Evaluating the Effects of Haptic and Visual Feedback on the Teleoperation of Remote Robots

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Abstract

This paper addresses the development and usability of a teleoperation program for two robots, one local and one remote, as well as the benefits of haptic feedback in teleoperation and human robot interaction. The system allows a user at either arm to manipulate both arms simultaneously while receiving haptic feedback from the remote arm. Several tests were performed to determine the accuracy and usability of the system. The tests were performed using two state of the art Barrett Whole Arm Manipulators (WAMs). The usability test showed that the haptic feedback of the teleoperation program increased proficiency among users.

Introduction

Robots have demonstrated a unique capacity to take on roles too difficult, too dangerous, or too undesirable for human workers. Industries have employed robots in hazardous work environments for decades. NASA has also used a wide range of robotic devices for space exploration. Urban search and rescue teams have deployed robots in hope of locating survivors [6]. In each of these situations, robots have served their purpose in places where humans cannot follow. Any enhancement of robots that increases their functionality in such situations is desirable. Therefore this study explores the ability to operate robots efficiently without dangers to users.

There is still a limit, however, on the complexity of the tasks that robots can perform autonomously. Therefore, it is sometimes vital that a human be able to control the robot from a distance. This has led to further work in human robot interaction and the development of teleoperated robots, which can be controlled remotely by human operators. A teleoperated robot is able to benefit from a human's perception, judgment, and adaptability, while the operator has the safety and convenience of a remote location. Unfortunately, many of the weaknesses of the current robot control interfaces are amplified when the user is in a remote location.

Robots cannot be used to the fullest extent of their potential until humans can work with them safely and easily. The main difficulty lies in determining the best way to exercise control over a robot. Various user interfaces, including joysticks, teach pendants and virtual reality interfaces, have been used to control robotic systems. Many of these interfaces have to present visually everything necessary for control of the robot. The need to interpret this information can very quickly place a large cognitive load on the user, making the robot much more difficult to operate [12]. Furthermore, many of the simpler interfaces cannot control each joint of a robot separately. An interface that only allows a user to control the end effector of a robot with multiple degrees of freedom will frequently move the robot in an undesirable manner. Also, some joints are capable of moving at unsafe speeds and can collide with other objects or people.

A way to lessen the cognitive load of trying to interpret all of the available information from the remote arm is to register any forces met by the robot as haptic feedback. Haptic feedback is a force applied to a control device in such a way that it will mirror the forces exerted by a user. When a user tries to push the robot past a haptic barrier, the robot will apply an equal force in the opposite direction, which results in the robot staying in place. In this way, haptic feedback can give a robot's user the sense of touch, including factors like weight, resistance, and friction.

Haptic feedback depends on a great deal of information. Depending on the level of detail required for a task, creating the haptic boundaries can be a very complex process Information about location, shape, and stiffness to generate a haptic object can be pre-programmed [1][2][13]. In many cases this preloading is needed because only one robotic interface is being used. However, in projects that work with the connection of two robotic interfaces, it is possible to render true real-time haptic feedback.

We propose that the combination of teleoperation, and haptic feedback will result in a significant improvement over what any of the three could produce alone. These improvements should be visible in a user's ability to control a robot when subjected to a combination of visual and haptical feedback. The more senses a person has when interacting with an object, the better they are able to control it. This means that the addition of haptic feedback to visual feedback, during teleoperation, would provide users with a better understanding and finer control of what they are interacting with. With these advantages, such an arm has the potential to be very useful for applications, including, search and rescue, manufacturing, and telesurgery.

Related Work

The history of research into the teleoperation of remote devices began with the creation of the first mechanically controlled master-slave system in the mid 1940s. By 1954 a way to mechanically separate the master from the slave had been developed. In the mid 1980s research began to focus on finding the optimal method for controlling a robot. By the 1990s, transparency, or the ability of a system to provide the user with the sense of actually being present in a remote environment, had become an area of interest [6].

