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Development of a Skin for Intuitive Interaction with an Assistive Robot

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Abstract—**Assistive robots for persons with physical limitations need to interact with humans in a manner that is safe to the user and the environment. Early work in this field centered on task specific robots. Recent work has focused on the use of the MANUS ARM and the development of different interfaces. The most intuitive interaction with an object is through touch. By creating a skin for the robot arm which will directly control its movement compliance, we have developed a novel and intuitive method of interaction. This paper describes the development of a skin which acts as a switch. When activated through touch, the skin will put the arm into compliant mode allowing it to be moved to the desired location safely, and when released will put the robot into non-compliant mode thereby keeping it in place. We investigated four conductive materials and four insulators, selecting the best combination based on our design goals of the need for a continuous activation surface, the least amount of force required for skin activation, and the most consistent voltage change between the conductive surfaces measured during activation.**

I. INTRODUCTION

In 1999 Harwin stated that in order for assistive robots to be successful they would need interact in such a way as to prevent damage to both the environment and the robot, and to be safe for a user with physical limitations [1]. Specialty assistive robotic devices have been created which help users with very specific tasks, while maintaining these fundamental properties. MySpoon is a commercially available 5DOF robotic manipulator arm which employs 1DOF end-effector and a dedicated 4-compartment meal tray which allows people with physical disabilities to feed themselves [2]. The desktop vocational assistive robot (DeVAR), developed in 1993, has a simple, single-user voice recognition with discrete word commands with no provision for adding or changing tasks [3]. It was followed by ProVAR, which incorporates force-based object manipulation and is controlled through the user's laptop computer. Recent research has focused on the use of the MANUS Assistive Robotic Manipulator (ARM), a 6+2DOF robotic arm which can be mounted on a wheelchair or mobile base. As shipped, the control inputs are through joystick, 4x4 keypad, or other user-specified switches/buttons [4]. Other work has been done in this field to create and evaluate new interfaces for the MANUS ARM, including using a wireless mouse [5]; human-in-the-loop combined with computer vision processing [6]; and a new method of mode switching, a new control mode, and an altered center of rotation for the gripper [7].

The most intuitive interaction with an object is through touch. By creating a skin for the robot arm which will directly control its movement compliance, we have developed a novel and intuitive method of interaction. This skin acts as a switch that is activated by touch, placing the robot into compliant mode and allowing the user to move the arm through space to the desired location without worry about harm to self or objects in the environment. When the user releases the arm, the switch is deactivated placing the robot into non-compliant mode thereby keeping it in place. We envision potential uses of the robotic arm to include stabilizing an object for someone who has hemiplegia due to stroke, or providing strength augmentation during a moving or lifting task for someone with limited muscle strength or limited leverage due to being in seated position.

This paper presents the development process of the robotic skin. Our design goals for the skin included the need to provide a continuous activation surface, while finding the optimal combination of conductive and insulator materials which required the least amount of force per activation and with the most consistent voltage change between conductive surfaces measured during activation.

II. METHODOLOGY

The skin we developed is a fabric switch, which consists of external covers, two conductive surfaces and an insulator which prevents unintentional contact (Fig 1).

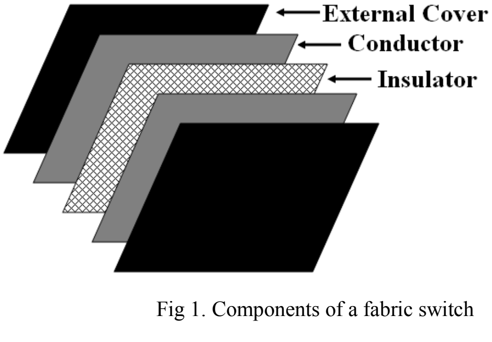

Fig 1. Components of a fabric switch

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A. *Conductive Materials*

The conductive surface needed to be durable and flexible. Conductive fabric, 80% metal and 20% silk (80/20), and soft metals were explored. Silver is the most conductive metal, however it is expensive. Copper is the second most conductive metal [8], and readily available in a variety of forms including adhesive tape [9] and sheet goods [10].

B. *Insulators*

The insulator needed to provide a continuous activation surface and allow the skin to be activated with the least amount of force possible.

