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## Editorial : pneumatic actuators

Davis, ST

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Editorial

# Pneumatic Actuators

Steve Davis

School of Computing, Science & Engineering, University of Salford, Greater Manchester M5 4WT, UK;  
S.T.Davis@salford.ac.uk

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Since the 1970s, when robots began to see widespread use, they have mainly been applied within the manufacturing sector with the automotive industry being by far the largest user of robots. However, in the last decade or so the application areas where robots are being used has changed and is increasing at a rapid rate. Robots are now seeing use in domains as diverse as healthcare, the home, and entertainment to name just a few. Where historically robots were kept separate from human for safety reasons it is now accepted that robots need to interact more closely with humans to either assist them or work collaboratively with them. It has been recognised that these new operational arenas require a fundamental change in robot design philosophy. This has resulted in developments in material, mechanical and particularly actuator technologies and a shift to a more biologically inspired design philosophy. This is particularly apparent through the rapid increase in interest in so called “soft robots”, which are more suited to direct human interaction due to softness being incorporated during design and through the use of compliant actuators and soft materials.

Historic limitations in mathematical skill and control theory meant that traditional robot design was primarily concerned with the development of structures and mechanisms that are highly predictable. Consequently structures have been rigid, typically formed in metal and have used stiff actuation systems, initially hydraulic before the electric motor became most common. However, experience shows us that humans, who are actuated by soft and compliant organic muscle, are able to perform accurate position control of highly flexibly structures, for example, an expert fisherman can determine the point where a hook enters the water precisely despite the fact that the rod may be many metres in length and extremely flexible. This is evidence of the highly dexterous behaviour that can be achieved with flexible structures and compliant actuation.

Pneumatic actuation is a simplified and cleaner version of hydraulics and uses fluids in gaseous form instead of liquid. Due to the lower density and therefore compressibility of the fluid pneumatic systems are less stiff i.e., are compliant. Although pneumatic actuation in the form of cylinders is very widely used in automation, pneumatic systems have proven difficult to control and ‘bang-bang’ methods are commonly used. However, recent increased interest in compliant and soft systems has lead the research community to reassess the potential of pneumatic actuation for more complex tasks.

Whilst the pneumatic cylinder remains the most widely used pneumatic actuator industrially, there are a plethora of other actuators that use the power of compressed air. Pneumatic bellows have been used for centuries and over the last 50 years or so many other systems have been developed. One of the earliest of these new designs was the McKibben Muscle that was developed by physician Joseph L. McKibben in the 1950s as an actuator for an orthotic device for polio sufferers [1]. The muscle contains a rubber bladder and woven sleeve, and when pressurised reduces in length and creates a tensile force. The McKibben muscles is probably the soft pneumatic actuator that has seen the greatest research and they have been demonstrated in a broad range of applications. Numerous groups have developed mathematical models and controllers for the actuators and this is comprehensively described in the review paper by Bertrand Tondu [2]. Due to the nature of their construction, McKibben muscles

suffer from friction, which reduces their force output, to address this Daerden et al. developed the Pleated Pneumatic Artificial Muscle [3]. Unlike the McKibben muscle, this actuator unfolds when pressurised and this reduces the losses that are associated with friction.

Other new pneumatic systems include fibre-reinforced soft actuators [4], these consist of an elastomeric bladder wrapped with inextensible reinforcement fibres. The fibres prevent the expansion of the bladder radially ensuring that when pressurised the actuator elongates and generates a force.

These actuators all produce linear motion, therefore if rotary motion is required (which is often the case for manipulators and grippers) this must be converted into torque by a mechanical system. For this reason there have been a range of pneumatic actuators that have developed that produce rotary or other bending motion.

Whitsides' group at Harvard University have developed a range of soft pneumatic actuators, including the "pneu-et" actuator [5]. The pneu-net is constructed from an elastomeric material, which contains a network of internal channels, dependent on which areas of the material are pressurised the actuator can be used to achieve complex bending and deformation behaviours. Similarly, Niiyama et al. proposed a pneumatic Pouch Motor that could be manufactured by printing [6]. These actuators are formed from sheets of material bonded using heat to divide them into chambers or pouches, as these pouches are inflated they cause the sheet to flex and change shape. These actuators have been demonstrated in manipulators, grippers, and even walking robots.

An altogether different form of pneumatic actuation can be seen in so called granular jamming systems. Granular jamming is based on the concept that grains of material can move freely relative to each other, however, when forced against each other while using air pressure the grains become jammed and motion is prevented. A well known example of this technique is the Universal Gripper that was proposed by Brown et al. [7], it is able to deform around an object but when the air pressure is reduced it becomes solid, resulting in a firm grasp.

These few brief examples show how pneumatic actuation has moved away from being just about heavy metallic cylinders. In this special edition Tomori et al. [8], Sekine et al. [9], and Martens et al. [10] have explored new designs, control and modelling of pneumatic artificial muscles. Miron et al. [11] have developed pneumatic soft bending actuators for use in grippers and Tarvainen et al. [12] have advanced the dexterity of fiber-reinforced actuators through the use of multiple air chambers and have proposed using the new actuator for hand rehabilitation. Krause et al. [13] also describe how they have exploited recent advances in additive manufacturing to produce a linear pneumatic actuator with integrated sensors allowing for it to be used for position, force, and impedance control, rather than just bang-bang control, which is typical. The special edition has shown that the applications for, and design of, pneumatic actuators is growing rapidly and they are being used in increasingly diverse domains.

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