Fluidically Driven Robots with Biologically Inspired Actuators

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Abstract

In this paper different robot applications are presented that are driven by flexible fluidic actuators. These pneumatically driven actuators are biologically inspired. The first robot presented is an eight legged walking machine with 48 compliant joints. Then an auto propulsive flexible endoscope will be presented, followed by a serpent and an elephant trunk.

Keywords: Robot, Bionics, fluidic actuator.

1 Introduction

The idea of using fluidic energy for actuation is a very old one and can be dated back to the Alexandrine Ktesbios (285-247 AC) [1]. For many decades pneumatic and hydraulic actuators are wide spread in industrial applications, such as heavy industries, mechanical engineering, transportation systems and medical engineering.

Fluidic actuators are characterized by a high force to weight ratio, however the efficiency is restricted by frictional loss. Therefore, pneumatic actuators for application in rehabilitation “McKibben artificial muscle” [2] and robotics „Rubbertuator“ [3] were presented. These actuators are made from an inflatable inner bladder sheathed with a double helical braid which contracts lengthwise when expanded radially. Thus a contraction principle is the basis for actuation, which can also be achieved by inflating a cascade of chambers made from two or more layers of sealed plastic film [4]. Some more advantages are: elastic energy can be stored in the actuator and inherent compliancy of the joints. However, the robot design possibilities are limited by the length of the linear actuator necessary to perform a required adjustment travel. Typically they contract by 10-20% of their initial length. A different type of fluidic actuators, "pouch type actuators" [5] and "flexible fluidic actuators" [4] are integrated to the joint. Joint actuation is performed by an expansion principle, as an elastic chamber moves the levers of a joint apart, when inflated. Different applications driven by biologically inspired flexible fluidic actuators designed at the "fluidic robot lab" of the Forschungszentrum Karlsruhe, Germany will be presented in three groups in the following chapter.

2 Applications

2.1 Pneumatic spider

The aim of designing an eight-legged walking machine was transferring a biological actuation principle into a mechanical design [6]. The extension movement of the femoro-patellar and the tibio-metatarsal joint in the chilenean red tarantula (Grammostola spatulata) is performed by a hydraulic driving mechanism: A liquid (hemolymph) is pressed from cavities of the body (lacunae) into the joint [7]. It was not intended to copy nature as closely as possible, because some spiders have 30 muscles and 12 DOF in each leg [8]. Therefore the number of actuators has been reduced to three pairs of antagonistically working actuators (Fig.1) in each leg which makes a total of 48 actuators.

