University of Wollongong

Research Online

Faculty of Engineering and Information
Sciences - Papers: Part A

Faculty of Engineering and Information
Sciences

1-1-2013

Tele-operation of a robot arm with electro tactile feedback

Daniel S. Pamungkas

University of Wollongong, dsp572@uowmail.edu.au

Koren Ward

University of Wollongong, koren@uow.edu.au

Follow this and additional works at: <https://ro.uow.edu.au/eispapers>

Part of the [Engineering Commons](#), and the [Science and Technology Studies Commons](#)

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

Tele-operation of a robot arm with electro tactile feedback

Abstract

Tactile feedback from a remotely controlled robotic arm can facilitate certain tasks by enabling the user to experience tactile or force sensations from the robot's interaction with the environment. However, equipping both the robot and the user with tactile sensing and feedback systems can be complex, expensive, restrictive and application specific. This paper introduces a new tele-operation haptic feedback method involving electro-tactile feedback. This feedback system is inexpensive, easy to setup and versatile in that it can provide the user with a diverse range of tactile sensations and is suitable for a variety of tasks. We demonstrate the potential of our electro-tactile feedback system by providing experimental results showing how electro-tactile feedback from a teleoperated robotic arm equipped with range sensors can help with avoiding obstacles in cluttered workspace. We also show how interactive tasks, like placing a peg in a hole, can be facilitated with electro-tactile feedback from force sensors.

Keywords

arm, electro, tactile, feedback, robot, operation, tele

Disciplines

Engineering | Science and Technology Studies

Publication Details

Pamungkas, D. S. & Ward, K. (2013). Tele-operation of a robot arm with electro tactile feedback. 2013 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM) (pp. 704-709). United States: IEEE.

Tele-operation of a Robot Arm with Electro Tactile Feedback

Daniel S. Pamungkas and Koren Ward *

Abstract— Tactile feedback from a remotely controlled robotic arm can facilitate certain tasks by enabling the user to experience tactile or force sensations from the robot's interaction with the environment. However, equipping both the robot and the user with tactile sensing and feedback systems can be complex, expensive, restrictive and application specific. This paper introduces a new tele-operation haptic feedback method involving electro-tactile feedback. This feedback system is inexpensive, easy to setup and versatile in that it can provide the user with a diverse range of tactile sensations and is suitable for a variety of tasks. We demonstrate the potential of our electro-tactile feedback system by providing experimental results showing how electro-tactile feedback from a tele-operated robotic arm equipped with range sensors can help with avoiding obstacles in cluttered workspace. We also show how interactive tasks, like placing a peg in a hole, can be facilitated with electro-tactile feedback from force sensors.

I. INTRODUCTION

Although robotic technologies are increasing, most remote, hazardous and non-repetitive tasks performed by robots still require tele-operation and considerable human interaction. Such tasks include: controlling a robot to disarm a bomb [1], manipulating radioactive isotopes, performing space and underwater exploration [2], [3], performing search and rescue in dangerous environments [4], performing tele-surgery [5]. In all these applications control is achieved by perceiving the robot's environment via cameras and remotely controlling the robot in an appropriate manner.

To remotely operate a robot to perform such tasks, the operator needs considerable visual information on robot's position and its environment as well as the current state of the robot. The operator may also need to sense and perceive what the robot is doing with its actuators. If the robot's task is intricate or difficult, this information will need to be precise and in a form that is easy for the operator to interpret.

Tactile feedback in the form of touch or force sensing from the robot can assist the operator to better interpret the remote situation and to manipulate items. Although, visual and/or audio feedback can be used for this purpose, haptic feedback in the form of touch or force sensing is preferred because it does not occupy the operator's eyes or ears and can provide force and/or touch sensations in an intuitive manner.

However, equipping both the robot and the operator with haptic feedback can be complex, expensive and restrictive. Furthermore, such feedback systems are often application specific and may not be able to be easily adapted to different tasks. To overcome this limitation we have devised an

electro-tactile feedback system to facilitate tele-operation of a robotic arm. The main benefits of our electro-tactile feedback system are that it is easy to setup, less expensive than force-feedback systems and has more bandwidth than vibro-tactile feedback systems. Furthermore, it is versatile in that it can provide the user with a diverse range of tactile sensations from various sensor types and is suitable for a variety of tasks.

