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AN ADMITTANCE GLOVE MECHANISM FOR CONTROLLING A MOBILE ROBOT

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ABSTRACT

This paper presents a bidirectional teleoperation admittance haptic glove (RML glove) which can be used to control mobile robots. The glove receives information from the environment and the internal status of the mobile robot, and generates a force feedback to the operator through the wireless module which in return communicates command signals to the robot. This haptic device is a lightweight and portable actuator system that fits on bare hands, and adds a haptic sense of force feedback to all fingers without constraining their natural movement. An embedded lead screw mechanism provides force feedback that ranges from zero up to 35 N for each finger. Based on this force feedback, the operator can feel what the robot feels (e.g., link torque amount and distance to an obstacle) which enables a smoother and safer human-control of the robot. To evaluate the performance of the haptic glove, a master-slave control experiment based on force feedback between the glove and the mobile robot is conducted. The results demonstrate that the proposed admittance glove can augment tele-presence.

KEYWORDS

Force control, haptic interface, mobile robot, teleoperation.

INTRODUCTION

During the last decade, haptic devices have been utilized in many applications of virtual environments, medical training, rehabilitation and telemanipulation [1-7].

Among a variety of haptic devices, haptic gloves became a choice of preference for their ability to provide a large array of force feedback. The high dexterity of haptic gloves also makes them applicable to the control of complex movements of remote robots, as opposed to other non-haptic devices such as joysticks and PHANTOM OMNI.

Several design issues concerning haptic gloves include: the *size* should be in general small enough to fit on human hands; the *weight* should be as light as possible for its portability on the hand; and the mechanism should be *flexible* in order to provide adequate dexterity without constraining hand motions, thus requiring back-drivability and sufficient degrees of freedom. The ultimate goal is to make the haptic glove comfortable to wear and operate in order to allow the operator to make desired motions.

Recently, many research activities have been performed on haptic gloves design. Turner *et al.* completed tests for a commercial haptic glove known as the CyberGraspTM [8]. The CyberGraspTM is a haptic device with one-direction active force feedback, which fits on the hand, and provides force feedback to each finger [9]. In order to reduce the weight and size of the mechanism, the glove joints were activated by a cable-driven mechanism which transmits the force between the fingers and a distant Actuator Unit. With this, the load of the haptic device was reduced on the hand, but the Actuator Unit still existed, albeit in a distant location connected by cables which still restricted the natural motion of the hand.

Blake *et al.* employed magneto-rheological brakes (MR brakes) to develop a haptic glove referred to as MR glove, with a wearable light-weight size placed on the back of the fingers [10]. Force was transmitted through small MR brakes connected directly to the exoskeleton links instead of using cables. Furthermore, MR brakes can apply passive torque up to 899 N·mm on three fingers in both flexion and extension directions. However, the entire glove weighed 640 g, with the load concentrated on the fingers, which creates a discomfort to the operator when using the glove for an extended period of

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time. Moreover, an MR brake requires high current drivers and high capacity batteries which are bulky and heavy. Another disadvantage of the MR brakes is the static friction and the complicated pulleys and links mechanism that are required to transmit the force to the finger joints.

On the other hand, the Rutger Master (Mouzit *et al* [11]) was developed using four custom pneumatic actuators arranged inside the palm of the hand. The objective of the mechanism was to deliver a compact and light-weight structure on the hand. The Rutger Master weighed 185 g including the wires and pneumatic tubing (excluding pneumatic actuator, power source, etc.), and provided relatively large forces up to 16 N on each of the four fingers in both flexion and extension directions. Despite its light-weight, the Rutger Master limits the hand work envelope due to the pneumatic actuators and accessories, and prevents a complete fist closure due to the placement of the actuators in the palm.

In general, a haptic system with a real force-feedback feeling should be capable of delivering a maximum force that matches the human hand output force. According to [12], the thumb/finger strength is 35 N. To the best of our knowledge, none of the aforementioned haptic devices could generate such high force. This represents the motivations of the work reported in this paper, where the objective is to develop a completely wearable haptic device that is light-weight, compact and can generate a minimum of 35 N of force at the finger joints.

