Development of Artificial Pneumatic Muscle

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ABSTRACT

The purpose of this study is to review current application areas of Pneumatic Artificial Muscle (PAM) actuator. This article analyses result of ongoing theoretical and experimental research on operational behaviour of pneumatic muscle such as muscle structure, as well as data on generated forces. Also, analyses that available materials to manufacture PAM. The speed of response of PAM actuator mostly depends upon its shape and size, pressure inputs and outputs. All these factors have impact on overall force which is generated by PAMs. The force generated purely depends on rate of pressure added and removed from PAM. It has wide application in robotics, industrial automation. Also, have medical application. PAMs are easy to manufacture, low cost and can be installed human operations without any large scale safety.

Keywords: ***McKibben muscle, Pneumatic Artificial Muscle, Braided Pneumatic Actuators, PVC gel, SMA (Shape Memory Alloy), Conductive Fibre etc.***

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1. INTRODUCTION

McKibben invented braided pneumatic actuator to help Polio patient. They are also called McKibben muscles or artificial muscles driven by the compressed air. In 1958 that R.H Gaylord discovered a pneumatics actuator which was used as the original applications such as, a door opening arrangement and an industrial hoist. These muscles were made by pure rubber latex, covered by a double helical braided wire which would contract when expanded radially. A PAM is a pneumatic actuator which converts pneumatic power to pulling force.

In 1980, Bridgestone Company introduced more powerful PAMs (Wickramatunge and Leephakpreeda, 2009). Pneumatic muscles were used for painting applications and for assist disabled individuals and service robotics. Conventional Pneumatic actuators with piston and cylinder were widely used in automation. A muscle produces more strength ten times greater than the strength of a conventional pneumatics actuator (Wszolek et al., 2007).

Lately robotic systems have started using pneumatics as a main motion power source. The main reasons for using pneumatics are: availability, dependability, flexibility, cleanliness, linear motions, variable speed and safety.

1.1 Characteristics of PAM

PAMs are operated by pneumatic pressure and are contractible naturally on inflation. Flexible inflated membrane which is reinforced with fibrous filament is used as construction material. When the membrane is pressurized, it bulges outward in radial direction, while contracting in length along is axial direction. Force exerted in axial direction. This force generated by PAM on the loads is unidirectional (Ramasamy et al., 2005). McKibben muscle, has some drawbacks, mainly with regard to its control but also with regard to service life: the flexible membrane connected to rigid end fittings which introduces stress concentration and there from possible membrane ruptures (Lynn, 2008). Cylinder, being entirely composed of rigid materials, does not suffer from these problems.

2. DEVELOPMENT OF PAM

In the robotic application, actuator should be strong and lightweight. Pleated muscles have been proven to be able to perform very accurate positioning tasks by actuating PAMs (Vanderborght, 2006). [1]

Ramasamy et al. (2005) mentioned the residences of PAMs which might be chargeable for their load-carrying capability and low weight capability in assembly. FE (Finite Modelling) is used to analyse design and capacity to operate as locomotion tool in robotics application. He also (Ramasamy et al., 2005a) mentioned the development of PAMs specifically such as bendy, inflatable membranes, which can behave as orthotropic cloth. [1] Wanderborght (2006) is describing the implementation of Pleaded Pneumatic synthetic muscle mass (PPAM) into modern robotic application. This actuator has a very excessive power to weight ratio. In recent times legged robots are gaining increasingly interest. However most of the robots are driven by electric drives which makes it heavy. An actuator, inclusive of the PAM lowers the robot weight and the artificial muscle can be exploited to lessen power intake. [1]

Deaconescu (2007) offered some of the end result of research carried out inside the Fluidtronics Laboratory of the nearby festo education centre.The experiments were performed for determining variation diagrams of feed pressure and flow of consumed air for a complete cycle of the pneumatic muscle. Similarly, the response instances of the muscle could be decided for various values of the feed pressure and the effect of quick exhaust valve which is introduced in circuit on muscle deflation could be studied. Figure 1 presents the numerous varieties of pneumatic muscles and Fig. 2 gives the evolution in time of positive solutions for pneumatic automation. [1]