In Section II of this paper we provide a brief overview of previous research on haptic feedback with respect to controlling robots via remote control. Section III outlines the implementation details of our electro-tactile feedback system. Section IV describes two experiments which demonstrate the feasibility of our electro-tactile feedback system and show how electro-tactile feedback from a tele-operated robotic arm can: (1) facilitate avoiding obstacles in cluttered workspace and (2) aid with placing a peg into a hole with relative ease. Concluding remarks are provided in Section V.

II. BACKGROUND

Recently, many applications have been found for tele-operated robots (see [6] for a comparative study). Tele-operation not only requires the operator to have control of the robot but also perception of the robot and its environment or work area. The most common form of information used to tele-operate robots is in the form of visual and audio feedbacks. This may be adequate for tasks like blowing up a bomb by firing a projectile into it, however, other tasks, like disarming a bomb [1] or tele-surgery [5], [7] may also require some form of haptic feedback so that the operator can actually "feel" what the robot's actuators are doing.

A number researchers have found that haptic feedback, in the form of force feedback, can improve the performance and decrease control effort of specific tele-operation tasks. For example, in [5] force feedback has been used to facilitate tele-surgery with positive results by making the operator more aware of the pressure being applied by tele-operated surgical instruments. Assembly tasks have also been found to benefit from force feedback. In [8], experiments were performed to determine how controlling a robot to do various assemble tasks performed both with and without force feedback. Similar experiments were also conducted in virtual reality to determine how force feedback can improve the interactivity and speed of various assembly tasks [9].

Tele-operated mobile robots have also benefited from force feedback (see [10] for a survey). In [11] a 2D joy stick with force feedback was used to implement a vector field navigation and obstacle avoidance algorithm. In this case, the virtual forces derived from the robot's range sensors are applied to the joystick instead of the robot. Hence, the robot resists moving too close to obstacles by preventing the joystick from moving in that direction.

* D. S. Pamungkas is with the University of Wollongong, NSW, 2522, Australia. (phone: +61 401889576; e-mail: dsp572@uowmail.edu.au).

K. Ward is with the University of Wollongong, NSW, 2522, Australia. (e-mail: koren@uow.edu.au).

Constructing specialized haptic interfaces for providing force feedback can be expensive, difficult and time consuming. To avoid this cost, some researchers have utilized commercial VR haptic interfaces such as Phantom [20], Novint [21] and Omega 3 [22].

For example, Phantom Omni and Phantom Premium have been used to provide a type of safe master/slave haptic interface for controlling a mobile robot. In [12] force feedback from the Phantom is used to facilitate following walls and avoiding obstacles with a mobile robot. Similarly in [13], a Novint Falcon 3D haptic joystick has been used as a force feedback controller for a robotic arm, and in [14] Omega 3 is used as a haptic controller for a simulated UAV.

Unfortunately, commercial haptic interfaces are limited to providing, at most, one point of 6 DOF force feedback in 3D space. To implement more complex haptic feedback controllers requires considerable hardware and expense. In [15] the authors implement a type vibro-tactile and mechanical torque feedback system for controlling a robotic arm. Here, a belt attached to a DC motor and the user's arm is used as force feedback to link the robot arm to the user's elbow joint. Six vibro-tactile feedbacks are also implemented as a large servo actuated bracelet for providing information about the profile of objects surrounding the robot's gripper.

Another type of robotic arm force feedback system was implemented by D.S. Ryu [16]. Here, pulleys attached to weights were used to effect forces between the user's waist and hand in order to send and receive information about the position of the robot arm. Stanley and Kuchenbecker [17] also investigated tapper, dragger, squeezer, twister feedbacks by using servo motors and vibration as the haptic feedback for performing various tasks.

Although the above applications show that haptic feedback systems, involving force feedback or vibro-tactile feedback, can facilitate many tele-operation tasks, generally, these systems are difficult to construct, setup and are application specific. In most cases they also weigh down and restrict the user's hands with cumbersome hardware fitted to the hands and arms.

To reduce the amount of hardware needed to receive haptic feedback and to deliver more haptic information to the user, we have been experimenting with electro-tactile feedback connected to tele-operated robots. This simply involves placing adhesive electrodes on the skin and applying electrical stimulus as the feedback signal.

Another advantage of electro-tactile feedback is that it can be modulated by varying the frequency and amplitude of the voltage delivered through the skin to the sensory nerves. This can give a diverse range of sensations, without desensitizing the nerves (as explained in [18] and [19]), and can be used to represent what the actuators "feel", or to deliver different signals to the user via single or multiple channels from sensors mounted on the robot.

In the following sections we describe the implementation details of our electro-tactile feedback system and some preliminary experiments that we have performed which demonstrate the potential of our electro-tactile feedback system.