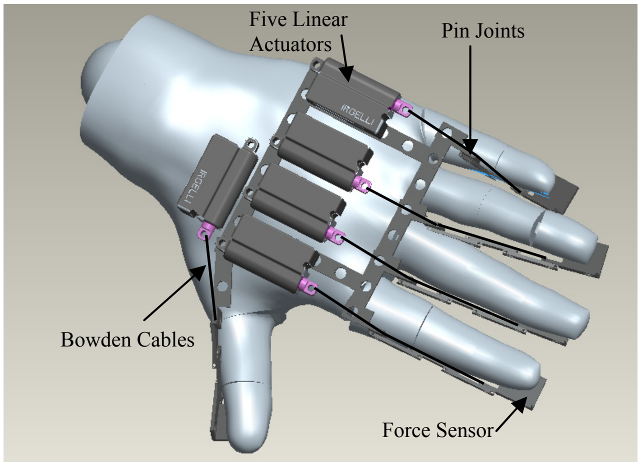

Figure 1. CAD MODEL OF RML-GLOVE.

As a result, a wearable haptic device, called RML-glove, was developed to accomplish this objective in a wearable, light-weight and compact glove system. The details of the mechanical design were presented in [13]. This haptic device fits on a bare hand and adds a sense of force feedback to each finger without constraining the natural movement of the hand. The CAD model of the design and a one-finger prototype are shown in Fig. 1 and Fig. 2, respectively.

An embedded lead screw mechanism provides force feedback from zero, up to 35 N on each finger tip in the direction of extension. A micro force sensor was employed to measure the applied force at the finger for feedback control. Based on this force feedback, the operator can “feel” what the robot “feels”, and can control the robot more smoothly and safely. The performance of this haptic glove is evaluated through experimentation, where a master-slave control scheme based on a force feedback control method between the glove and a candidate mobile robot is conducted. The results prove that this new admittance glove is capable of augmenting telepresence.

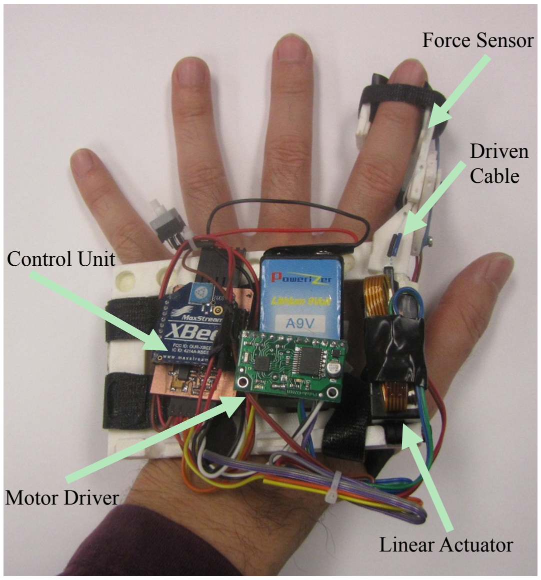

Figure 2. ONE FINGER RML-GLOVE PROTOTYPE.

MECHANICAL DESIGN

The RML-glove is designed to fit onto the back of the hand, so the operator can manipulate it intuitively. This type is more suitable for multiple finger inputs and has a larger workspace.

All the joints in the design were realized through revolute pin connections, which make the movement of flexion/ extension and adduction/abduction possible with this mechanism. The whole mechanism (as shown in Fig.3) is about 40 grams. The total weight of the one-finger prototype is 100 g, including the battery, control unit and wireless module. With the addition of another four linear actuators (PQ12-100-6-P from Firgelli Tech. Inc., 15g each) and additional four other fingers, the final full-hand glove will weigh approximately 180 g.

The active force output of this actuator is 35N. Due to the inherently high friction of the lead screw mechanism, this actuator is almost self-locking (back drive force is 60 N) without power consumption, so the passive output force is extremely high (~95N). With the close loop force feedback control, this haptic glove could provide almost real feeling of both hard and soft matter to the operator (e.g., a concrete wall or soft cotton). The maximum speed of the actuator is 13 mm/s when the actuator is powered with 9V battery.

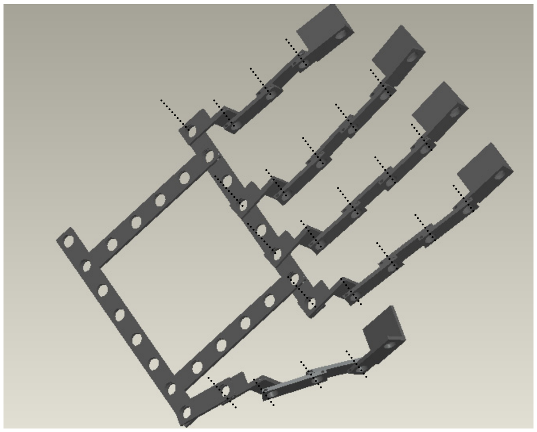

Figure 3. CAD MODEL OF RML-GLOVE SKELETON.