There is a constant development of new ways to teleoperate a robot. Yokokohji and Yoshikawa implemented a master-slave system using acceleration data to control one joint of a robot [15]. Zhou et al. successfully used a Barrett WAM in a unilateral master-slave setup to control the end effector of a Titan II slave [9]. This is not the only research that suggests the WAM as an ideal platform for a system of the type we propose. Heinzmann and Zelinsky recognize the WAM's potential as a safe, human friendly robot [5].

Other research has focused on what can be accomplished using haptic feedback. Turner et al. used a bilateral haptic glove in a series of experiments as an anthropomorphic controller for a remote robot hand [8] [7]. Ansar et al. designed a system to make a real object into something that can be modeled virtually through the use of a head-mounted virtual reality display and haptic feedback felt through a robot arm [13]. Cotin et al. proposed a surgical use of haptic feedback. They designed a system that allows a surgeon to practice a procedure by using a robot on a preprogrammed haptic model [2]. Çavuşoğlu et al. propose another system that has the potential to be used as a way of performing telesurgery. This system uses haptic feedback to enhance teleoperation, but the feedback must still be calculated by the computer rather than determined directly from the remote environment [1].

Remote Teleoperation with Haptic Feedback

Haptic feedback must be presented to a user through some kind of mechanical interface. The capabilities and limitations of that interface strongly affect the quality and usefulness of the haptic information. In order to completely represent the forces applied to a remote robotic arm, we chose to use a second, identical arm as a local user interface.

There are several advantages to using an identical robotic arm as a control interface for remote teleoperation, and these advantages are fully realized when the robotic arms are backdrivable. Backdrivability allows an operator to physically manipulate the local arm in order to precisely control the movements of the remote arm. If the arms are capable of delivering haptic feedback, then the user can be made to feel the remote environment just as the remote robot does. The information can be instantaneous and complete, enabling the user to interact intuitively and proficiently with the remote environment.

In order for a local arm to control a remote arm, any force applied to the local arm should be transmitted and applied to the remote arm. Conversely, in order for the local arm to respond accurately when the remote arm encounters resistance, any forces applied to the remote arm should be transmitted and applied to the local arm. So the behavior of the "controlling" and "controlled" arms is actually identical, making those roles fundamentally ambiguous.

We developed the following algorithm for remote teleoperation of a robotic arm with haptic feedback. Initially, both robots are oriented in exactly the same position. Then, during each control cycle, the following procedure is executed on both robots:

1. Receive joint angles from the other robot via a network connection.

2. For each joint, calculate the average joint angle between the local and the remote robot.

3. Use a PID control algorithm to calculate the additional torque that should be applied to each joint, in order to reach the "average" angle calculated in step 2.

4. Transmit the current joint angles of this robot to the remote robot.

5. Add the values calculated in step 3 to the torques that are to be applied to each joint.

6. Apply the torques calculated in step 5 to each joint.

When two robot arms run this algorithm, they both try to move towards the average of their positions. This allows either arm to be the "master" or "slave." When one arm is moved, the two arms become misaligned. The arm that was moved torques back towards the position of the one that did not move, and the arm that did not move torques towards the position of the one that did. The user who moves the arm feels extra resistance, as if the arm has the inertia of the two arms combined. The remote arm follows behind the moved arm, trying to reach the midpoint between the two. If the arms respond quickly enough, and with enough force, they appear to mirror each other.

If a user moves one of the arms, and the other arm hits an obstacle, the agent will "feel" the remote obstacle. More specifically, the remote arm will stop, and press against the obstacle. As the local arm is pulled further along the trajectory, it will torque back towards the joint position of the stuck remote arm. This feedback gives the tactile illusion that the local arm has hit an invisible obstacle.

The actual behavior of the arms is highly dependent on the control algorithm used in step 3, as it affects how quickly the torques are applied. That is, the rate at which the torque increases as the deviation between the arms grows. We used the standard PID controllers packaged with the API of the robot arms. The result was firm and realistic haptic feedback, without any noticeable lag or "softness" between the arms. Experimental data is provided later on, under the section, Precision Testing.