III. CONTROLLING A ROBOT ARM WITH ELECTRO TACTILE FEEDBACK

To test our electro-tactile feedback system we equipped a CRS A465 robotic arm with both force and distance sensors, as shown in Figure 1(a). The robot arm is controlled by a wireless data glove and tracking system, as shown in Figure 1(b). Electro-tactile feedback is delivered to the user via wireless adhesive electrodes attached to the user's arms, hands or other region. The user can also monitor the robot's work area via a remote monitor (see Figure 1b).

Figure 1. Tele-Operation of Robot arm with Electro-tactile feedback..

The electro-tactile feedback control loop is shown in Figure 2. To enable the arm to be accurately controlled by the data glove, coordinate transforms and a user control protocol is used. This protocol involves pressing buttons on the data glove with the left hand to either engage the arm or alter the control settings. The sensor data from the robot arm is also processed to deliver appropriate pulse sensations to the user's arms or hands in response to changes to the sensor data.

Figure 2. Block diagram of tele-operation with electro-tactile feedback

In the following sections we provide implementation details of the robot's sensors, the data glove controller and the electro-tactile feedback system.

A. Arm Robot and the Sensors

To conduct the electro-tactile feedback experiments a CRS A465 robotic arm is used. This arm is a 6 DOF arm with a gripper, as shown in Figure 1. To monitor the space surrounding the arm's gripper and the forces applied to the gripper, four Sharp GP2D 120 infra red range sensors and two Tekscan FlexiForce A20 force sensors are used, as shown in Figure 3 and 4. The Sharp GP2D 120 IR range sensors are able to continuously measure distances within the range of 4 cm to 30 cm. The Tekscan A201 FlexiForce sensors can measure forces between 0 to 110N.

Figure 3. a. Infrared range sensor. b. Force sensors

The infrared range sensors are fitted to the body of the robot's gripper to detect objects in close proximity to the gripper (3-30cm). Feedback from these sensors is used to assist the user to locate the target object and avoid any obstacles that are in the way. The force sensors are epoxied to a piece of aluminium angle which has had the contact surface slightly raised to make good contact the centre of the sensor's detection area, as shown in Figure 3b. This assembly is then adhered to the one of the gripper's fingers with flexible silicon adhesive, as shown in Figure 4. The other gripper finger has a piece of aluminium angle, without force sensors, adhered to it for uniformity. The internal exposed surface of the angles is lined with neoprene to facilitate gripping objects, as shown in Figure 4. This arrangement enables x, y forces applied to the gripper along a vertical plane to be detected.

Figure 4. Force and range sensors mounted on the gripper of the Robot

Although this sensor configuration provides only limited perception of the robot's environment and gripper forces, we found this arrangement adequate for testing our electro-tactile feedback system on our preliminary experiments.

B. Data Glove

The data glove is a P5 Virtual Reality Glove which can monitor the glove's x, y, z position and its orientation in terms of roll, pitch and yaw. The glove can also monitor the bend of all five fingers and the position of three buttons mounted on the glove, as shown in Figure 5. The buttons are programmed for two purposes. In normal mode, one button engages the glove with the robot arm and the other two buttons select specific joints to be moved. Also, when a tight fist is made, the buttons enable settings, such as the speed and the x, y, z translation factor, to be altered.

The data glove has to be held in front of its receptor tower to be read. To accommodate for making large movements, the glove is reputedly engaged and disengaged, similar to how one lifts a mouse off and on a mouse pad to make large movements. The bend of the forefinger and thumb are measured and used to open and close the gripper. This protocol was found to enable the operator to intuitively move the robot arm within its workspace and manipulate objects with relative ease.

Figure 5. P5 Data Glove and receptor tower.

C. Electro-tactile Feedback

To provide feedback to the user from the sensors mounted on the robot a custom built single wireless TENS1 unit is used, as shown in Figure 6. This unit is capable of delivering neural stimulus signals to the skin with controllable frequency and intensity. It consists of a USB transmitter unit and a receiver unit with two adhesive electrodes attached to it, as shown in Figure 6a, 6b & 6c respectively. One electrode is for delivering the feedback signal from the sensors mounted on the robot and the other electrode is for ground return.

¹ TENS: Transcutaneous Electrical Nerve Stimulation

Figure 6. a. TENS receiver b.USB transmitter c.Adhesive TENS electrode.

