CISE Computing Research Infrastructure (CRI)

II-EN: Robotic Equipment for the Investigation of Dexterous Two-Handed Manipulation

1 Overview

One of the grand challenges in robotics is to achieve dexterity. A dexterous robot should be capable of navigating varied terrain, adapting to and cooperating with people in its environment, and accomplishing a variety of tasks, many of which will require manipulating objects of varying shape, weight, and size. The state of the art today, however, is far from this goal. Despite notable and very public successes, such as Honda’s ASIMO humanoid robot [1], today’s robots typically perform only a small number of scripted tasks within tightly controlled scenarios. Robotic capabilities in manipulation are especially limited. In some ways, we are not very far from the demonstrations that were created for the early multifingered hands developed in the 80’s.

One of the technologies that promises a large leap forward at this time is our ability to capture sizeable quantities of detailed human motion data. We can now capture the detailed performance of tasks that involve dexterous manipulation of objects in our environment (Figure 1). Our group has been using such an approach for the exploration of one-handed grasping and manipulation as well as developing basic two-arm manipulation capabilities (see Figures 6, 7, and 9). We received in 2004 a grant to research the state of the art in humanlike robotic hands and purchase such a hand for our laboratory. This funding has motivated and enabled a great deal of research [20, 14, 4, 6, 11, 5, 13, 7, 9, 8, 12]. With this funding, we were the second group worldwide to purchase a Shadow Robot Hand, and have seen that hand through several hardware updates and substantial software development. It is used in our lab on a daily basis.

We are now seeking funding for equipment to expand our equipment base to support investigation of complex, humanlike, two-handed dexterous manipulation tasks. The equipment, described in Section 2, includes a robot torso with two arms (shown in Figure 2) and funding to design and fabricate a custom second hand.

Our motivation comes from everyday life. If we observe people performing everyday tasks, we will notice that a large percentage of those tasks are done using two hands. Figure 4 shows some examples. Without a second hand to provide support for these tasks, all of the tasks shown would be significantly more difficult to accomplish.

A small number of other research groups worldwide are leading significant research efforts in the area of two-handed dexterous manipulation (e.g., [2, 21, 28, 9]). What distinguishes our efforts from these groups is our focus on understanding in detail how people perform grasping and manipulation tasks and transferring that knowledge for use in robotic manipulation (see, for example, Figure 9).

Intellectual Merit. Research made possible by the equipment requested in this proposal will include:

- **Task transfer of two-handed manipulation tasks from human demonstrations** through a combination of (a) task understanding (e.g., as in [19, 17, 20]), (b) planning and learning (e.g., as in [14, 13]), and (c) direct user interaction (e.g., as in [12]). Two-handed manipulation is substantially more complex than single handed activities, which will give us an opportunity to expand our existing algorithms and explore new approaches for obtaining robust manipulation from human examples.

- **Application domain specific designs for a non-dominant robot hand to be used in two-handed manipulation.** With funding from this proposal, we will design and test several robot hand prototypes
Figure 1: (Top) Existing equipment includes a 24 degree-of-freedom, five-fingered robotic hand, manufactured by the Shadow Robot Company. We also have available a 16 camera Vicon human motion capture system, with a working kitchen and other equipment for motion capture of everyday activities. The rightmost top images show a subject whose motion is being recorded in our kitchen environment and subjects instrumented for hand motion and hand force capture. (Bottom) We also have available a high speed camera to aid motion understanding and facilitate capture of timing of contact events.

which have been optimized to have the simplest possible design capable of accomplishing a suite of everyday tasks, operating as the non-dominant hand. Optimization of hand kinematics and drive mechanism based on a suite of specific applications drawn from human subjects experiments is unique and promises new insights into the required number of degrees-of-freedom of the hand, the required number of drive motors, and the geometry of critical but often ignored parts of the hand, such as the palm.

**Broader Impact.** Broader impact of the proposed activities includes forming a better understanding of human motion itself. We believe that we can only successfully transfer a task from a human demonstration to a robot performance if we understand a great deal about why a person chooses to perform a task in a certain way. Our proposed robot hand design project also has great implications for prosthetic design, as our robot hand design process will be driven with goals of (1) simplicity in design – leading to a relatively inexpensive hand that is easy to control, and (2) ability to perform tasks from everyday life, from cooking and cleaning to bicycle repair.

