Theme Title	Small-sized shape memory alloy (SMA) artificial muscle actuator with high responsivity and flexibility that can be attached directly to human body
Name of Organization	Kaneko Code Co., Ltd.
Technical Field	Manufacturing, medical-engineering collaboration / life science

Overview

In recent years, artificial muscles have attracted attention for the purpose of power assistance by mounting to human body, and the development of artificial muscles using electric motors and air pressure is underway. However, electric motors have issues on low power generation and flexibility per weight, while artificial muscles using pneumatic rubber have issues on responsivity, quietness, and mobility (portability).

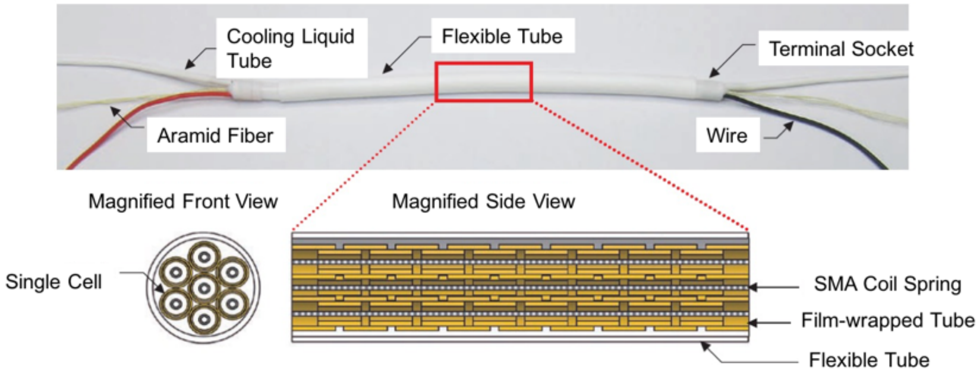
The system shown here was realized by a joint research between Kaneko Code Co., Ltd. and Nakamura Group in Department of Science and Engineering, Chuo University. This epoch-making system solved the issue of low responsivity, the top issue of SMA actuator. The response speed of this system is 5 times faster than that of conventional SMA actuator. Also, this system can be reduced in size and weight and can be attached directly to the human body thanks to its high flexibility. Therefore, this system is expected to have multiple applications including medical use. We welcome companies that are motivated to develop applied products and businesses using this technology.

Simplified Image

Small-sized shape memory alloy (SMA) artificial muscle actuator with high responsivity and flexibility that can be attached directly to human body

[Technical Features]

・ Flexibility comparable to that of biological omuscles (highly safe and can be used for human body)
・ High quietness (no noise source such as deceleration gear s or air compressors)
・ Small outer diameter, compact, and lightweight (ϕ 4.8 x 116 mm, weight 4.5g)
・High generating force, 820-fold of its own weight (maximum generation force of 36N, about 5-fold larger of that of biological muscles)
・ Generated displacement comparable to that of biological muscles (maximum displacement 40 mm → 34.5%)
・Responsivity comparable to that of biological muscles (minimum time of 200 ms)
・Can be directly energized and driven (direct control by microcomputer is possible).
・ Antagonistic stiffness control is possible (stiffness and displacement can be set by input balance).



[Application]

・Rehabilitation equipment, nursing equipment, wearable equipment, etc.
・ Industrial equipment that attaches with an emphasis on safety for humans.
・ Manipulation equipment for robots such as robot hand actuators

Background

Recently, electric motors and pneumatic actuators have been used as artificial muscles for robots, power assist suits, and so on. Electric motors are a major actuator for robots because they can be directly energized and driven with high responsivity and power efficiency. However, their generation power per weight is small, and they have problems with noise due to the incorporated reduction-geared motor to gain required torque. In addition, since electric motors are composed of heavy, hard gears, such as iron cores, coils, magnets, etc. made of iron and copper, they had issues of low flexibility and portability.

In order to solve these problems of electric motors, pneumatic actuators have recently attracted attention, and artificial muscles using pneumatic rubber have been developed. Pneumatic rubber artificial muscles have strong, lightweight, and flexible features. However, since they use air, the responsivity is low and their manipulation is difficult. They require air compressor and solenoid valves, which makes it difficult to make the entire system compact and mobile. Their large noise is also a problem.

