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Development of a Human Trunk Exoskeleton with Pneumatic Artificial Muscles

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Exoskeletons are specific type of wearable robotic suits that are specifically designed to improve the physical capabilities of humans by means of increasing strength, stability and duration of motion. In this paper, an on-going research on developing a human trunk exoskeleton with pneumatic artificial muscle actuators with very high force-mass ratio and new PAM Fabrics will be present. The aim of this project is to support human trunk motion and prevent occupational injuries. The Human Trunk Exoskeleton consists of a pneumatic artificial muscle groups that has been installed on spinal support mechanism and a harness for fixing it to body. There are total of 3 muscle groups on the spine mechanism and 2 muscle groups on the front for allowing human trunk to move freely.

Key Words: Exoskeleton, Spine, Pneumatic Artificial Muscle

1. Introduction

In today’s industry, spinal disorders like slipped discs are still very common as occupational injuries due to nature of assigned jobs. Main reasons of these kinds of occupational injuries can either be continuous loads acting on human spine or heavier loads that start to act suddenly. In this research, main objective is to develop an exoskeleton that will support the human back joint during routine industrial work such as using heavy welding machines or lifting parts coming out of presses. Since most of the mass production facilities deploy pneumatic lines for powering their equipment, the Human Trunk Exoskeleton is designed to be supplied by pneumatic power line which in fact makes it practical for industrial usage.

Exoskeletons are one of the most promising technologies of the future because of their potential usage in industrial applications and assisting physically handicapped people. Additionally, Exoskeletons should also meet many design requirements such as being lightweight with decent power output while preserving flexible motion ability. However, fulfilling these requirements is quite difficult while using electric motor actuators with relatively heavy gearboxes and coils which are commonly used in today’s exoskeletons. Our solutions for replacing heavy actuators and structural elements are to deploy flexible McKibben pneumatic artificial muscle bundles as actuators and to design a suit made of pneumatic artificial muscle (PAM) fabrics. In ongoing sections of this paper, details of knitted and weaved type artificial muscle fabrics and design of Human Trunk Exoskeleton will be explained.

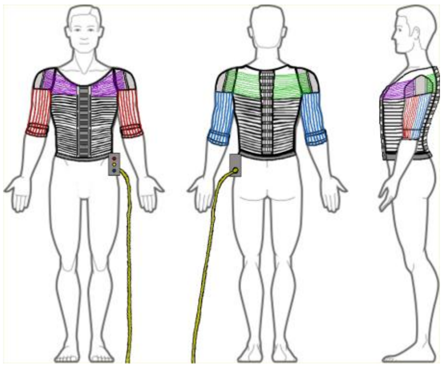

Fig. 1 Conceptual Design

2. Flexible McKibben Pneumatic Artificial Muscles

Pneumatic rubber tube actuators are a common variant of artificial muscles that use air pressure to exert force by contraction at the ends due to expansion on lateral surfaces. McKibben pneumatic artificial muscles are specific type of pneumatic rubber tube actuators that are covered with braid meshes with specific angles to improve force characteristics. Because of the non-extensive nature of the fibers used in the braid meshes, when the volume of the rubber tube is increased by air pressure, muscles shorten and exert force in case of mechanical load.

McKibben pneumatic artificial muscles are light-weight, easy to produce, safe and low-cost actuators compared to other types of electric and fluid actuators. Although, McKibben pneumatic artificial muscles can be designed as single large actuators, they can also be deployed as muscle fiber bundles similar to muscles of animals [1][2].

In our research, thin McKibben artificial muscles about the diameter of 2.5 mm with nylon fiber braid meshes and silicone rubber tubes have been used for producing PAM Fabrics and muscle bundle actuators for the Human Trunk Exoskeleton [3][4].