Barrett Robotic Arm

Implementation of a system like this requires very specific capabilities of the underlying hardware. The robotic arms must be backdrivable, and capable of delivering realistic haptic feedback. We used a Barrett Whole Arm Manipulator (WAM), which has these properties. The Barrett WAM is a human-scaled robotic arm with seven degrees of freedom. It utilizes a cable drive system, which generates less resistance than a gear mesh. This allows the arm to be backdrivable without mechanical or torque sensors. Force can be applied to any part of the arm, and it will comply. The cable drive system is controlled by PUCKs, high performance miniature servo controllers connected via a CAN bus running at 500 Hz [11]. This allows the arm to respond quickly to user input, or to apply torques to provide haptic feedback.

Additionally, the WAM is able to apply "gravity compensation" torques during real time operation. The robot applies the appropriate torque to each joint to negate its own weight, and thus remains suspended in place. An agent can manipulate the robot as if it is in a weightless environment, which allows for easy and natural control.

These capabilities are precisely the requirements for remote teleoperation with haptic feedback as we have described. We used two Barrett WAM arms to implement our algorithm, and to perform all of our experiments.

Teleoperation Program

The two WAM arms were configured to run their control cycle 500 Hz. In order to keep up with these updates, we used the UDP protocol to broadcast the robots' joint angles. This allowed us to broadcast quickly enough to keep up with the robot's controller. We were able to broadcast joint angles at about 5000 Hz, which was more than fast enough to keep up with the WAM arms.

Each WAM arm has 7 degrees of freedom, but we elected to only control the first 6 with our program. The 7^{th} joint is the rotation of the hand, which is the weakest one on the robot, and extremely sensitive. For reasons like this we found that some of the pre-programmed PID controller parameters had to be adjusted to allow for smooth operation of the arms.

Specifically, the proportional constant for joint 4 was set too high, and the derivative constant too low. This tended to cause oscillation in the arm. By hand tuning these constants we were able to improve the operation of the arm.

We ran the WAM arms with gravity compensation turned on in all of our experiments. Step 5 of our algorithm then consisted of adding the joint torques needed for gravity compensation to the torques calculated in step 3. A user manipulating one of the arms would feel the arm as if it was weightless, but had twice the inertia of a single arm.

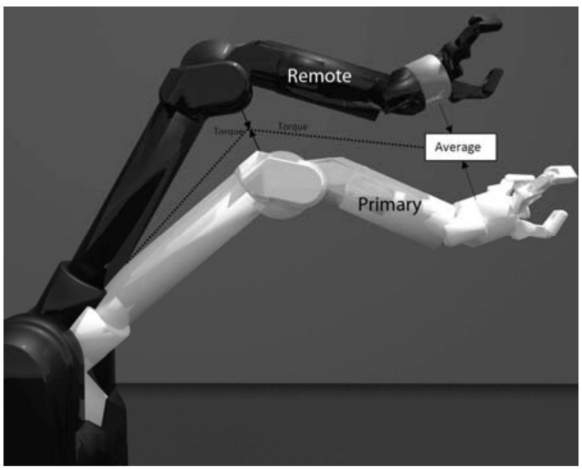

Figure 1: Visualization of how the system works

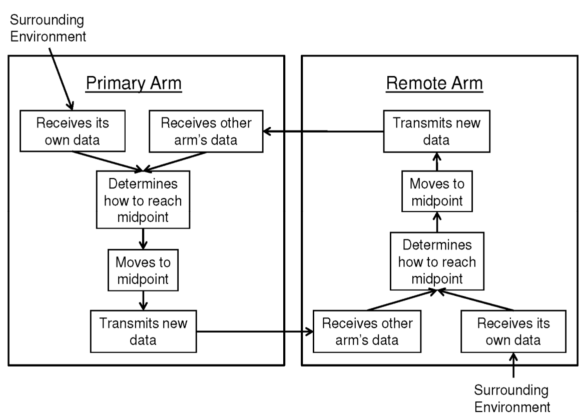

Figure 2: The system architecture of the two-robot real-time haptic feedback system.

