

# US Patent & Trademark Office

## Patent Public Search | Text View

United States Patent	12392363
Kind Code	B2
Date of Patent	August 19, 2025
Inventor(s)	Arslan; Ayse Feyza et al.

### Actuators for soft robotic applications

#### Abstract

Soft actuators controlled by fluid pressure comprise two sacs which provide for the flexion of a structure upon pressurizing this structure that has an anisotropic flexibility, which is provided by different knitted layers. The knitted layers are produced as integrated with each other by means of the three-dimensional whole-garment knitting technique. The actuators can be adapted according to the different requirements and produced with standard qualities.

<b>Inventors:</b>	Arslan; Ayse Feyza (Istanbul, TR), Ozlem; Kadir (Bursa, TR), Khalilbayli; Fidan (Istanbul, TR), Elmoughni; Hend (Istanbul, TR), Tuncay Atalay; Asli (Istanbul, TR), Ince; Gokhan (Istanbul, TR), Atalay; Ozgur (Istanbul, TR)
<b>Applicant:</b>	ISTANBUL TEKNIK UNIVERSITESI (Istanbul, TR); MARMARA UNIVERSITESI (Istanbul, IT)
<b>Family ID:</b>	1000008764564
<b>Assignee:</b>	ISTANBUL TEKNIK UNIVERSITESI (Istanbul, TR); MARMARA UNIVERSITESI (Istanbul, TR)
<b>Appl. No.:</b>	18/557602
<b>Filed (or PCT Filed):</b>	April 27, 2022
<b>PCT No.:</b>	PCT/TR2022/050384
<b>PCT Pub. No.:</b>	WO2022/231556
<b>PCT Pub. Date:</b>	November 03, 2022

#### Prior Publication Data

<b>Document Identifier</b>	<b>Publication Date</b>
US 20240209876 A1	Jun. 27, 2024

## Foreign Application Priority Data

TR

2021/007340

Apr. 29, 2021

---

## Publication Classification

**Int. Cl.:** F15B15/10 (20060101); B25J9/14 (20060101)

**U.S. Cl.:**

**CPC** F15B15/10 (20130101); B25J9/142 (20130101)

## Field of Classification Search

**CPC:** B25J (9/142); F15B (15/10); F15B (15/103)

---

## References Cited

### U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
4784042	12/1987	Hardin	N/A	N/A
6178872	12/2000	Schulz	N/A	N/A
6718766	12/2003	Seto et al.	N/A	N/A
2002/0157388	12/2001	Seto	N/A	N/A
2016/0250758	12/2015	Shepherd et al.	N/A	N/A
2019/0015233	12/2018	Galloway	N/A	B25J 15/12

### FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
109909990	12/2018	CN	N/A
2015066143	12/2014	WO	N/A
2017120314	12/2016	WO	N/A
2018136004	12/2017	WO	N/A

---

*Primary Examiner:* Wiehe; Nathaniel E

*Assistant Examiner:* Collins; Daniel S

*Attorney, Agent or Firm:* Bayramoglu Law Offices LLC

---

## Background/Summary

### CROSS REFERENCE TO THE RELATED APPLICATIONS

(1) This application is the national phase entry of International Application No. PCT/TR2022/050384, filed on Apr. 27, 2022, which is based upon and claims priority to Turkish Patent Application No. 2021/007340, filed on Apr. 29, 2021, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

(2) The invention is related to soft actuators controlled by fluid pressure.

## BACKGROUND

(3) For the production of fluid controlled soft actuators, generally, elastomeric materials such as silicone and rubber are used and by applying pneumatic pressure on these structures, the desired movement is obtained. The desired movement is obtained by the elastomers being molded and added anisotropic attributes. Although elastomeric materials offer certain superior features such as thermal resistance, chemical resistance and conformity to different movements, the attributes—material density, hardness, endurance—of the elastomeric materials can cause difficulties in wearable applications (for example, the hardness and weight of the materials hinder the movement range of the user) or when the design is required to be scaled to size; limit the design options. In order to eliminate these disadvantages, some textile-based soft actuators have been developed. As in many textile products, these are combined and produced by sewing and attaching the cut pieces. Therefore, there are difficulties in achieving the quality objectives depending on high labor costs and a great number of production steps in the production of textile-based soft actuators.

(4) Several solutions for developing the movement possibilities and production methods of soft actuators are known in the present art.

(5) In the document number WO2017120314A1, actuators comprising a sac positioned between two fabric layers have been described. It was indicated that both fabric layers can have anisotropic and isotropic strain properties.

(6) In the document number WO2015066143A1, actuators comprised of a receptacle on which there are support structures have been described. The twisting, straining, torsion behavior of the actuator or a combination thereof is determined by the support structures. Applications making use of more than one receptacle in order to ensure that certain shape variations can be chosen for actuators suitable for more than one action.