Four insulators were selected for testing based on their durability, likely resistance to false positives, and widespread availability. Insulator 1: A yellow foam sheet with square perforations measuring 2.0mm x 2.0mm, set 2.1 mm to 2.6mm apart depending on orientation, and maximum thickness of 2.3mm (Fig 2). 6.0mm x 8.0mm openings were created to allow the end-effector on the sensor to activate the switch. Insulator 2: A fine nylon net with perforations set in a continuous diagonal pattern measuring 1.73mm x 1.8mm (Fig. 3). Insulator 3: A wide nylon net with perforations set in a continuous honeycomb pattern measuring approximately 3mm across the hexagon (Fig. 4). Insulator 4: A very thin foam material with rectangular perforations measuring 6.5mm x 8mm, set 1.20mm to 2.20mm apart depending on orientation, and a maximum thickness of 1.25mm (Fig. 5).

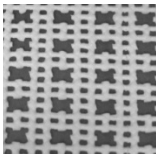


Fig. 2 Insulator 1;

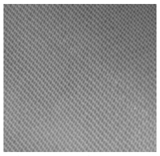


Fig. 3 Insulator 2;

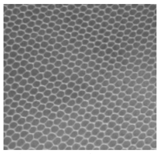


Fig. 4 Insulator 3;

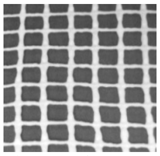


Fig. 5 Insulator 4

C. *Construction*

All skin prototypes began with a cotton cloth external surface. Two designs were created using 80/20 conductive fabric and two designs were created using copper tape.

The first 80/20 design consisted of a single layer of fabric, with lines of conductive thread stitched through. The second design consisted of three layers of 80/20 fabric with conductive thread securing the layers together (Skin B) (Fig. 6). The thread was stitched by hand using an approximately ¼”-long running stitch with approximately ¼” between the rows.

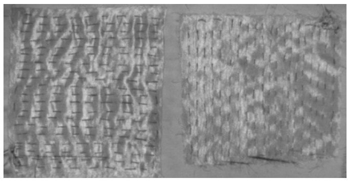
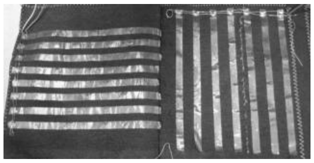


Fig. 6 Skin (B) Three-layer 80/20 fabric with conductive thread skin sample

The first copper tape design (Skin A) used ¼”-wide tape with ¼” spacing between the rows (Fig. 7). The rows were arranged orthogonally on opposite sides of the switch. The second copper tape design (Skin C) used contiguous tape strips, with the rows slightly overlapping. The rows for Skin C were also arranged orthogonally to each other (Fig. 8).



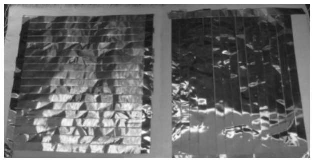


Fig. 7 Skin (A) Spaced copper tape skin sample (left)
Fig. 8 Skin (C) Contiguous cooper tape skin sample (right)

D. *Test Design*

The skins were tested as a combination of conductive materials and insulators. Raw initial voltage across the skin was approximately 5.28 volts when the switch was open, moving towards 0 volts when activated/closed. The force required to close the switch was determined using a Nano17 sensor (ATI Industries) with a ¼” round end-effector attached to the flat end. The Nano17 is a 6DOF sensor, recording both forces and torques in the x, y, and z axes, with a resolution of 0.003 Newtons [11]. A NIDAQ board (National Instruments) was used to read both the raw sensor data and the voltage across the skin.

The external fabric side of each skin was marked with a 5x5 grid of points, and each point was activated 20 times (Fig. 10) while 6-axes of force and torque were recorded at 100Hz.

The activation points on Skin A were shifted horizontally as needed to ensure contact between the tape strips. Testing of Insulators 1 and 4, for all Skins, required subtle shifting of the test points to ensure non-conflict with the insulator surface.

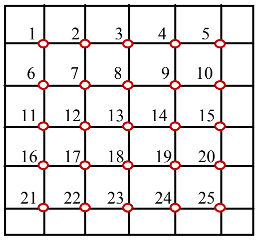


Fig. 10 Test points on skin

E. *Data Analysis*

Based on the data recorded at each skin point we calculated the activation force, the minimum force required to activate the switch. The activation force was based on the voltage threshold (or activation voltage), the first voltage less than the minimum raw voltage (MIN) + 0.05 volts. We calculated the mean and standard deviation of the activation forces and voltages.

III. RESULTS

A. *Conductive Materials*

The single layer of fabric with conductive thread did not conduct enough current, when measured with a multimeter, to warrant continued testing. The three-layer 80/20 fabric

(Skin B) had good conductivity but varying activation voltage change across the surface of the skin. Unfortunately, due to technical difficulties, only Insulators 1 and 3 were tested with Skin B.

The copper tape skins, both spaced (Skin A) and contiguous (Skin C), had large activation voltage changes when the switch was closed. Testing was completed with all insulators for both Skin A and Skin C.