Precision Testing Experiments

In order to test the accuracy of the mirroring of the two WAM arms, we ran three separate tests. Each test lasted for one minute, and during each test all joint angles were recorded for both robots during each control cycle. Since the WAM updates at 500 hertz, 30,000 data points were recorded for each joint during each test.

Test 1: The arms were positioned in a neutral, stationary pose.

Test 2: An experimenter constantly moved one of the arms through random positions, while the other arm was free to mirror the first arm.

Test 3: An experimenter held one arm in place by one experimenter, while another experimenter applied firm pressure to each joint of the other arm.

The difference (in degrees) between the two arms was calculated for each joint at each timestep in each test. For each test and for each joint the mean average error was calculated. This gives a measure of the average error between the joints when the arms are still, when they're moved freely, and when one has encountered an obstacle. The results are summarized in Table 1.

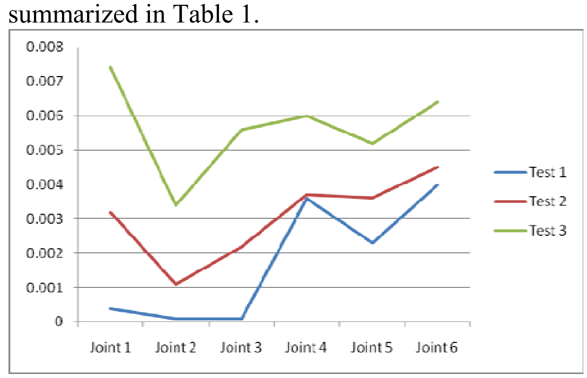

Table 1: Average difference in joint angles (degrees)

As expected, Test 1 showed the lowest error. The error in each joint increased in test 2 and test 3. However, even in Test 3, in which one arm was held still and firm pressure was applied to the other, the error is very low. In no case did the average error climb above $1/100^{th}$ of a degree. This demonstrates very clearly that the arms mirror each other precisely, even when they encounter obstacles and provide strong haptic feedback.

Anecdotally, we observed that the arms would surpass their torque limits and automatically shut off before they would allow a high degree of error between the joints. The users generally experienced the arms to be connected "solidly," with little or no perceived error between them.

Usability Testing Experiments

An important factor for any control method is its usability. We ran the system through several usability tests in order to investigate both participants' proficiencies in using the system and their opinions of the robotic interface.

As approved by the IRB (08-275, July 9, 2008), thirty participants were randomly assigned to one of three groups. Each group was given a different form of feedback: haptic feedback only, visual and haptic feedback, and visual feedback only. In the haptic feedback only group, participants could feel obstacles encountered by the remote arm, but they had no visual information about the remote environment around the remote arm. The haptic and visual feedback group was also shown a live video stream recorded by a camera located in the remote environment. The visual feedback only group had the same camera setup, but the remote robot was controlled by a unilateral master-slave system (one robot controlling the other with no feedback). In this case, the a system was implemented that used the primary arm to send joint positions to the remote arm without the primary arm receiving any new positions itself. This meant that the participants did not have any haptic feedback from the remote arm.