(7) In the document number CN109909990A, modules corresponding to certain shape variations and actuators comprised of combination of different modules have been described.

(8) In the document number WO2018136004A1, actuators each of which comprising a limiting element that has an inner sac and a twister element have been described. The twister element has an undulated structure. Use of the limiting element for straightening the actuator has been discussed as well.

(9) In the document number U.S. Pat. No. 6,718,766B2, actuators comprising more than one receptacle positioned in parallel to each other have been described. The pressure of these receptacles is provided by means of the fluid transfer between the same and the twisting of the actuator is ensured.

(10) In the document number U.S. Pat. No. 10,882,195B2, the production of an elastomeric actuator embedded with a fiber within a mold has been described.

## SUMMARY

(11) The purpose of the invention is to develop a soft actuator controlled by fluid pressure.

(12) Another purpose of the invention is to develop soft actuators controlled by fluid pressure having high pressure resistance.

(13) Yet another purpose of the invention is to develop a production method that provides for the production of actuators adapted according to different requirements.

---

## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

(1) Soft actuators realized in order to achieve the purposes of the invention have been shown in the attached figures.

(2) FIG. 1 is a schematic view of a loop structure of the knitted fabric used in an actuator according

to the invention.

(3) FIG. 2 is a stress-strain curve of the layers used in an actuator according to the invention.

(4) FIG. 3 is a schematic exploded view of an actuator according to the invention.

(5) FIG. 4 is a schematic exploded view of a sensor-integrated actuator according to the invention.

(6) FIG. 5 is a top view of an actuator according to the invention.

(7) FIG. 6 is a side view of an actuator according to the invention in a twisted state.

(8) FIG. 7 is a side view of an actuator according to the invention in an elongated state.

(9) FIG. 8 is a view of a glove comprising actuators according to the invention.

(10) FIG. 9 is a pressure graphic of the actuators according to the invention relative to the end force.

(11) FIG. 10 is a pressure graphic of the actuators according to the invention relative to the retention force.

(12) FIG. 11 is an electromyogram showing the flexor muscle activity measured without the glove.

(13) FIG. 12 is an electromyogram showing the flexor muscle activity measured with the glove seen in FIG. 10.

(14) FIG. 13 is an electromyogram showing the extensor muscle activity measured without the glove.

(15) FIG. 14 is an electromyogram showing the extensor muscle activity measured with the glove seen in FIG. 10.

(16) The parts in the figures have been individually numbered and their corresponding have been given below. 1. Actuator 2. First layer 3. Second layer 4. Third layer 5. First sac 6. Second sac 7. Course 8. Wale 9. Gather 10. Sensor 11. Glove

#### DETAILED DESCRIPTION OF THE EMBODIMENTS

(17) Broadly, the soft actuator (1) of the invention which can be moved by means of fluid pressure between a first state in which it extends along a direction and a second position in which it is twisted away from this direction along at least a portion thereof, basically comprises; a first layer (2), a second layer (3) whose flexibility is greater than the flexibility of the first layer (2), a third layer (4) between the first layer (2) and the second layer (3), having equal flexibility with the first layer (2), a first sac (5) located between the first layer and the third layer, a second sac (6) located between the second layer and the third layer, pressurizing elements that provide the regulation of the pressures of the first sac (5) and the second sac (6).

(18) The first sac (5) and the second sac (6) are produced of leakproof and flexible materials. In a preferred application of the invention, the actuator (1) is pressurized with air and the sacs have airtight quality. For example, the sacs can be manufactured from thermoplastic polyurethane.

(19) With the pressurizing of only the second sac (6) by the pressurizing elements, the third layer (3) is elongated, however, since the first layer (2) and the third layer (4) are not elongated to the same extent, the actuator (1) is twisted towards the first layer (2). By increasing the pressure of the second sac (6), the rigidity of the actuator (1) in a twisted state can be increased.

(20) In the case that only the first sac (5) is pressurized, the actuator (1) is straightened. By increasing the pressure of the first sac (5), the rigidity of the actuator (1) in the straight state can be increased.

(21) By pressurizing both two sacs at the same time, it can be provided that the actuator (1) is twisted at a limited level compared to what is provided with the pressurizing of only the second sac (6).

(22) The first layer (2), the second layer (3), and the third layer (4) are knitted fabrics whose courses (7) extend perpendicular to the direction and the wales (8) parallel to the direction. Thereby, their flexibility under the effect of the forces parallel to the direction can be controlled with the knitting parameters.

(23) The first layer (2), the second layer (3) and the third layer (4) are knitted as integrated with each other by using the three-dimensional whole-garment knitting technique. Providing the

continuity of the connection between layers ensured that the resistance of the actuator (1) to be increased and the forces on the actuator (1) to be distributed evenly. In addition, thanks to the production being carried out in a computer assisted manner entirely, it is provided that the actuators (1) can be easily adapted to different use areas and measurements and produced with standard qualities even though different knitting parameters are used. The labor requirement can be considerably decreased and the formation of fabric scraps can be entirely eliminated.