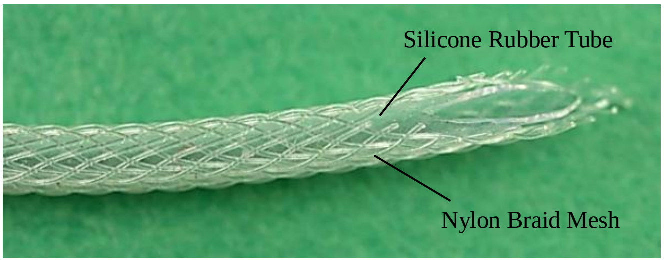

Fig. 2 Soft McKibben Pneumatic Artificial Muscle

3. Pneumatic Artificial Muscle Fabrics

Pneumatic artificial muscle fabrics can be basically described as the fabrics that has been produced by deploying various textile techniques, mainly knitting and weaving. Additionally, in textiles, properties of fabrics, depend on the specific textile parameters such as density and thickness of fibers. Same principle also applies in the case of pneumatic artificial muscles such that response to air pressure and mechanical behavior is directly affected.

Since responses and mechanical behavior of PAM Fabrics can be simply adjusted by method of weaving-knitting and dimensions of the fibers used, PAM Fabrics can be configured to be used in many applications. To illustrate, intelligent suits that adjust themselves according to body shape of the users can be designed or similar to project in this article, PAM Fabrics can be used to support structure of exoskeletons and can even replace the main actuators. In the following sections, specifications of the knitted and weaved type PAM Fabric samples will be given.

3.1 Knitted PAM Fabric

Today, Knitting is one of the most common methods that can be used to produce fabrics. Textiles that have been produced by knitting consist of several rows of loops that are called stitches. The fibers used in knitting are called yarns. In case of Knitted PAM Fabric, the yarns are simply replaced with pneumatic artificial muscles. Because of relatively simple nature of knitting, the first sample has been produced by using a basic knitting loom.

In knitting, only 1 line of artificial muscles are required due to structure of stitches. Hence, the sample fabric has 1 inlet and 1 outlet for air pressure. The sample has been produced by plain knitting and it consists of 18x9 loops in total. The non-pressurized dimensions of the Knitted PAM Fabric are 12 cm x 8 cm.

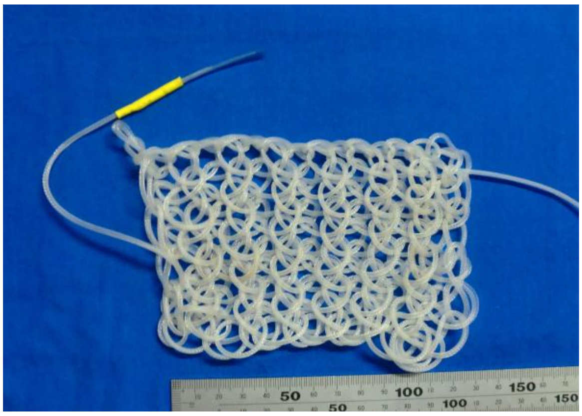

Fig. 3 Knitted PAM Fabric Sample

When air pressure is applied, the response of the Knitted PAM Fabric is basically shrinking in x-y axes and slight expansion in z axis. Knitted PAM Fabric can operate at pressures below 0.35 MPa

3.2 Weaved PAM Fabric

Weaving is an old and widely used technique for fabric production in which two or more different lines of yarns are interlaced at each other with specific angles. Today, weaving is the most common method for producing fabrics in industrial scale. Similar to knitted version, yarns are replaced with pneumatic artificial muscles to produce Weaved PAM Fabric. A basic weaving loom has been used for producing the first sample.

In Weaved PAM Fabric, total of 2 lines of artificial muscle yarns are used in x-y axes. As a result, there are total of 2 inlets and 2 outlets (1 inlet and 1 outlet for each axis) for air pressure. In order to prevent excess friction between artificial muscles, plain weaving is used for Weaved PAM Fabric.

Weaved PAM Fabric has 2 degrees-of-freedom since it has 1 inlet and 1 outlet for each axis. Therefore, the response of the Weaved PAM Fabric depends on applied pressures on each axis. During the pressure tests, it has been seen that the response of x and y axes differs due to friction. Muscles on the x axis can easily shrink because of straight orientation. On the other hand, muscles on the y axis are subject to additional crimp and are not able to shrink freely compared to x axis. Lastly, it has been observed that Weaved PAM Fabric with high textile density cannot operate at pressures like 0.35 MPa like pneumatic artificial muscle bundles or Knitted PAM Fabrics. The maximum operable pressure is approximately 0.30 MPa to avoid blowing up rubber tubes inside the muscles.

