Robotics and Autonomous Systems 100 (2018) 267–277

Contents lists available at ScienceDirect

Robotics and Autonomous Systems

journal homepage: www.elsevier.com/locate/robot

A novel underactuated multi-fingered soft robotic hand for prosthetic application

Mata Amritanandamayi Devi [a], Ganesha Udupa [b,*], Pramod Sreedharan [b]

[a] Amrita Vishwa Vidyapeetham, Amritapuri, India
[b] Department of Mechanical Engineering, Amrita Vishwa Vidyapeetham, Amritapuri, India

HIGHLIGHTS

- The principle of working of AFPA or ABFPA is based on an anti-Bourdon tube principle.
- Asymmetric actuators give bending performance better than the symmetric actuators.
- Asymmetric actuators can be bent in any direction by rotating the actuator itself that direction.
- The fingers are made with 2 DOF whereas the general soft hand has 1 DOF in one finger.
- The dynamic modeling will offer an insight into the dynamic system to design a soft robot.

ARTICLE INFO

Article history:
Received 10 May 2017
Received in revised form 27 September 2017
Accepted 15 November 2017
Available online 2 December 2017

Keywords:
Asymmetric bellow flexible pneumatic actuator
Finite element analysis
Multi-fingered soft Robotic hand

ABSTRACT

Robotic hand plays a very important role as it is required to hold and place the object at the desired location. There has been a lot of research on the flexible pneumatic rubber or polymer based actuators for soft gripper applications. This paper is investigating asymmetric bellow flexible pneumatic actuator (ABFPA) as a bending joint made of suitable rubber material in the construction of a novel underactuated multi-jointed, multi-fingered soft robotic hand for prosthetic application. The proposed asymmetric actuator has a single internal chamber and is simple, compact and easy to manufacture. Several actuator designs are analyzed and validated experimentally. It is found that the effect of shape and eccentricity of the ABFPA plays an important role in the bending of the actuator. By proper selection of materials and manufacturing of the ABFPA with reinforcement, a versatile dexterous hand can be fabricated. The present work has paved the way for extensive research on this innovative technique as it holds out the true potential for innumerable and very interesting application in various areas.

1. Introduction

The Robotic hands are essential components of any Robotic system as they are required to work as human hand. Robotic or artificial hands, those with four fingers and a thumb, have demanding responsibilities that will improve the efficiency and usefulness of the robot if they can establish a power grasp and precision grip. Nowadays it is more and more important for robots to serve and help people, especially the old and the disabled. There are about 1,000,000 people who had an amputation of a hand or a complete arm worldwide [1]. The main factors for a loss of upper or lower limbs are accidents followed by general diseases and injuries. For diseases and tumors, amputation is a way of stopping the spread of the disease to the rest of the body. About 30 to 50% handicapped persons do not use their conventional prosthetic hands regularly since the hands are heavy in weight, low functionality and limited DOF's cause inability to adapt to the shape of an object [2]. In order to serve them adequately, it is indispensable for the robots to have soft-moving hands. The various artificial hands that are available are essentially based on linkage-mechanisms or hydraulic and pneumatic elements such as wires, cables and chains, belts, artificial muscles etc. [3–6]. The artificial hands presently in use are complicated in design and control structure and also costly to be implemented for robotic or prosthetic applications.

The need for an adaptable hand with flexibility, dexterousness and load carrying capacity analogous to the human hand seems to be the ideal one for robotic or prosthetic application. An extensive research in this area has lead to the design and development of such hands which are becoming more and more complicated in structure, components along with programmable control systems being developed. Several kinds of flexible pneumatic rubber actuators have been developed and reported with two or more internal chambers having symmetric cross section or attached to

* Corresponding author.
E-mail address: ganesh@am.amrita.edu (G. Udupa).

https://doi.org/10.1016/j.robot.2017.11.005
0921-8890/

a joint to create bending motion. Also their internal pressures are controlled independently through flexible tubes, which are connected to pressure control valves. Examples of them are Rubber gas actuator driven by hydrogen storage alloy [7], Flexible micro actuator (FMA) [8,9], Pneumatic wobble motor [10], Pneumatic soft actuator [11], Flexible fluidic actuator (FFA) [1,12] and Flexible pneumatic actuator (FPA) [13,14]. Even though the FMAs [8,9] with two or more chambers provide multiple DOF, it requires multiple pressure supplies, valves and sensors as well as complicated manufacturing. Compared with the typical FMAs, the FPA [13] uses spring or wire rather than fiber as its constraint, which results in the bending deformation of the actuator. Also many research groups have developed artificial hands with a fluidic actuator that is called McKibben artificial muscle or Pneumatic Muscle Actuator (PMA) [15,16]. The multi-fingered hands actuated by pneumatic artificial muscle are costly and difficult to miniaturize. Also there is hardly any space left in the socket that covers the stump of the forearm of a handicapped person, to keep the contracting artificial muscle which provides force to the movement of the hand joints. However, grippers having flexible tube like pneumatic fingers constrained by the supporting member such as thin plate or rod along one side have been proposed [17,18]. This may be called as composite material flexible pneumatic actuator (CMFPA). An attempt has been made with dual compartment, differential pressure flexible pneumatic actuators (DPFPA) in the construction of robotic grippers for soft fruit packing [19] but not for the investigation on the multi-jointed multi-fingered prosthetic hand based on asymmetric bellow flexible rubber actuators. The main disadvantage with the above type of grippers is the fingers inability to grasp both soft and hard objects of different shapes, sizes and weights.