The TENS feedback signals are comprised of 20Hz pulses with amplitude between 40V to 80V, as shown in Figure 7. The peak voltage can be adjusted to suit user comfort. To control the intensity felt by each finger the pulse width is adjusted between 10 to 100 μ s. For the experiments described in Section IV the frequency was left at 20Hz and the intensity was adjusted in proportion to the output from the sensors mounted on the robot.

Figure 7. TENS output waveform

IV. EXPERIMENTAL METHOD

To test our electro-tactile feedback system we conducted two tele-operation experiments with a CRS A465 robot arm fitted with the sensors described in Section III. The first experiment involved manipulating the robot's gripper and avoiding obstacles in a confined workspace. The second experiment involved picking up a round peg and placing it into a matching hole.

In order to receive appropriate sensations from the electro-tactile feedback system the wireless electrode are placed on the user's right and left arm and positioned, so that the signals can be easily interpreted as shown in Figure 8.

Figure 8. a. Electro-tactile receiver. b. Corresponding robot sensors.

A. Obstacle Avoidance

Avoiding obstacles involves controlling the robot arm with the data glove, while observing the work area with a fixed camera, and reacting to the stimulus intensity delivered by the TENS electrodes. High stimulus from a specific TENS electrode, linked to a specific range sensor on the robot indicates that an object has been detected close to the corresponding range sensor on the robot. To assist in aligning the four range sensors on the robot with the four corresponding TENS electrodes on the user, the front IR range sensor on the robot is color coded red.

The electrical stimulation delivered to the user from the range sensors is calibrated so that strong sensations are felt at the minimum range (4cm), light sensations are felt at 8cm range and no sensation is felt at 12cm or greater. Stimulation from the force sensor associated with gripping an object was calibrated to range from zero (indicating nothing held) to light (indicating an object is held by the gripper). Stimulus from the other force sensor (which measures the downward force applied to a gripped object) was calibrated to produce zero stimulus, when no downward force is applied, to intense when the robot is pushing the gripped object hard against the surface.

To test the ability of our electro-tactile feedback system to improve tele-operation tasks involving obstacle avoidance, we constructed a constrained path for the robot gripper to negotiate, as shown in Figure 9. This task involved positioning the gripper at the home position, labeled A in Figure 9a, then moving cylinder located at location B to location C without lifting the gripper above the walls shown in Figure 9b.

A number of trials were conducted with different users. Five minutes was provided to become familiar with controlling the robot arm in the environment, both with and without electro-tactile feedback. Each user was then timed at how long it took to perform the task both with and without electro-tactile feedback. All users reported that the electro-tactile feedback enabled this task to be completed faster and with more accuracy.

Figure 9. Obstacles avoidance experimental Setup

B. Peg in Hole

Although the robot's gripper contains only two force sensors, linked to two channels of electro-tactile feedback, we found this adequate for providing the user with tactile sensations from both holding an object, and any contact the held object makes with other surfaces. When combined with visual perception of the work area we were able to perform the peg-in-hole assembly task shown in Figure 10.

Figure 10. Peg-in-hole assembly task.

This was achieved by firstly, calibrating the electro-tactile feedback linked to the force sensors to give appropriate tactile sensations (intensity) of the forces being applied to the object and surfaces, and secondly, deploying a linear tap-drag-push strategy to locate the hole and manipulate the peg into the hole. This strategy required the gripper to be posed at a slight angle to the surface, as shown in Figure 11. To find the hole the user first makes contact with the surface, then drags the peg across the surface and stops when the hole is "felt". The user then repeatedly "touches" the peg against the edge of the hole, while manipulating the peg into the upright position. This is repeated until the peg inserts into the hole. Figure 11a and 11b show typical forces that could occur during the insertion procedure and how these forces are applied to the force sensors. Without electro-tactile feedback this task proved difficult even with the camera zoomed in on the hole.

Figure 11. a. Peg, hole and applied forces b. Peg and typical force vectors

V. CONCLUSION

Although various methods have been used for receiving tactile and force feedback from tele-operated robots, electro-tactile feedback has been largely overlooked. This paper describes an electro-tactile feedback system for a robotic arm comprised of IR range sensors and force sensors mounted on the robot's gripper, and wireless TENS electrodes placed on the user's skin. This feedback system is inexpensive, easy to setup, versatile and avoids complicated mechanical hardware and software required by other tactile feedback systems. The experimental results show how this electro-tactile feedback system fitted to a robotic arm can help with avoiding obstacles in cluttered workspace and facilitate placing a peg in a hole via tele-operation.