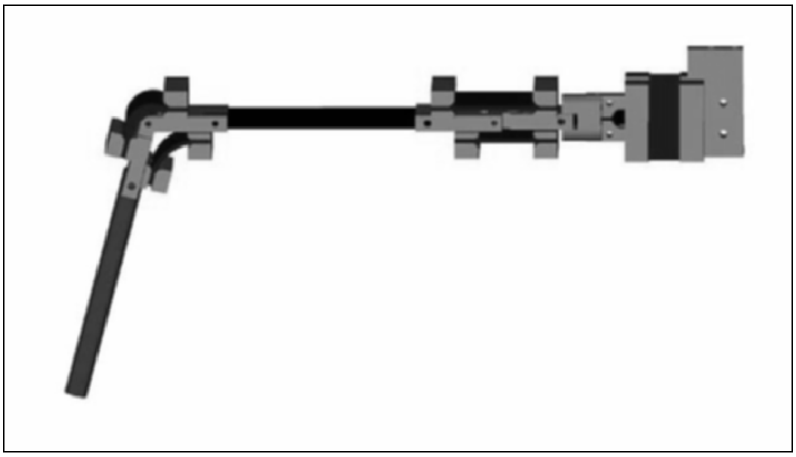

Fig. 1. Design of a single leg

All eight legs are designed with the same geometrical parameters. The proximal joint enabled the leg to move 30° forward and 30° backward from starting position, which was vertical to the bodies' longitudinal axis. The range of motion of the middle and distal joint was 50° and 70° flexion and 20° extension. Stable gait was obtained using a tetrapod gait pattern, that can be observed in a slow walking spider [8]. Due to the compliant joints of the spider's legs forces are distributed resulting in self adaptability to uneven terrain. Stable walking without any sensory information is possible up to a rise of 5% (Fig. 2). Like natural spiders the fluidic walking machine is able to continue walking, even with one or two disabled legs. Pressurized air from a gas tank has been favoured as energy source because of its lighter weight compared to a hydraulic system. The weight of the spider is 12 kg and the body length is 40cm and the span width from the tip of one leg to the contra lateral leg is 160cm when lying flat on the ground. Without external power supply the pneumatic robot-spider is able to walk 15 minutes.

Fig. 2. Pneumatic Spider

2.2 Inch worm colonoscope, serpent and elephant trunk.

Three different robot applications were designed based on the same longitudinal actuation principle. Three actuators were arranged symmetrically around the centre axis. Each actuator consists of a cascade of flexible chambers that can be inflated with pressurized air. When all three actuators are inflated simultaneously the robot elongates. By applying pressure only to one or two of the longitudinally orientated actuators a flexion movement to the opposite direction is performed. It has to be noted that in this case actuation was different to a real inch worm, serpent or elephant trunk, where muscles contract at the longitudinal axis. A prototype of a self propelled colonoscope was designed (Fig. 3) using a combination of this actuation principle and inflatable elements on either end working as „anchors".

Fig. 3. Inch worm Colonoscope

The locomotion principle is inspired by inch worms. The movement sequence starts by inflating the proximal element, resulting in contacting the colon wall and holding the colonoscope in place (Fig. 4, upper row). Then all three of the middle section actuators are inflated, elongating the body and pushing the head along the colon. Next the distal actuator is inflated, holding the head of the colonoscope in place (Fig. 4, middle rows). At the end of the sequence the distal element is inflated connecting the colon wall and the proximal and intersection elements are deflated (Fig. 4, bottom row). Compared to conventional colonoscopy the examiner does not need to manually push the device. Instead the movements are controlled via a joystick. It is expected that the examination will be less painful for the patient and analgesic drugs can be abandoned. The new colonoscope has a diameter of 18 mm.

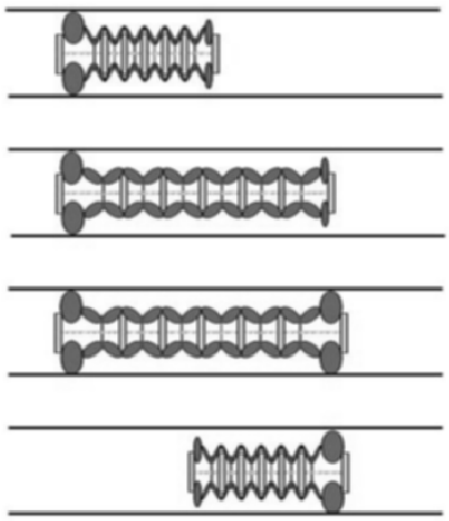

Fig. 4. Inch worm actuation principle

Two larger robots were designed using the longitudinal extension principle. The first one is a serpent with a "neck" that is animated by 9 actuators (Fig. 5). Each actuator can be controlled individually resulting in very realistic movements. The head of the serpent weighs 3kg, so the stiffness and operating pressure (8 bar) of the actuators are much higher than the actuators used in the second robot (elephant trunk).

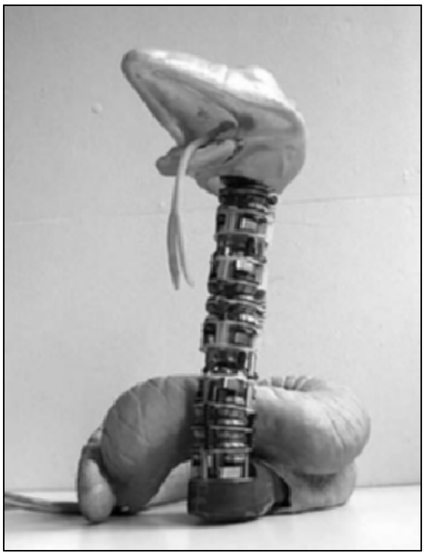

Fig. 5. Serpent with actuated "neck" before colouring.