In the search for a simple soft robotic gripper design, a new technique altogether different from others yet versatile has been found and developed based on an asymmetric (eccentric) polymer/rubber tube or bellow actuators with or without reinforcement [20,21]. Actuators made of bellows or tubes with asymmetric cross section has been investigated to overcome the disadvantages of FMA and FPAs or FFAs and applied for the robotic soft gripper construction and the same technique is proposed for the development of a dexterous hand [20,21]. It has also been applied to fabricate a micro walking robot [22], robotic fish [23] and a soft gripper [21,24]. Later many research groups further explored our technique with different arrangements of fibers embedded within the actuator wall [25] or by changing the shape and material of the actuator [26–28]. The above research groups use embedded PneuNets (pneumatic networks) channels in elastomers of square shaped tubes and these channels inflate when pressurized, creating motion either by varying the thickness of the walls of the tube [26] or by changing the material of the active and passive layers of the square shaped tube [27,28] or square shaped molded silicone actuator with rounding on one side [29]. The hand developed [27] is like a five finger gripper not resembling the finger joints of the human hand and also it is controlled by external pneumatic components and air supply. A complex construction of fiber-reinforced tubular soft prosthetic hand with stretchable optical waveguides for strain sensing has been developed using external control devices and air supply [29]. A hybrid actuation principle combining both pneumatic and tendon-driven actuators for a soft robotic manipulator has been constructed which needs both external motors and compressor [30]. Comprehensive modeling and construction of such type of complicated fiber-reinforced soft robotic actuator designs were presented [31]. Recently research on bellows to generate bending motion using symmetric thickness actuator [32] and polymer Bi-bellows [33] have been carried out. The above group [32] has not worked on the asymmetricity along the longitudinal direction of the actuators. The problem in the symmetric thickness actuator is that it cannot withstand higher pressure ranges. Also the rubber bonding process using ultraviolet light of 172 nm wavelength could be dangerous and expensive.

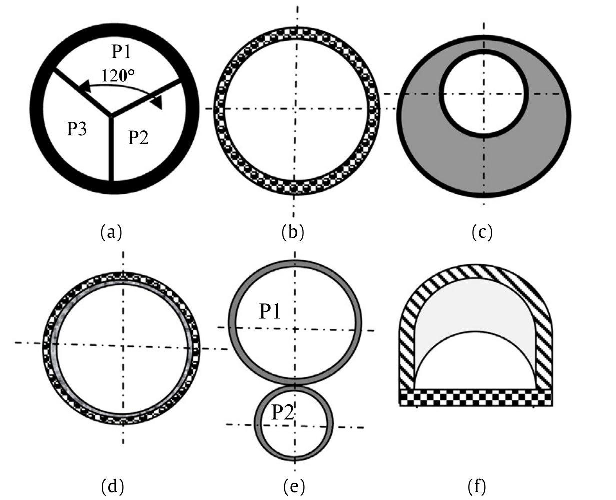

Fig. 1. Cross section design of various Flexible Pneumatic Actuators (a) FMA (b) FPA (c) AFPA (d) PMA (e) DPFPA (f) CMFPA.

Instead of two or three internal chambers in FMA made of rubber or fiber-reinforced rubber, the proposed actuator not only has a single internal chamber but also simple, compact, stable, less in weight and easy to manufacture. It is mentioned that in the case of symmetric actuators (FMA's), there is an unstable phenomenon which occurs while gripping when the pressure of the working fluid reaches some limit [8,9]. The asymmetric actuators can be bent in any direction by just rotating it to the desired angle and thus eliminating the usage of more number of control devices. The AFPAs or ABFPAs show better deflection up to certain amount of eccentricity provided in the asymmetric actuators. The need for totally new approach to achieve flexibility or dexterousness similar to the human hand is felt. The design of robotic hand by an asymmetric nitrile rubber (Acrylonitrile–Butadiene rubber) bellow actuator has been studied [34–36]. The applicability of ABFPA using rubber for the fabrication of a novel underactuated multi-fingered robotic hand has not been investigated. The hand is also known as Amrita Prosthetic Hand. The finite element analysis of the ABFPA has been carried out using Abaqus 6.13 software and the effect of various factors affecting the bending of the actuators are presented. These actuators have the advantages of high force density and relatively simple structure over other types of actuators. The cross section of AFPA or ABFPA is asymmetric as compared to symmetric section of FMA [8], FPA [13], PMA [15,16], DPFPA [19] and CMFPA [17] as shown in Fig. 1.

2. Principle

The principle of working of asymmetric tube or bellow actuator is exactly opposite to that of the principle of actuation of the Bourdon tube. An over simplified statement of this new principle is to dub it as an anti-Bourdon tube principle [37]. The Bourdon tube used is initially in curved form with flat or elliptic cross section which under the application of internal pressure will tend curved tube to open up because of the action of the flat or elliptic section becoming circular under pressure. Contrary to this a straight asymmetric (eccentric) tube or bellow actuator with circular cross section under the application of pressure will become curved and elliptic in cross section. This behavior is exactly opposite to that of the above case.