B. Conductive Material and Insulator Combination

The mean and standard deviation of the skin activation forces (top) and skin activation voltages (bottom) are shown in Figs. 11 through 18. When the skin was not activated, the starting voltage was approximately 5.28 volts. The ideal combination includes low mean activation forces and low mean skin activation voltages (note that the y-axis scales vary).

Table 1 details that for Skin C Insulators 3 and 4 required very low activation forces.

TABLE I
ACTIVATION FORCE MEANS AND STANDARD DEVIATIONS BY CONDUCTIVE SKIN AND INSULATOR COMBINATION

Skin A	I1	I2	I3	I4
Mean Force (N)	2.002351	3.982867	0.902094	1.606096
StdDev Force (N)	0.636856	1.767656	0.379506	0.903534
Skin B*	I1	I2	I3	I4
Mean Force (N)	3.746192	--	1.304928	--
StdDev Force(N)	0.61958	--	0.339156	--
Skin C	I1	I2	I3	I4
Mean Force (N)	2.25794	2.740765	0.959152	0.778704
StdDev Force (N)	1.386042	1.636751	0.447444	0.377291

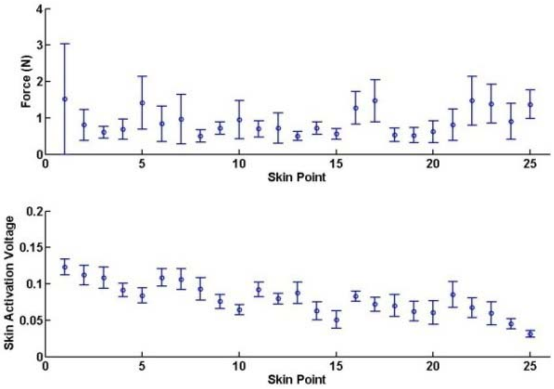


Figure 11: Skin A, Insulator 3 combination

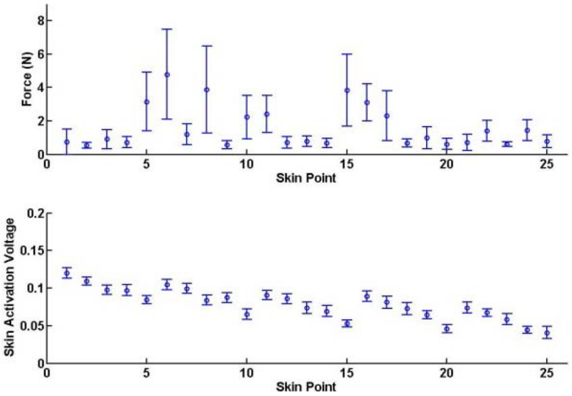


Figure 12: Skin A, Insulator 4 combination

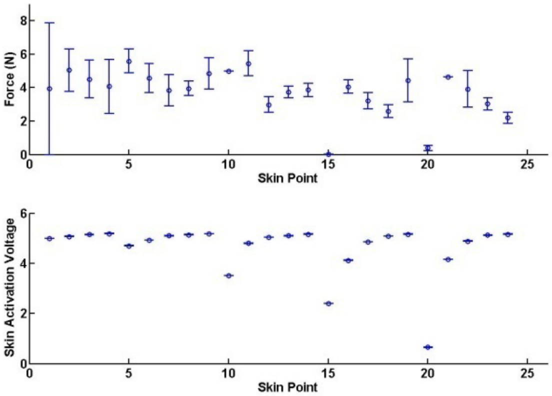


Figure 13: Skin B, Insulator 1 combination

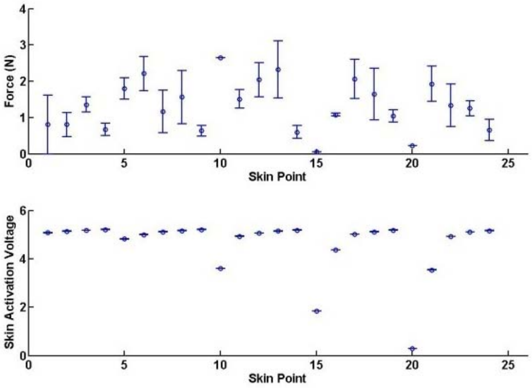


Figure 14: Skin B, Insulator 3 combination

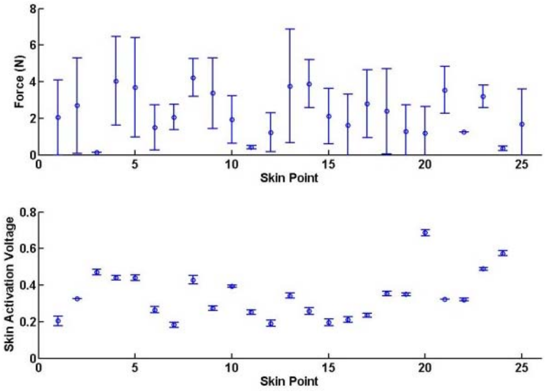


Figure 15: Skin C, Insulator 1 combination

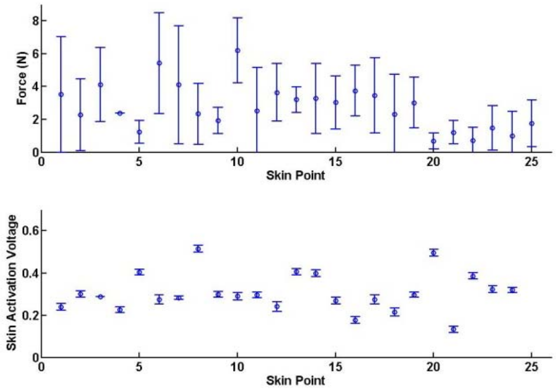


Figure 16: Skin C, Insulator 2 combination

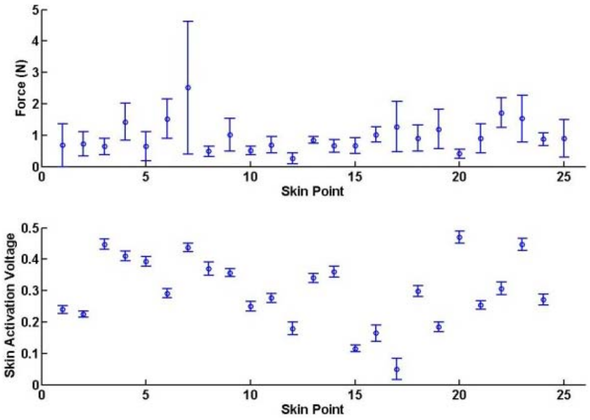


Figure 17: Skin C, Insulator 3 combination

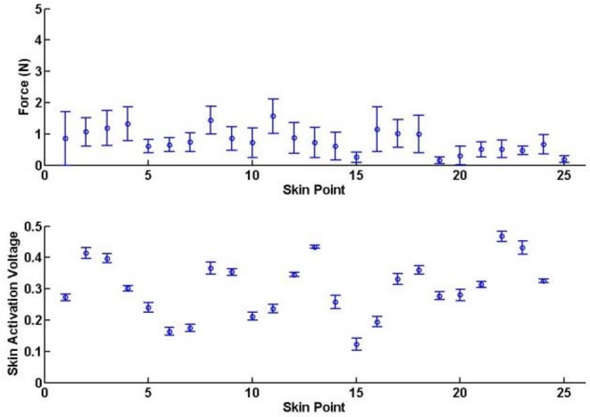


Fig. 18: Skin C, Insulator 4 combination

IV. DISCUSSION