In contrast, shape memory alloy (SMA) actuators show shape memory effect by energizing and heating SMA wire or coil springs to be used as an actuator. Therefore, it is possible to directly energize and drive them, which makes them quiet and easy to reduce their size and weight, and shows highly flexible feature because the material itself is soft and flexible. On the other hand, because of the need to wait for cooling after heating, there was a problem with responsivity, and their use was limited to micromachines and other small devices that use thin wires with small heat capacity, where low generation force is not an issue. The following is a table comparing these actuators.

Items	Android actuators	Conventional SMA actuators	Pneumatic artificial muscles	Electric motors
Generating power	◎	–	◎	–
Displacement	O	X	O	O

Responsivity	0	X	-	◎
Power efficiency	-	-	0	◎
Flexibility	◎	◎	◎	X
Quietness	◎	◎	X	-
Portability	◎	◎	0	X
Mobility	0	0	X	◎

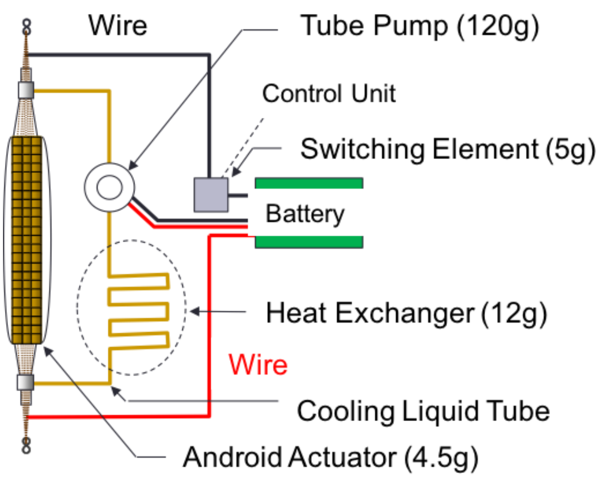
Android actuator (Trademark Registration application : 2017 - 76430)

* The Android actuator is a trademark under the registration application of Kaneko Code Co., Ltd.

In order to use SMA actuators in human-sized devices, large force can be generated by making SMA wires thicker or by bundling many thin wires. However, if the wire is made thicker, the heat capacity becomes larger, and the heating and cooling times become longer, resulting in low responsivity and large power consumption. On the other hand, when many thin wires are bundled together, heat is accumulated between the wires, which makes the cooling efficiency even worse.

In the artificial muscle of this system, a special SMA coil spring is first placed inside a film tube of special shape and material, which is bundled together to form a single cell. By placing this cell into a flexible tube and flowing cooling liquid, we were able to improve the responsivity and flexibility and solved the problems of the conventional shape memory alloy (SMA) actuators, making it possible to apply the actuator to human-body sized devices.

As a result, we achieved in downsizing the whole system and realized a flexible artificial muscle with high generation power and responsivity that



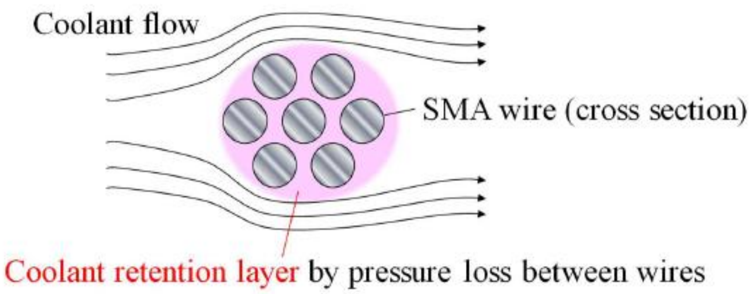
can be mounted directly to the human body.

The artificial muscles of this system show flexibility, quietness, small size and weight, displacement, and responsivity comparable to those of biological muscles. Moreover, their generation power is 5-fold larger than that of biological muscles, and they can be directly energized and driven and allows antagonistic rigidity control. Therefore, it can be used as an actuator suitable for machine systems that have many opportunities to come into direct contact with humans, such as rehabilitation robots and human-mounted power assist systems. In addition, there is little noise because no air compressors are used. Furthermore, since the power supply is a battery and the cooling system is a compact, closed system, it can be used in factories, warehouses, and outdoors, and can also be applied to portable systems. We welcome companies that are motivated to develop applied products and businesses using this technology.