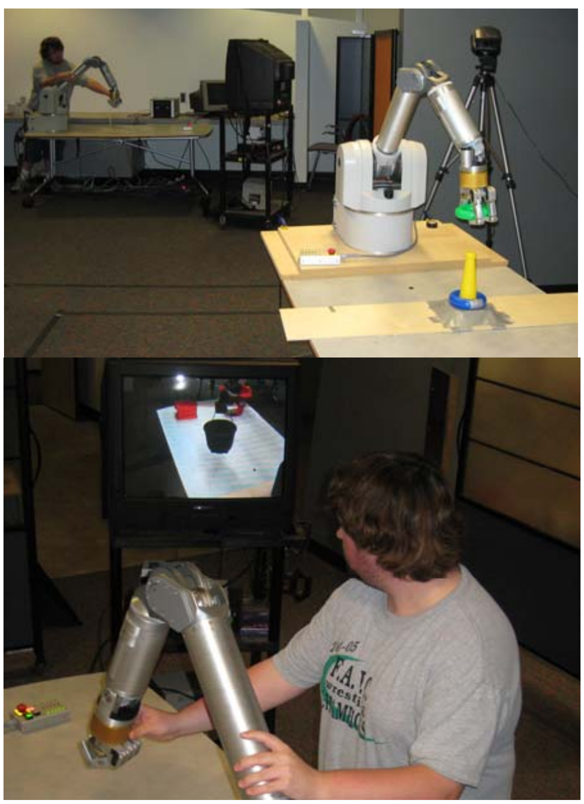

Figure 3: Remote arm being controlled by the user in the top left corner. During experiments, a screen prevented the user from seeing the remote arm. The camera on the right provided visual feedback through the television.

The ten participants assigned to each condition completed three tasks. In all conditions, the experimental setup consisted of two Barrett WAM robot arms, two Ubuntu Linux computers running the robots, two video cameras, and a television set (see Figure 3). One of the cameras was capable of providing a video feed of the environment around the remote arm to the television to give participants visual feedback in the conditions that required it, and the other recorded the participant's actions, (see figure 3). During the tests, participants were not able to see the remote robot, except through the video feed. Participants were briefed on the capabilities of the robot arms and the configuration in which they were setup. Upon completion of the tasks, each participant was given a post task survey. This survey asked participants to rank usability of each condition for each task on a scale from one to ten with ten as the highest and one as the lowest.

Task 1: Guiding the robot through a maze

Task 1 required the participants to guide the remote arm through a maze. The ability to navigate an arm through a complex environment is important in many real-life applications. The maze used in this test was constructed from plywood, birch wood, and drawer liner to protect the robot. The maze itself measured approximately two feet by three feet with four inch wide paths. Certain areas of the maze were not accessible unless the participant was manipulating all six joints of the robot.

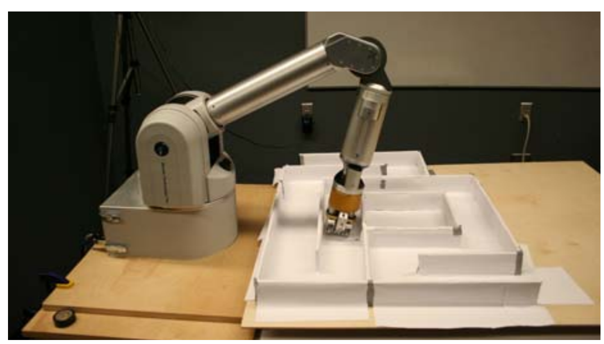

Figure 4: The remote arm as a user was guiding it through a maze

We evaluated participants based on the time they took to complete the maze task and the number of errors they made, where an error was defined as moving the robot out of the maze, or over a wall, or pushing the robot past its safety limits. When a participant made an error, we paused the timer and returned the arm back to the point where the error occurred. The completion times were recorded for all participants, along with any errors they made while traversing the maze. After five minutes, participants were offered a choice to continue or to stop. At any point after that, they were permitted to stop their attempt if they believed that they would be unable to make further progress. Stopping an attempt before reaching the end of the maze was counted as a failure.

Group	Average Completion Time (s)	Standard Deviation	Success Rate
Haptics and Vision	82.40	27.31	100%
Vision Only	107.80	25.39	100%
Haptics Only	459.66	216.17	66%

Table 2: The average time, standard deviation and success rate of all three groups of participants in the maze task.

Maze Task	Haptics Only	Haptics and Vision	Vision Only
Task Difficulty	**8.11**	**7.3**	**5.0**
Benefits of Vision	**9.77**	**7.2**	**7.6**
Benefits of Haptics	**7.88**	**9.0**	**8.7**

Table 3: The average rating of task difficulty and the benefits of visual and haptic feedback by each group of users. All results were based on a 10-point scale.

Both groups with visual feedback had times significantly faster than those of the haptic feedback only group. The haptic feedback only group was the only one in which participants became frustrated enough with the arm that they chose to give up rather than continue.