Kawashima et al. (2004) has described using Fibre Knitted Pneumatic synthetic muscle Rubber Muscle (PARM) which was selected as the actuator for the arm. This arm may be designed for smooth set up and portability. Experimental consequences carried out through the setup shown in the Fig. 3, confirmed that the evolved device correctly operated in material handling system. [1]

Figure 1: Constructive variants of constructive muscle

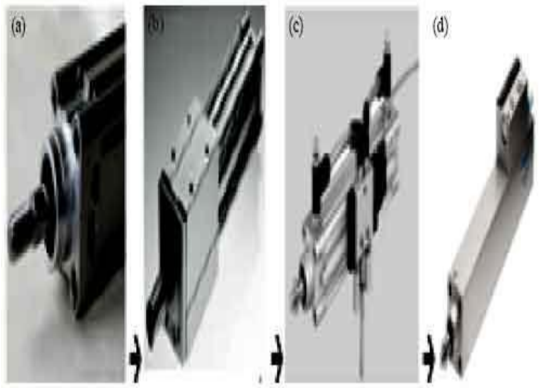

Figure 2: Constructive variants of pneumatic drives

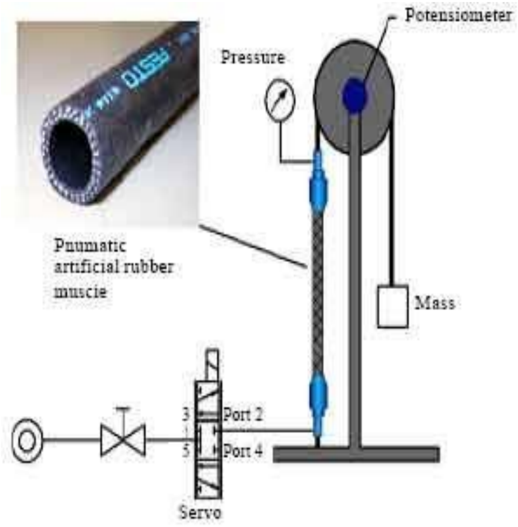

Figure 3: Knitted PARM and Experimental Apparatus

Ahn and Nguyen found solution for position control of a robot arm with slow motion which is driven by two PAMs. There are some limitations like a deterioration of the performance transient response because of change in external load. [1]

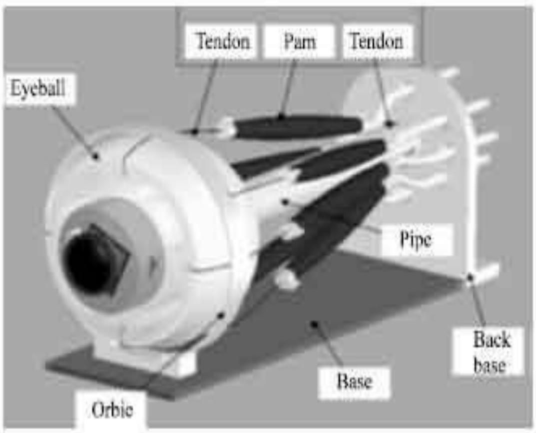

Figure 4: Prototype of Humanoid Eye

Wang et al (2008) proposed a novel humanoid robot eye, which is driven by six PAM and rotates with 3 degree of freedom as in figure4. The design of the mechanism and motion type of the robot eye are inspired by that of human eyes. The design and kinematic analysis of the prototype could be a significant step towards the goal of building an autonomous humanoid robot eye with the movement and especially the visual functions similar to that of human. [1]

3. PERFORMANCE EVOLUTION OF PAMS:

In Deaconescu and Deaconescu (2008), presented results of the ongoing theoretical and experimental research on the operational behaviour on pneumatic muscle. Information is presented regarding muscle structure, as well as the data on the generated forces, the maximum working frequency and positioning accuracy of these pneumatic actuation elements.