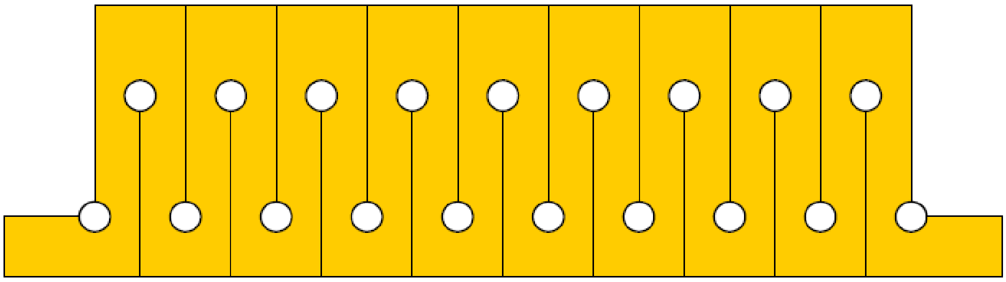
Technology

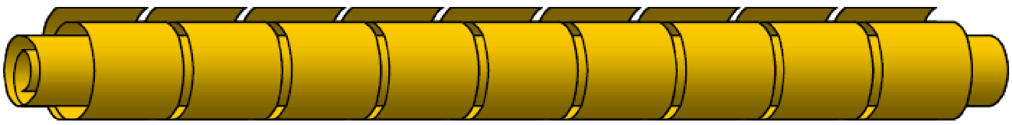
The contraction mechanism of this artificial muscle is similar to that of the SMA wires, but the displacement generated by the SMA wire is smaller (about 5%) and therefore expanded to about 50% by coiling. The SMA coil spring is a rectangular cross-sectional bare-wire coil spring.

In this artificial muscle, multiple SMA coil springs are used in a bundle, but when multiple springs are bundled in this way, there was a problem that cooling efficiency decreases or cooling becomes uneven due to pressure loss and retention of cooling fluid between the SMAs upon flow (the pink area in the following figure shows the retention layer of the cooling fluid).



Therefore, we wrapped a polyimide film of a special shape, shown in the following figure (top), to create a tubular-coating material with the structure shown in the figure (bottom).





The SMA coil springs are placed in a special polyimide tube, bundled, and put into a flexible tube (natural rubber tube). By flowing the cooling liquid, we solved the problems of cooling liquid retention and uneven cooling, realizing high responsivity,

In addition, this unitization allows for constructing a similar structure to that of a biological muscle.

Strengths of the Technology and Know-How (Novelty, Superiority, Utility)

The advantages of this artificial muscle are as follows.

・Flexibility comparable to that of biological muscles (highly safe and can be

used for human body)
・ High quietness (no noise source such as deceleration gears or air compressors)
・ Small outer diameter, compact, and lightweight (ϕ 4.8 x 116 mm, weight 4.5g).
・ High generating force, 820-fold of its own weight (maximum generation force of 36N, about 5-fold larger of that of biological muscles)
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・Can be directly energized and driven (direct control by microcomputer is possible).
・Stiffness and displacement can be controlled (they can be set by input balance).

Image of collaborative companies

For example, we can work with the following companies.
1) Rehabilitation equipment, nursing care equipment, wearable equipment, etc. Companies that develop and sell industrial equipment with an emphasis on safety for humans.
2) Companies that develop and sell prosthetic limbs and medical robots.
3) Nursing care services, transportation and warehousing businesses, health and sports industries (gyms), etc.
Companies with businesses that can use power assist or power resist.
4) Companies that develop and sell manipulation equipment for robots, such as actuators, robot hands, and manipulators.
5) Companies that are motivated to commercialize and utilize this technology, including industrial robots.

Utilization of Technologies and Know-How (Images)

This light, soft material can be attached directly to the human body and generates high power, making it suitable for rehabilitation equipment and power-assisted devices for mounting to human body, which require safety. In particular, because of its light weight and small size, it could be used in nursing services and transportation and warehousing industries, where it is necessary to move around with the power-assisted devices attached to the human body.