However, adding haptic feedback to visual feedback was clearly beneficial. A one-tailed t-test of the haptics and vision group and visual feedback only group revealed a significant difference, with less than a .04 chance of error with 18 degrees of freedom.

Several general trends became apparent over the course of the test. Users in the haptic feedback only group were less likely to change where they were holding the robot throughout the test. In many situations, the joints they were manipulating would be as close to a corner as possible, but still unable to go around the corner without changing one of the other joints. This problem occurred most often where the arm entered the straight-aways either closest or farthest from its base. Several participants from the haptic feedback only group commented that while approaching these corners, they had reached positions where the arm would not go any farther in the direction they desired. This often led to extensive backtracking.

Participants in the groups with visual feedback avoided these problems. They were much quicker to switch their grasp of the robot when they knew where it had to go. The only instances of backtracking in these conditions occurred in the straight-away closest to the base of the robot. The exit from this straightaway was blocked from view by the base of a robot, so it seems that participants were unable to tell when they had made it past the corner.

It should also be noted that teleoperation of the remote arm was much smoother in the conditions with haptics. Often when a participant was only given visual feedback, he or she would not stop moving the primary arm when the remote arm hit an obstruction. As the difference in the positions of the arms grew, the remote arm applied higher amounts of torque necessary to realign the arms. This resulted in the remote arm applying a great deal of force against the unyielding walls of the maze. Once the arm did get past the place where it was stuck, it quickly achieved high speeds, which frequently ended in collisions with the walls of the maze. These violent collisions were not observed in the groups with haptic feedback.

Task 2: Stacking Rings on a Peg

Task 2 was designed to test participants' ability to manipulate objects with the remote arm. The rings and peg used for ring stacking were part of the Fisher-Price Rock-a-Stack® children's toy. The rings were loaded manually into the robot's hand by the researchers. Participants were then asked to orient the arm in such a way that the ring would be placed on the peg when the ring was released from the hand. Because parts of the Barrett hand do not have backdrivable capabilities, it was necessary for the participant to notify the researchers when he or she wished to release the ring. Participants were timed to see how quickly they could orient the arm to the desired location. If the released ring fell on the peg, the task was counted as a success. Experimenters recorded the times along with the success rates of the test.

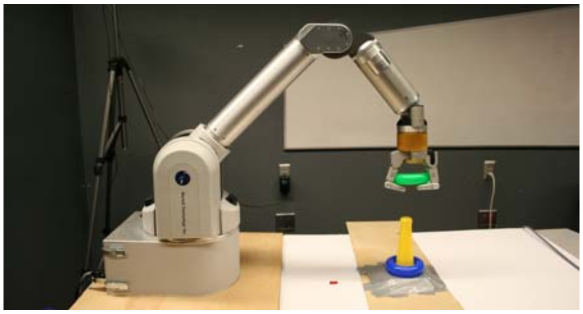

Figure 5: View of the remote arm under the control of the primary arm during the ring stacking task.

The results for stacking rings on a peg were mixed. The haptic and visual feedback group had a slight advantage over the visual feedback only group in success rates (see Table 4). The haptics and vision group also had a significantly higher success rate than the haptic feedback only group. Times for completing the task, regardless of success or failure, were best for visual feedback only on the first trial, but both conditions with visual feedback had very similar times for the second ring. Difficulties with the hand invalidated results from one participant in each condition.

Both haptics and vision seem to be necessary for optimal performance on this task. Participants in the group with visual and haptic feedback would frequently start by lining the ring up visually, and then use the haptic feedback to fine tune their position. Haptics helped increase the success rate of the ring test, but haptic feedback alone was not enough to complete the task consistently.

A major hindrance to using visual feedback from one camera is the lack of depth perception. The two dimensional view made it difficult for some participants to accurately judge the position of the ring in relation to the peg. When used to its fullest potential, haptic feedback is a solution to this problem. It allows participants to sense when the ring is in contact with the peg.