Because of the difference in fingers' shape and size which vary from one individual to the other, the RML-glove is designed to accommodate for these constraints by incorporating a redundant multi-link mechanism for each finger as shown in Fig. 4.

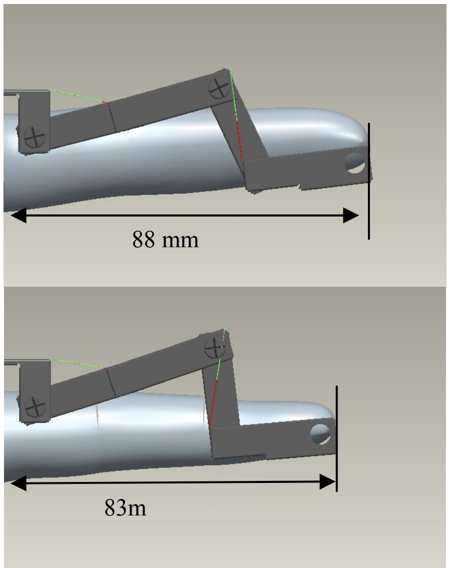

Figure 4. MULTI-LINK MECHANISM FOR DIFFERENT FINGER LENGTH.

ELECTRICAL DESIGN

The haptic system is composed of a glove skeleton and a control interface. The interface uses a MEGA168 (Atmel Corp.) microcontroller to read force sensor data, control the force magnitude applied at the user's fingertips, and communicate with the robot or host PC. The software control loop running at 1.3 KHz ensures a precise and stable output force. This updating frequency is ~30% larger than 1 KHz which is the typical frequency recommended for haptic devices [14]. This high update rate, not only provides realistic touch feelings to the haptic glove user, but also helps maintaining the stability of the whole system.

Additionally, software running on the microcontroller filters the data from the force and position sensors through an A/D converter, and transforms it into joint angles. Communication between the control interface and the host computer or the robot is accomplished through a wireless XBee module. The transmitted data contains joint angles, measured forces, and speed data for the linear actuators and the robot motors. Received data includes commands and robot status or forces to be communicated to the operator. The wireless transmitting speed is 57,600 bits/second as shown in the electrical design diagram in Fig. 5.

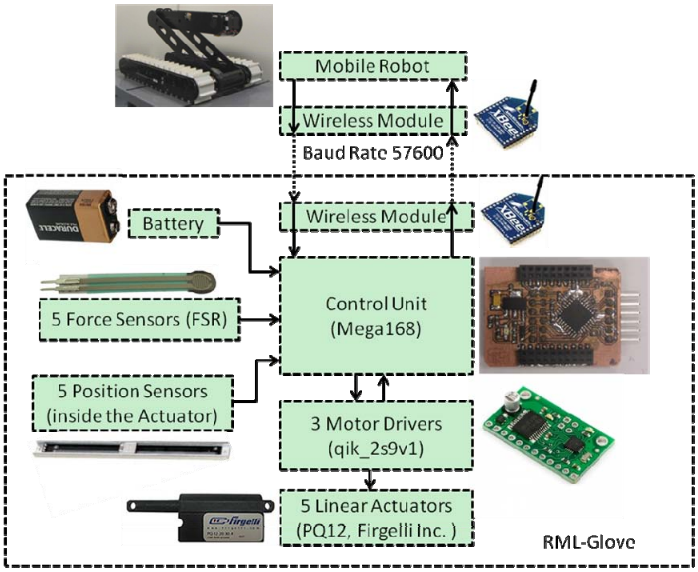

Figure 5. ELECTRICAL DESIGN DIAGRAM.

CONTROL SYSTEM DESIGN

Building on the recent immersive and intuitive teleoperation trend in robotics [15, 16], RML-glove represents a bidirectional teleoperation admittance haptic glove that augments traditional control interfaces developed with simple but non-immersive devices such as keyboards, joysticks, and PHANTOM. The glove receives information from the environment and the internal status of the robot, and generates force feedback signals to the operator while sending command signals to the robot through the wireless module. When the glove is powered off, each lead screw mechanism becomes non-back drivable. When the glove is powered on, with proper speed command to each lead screw mechanism, the actuator can provide force feedback proportional to the velocity difference between the finger's motion and that of the lead screw mechanism.