We prefer Insulator 3 to Insulator 4 because Insulator 3 had a continuous activation surface, whereas measurement of the force for Insulator 4 required adjustment of sensor's end-effector to ensure non-conflict with the insulator materials. Measurement of the force for Insulator 1 also required alignment of the sensor's end-effector to ensure non-conflict with the insulator material, and required the second-largest mean force to activate the switch, due to the thickness of the material. Insulator 2 required the greatest mean force to activate the switch, due to the smallness of the perforations in the material.

For home use, a higher threshold (MIN + 0.1 volts or greater) will be more appropriate, to prevent the robot skin from being activated unintentionally.

We will be fabricating a large scale prototype, using the selected materials, and applying it to the MANUS ARM for user testing this summer. Users will be able to grasp the robot to position it for use as an assist or for strength augmentation for several daily tasks (Fig 18). Additionally, we will be soliciting user feedback about the choice of materials for the external covering of the skin, as well as differences between Insulators 3 and 4. Through programming, the robot arm will move frictionlessly, providing smooth movement for persons with limited physical capabilities.

In addition to direct interaction, we will be applying the skin to a smaller robotic arm which will be used to control the MANUS ARM. This teleoperation will enable users with very limited range of motion to receive the benefits of robotic arm interaction (Fig 19).

Figure 18: Direct Interaction

Figure 19: Teleoperation

In the future, we are interested in knowing where the skin was touched. This is not possible with the skins discussed here. We are collaborating with the Bayer Company to develop a more advanced robotic skin.

ACKNOWLEDGMENT

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