	Ring 1 Success Rate	**Ring 2 Success Rate**	**Ring 1 Time**	**Ring 2 Time**
Haptics & Vision	77.8%	77.8%	24.3	14.4
Haptics Only	33.3%	22.2%	49.7	29.5
Vision Only	44.4%	55.6%	18.0	14.6

Table 4: The average successrate and time in which the two rings were stacked by users during the study.

Ring Task	**Haptics Only**	**Haptics and Vision**	**Vision Only**
Task Difficulty	**7.44**	**6.1**	**5.66**
Benefits of Vision	**10.00**	**7.7**	**5.62**
Benefits of Haptics	**7.33**	**8.1**	**9.22**

Table 5: The average rating of task difficulty and the benefits of visual and haptic feedback by each group of users. All results were out of 10.

In general, post task surveys showed that participants did not believe haptics to be especially beneficial for this task. Participants in the haptic feedback only group wished that they would have been able to see their task, while participants who had vision and haptic feedback rated the usefulness of haptic feedback as better than average. Furthermore, slightly more than half of those who had visual feedback only stated that they would find haptic capabilities beneficial. In fact, the visual feedback only group rated the difficulty of this test lower than any other group. It is interesting to note that people's perceptions of the usefulness of haptic feedback do not seem to reflect the benefits that they actually received from it.

Task 3: Comparing the Weights of Buckets

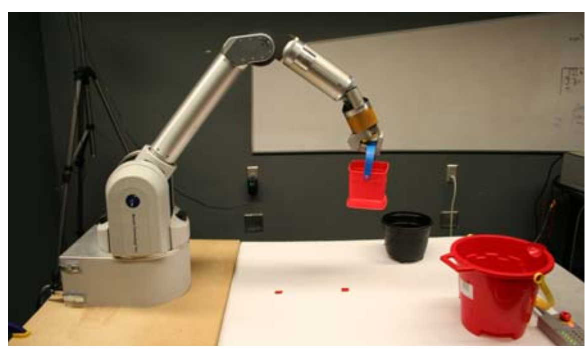

Figure 6: The remote site while users try to compare the weight of three buckets

In order to test the ability of humans to sense weight through haptics, we created a weighted bucket test. Three buckets were used each of a different size, shape and weight. The largest bucket weighed .875 pounds and held no additional weight. The medium-sized bucket together with weights placed inside it, weighed a total of 2.5 pounds. The smallest bucket and its weights totaled 1.5 pounds. Each bucket was manually loaded into the robot hand by the researchers. Test participants were asked to lift each bucket and rank the buckets in order of their weight. Assigning all three buckets the correct rank was counted as a success. The completion times were not recorded for this test and subjects were allowed to lift each bucket as many times as they wanted.

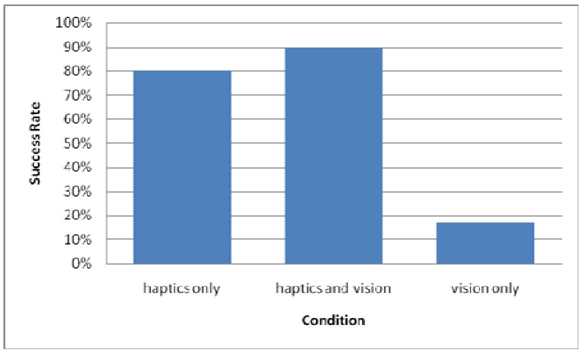

Table 6: Success rates of comparing the weighted buckets by the three conditions.

As expected, participants did significantly better at this task when they had haptic feedback. A more surprising result was that participants in the haptics and vision group gave a very low rating for the usefulness of haptics (see Table 7). This suggests that users are not aware of haptics when they have not been deprived of either sense.

Bucket Task	**Haptics Only**	**Haptics and Vision**	**Vision Only**
Task Difficulty	**5.22**	**6.9**	**5.8**
Benefits of Vision	**5.0**	**8.0**	**9.4**
Benefits of Haptics	**8.33**	**5.4**	**8.0**

Table 7: The average rating of task difficulty and the benefits of visual and haptic feedback by each group of users. All results were based on 10.

