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 (Fig. 1) 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 graph in Fig. 2 gives the generated force for different pressures of a muscle with initial length 11 cm and unloaded diameter 2.5 cm. Forces up to 5000 N can be generated with gauge pressure of only 300 kPa while the device weighs about 100 g. At low contraction, forces are extremely high causing excessive material loading, on the other hand the generated forces drop too low for large contraction. Thus contraction will be bounded between two limits, 5 and 35 %, in practise.

Fig. 1. Photograph of 3 contraction levels of the PPAM

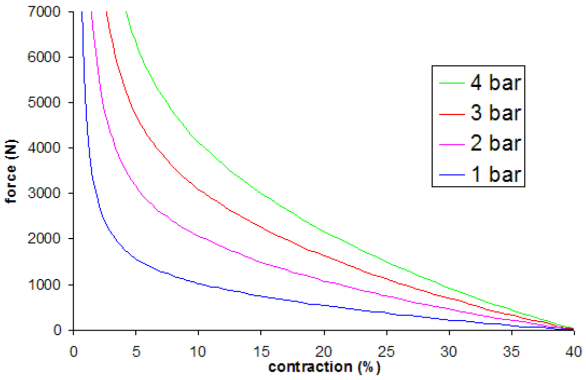

Fig. 2. Generated forces of the PPAM

The artificial muscles have specific properties that are of special interest in the field of legged robots and manipulators operating in direct contact with a human:

- High torque/weight and power/weight ratios

- The actuator can be positioned at the joint without complex gearing mechanisms
- Adaptable passive behaviour suited for energy storage (Muscles' natural compliance)
- Shock absorbance during impact.

II. THE ANTAGONISTIC SETUP

Pneumatic artificial muscles can only pull. In order to have a bidirectionally working revolute joint one has to couple two muscles antagonistically. The muscle connections -pull rods and lever mechanism- were designed such that the muscle highly non-linear force-length characteristic is transformed to a more flattened torque-angle characteristic. 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.

III. THE PPAM FOR LEGGED ROBOTS

Bipeds can be divided into 2 main categories: on one side the fully controlled robots, like Asimo [1], Qrio, HRP-2 [2] and on the other side the "passive walkers" using minimal little actuation just enough to overcome friction when walking over level ground like the Cornell biped, Delft biped Denise and MIT robot Toddler [3].

The main advantage of the last group of robots is that they are highly energy efficient but unfortunately they are of little practical use. They have difficulties to start, they can't change their speed and cannot stop. But completely actuated robots consume a lot of energy.

The goal is to develop a robot with the advantages of both categories. The idea is to adapt the natural dynamics as a function of the imposed trajectories. Therefor joints with adaptable compliance are needed. Electrical drives need a gearbox to produce enough torque at low angular velocities which make the joint stiff. Pleated Pneumatic Artificial Muscles are chosen because in an antagonistic setup the compliance is controllable [4].

The biped "LUCY" (Fig. 3) is a two dimensional walking robot with two articulated legs and a body [5]. The movement of Lucy is restricted to the sagittal plane by a guiding mechanism. The goal of the biped project is to build a lightweight bipedal walking robot able to walk in a dynamically stable way while exploiting the adaptable passive behaviour of the pleated pneumatic artificial muscles in order to reduce energy consumption and control effort. The complete robot weighs about $33kg$ and is $150cm$ tall. The robot has 12 pneumatic actuators for 6 DOF's.

The control architecture consists of the joint trajectory generator and the joint trajectory tracking controller [6]. The trajectory generator calculates polynomial trajectories based on objective locomotion parameters, which are average forward speed, step length, step height and intermediate foot lift [7]. The joint trajectory tracking controller is divided in three parts: a computed torque module, a delta-p unit and a bang-bang pressure controller. The trajectory planner, computed torque module and delta-p unit are implemented on a central computer; the bang-bang controller on a micro-controller. Every joint has its own 16-bit micro-controller (MC68HC916Y3 made by Motorola). The used sensors are the HEDM6540 incremental encoder for reading the joint position and velocity and two pressure sensors inside each muscle. A seventh microcontroller measures the absolute position of the upper body, detects ground contact and measures ground reaction forces to calculate the Zero Moment Point. The communication system between computer and microcontrollers uses the USB 2.0 high speed protocol and has a sample rate of 2000Hz.