It is also expected to be applied to prosthesis and medical robots.

Going outdoors with the power-assisted devices attached to the human body is possible, so this material could be used in health businesses and gyms. In this regard, it can also be used as a power-resist device for human body with increased resistance to exercise. In other words, since it is possible to perform muscle exercises with a load, it is also possible to safely perform exercises that were dangerous with conventional equipment such as bench press.

The applications of this artificial muscle are as follows. A variety of applications is possible depending on the ingenuity of the design.

[Application Example 1: Artificial Muscle Prosthesis]

Conventional prosthetic limbs are mainly mechanical, and to achieve complex movements, equipment configuration becomes complicated, making it difficult to reduce weight.

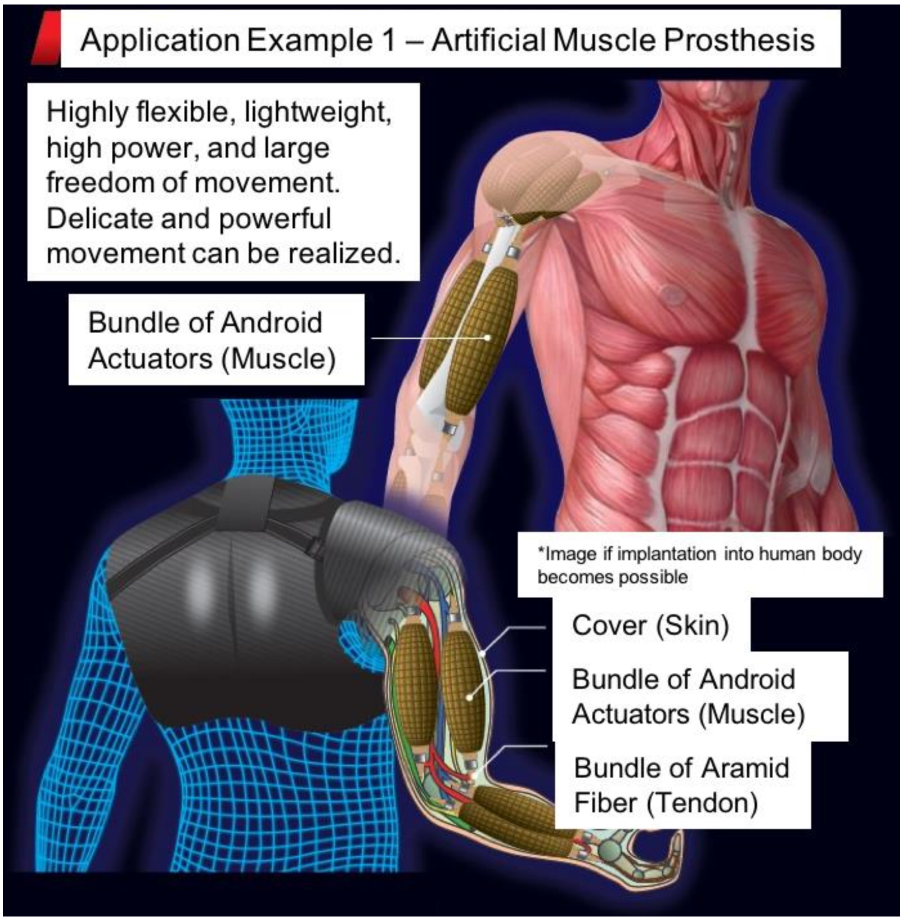
Artificial muscles have the following characteristics: they are lightweight but have a large output density, are easy to maintain because they do not have sliding parts, are flexible, and have the same characteristics as muscles. Therefore, they have potential applications for prosthetic limbs. However, pneumatic rubber artificial muscles are driven by air pressure, which makes the sound of the compressor and the air being pumped noisy, so it is difficult to keep the compressor on the human body at all times or to move around while wearing it.