(24) The second layer (3) of the actuator (1) produced with the three-dimensional whole-garment knitting technique comprises more courses (7) per unit length compared to the first layer (2) and the third layer (4). In the second layer (3), yarns that comprised more flexible materials such as lycra can be used as well.

(25) Preferably on the second layer (3), there are gathers (9) which makes twisting easier and increase the twisting amount. These gathers (9) are formed by knitting the second layer (3) in the way that the course (7)—wale (8) ratio on the inner parts will be greater compared to the one on the sides. By this means, the second layer (3) can be attached to the first layer (2) and the second layer (4) properly, without requiring stitches. The gathers (9) contribute to the determination of the twisting direction by providing an anisotropic flexion possibility to the second layer (3).

(26) The actuator (1) as the subject of the invention can comprise at least one sensor (10). The sensors (10) could be positioned on one or more than one of the layers. Preferably, the sensors (10) are created by being integrally knitted with the related layer during the knitting of the actuator (1). The sensors (10) are sensors (10) that are formed by using conductive yarns and whose electrical features such as impedance vary with the pressure affecting the same or shape variations thereof. The sensor (10) impedance can be dependent on resistance, capacitance, inductance or a combination thereof. In order to monitor the capacitance, two conductive layers on the related layer, and a dielectric layer located between them can be formed, or a conductive layer can be formed on each of the two surfaces of the layer so that the related layer will serve as a dielectric later. In order to monitor the inductance, various shapes can be formed on the related layer from conductive yarns.

(27) The status and operational conditions of the actuator (1) can be monitored with sensors (10). Feedback related to the activity of the actuator (1) can be obtained by means of the sensors (10), and the forces affecting the actuator (1) can be monitored, and the control of the actuators (1) used within the supporting devices can be provided.

(28) The actuators (1) according to the invention are basically produced with the steps of producing the first layer (2), the second layer (3), and the third layer (4) as a whole simultaneously with the three-dimensional whole-garment knitting technique, placing a first sac (5) and a second sac (6) between the layers and connecting pressurizing elements to the sacs. The first layer (2), the second layer (3) and the third layer (4) are produced seamlessly and in one piece by using the knitting parameters suitable for providing the desired measurements and flexibility. The second layer (3) is knitted in the way to comprise more courses (7) per unit length compared to the first layer (2) and the third layer (4). In addition, by decreasing the number of courses (7) on the unit length towards the sides of the second layer (3) wherein it intersects with the first layer (2) and the third layer (4), it is provided that on the sides, the first layer (3) and the third layer (4) have equal course (7) numbers on the unit length. By this means, the integrated layers can be produced such that the flexibility of the second layer (3) is more than the flexibility of the first layer (2) and the third layer (4).

(29) The results of the measurements realized with four different actuators (1) produced by using different yarns according to the invention are shown in FIGS. 9 and 10. In FIG. 9, the forces applied by the end points of the actuators (1) with the first sac (5) is in a pressurized state, in FIG. 10, the retention forces of the actuators (1) with the second sac (6) in a pressurized state, i.e., the forces applied by their concave surfaces in their twisted state are shown as dependent on the related sac pressures.

(30) The actuators (1) as the subject of the invention (1) can be used in automation application wherein delicate and irregularly shaped parts are used, in rehabilitation equipment, and orthoses. (31) An example use of the invention is shown in FIG. 8. The hand movements of a user can be supported with a glove (11) with an actuator (1) according to the invention connected on each finger. This glove can be used for rehabilitation purposes by operating the pressurizing elements according to a certain program. Instead, the pressurizing elements can be operated by monitoring the movements of the user by means of the sensors (10), in the way to support these movements. In order to evaluate the activity of this application in which the user movements are supported, the electrical activity of the flexor and extensor muscles have been monitored during the closing and opening of the hand with the glove (11) and without the glove (11). The related electromyograms are shown in FIGS. 11 to 14. In the light of these results, the glove (11) comprising actuators (1) can significantly support the hand movements.

## Claims

1. An actuator component production method comprising: knitting a first layer, a second layer, and a third layer between the first layer and the second layer, and placing a first sac and a second sac between the first layer, the second layer and the third layer, and wherein the first sac and the second sac are configured such that pressures of the first sac and the second sac are regulatable, wherein the first layer, the second layer and the third layer are produced as a whole with a three-dimensional whole-garment knitting technique, wherein the second layer is knitted in a way to comprise more courses on a unit length compared to the first layer and the third layer, wherein a number of courses on the unit length towards sides of the second layer intersecting with the first layer and the third layer is decreased so that the second layer has equal course numbers on the unit length with the first layer and the third layer.

---