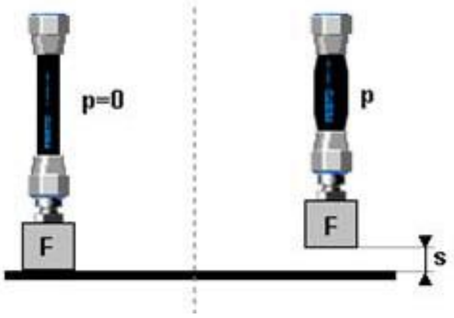

Figure 5: The Stroke Carried Out By PAM

Figure5 elaborate the stroke carried out by muscle depending on the level of the feed pressure. Pneumatic muscles are actuating elements that transforms pneumatic energy into mechanical energy. A characterization of the behaviour and performance of pneumatic muscle entail both analytical calculations and thorough experimental research. In order to determine the working characteristics of a pneumatic muscle, first its structure need to understand. A pneumatic muscle includes an interior tube of various lengths made from an elastic material, generally neoprene. This is wrapped in a multilayer nylon tissue ensuring its strength and protection from the influence of the working environment. [1]

In Lynn (2008) described the use of biomechanical phenomenological model to commercially available pneumatic muscle actuator. Experiments shows that boundaries of operation where linear approximation can be used to explain dynamics of pneumatic muscle. The dissertation shows that nonlinearities exist more dominantly at higher loads of PAMs. [1]

In Toman et al. (2009) designed an apparatus which would show experimental investigation of pneumatic muscles. The stand used in this study is a stand of didactic laboratory stand, which can investigate and gather knowledge of construction of working elements PAM such as: a PLC controller, a fluidic muscle, DSP system as well as proportional pressure control technique. The stand was designed and visualised by utilization of professional CAD software-Autodesk. [1]

In Shen (2010) proposed a control methodology of the pneumatic artificial muscle which actuated two servo systems. The four major processes including the pressure dynamics, load dynamics, force dynamics and flow dynamics are studied to develop a full nonlinear model taking a valve command as input and calculating a third order derivative of the load position as the output. Based on this model the standard sliding mode control approach was applied to obtain a robust control in the existence. [1]

In Kuriyama et al. (2009) proposed a method of estimating the length from the circumferential displacement, which can be measured by a sensor mode of electro conductive, flexible rubber. Higher accuracy is obtained by measuring circumferential displacement than measuring axial displacement using sensor. The flexibility of sensor allows us to control the actuator without any loss in flexibility or increase in weight. Furthermore, the sensor does not need attachment of any rigid fixtures. The accuracy of the estimate is successfully estimated and the usefulness of the proposed method is verified through is application to multi-link arm. [1]

Chang (2010), developed an adaptive self-organizing fuzzy sliding mode control (ASOFSMC). Its fuzzy sliding surface can help reduce the no of fuzzy rule. The self-organising mechanism is employed to modify fuzzy rule online. The model matching technique is then adopted to adjust the scaling factors. In Wickramatunge and Leephakpreeda, 2010 proposed models that are experimentally derived to describe mechanical behaviours of the PAMs. The experimental results shows a non-linear relation between contraction as well as air pressure within the PAMs and a pulling force of the PAMs. Three different size of PAMs available in industry are studied for empirical modelling and simulation. The case studies are presented to verify close agreement on simulated results to the experimental results when the PAMs perform under the various loads. [1]

In Zhu et al. (2008) described a discontinuous projection-based adaptive strong control strategy is being adopted to compensate for both the parametric uncertainties and uncertain nonlinearities of a three- pneumatic-muscles-driven parallel manipulator to achieve precise posture trajectory tracking control. The resulting controller effectively handles the effect of change in various parameter and the hard-to-model nonlinearities such as the friction forces of the pneumatic muscles. Simulation and experimental results are obtained to explain the effectiveness of the proposed adaptive robust controller. [1]

4. DIFFERENT MATERIALS FOR PAM

There are different materials for manufacturing PAM such as conductive fibre, SMA (shape memory alloy), PVC gel, SMP (shape memory polymer)

Conductive fibres are easy to manufacture, lightweight, control over it is easy by servo control technique, and S/N ratio can be improved by using multiple conductive fibres. [2]