This is accomplished based on the control scheme of the RML-Glove shown in Fig.6. The position and status of each finger is calculated via inverse kinematics solution of the mechanism. According to the operator's position and force, the control unit calculates the motors speed value, and sends it via wireless transmission to control the position and orientation of the robot and the arm. The objective of the controller is to convert the reactive torque from the Mobile

Robot into an equivalent force applied at the fingertips of the operator, while compensating for the static friction of the device.

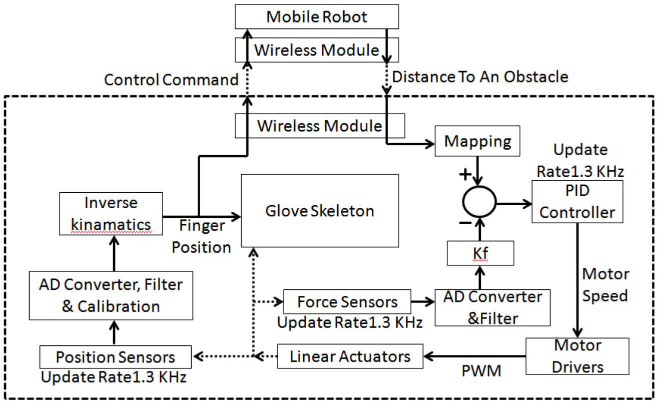

Figure 6. CONTROL SCHEME OF THE RML-GLOVE.

Three different modes were used for the implementation of this haptic system:

1. Variable parameters configuration mode: In this mode, variable parameters could be changed through wireless communication, such as object stiffness, position parameters, PWM frequency, device address (for multiple gloves), serial baud rates and timeout value.
2. Human Computer Interface (HCI) modes: where forces are calculated on the host computer and transmitted wirelessly to the glove to be communicated to the user. This feature is particularly useful when dexterous manipulation in Virtual Reality Simulation is involved.
3. Human Robot Interface (HRI) modes: where the glove is used to control a mobile robot and, torque or object distance feedback is displayed locally on the glove in the form of a variable force.

EXPERIMENTSAND RESULTS

Mechanical Bandwidth Experiment

To evaluate the performance of the prototype, the mechanical bandwidth was tested with regards to step excitations with the results shown in Fig. 7. We note that the mechanical bandwidth in this paper is not as high as other haptic glove systems [8, 9, 11]. The reason was that the driving cable is implemented with fishing wires with high mechanical strength but low stiffness. Furthermore, the motor gear-ratio in the linear actuator was too high (100:1), so that the motor speed was fairly slow. This performance could be greatly improved by changing the system to a lower gear ratio motor (30:1 and passive output force is about 30N) in the actuating module and using steel wire ropes.

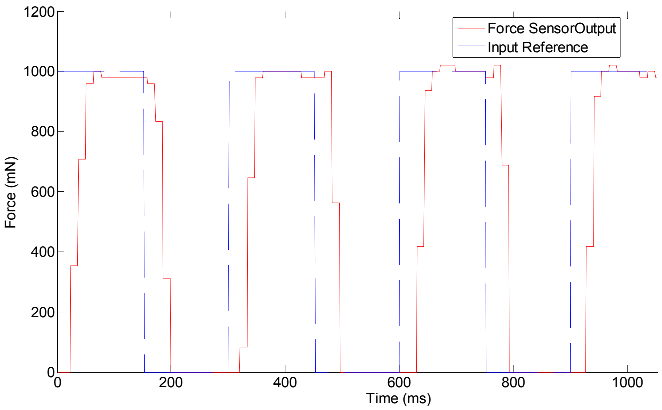

Figure 7. STEP RESPONSE OF RML-GLOE.

Free Motion Experiment

Free motion is considered as a fundamental behavior of the haptic device. In such case, the operator should be able to move his/her fingers freely without feeling the friction and the inertia induced by the glove. The friction of the device should be eliminated via real-time control to enable free motion with zero force input from the robot. An experiment that evaluates this free motion was established in order to demonstrate the effectiveness of friction compensation in the control algorithm.

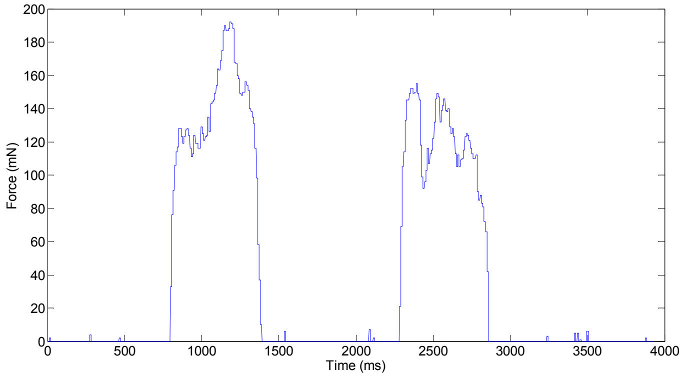

Figure 8. FREE MOTION EXPERIMENT.