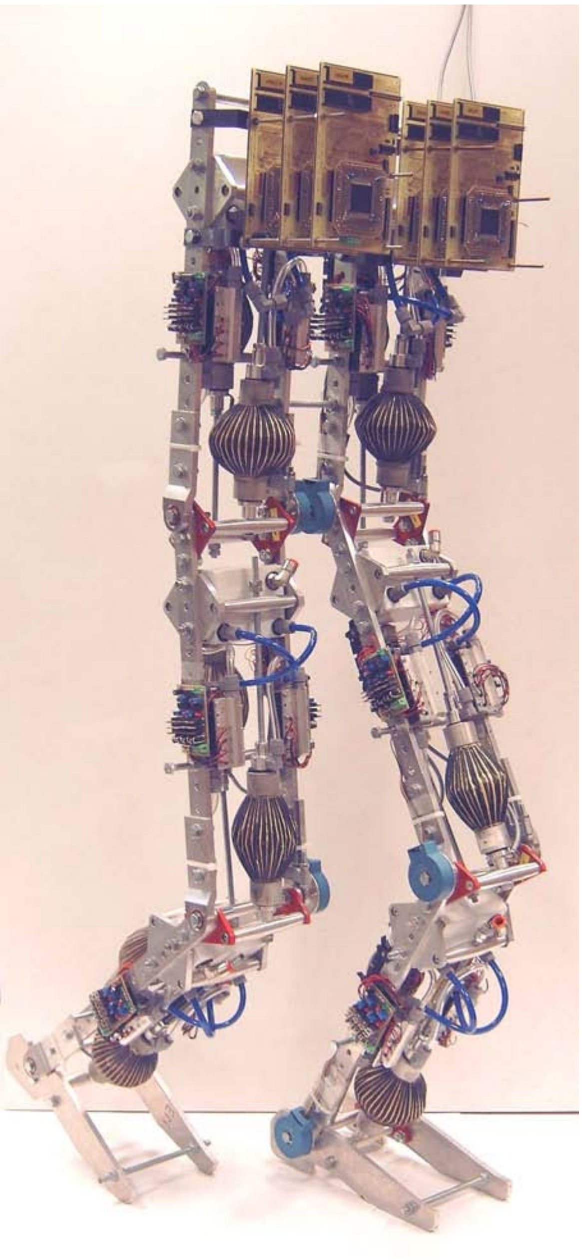

Fig. 3. Photograph of Lucy

Currently the robot is able to walk at different speeds and step-lengths. A video of the walking robot can be seen in the video-submission “Pleated Pneumatic Artificial Muscles for Robotic Applications” and at our website **http://lucy.vub.ac.be**. The guiding mechanism is limited in length, so a treadmill is used to be able to walk longer distances. Hybrid simulations, where both the pneumatics and mechanics are put together in a dynamic simulation, show that with the current control strategy higher walking speeds are possible [8].

Strategies to adapt the compliance to exploit the natural dynamics of different walking patterns, are currently under development. The idea is to fit the controllable actuator compliance to the “natural” compliance of the desired trajectory, and combine that with trajectory tracking control. The compliance adaptation strategy is not yet implemented for the robot Lucy, but some experimental results on a one DOF pendulum structure clearly show the effectiveness and importance of the adaptation strategy [9].

IV. THE PPAM IN A ROBOTIC MANIPULATOR APPLICATION

Repetitive manual handling of heavy loads 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. Robotic assistants helps people in performing those 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 to develop a manipulator that combines ergonomics, operator safety, low cost, low weight and ease of operation.

The goal of the research is to develop a manipulator (Fig. 4, [10]) 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). The system will behave as follows: when the operator tries 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 detects and estimates the forces applied by the operator and assists him in accomplishing the movement of the object. 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 human environment is safety. The PPAM actuators greatly contributes to the overall safety of a 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.

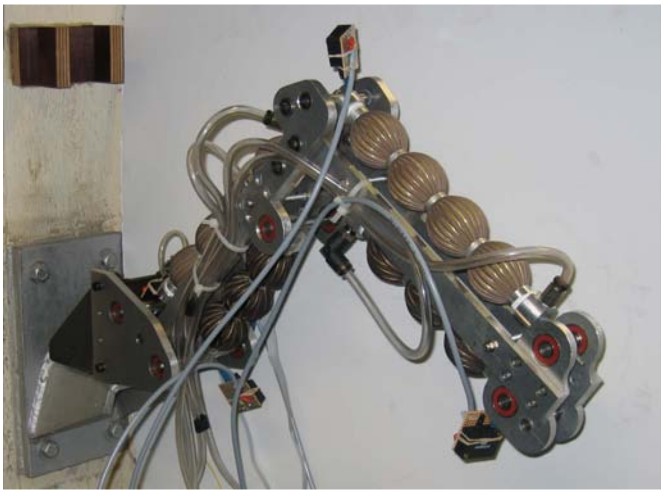

Fig. 4. Photograph of the manipulator

At present, the hardware setup of a small-scale manipulator is nearing completion. It consists of two PPAM actuated links in an inverse elbow configuration. The softarm is controlled by a dSpace rapid control prototyping system and uses a sliding mode tracking controller.

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