PVC gel based artificial muscles showed a great potential for practical applications. PVC gel artificial muscles as a robust actuation device. PVC gel artificial muscles based actuation modules are capable of generating a stable movement in the air without any noise, with a large strain and stress, a fast response rate with a low power consumption. In addition to these advantages, a more than 5 million times' cycle life is also sufficient for practical uses. Therefore, as an alternative among the artificial muscles or the traditional mechanical actuators, many applications are expected. [3]

SMA coils are lightweight, and on rise of temperature it contracts and after cooling it regains its shape. [4]

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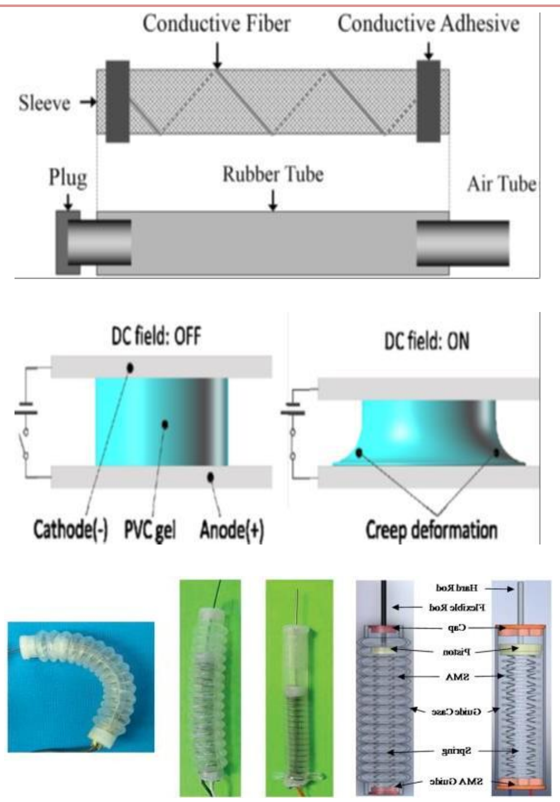

Figure 5: Conductive Fibre, PVC Gel, SMA

5. APPLICATIONS OF PNEUMATIC ARTIFICIAL MUSCLES:

5.1 Biorobotic Applications

Until now PAMs have been applied mostly in the area of biorobotic applications or in biomimetic robots. As these actuators resemble the characteristics of actual skeletal muscles, researchers have tried to emulate the ―soft" compliant structure of organic muscle, bone, tendons and skin by PAMs. This approach has led to the development of biologically inspired robots that mimic the morphology and physiology of humans and animals. Several biorobotic applications of PAMs are presented in Figure 5.

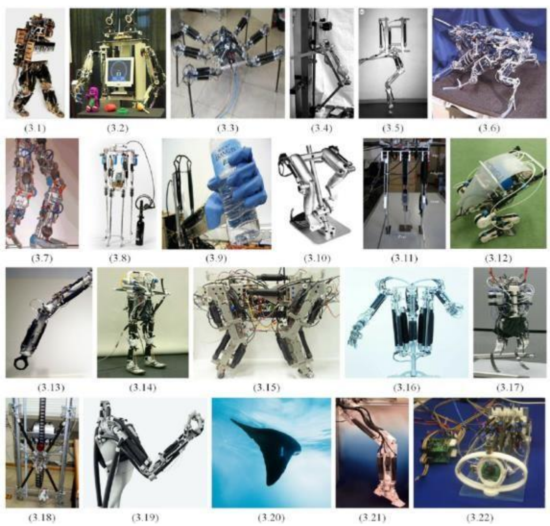

Figure 5: Bio robotic Application: (3.1) Shadow biped walker, (3.2) Isac, (3.3) Airbug, (3.4) Hopping robot, (3.5) Panter leg, (3.6) Ajax, (3.7) Lucy, (3.8) Stumpy, (3.9) Low cost humanoid hand, (3.10) Pneumatic bicycle, (3.11) Three – legged robot, (3.12) Mowgli, (3.13) Robotic arm, (3.14) Bipedal robot, (3.15) Quadruped robot, (3.16) Pneumatic torso, (3.17) Pneumatic athlete robot, (3.18) Pneumatic climbing robot, (3.19) Airic's arm, (3.20) Aqua Ray, (3.21) Shadow robot leg, (3.22) Robotic eye with pneumatic actuation