In this experiment, the operator wears the one-finger prototype and moves the index finger freely. The experiment consists of six open/close maneuvers in 10 seconds with the results shown in Fig. 8. At this speed, the maximum force that the operator could feel is less than 200 mN, which implies that the control algorithm compensated for the friction successfully. The resistance force on the other hand is much stronger if the operator tries to move the finger at a faster speed. Apparently, the low mechanical bandwidth limits the maximum speed for real-time free motion of the glove. A new high gear ratio linear actuator will improve this weakness where the speed of response could theoretically be tripled.

Experiment of Controlling a Mobile Robot

A master-slave robot controlling experiment was undertaken using sonar feedback where the acoustic sensors are located at the front of the robot. Since the prototype has only one finger, the mobile robot could only be controlled to move in the forward or backward direction. The control gesture of the hand is shown in Fig. 9.

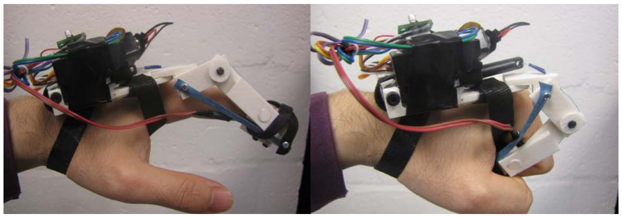
(A) (B)

Figure 9. GESTURE DEFINITION (A) MOVE FORWARD (B) MOVE BACKWARD.

The RML-Glove keeps reading the sonar data from the robot through the wireless module, and calculates the value of the force feedback. If the robot moves towards an obstacle, such as a wall, an appropriate force feedback is generated at the fingertip of the operator. The closer the robot gets to the obstacle, the larger the force that the operator feels. In this scheme, it becomes easier to control the robot and avoid collision. Such experimental data is shown in Fig. 10. The operator should not feel the resistance force if the robot moves away from an obstacle. Therefore, when the robot starts to move backward, the force sensor value becomes very small and that's the reason for the sharp drop of the force sensor value.

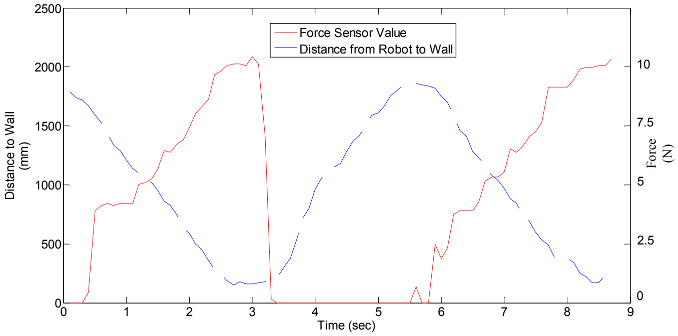

Figure 10. CONTROLLING A ROBOT WITH THE SONAR FEEDBACK.

SUMMARY

This paper presented the design and experiments of a new haptic glove. This haptic device is a lightweight and portable actuator system that fits on a bare hand and adds a sense of touch force feedback to each finger without constraining the natural movement of the hand. An embedded lead screw mechanism provides force feedback from near zero, and up to 35 N at each fingertip. The design is also flexible in a way to accommodate different sizes and shapes of anthropomorphic fingers.

This glove is used to control the mobility and manipulation of robots based on the operator's hand gestures. This data is communicated bilaterally between the robot and the glove via a wireless module embedded in the glove. Because of the integrated force feedback, the operator can "feel" what the robot "feels" (e.g., link torque amount and distance to an obstacle), which enables a smoother and safer human-in-the-loop control of the robot. The performance of the haptic glove was evaluated experimentally on a mobile robot in a master-slave control experiment with force feedback. The results show that this new admittance glove can augment telepresence.

In the future, a lower gear ratio linear actuator will be adopted in the next version of the glove, thus improving the mechanical bandwidth and response time. A full five-finger glove is currently under integration. This system will employ all anthropomorphic fingers with sufficient dexterity to control the navigation and manipulation of a Hybrid Mobile Robot. More experiments will be performed in the new version of the prototype.

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