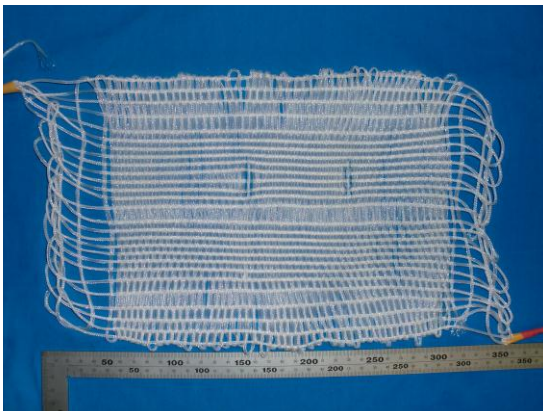

Fig. 4 Weaved PAM Fabric Sample

4. Human Trunk Exoskeleton

In this section, details of the Human Trunk Exoskeleton that aims to support human trunk joint during activity will be discussed. In general, Human Trunk Exoskeleton consists of three main sections which are spine mechanism, pneumatic muscle bundles for actuation and a full body harness for fixing the system into human body.

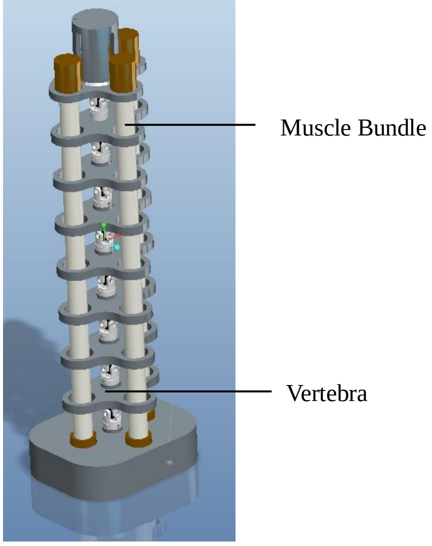

Fig. 5 Spine Mechanism

The main principle for supporting spine with Human Trunk Exoskeleton is exerting moments about pilot's sacrum by using pneumatic artificial muscle bundles. In order to accomplish this objective, a spine mechanism that carries the artificial muscle bundles is designed.

4.1 Spine Mechanism

Spine Mechanism is the main structural element of the Human Trunk Exoskeleton. Spine Mechanism consists of artificial muscle bundle housings called vertebrae. Similar to bones located in human vertebral column i.e. spine, these vertebrae are mechanical parts designed for allowing user to move freely and aligning the artificial muscle bundles in parallel to user’s body. Spine Mechanism is approximately 45 cm long.

Fig. 6 Top view of Vertebra Sample

Vertebrae are connected to each other with coupling-shaft couples to provide 2 degrees of rotational freedom in sagittal and frontal axes. There are 3 artificial muscle bundle passages in each vertebra. Diameters of the muscle bundle holes and connection holes are 35 mm and 5 mm respectively. The lowest vertebra connects the artificial muscle bundles onto valve box where the applied pressures on each muscle groups are controlled. Vertebrae are produced with the material called MC Nylon by using CNC milling machine.

5. Conclusion

In this article, details of the knitted and weaved versions of PAM Fabrics and the recent study of developing and Human Trunk Exoskeleton using Pneumatic Artificial Muscles which consists of a spine mechanism and artificial muscle bundle actuators have been presented.

In future, new types of weaving patterns such as twill, basket and leno weaving will be produced as new versions of Weaved PAM Fabric. It has been found out that plain weaving with high density is not compatible for 2.5 mm artificial muscles. Mixed weaving of pneumatic artificial muscles with composites is another option for higher stability and efficiency. Moreover, new semi-automatic systems for weaving and knitting will be designed in the future. The aim of automation is to produce PAM fabrics in larger dimensions in short amounts of time for designing various intelligent clothing. These PAM Fabrics will eventually replace the full body harnesses in Human Trunk Exoskeleton. In conclusion, this research has been a great opportunity for experimenting the behavior of PAM Fabrics and designing a new generation exoskeleton for supporting human spine with pneumatic artificial muscle bundle actuators.

Achknowledgement

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