The design of an elephant trunk consists of two different actuator sizes, as the trunk reduces the diameter to the end (Fig. 6). Flexion up to 360° is possible.

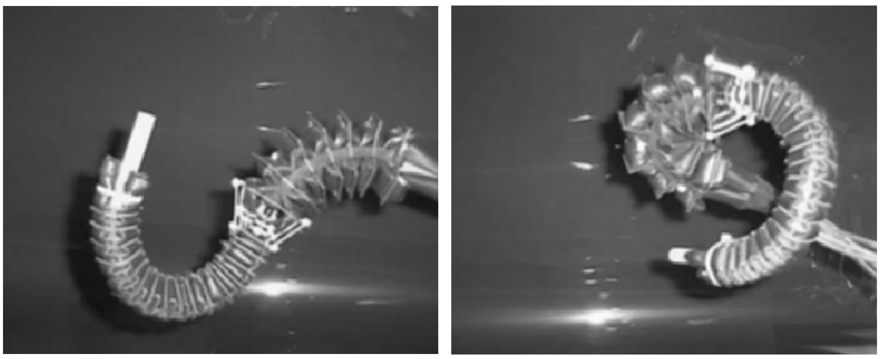

Fig. 6. Two different views of a moving elephant trunk robot.

3 Conclusions

Different robotic applications driven by biologically inspired actuators are presented. For each application different actuators have been designed in order to provide sufficient forces, stiffness, moments and stroke. All robots presented are controlled with open loop. Due to inherent compliance of the actuators the spider robot can walk over smaller obstacles and the inch worm colonoscope can move in a mechanically sophisticated surrounding. This reduces manufacturing costs and accounts for robustness. As positioning of flexible fluidic actuators is difficult, suitable angular sensors and closed loop control are under development. However, the robots presented are designed to be controllable without sensor integration.

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References

1. Maskrey RH, Thayer WJ (1978) *A brief history of electrohydraulic servomechanisms.* ASME J. Dynamic Systems Meas. Control, pp. 110-116.
2. Schulte H F Jr (1961) *The characteristics of the McKibben artificial muscle.* In: *The Application of external power in prosthetics and orthotics.* National Academy of Sciences-National Research Council, Washington D. C., Appendix H, pp. 94-115.
3. Inoue K (1988) *Rubbertuators and applications for robots.* Robotics Research: The 4th International Symposium, Bolles R, Roth B (eds). MIT Press, Cambridge, Mass. p.57-63, May 1988, Univ. of California, Santa Clara, California, United States.
4. Schulz, S.; Pylatiuk, C.; Bretthauer, G.(1999) *A New Class of Flexible Fluidic Actuators and their Applications in Medical Engineering.* Automatisierungstechnik, Vol. 47, No. 8, pp. 390-395.
5. Kato I. (1985) Development of Waseda Robots - The Study of Biomechanisms at Kato Laboratory, Tokyo, Waseda University publication dedicated to I. Kato 60th anniversary jubilee.
6. S. Schulz, C. Pylatiuk, G. Bretthauer: *Walking Machine with compliant joints.* 4th International Conference of Climbing and Walking Robots (CLAWAR 2001), 24th-26th September 2001, Karlsruhe, Germany.

7. Parry, D.A.; Brown, R.H.J. (1959) *The hydraulic mechanism of the spider leg.* J. Exp. Biol. 36, pp. 423-433.
8. Sens, J. (1996) *Funktionelle Anatomie und Biomechanik der Laufbeine einer Vogelspinne.* Master Thesis, (in German), University of Saarland, Saarbrücken, Germany.