A pioneering PAM–actuated robot has been the Shadow Biped Walker by Shadow Robot Co., a life–size humanoid robot that has been in development since 1988. Twenty–eight PAMs (fourteen on each leg) were acting across the eight joints of the robot, enabling a total of twelve Degrees of Freedom (DOF). The humanoid robot Intelligent Soft Arm Control or ISAC, was consisted by two six–DOF arms and multiple PAMs that antagonistically actuated each joint of the arms. The construction of a six–legged, insect–like robot, called―Airbug", with fluidic muscles as actuators and the control concept of antagonistic actuators, has been presented. [5]

5.2 Medical Applications

Among the several advantages of the PAM actuator, is the ability to provide high power outputs, with relatively light weights and possesses inherent compliance, thus, meeting the need for safety, simplicity and lightness that human–robot interaction requires. Those characteristics, combined with the fact that pneumatic muscles possesses similar properties with those of the human muscle, make it a promising actuator choice for therapeutic devices, which are designed for rehabilitation therapy of patients suffering from degenerative muscle diseases, extremity impairment or neurological injuries that affect their kinetic abilities. In this subsection, pneumatic muscles that are focused in medical applications will be presented. Most of these applications are depicted in Figure 6.

The performance of a pneumatic muscles (PAMS) used in a prototype wheelchair–mounted robot arm has been reported. The design and control of a Human Muscle Enhancer (HME) system was described. The system augmented the muscle capabilities of subjects requiring partial lower–limb weight–bearing gait support. [5]

Figure 6: Medical Applications: (4.1)PAM – actuated forearm, (4.2)Muscle suit, (4.3) Powered-ankle foot orthosis, (4.4) Rupert, (4.5) Pneumatic hip orthosis, (4.6)Pneumatic foot orthosis, (4.7) Haptic arm exoskeleton, (4.8) Upper body exoskeleton, (4.9)Upper body exoskeleton, (4.10)Lower body exoskeleton, (4.11) Pneumatic power assist glove, (4.12) Knee rehabilitation device, (4.13)Orthosis for home training, (4.14)Isokinetic equipment for recovery exercises

5.3 Industrial Applications

The utilization of PAMs in the construction of industrial robots has received significant attention during the last years. PAMs are able to generate high torques at low and moderate speeds, able to be installed easily without gearing and able to work as the actuator of portable machinery due to their lightweight properties. Having, also, a natural compliance and shock resistance, PAMs are a suitable solution for actuation of industrial machinery and particularly industrial robots for safe human–robot interaction. Several industrial applications of PAMs are presented in Figure7. [5]

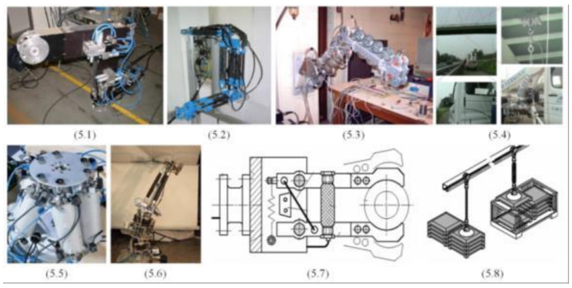

Figure 7: Industrial Applications (5.1) Pneumatic 3-DOF robot, (5.2) PAM – actuated robot arm system, (5.3) 2 – DOF planar robotic manipulator (5.4) PAMs used in modal parameters of bridges, (5.5) Parallel – kinematic hexapod tool, (5.6) Hybrid robot for safe human – robot interaction, (5.7) Industrial gripper, (5.8) Positioning system

6. CONCLUSION

The PAMs has a wide choice for applications in automation, robotics and material handling devices. The construction and the capabilities of PAMs have been analysed by various authors by adopting experimental and numerical methods. Apart from finding the characteristics of the PAMs, there are different strategies for analysing the behaviours under different applications. Various techniques of modelling like Artificial Neural Networks (ARNN) and fuzzy modelling system have been adopted for analysing the rigidity and non-linear behaviour of PAMs for getting good performance in controlling the PAM actuator for real time industrial and human friendly applications.

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