REFERENCES

- [1] Kron, A., et al., "Disposal of explosive ordnances by use of a bimanual haptic telepresence system," in Robotics and Automation, 2004. Proceedings. ICRA '04. 2004 IEEE International Conference on. 2004.
- [2] Sheridan, T.B., "Space tele-operation through time delay: review and prognosis," Robotics and Automation, IEEE Transactions on, 1993. 9(5): p. 592-606.
- [3] Spennberg, D., C. Waldmann, and R. Babb, "Exploration of underwater structures with cooperative heterogeneous robots," in Oceans 2005 - Europe. 2005.
- [4] S. Hirche, B.S., and M. Buss, "Transparent exploration of remote environments by internet telepresence," in Proc. Int. Workshop High-Fidelity Telepresence Teleaction/IEEE Conf/ HUMANOIDS, 2003.
- [5] King, C.H., et al., "Tactile Feedback Induces Reduced Grasping Force in Robot-Assisted Surgery," Haptics, IEEE Transactions on, 2009. 2(2): p. 103-110.
- [6] M. D. Penny, S.C., N. Beagley, N. Smith, and K. Wong, "A comparison study of operator performance with three controllers for a remotely operated vehicle," IARP workshop on robots for humanitarian demining, 2002: p. 87-92.
- [7] Perez, V.Z., et al., "Force feedback algorithms for master slave surgical systems" in Robotics Symposium, 2011 IEEE IX Latin American and IEEE Colombian Conference on Automatic Control and Industry Applications (LARC). 2011.
- [8] Wildenbeest, J., et al., "The Impact of Haptic Feedback Quality on the Performance of Teleoperated Assembly Tasks," Haptics, IEEE Transactions on, 2012. PP(99): p. 1-1.
- [9] Sagardia, M., et al., "Evaluation of visual and force feedback in virtual assembly verifications," in Virtual Reality Short Papers and Posters (VRW), 2012 IEEE. 2012.
- [10] S. Lee, G.S.S., G. J. Kim, and C.-M. Park, "Haptic control of a mobile robot: A user study," in Proc.Of IEEE/RSJ IROS 2002, 2002.
- [11] Mitsou, N.C., S.V. Velanas, and C.S. Tzafestas, "Visuo-Haptic Interface for Tele-operation of Mobile Robot Exploration Tasks". in Robot and Human Interactive Communication, 2006. ROMAN 2006. The 15th IEEE International Symposium on. 2006.
- [12] Nadrag, P., et al. "Remote control of an assistive robot using force feedback," in Advanced Robotics (ICAR), 2011 15th International Conference on. 2011.
- [13] Ajoudani, A., N.G. Tsagarakis, and A. Bicchi, "Tele-Impedance: Preliminary results on measuring and replicating human arm impedance in tele operated robots," in Robotics and Biomimetics (ROBIO), 2011 IEEE International Conference on. 2011.
- [14] Alaimo, S.M.C., et al., "A comparison of Direct and Indirect Haptic Aiding for Remotely Piloted Vehicles," in RO-MAN, 2010 IEEE. 2010.
- [15] A.Bloomfield, I.B., "Virtual Training via Vibrotactile Arrays," Presence: Teleoperators and Virtual Environments, 2008. 17: p. 103-120.
- [16] Dongseok, R., et al., "Wearable haptic-based multi-modal tele-operation of field mobile manipulator for explosive ordnance disposal," in Safety, Security and Rescue Robotics, Workshop, 2005 IEEE International. 2005.
- [17] Stanley, A.A. and K.J. Kuchenbecker, "Evaluation of Tactile Feedback Methods for Wrist Rotation Guidance," Haptics, IEEE Transactions on, 2012. 5(3): p. 240-251.
- [18] Peruzzini, M., "Electro-Tactile Device for Texture Simulation," IEEE/ASME International Conference on Mechatronics and Embedded Systems and Applications (MESA), 2012: p. 178-183.
- [19] S. Meers, and K. Ward., "A Vision System for Providing 3D Perception of the Environment via Transcutaneous Electro-Neural Stimulation," Proceedings of the 8th IEEE International Conference on Information Visualisation, 2004: p. 546-552.
- [20] Geomagic, 2012, "Phantom omni @ haptic devices," retrieved February 29, 2013 from <http://www.sensable.com/haptic-phantom-omni.htm>
- [21] Novint Technologies, inc., 2012, "Novint Falcon@," retrieved February 29, 2013, from <http://www.novint.com/index.php/novintfalcon>
- [22] Force Dimension, 2013, "Omega3," retrieved February 29, 2013 from <http://www.forcedimension.com/omega3-overview>