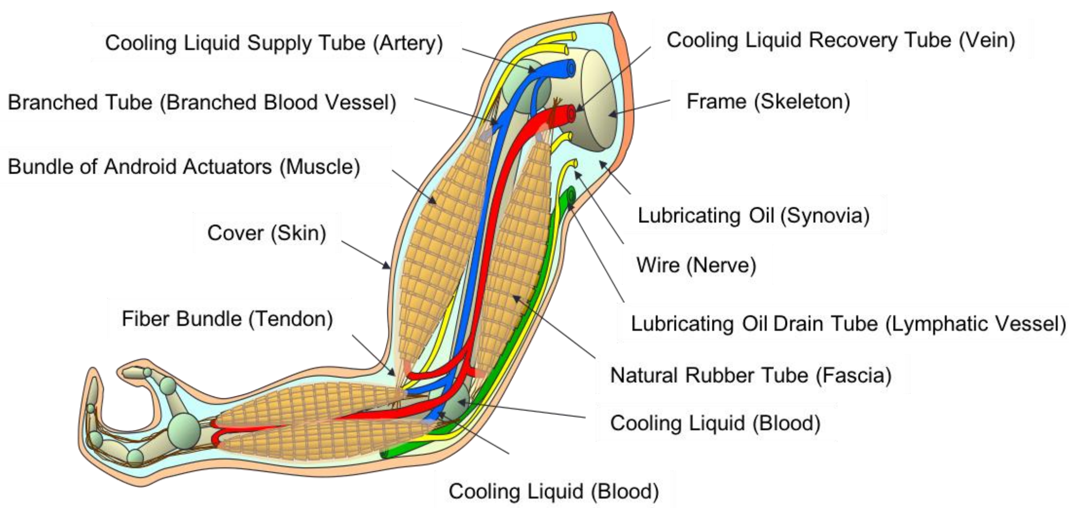
If the artificial muscle of this system is used, an artificial muscle prosthetic hand can be constructed as a system similar to the hands or arms of a living body, as shown in the figure below. This artificial muscle prosthetic hand consists of this artificial muscle actuator as the muscle part, a flexible tube as the myofascial part, cooling liquid as a vascular part of, and a control wire as a nerve part; therefore, this prosthetic hand corresponds to biological hands and arms.

Compared to other prosthetic limbs, this artificial muscle prosthesis has the advantages of being lighter, having a flexible joint, a biomimetic and simple mechanism, and not requiring much space for the driving system. In addition, since the drive control is based on electrical signals, it is compatible with the application as myoelectric prosthetic hands.

In addition, further miniaturization is facile (1 unit: ϕ4.8×116mm, 4.5g),

and since the antagonistic stiffness control is possible, this system can realize not only arm-level- but also hand and finger-level, delicate movements.



