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Design and characterization of artificial muscles from wedge-like pneumatic soft modules

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Highlights

- The article reports the design, characterization, modelling and control of a novel artificial muscle.
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The fabricated soft robotic muscle is made completely of silicone rubber and exhibits contraction, expansion and bending motion through variation of internal air pressure in its channels.

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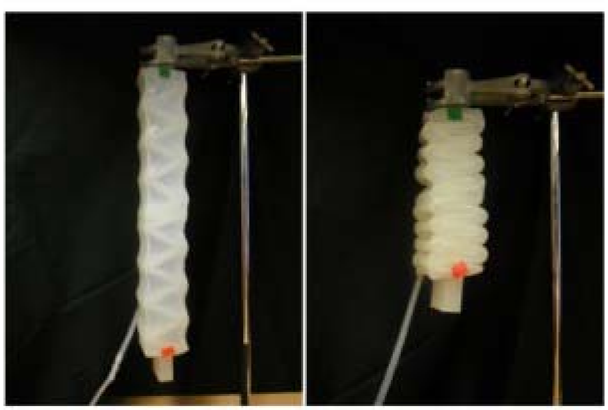
The novelty and significance of this article comes from the novel design and characterisation of the soft muscles and analyses optimum design parameters responsible for its functionality.

Abstract

This work is based on the design of a muscle actuator made entirely of silicone rubber that contract upon actuation. The manufacturing procedure, design parameters and measurement results of performance of these muscles such as the velocity of shortening, isometric and isotonic contraction is described. In order to measure these performance data of the Soft Robotic Muscles (SRM), visual processing is made use of. The Soft Robotic Muscles are manufactured to mimic the skeletal muscles present in the human body. These muscles are composed of a number of wedge-like units in series, the number of these wedge units increase the contraction. The soft muscles were tested on a model hinge joint to execute flexion/extension of the forearm at the elbow. These muscles were characterized in order to find optimum design parameters that result in more contraction and speed. Aside from contracting, the Soft Robotic Muscle has an interesting capability of producing bidirectional bending by the regulation of internal air pressure in each wedge unit.

Graphical abstract



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Introduction

A muscle is a type of soft tissue that connects, supports or surrounds other structures or organs of the body. It converts chemical energy to kinetic energy through a process called cellular respiration. Muscles function by contracting, which under normal circumstances causes muscle shortening. Muscle contraction is triggered through electrical stimulation either by nerve impulse produced internally or electrically applied from the external environment. There are 3 types of muscles in the human body - skeletal muscle, cardiac muscle and smooth muscle. The human muscles form an integral part of the human body, constituting nearly half of the body weight. The skeletal muscle attaches to the prominence of 2 bones across a joint and pulls them closer together when it contracts. Usually, one bone will be relatively fixed, called the origin while the other bone would move more, called the insertion. The origin is the fixed point to which a skeletal muscle attaches and the insertion is the movable point. Many skeletal muscles in the human body do not attach to a bone directly, but attach to bones via tendon which is inelastic in nature to allow force transmission [1].
Artificial muscles are fabricated from nanomaterials, polymers, composites, alloys and are actuated using electrical, mechanical, magnetic, thermal, light or pneumatic energy [2]. Artificial muscles generate motions such as bend, torsion, linear and bidirectional movements in order to generate expansion and contraction muscle actuators [3]. The most common types of pneumatic artificial muscles generate a tensile pulling force when pressure is applied due to anisotropic membrane stiffness and relax when the actuation force is removed. Artificial muscles are designed to mimic the skeletal muscles in humans and animals to achieve contraction. There have been increasing researches in designing structures that mimic the skeletal muscle using pneumatic pressure. They are generally referred to as Pneumatic Artificial Muscles (PAM). Sub-categories of PAMs are braided, netted, pleated and embedded pneumatic muscles. Braided muscles are McKibben-type actuators in which volumetric expansion of internal bladder results in contraction motion; netted muscles have large hole mesh in place of woven braid, examples are Yarlott, ROMAC, Kukolj; Pleated muscles have their internal bladder pleated; Embedded muscles have their bladders embedded with load elements, examples include Morin muscle, Baldwin muscle, UPAM, and Paynter knitted muscle [2].

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  Also, the SA is a natural and linear copolymer extracted from sargassum or kelp, and it is irregularly connected by α-1,4-l-guluronic acid chains (G) and β-1,4-d-mannuronic acid links (M), whose M/G ratio is 1:1 and the average molecular mass is about 222.00. In recent years, there are few researches on the IPAM about its preparation process and output force performance, and then a lot of work needs to be carried out in depth [9–13]. For instance, Bekin and Jiang et al. [14,15] have studied dielectric properties and electrical response of the SA/polyacrylic acid interpenetrating polymer cross-linked by glutaraldehyde, which founds that the dielectric constant and electrical conductivity of SA are reduced after the cross-linking reaction, and its total bending degree reaches the highest in 0.15 mol/L NaCl solution.
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  An appropriate control system comprising both software and hardware components are therefore required to control these various movements experienced by soft actuators. The control hardware usually used to actuate non pneumatic soft robots includes Dielectric Elastomer Actuators (DEAs) [7], Shape Memory Alloys [8], Hydrogels [9] and Pneumatics [2]. Pneumatic soft actuators are controlled using pistons, cylinders, valves, compressors, air and vacuum pumps.
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