The 30% success rate of participants in the visual feedback group is higher than initially expected. However, these findings are consistent with research showing that people can judge the weight of an object from visual cues alone [3][4]. Observations of the participants showed that while many of the participants attempt to judge the weight of the buckets by simply picking them up, the three successful participants in the visual feedback only group used different techniques. These techniques included swinging each bucket, bouncing the bucket on the hand, and by hitting the buckets against each other. The visual cues provided by these techniques can partially compensate for the lack of haptic feedback.

For the weighted bucket task, the haptics and vision group had the highest success rate. Its users also judged it to be the easiest to complete while the haptic feedback only group found it to be the hardest to complete. These low ratings on the ease of the task could be due to several factors. For example, some participants commented that it was difficult to determine the weight of the bucket because they could not determine the weight of the arm. Low ratings could also occur because the difference between the weights of the buckets was small, just over a pound difference. Furthermore, low ratings for the haptic feedback only condition could result from the lack of visual feedback. Responses from the participants show that the haptic feedback only group was the sole group that thought vision was not beneficial for the task. The vision and haptic group in fact saw haptic feedback dramatically less beneficial than the other groups. This recognition of visual feedback as a benefit in judging the weight of object may occur because people rely primarily on their sense of vision for input. This in turn creates an apparent need for visual input even in tasks which can be completed using other senses. It was also noted that members of the visual feedback only group seemed to forget that they did not have haptic feedback during this task.

Conclusion

In this paper we have discussed the development and use of a system for teleoperation of two robots in order to deliver real time haptic feedback to users of either interface. The system was used in a human usability study as well as subjected to a battery of tests determining its constraints and abilities.

During the usability experiment it was found that while the participants were aided by the haptic feedback of the remote arm, haptic feedback by itself was insufficient to replace visual feedback for successful and timely task completion. However, the visual and haptic feedback group was the most successful of the groups in all three tasks. This suggests that including haptic and visual feedback in the interface for a teleoperated robot significantly improves the operator's performance.

In addition to the success rate of the haptic and vision group, feedback from users showed a consistent preference to have visual feedback when completing a task. This is found even in tasks where one might assume the sense of vision to be unnecessary, i.e., determining the weight of buckets. Depriving participants of various visual clues made successful completion of each task more difficult. When participants were deprived of sight they lost several visual clues which aided other participants in the successful completion of the tasks.

While people prefer visual feedback when completing tasks through teleoperation, haptic feedback does provide a finer control of the equipment. During the visual feedback only trials the remote arm would often drag heavily against the maze or snap free of obstacles only to knock into something else. In real world applications, e.g., telesurgery or manufacturing, these events could be detrimental, or even life threatening. These situations happened because after hitting an object the remote arm would often become misaligned from the local arm, meaning that the remote arm would torque into solid obstacles or snap free of obstacles trying to realign with the primary arm. This is not only hazardous to people but to the equipment as well.

The current state of robotic teleoperation does not provide the level of control necessary for safe, proficient operation of a remote robot. Therefore, \we have shown that adding haptic feedback is an effective way to improve the proficiency of remote teleoperation. Implementation of haptic feedback in teleoperation of remote robots improves interaction between humans and robots; as well as the safety and overall control of remote sites.

Future Work

Possible future work could be to expand the usability testing to include visually impaired participants. Clearly most of the participants in this study heavily relied on vision. Individuals with limited access to visual feedback on a consistent basis learn to make better use of their other senses. Our hypothesis is that visually impaired participants could prove to be quite adept at using haptic technology. The same tests procedures could be used and compared with the results obtained for non-visually impaired subjects.

Other possible avenues for future work may include creating a program to generate a three dimensional map based on the haptic input of one of the robot arms. As the mapping arm would encounter obstacles higher torques would result on the primary arm. Any point that created higher torques could be treated as a non-penetrable surface. When such a surface is detected, the program could map it accordingly and generate surfaces based on a large collection of points. In addition to this, different levels of torque could be used to determine the hardness of the object. Such a technology could prove to be well suited for a Barrett WAM.

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