# FORCE FEEDBACK INTERFACE WITH PNEUMATIC MUSCLES

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## ABSTRACT

This work summarises main exceptional properties of McKibben pneumatic muscles and a development and design of a force feedback glove interface for the use in robotics, especially in telepresence, or in VR. The force and touch feedback is provided by Pneumatic Muscle Actuators. The design is light and compact.

**Fig. 1:** *Haptic Glove with Pneumatic Muscles.*

## 1 INTRODUCTION

The most of contemporary robots use DC or AC motors like the actuators. However, these implementations are often too heavy and rigid, particularly for work in contact with human. Using of these “traditional” actuators in the field of haptic and force feedback devices is especially unsuitable, because haptic gloves are usually grounded on the user forearm. DC motors in combination with tendons fail because there are simply too heavy to be supported by user hand.

That is the reason why the researchers try to find an actuator similar to human muscles. The most promising actuator in this field of research is undoubtedly McKibben pneumatic muscle actuator.

The McKibben muscle was invented in the 1950s by physician J. L. McKibben to motorize pneumatic arm orthotics. Although this pneumatic artificial muscle became rather active, this actuator type was finally replaced in the 1960s by electric motors because of problem with the gas supply and difficult control.

Recently, the interest of robotic researchers is renewed in that original actuation mode, particularly in applications to assist disabled people as well as to service robotics and also in haptics. Using of pneumatic muscles in this field is a progressive solution, which can significantly help to spread the haptic interfaces around.

## 2 ACTUATING OF HAPTIC GLOVE

The main property for the haptic glove are lightweight, compactness, easiness to wear and it should provide full free motion of fingers. An actuator, which fulfils these conditions, is a Pneumatic Muscle Actuator (pMA) based on the McKibben muscle.

The pMA consists of two-layered cylinder with an inner rubber liner, an outer containment layer of a nylon shell braided according to helical weaving. The muscle is closed by two end caps with air input(s) and attachment points. The structure gives the actuators number of desirable characteristics:

I. Actuators have exceptionally high power and force to weight volume ratios.

II. The pMA can be made in any diameter and length.

III. The structure of pMA makes it comparable in shape, properties and performances to human muscles which makes it easy to implement a human/computer interface.

IV. The actual achievable displacement (contraction) is typically 30% of the dilated length.

V. The muscles are highly flexible, soft in contact and have excellent safety potential (the contraction of 30% prevents the system from moving fingers to hypertension which could be painful and/or dangerous).

VI. Controllers developed for the muscle systems have shown them to be controllable to an accuracy of 1% of displacement. Bandwidth of muscles of up to 5 Hz can be achieved.

VII. The contractile force of actuator can be over 300 N/cm2 for pMA (compared to 20-40 N/cm2 for natural muscles).

VIII. Accurate smooth motion from start to stop.

IX. Low hysteresis and friction.

X. Low cost, powerful actuation, lightweight compact device.

XI. High safety – it works in wet or explosive environment.

High-speed solenoid MATRIX valves operating in pulse width modulation structure actuate the muscles. 150 Hz pulses were found to be adequate for smooth and fast pressure control.

## 3 MECHANICAL STRUCTURE

The glove consists of two parts:

- A leader (golf) glove with inbuilt bend sensors.
- An exoskeleton structure to hold the muscles.

The leader glove is shown in the Figure 2a. Flexpoint bend ink sensors are placed in the small pockets on the upper side of fingers. They are fixed on the second metacarpal of each finger and sense the angles of joints between first phalanx and second metacarpal.

**a)** **b)**

**Fig. 2:** *The position-sensing glove (a) and the exoskeleton structure (b).*

The exoskeleton structure (Figure 2b) consists of a thermoplastic base moulded on the back of the user's hand, a fastening belt and a muscle holder and supporter. Thus the pMAs could be attached to the exoskeleton. The muscles are positioned along the user's fingers with the other end attached to thimble-like structures. The muscle supporters improve the direction of force applied against bending fingers. This arrangement allows full motion of the user's fingers.

Only agonic muscle per finger has been used in present stage of project. However it implies only passive actuation allowed, on the other side this arrangement allows full and unconstrained motion of the user's fingers and is suitable for grasping sensations that the glove is designed for. The overall weight of the structure is about 500 g.

## 4 CONTROL ELECTRONICS

Control electronics consist of the pressure and strain gauge amplifiers board, the data acquisition board and the driver board.

The pressure and strain gauge amplifiers board provides necessary amplification and filtering of low-level signal from sensors to meet input range of A/D converter. The whole board has 10 of these channels, 5 for attached pressure sensors and 5 for strain gauges mounted on the exoskeleton.

The data acquisition board is responsible for the data collection from sensors, converts this data to the digital form, transmits them into the PC, receives the computed regulator output from the PC and converts it back to the analogue form. The input has 16 analogue channels. They are switched by the multiplexer and processed by A/D converter. The output has six analogue channels, each equipped with a D/A converter.

The driver board converts an analogue output of D/A to a PWM signal capable to drive valves. The board also provides an electronic speed up for opening and closing of solenoid valves.

## 5 CONTROL SOFTWARE

The software is built in Visual C++ environment and runs under Windows 2000. The sequence of implemented procedures follows:

- Reading of sensor values via RS 232.
- Digital Filtering.
- Checking for intersections with object.
- Computing of forces to be applied to fingers.
- Computing of PID outputs.
- Sending “action” values via RS 232.

The software also displays to user important data, like finger positions, finger position errors, desired and real pressure in muscles. User can set stiffness, damper constant and size of the grasped object.

## 6 THE FORCE CONTROL

In previous version of our haptic glove we have been using proportional valves. It brought a lot of additional problems with muscle pressure control due to the slow response, hysteresis and other nonlinearities of valves. Advanced approach, than an ordinary PID controller had to be applied.

Using of fast solenoid valves in present project stage allows better simpler and faster muscle pressure control. The value of desired pressure is computed according the Chou-Hannaford pneumatic muscle model [2] from the depth of penetration into the simulated object and current finger position.

In the second stage also the force controler was added. The strain gauges were attached to the metal strips coupling muscles to thimble-like structures. These strain gauges measure the force applied to the fingertips by muscles. This signal is employed like input of higher-level force PID controller after subtracting from the computed desired force. The output of this controller is connected with input of the pressure control stage. This version actively eliminates highly non-linear dependence of force on pressure for pMAs, but doesn't give so reasonable results like the approach with the muscle model.

## 7 CONCLUSION

The haptic glove (Figure 1) provides quiet realistic grasping sensation particularly for simulations of low-stiffness objects. Just cylinder objects are implemented now, but it is easy to change the program to simulate any other shape.

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