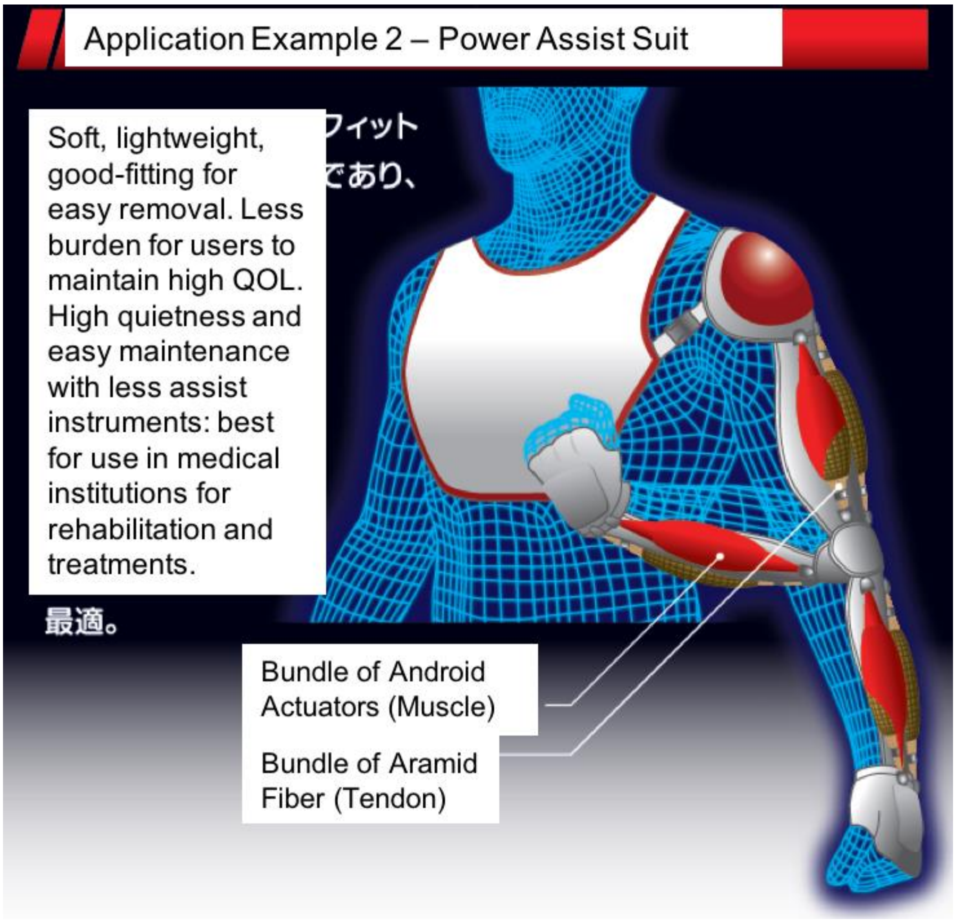


This artificial muscle prosthesis is as light as a biological muscle. The contraction force as an artificial muscle is equivalent to that of a biological muscle, but the maximum generation force is greater than that of a biological muscle; therefore, sufficient muscle strength can be achieved.

[Application Example 2: Power Assist Suit].

This is an example of a power assist suit that takes advantage of the fact that this artificial muscle has similar properties to biological muscles and is arranged in a similar way to living body. It has a pump unit and is used by flowing cooling liquid. PFPE (perfluoropolyether) is used as the cooling liquid. This liquid is heat resistant, inert and lubricated at room temperature, providing sufficient cooling effect only by circulation. Cooling at body temperature is also possible. Of course, other cooling liquids can be used depending on the conditions of use. By attaching sensors to joints, etc., an intelligent and smart power assist suit can be realized. It can also be used to cover the disabilities of animals other than humans (pets, etc.).

Conventional power assist suits have the disadvantage of being very heavy, with stiff joints and a weight of over 50kg. Also, because of its hard structure, there was a risk of injury if a human came into contact with it. In contrast, this power assist suit is safe and easy to handle because it has soft joints and is extremely lightweight, making it suitable for cooperative activities with human movements.



Flow of Technology and Know-How Application

If you are interested in utilizing this technology or product development, please feel free to contact us. We will introduce you with demonstration.

Description of the Technical Terms

[Artificial Muscles]

Artificial muscle is a generic term for flexible actuators that expand and contract under some kind of external control to perform their work. Other than the ones using shape memory alloys (SMA), there are also types using pneumatic rubber, piezoelectric elements that shrink and expand upon electric field application, gels that deform depending on differences in ion concentration, and polymers that swell and contract by light.

[Shape Memory Alloy (SMA)]

Shape memory alloys can be deformed by external forces at or below a certain temperature (transformation point) but return to their original shape when heated above the transformation point. One familiar application is the wires in the cups of brassieres, which, even if deformed by washing, return to their original shape at skin temperature and maintain that state.

[Antagonistic Stiffness Control]

This artificial muscle can change its spring stiffness, i.e., the property that it tries to shrink, depending on the amount of power applied. This is called variable stiffness. Thus, by placing a pulley between two artificial muscles in an antagonistic state, as shown in the figure below, the balance of stiffness (k) can be altered by adjusting the balance of power applied to the left and right artificial muscles, creating a difference in contraction between the antagonistic artificial muscles. This difference in the amount of contraction is converted into a rotational motion by the pulley to drive the joint. This method makes it possible to hold objects of different weights at the same angle or height, as well as objects of the same weight. This is the antagonistic stiffness control. Since the biological muscles contract only in the axial direction, they usually take an antagonistic arrangement. Therefore, it can be said that antagonistic stiffness control is a control method commonly used in living body. The complex, precise, and powerful movements of living body are realized by this control method.