2 Resource Description

2.1 Existing Equipment

We currently have available in our lab a 24 degree-of-freedom hand from the Shadow Robot Company (Figure 1). We do not currently have a robot arm dedicated to this project. The arm shown in the photo was borrowed for our experiments and is not adequate for the load placed on it by the robot hand (which weighs 3.5kg, with a center of mass displaced by 10cm from the mount point). As a result, motions of the arm currently display substantial vibrations, which interfere with the appearance of the motions and performance of more dynamic tasks.
Figure 2: (Left) Motoman SDA10 1 degree-of-freedom torso with two 7 degree-of-freedom arms. On this platform, we will mount our existing Shadow Robot Hand (Figure 1) as the dominant hand and a non-dominant hand of our own design. (Right) Our investigation of custom hand designs for the non-dominant hand will begin from a typical multifingered hand configuration. However, degrees-of-freedom will be coupled for simpler design and control. Of particular interest in our design investigation will be (1) to find an optimal coupling to maximize performance on a large suite of everyday tasks performed by the non-dominant hand in two-handed manipulation, (2) to investigate the use of degrees-of-freedom in the palm of the hand, and (3) to investigate the use of a silicone skin and the effectiveness of different palm shapes for more robust grasping.

We also have access to:

- a state of the art motion capture laboratory, equipped with a working kitchen and other “stage sets” for capturing everyday tasks,
- a pressure sensitive glove for capture of some force information during grasping, and
- a high speed camera for detecting contact events and detailed manipulations such as rolling contact with high resolution.

2.2 Proposed Equipment: Robot Torso and Two Arms

The proposed equipment to be purchased includes a 15 degree-of-freedom torso with two arms (Figure 2, left). This robot has a load capacity which is adequate for mounting our Shadow Hand, as well as the hand we will manufacture. The specifications for this torso and arm appear more than adequate for our needs. However, we have made plans for a trip to Cleveland to verify through experiments that the load capacity, top velocity of the arms, and joint range of motion will be sufficient for humanlike manipulation tasks of the type shown in Figure 4. Cost for the torso and two arms is approximately $120,000, as outlined in the budget and detailed in the supporting documents. Our existing Shadow Hand will be mounted on this platform as the right hand (Figure 3).
Figure 3: Mockup of two hands mounted on a Motoman torso. Note that this mockup uses specifications for older models of the torso and arms. The newer model which we propose to purchase (shown in Figure 2) is substantially slimmer.
2.3 Proposed Equipment to be Designed and Manufactured: A Custom Left Hand

The proposed equipment to be designed and manufactured includes a second robot hand to complement our existing Shadow Hand. We had two motivations for designing our own hand. First, the cost of a state of the art humanoid robot hand today is quite prohibitive. We received a recent quote of $273,000 to obtain a Shadow Hand of the most recent design. Second, we believe that hand design, even for humanoid appearance and function, can be much simpler than the hands on the market today. For the non-dominant hand especially, we believe that the simple set of supporting functions played by the hand can be accomplished with a relatively small number of degrees-of-freedom, given careful arrangement and coupling of those degrees-of-freedom and care given to skin and palm design. We are requesting funding to test this hypothesis through one simple bench test of a single finger and a series of three full hand prototypes. The cost of equipment for these prototypes is approximately $80,000, as outlined in the budget and detailed in the supporting documents.

Cost for a part-time highly experienced staff member and designer to manage purchasing, installation, design, manufacture, and software development for the project (see Section 5) is approximately $225,000, covering a total of three years, as outlined in the budget.

3 Project Description

Two areas of research will be made possible by the equipment requested in this proposal. The first is an exploration of two-handed dexterous manipulation. The second is exploration of minimalist design of a non-dominant hand to support everyday two-handed manipulation activities.

3.1 Two-Handed Dexterous Manipulation

A substantial percentage of everyday activities are performed with two hands (Figure 4). A second hand makes manipulation easier in several ways. First, using the non-dominant hand to “fixture” the object localizes the object so that it is in a known configuration relative to the robot. Second, the non-dominant hand supports the object so that it does not move in an unexpected way in response to disturbances from the second hand. Third, the non-dominant hand can carry out simple manipulation tasks such as adjusting the object’s position to make the task easier to achieve.

With the equipment described in this proposal, we will explore a number of questions in two-handed dexterous manipulation:

- Achieving a proper fixturing grasp with the non-dominant hand.

  We consider two separate research problems in this section. The first is estimating the quality of a grasp in-situ, and the second is adjustment of the grasp for improved quality. In previous work, we have developed measures of grasp quality that consider both the ability to apply forces to an object [17] and the constraints of a particular robotic device (or human muscles) [11, 13]. However, measuring the quality of a grasp in-situ is in fact quite difficult, as sensors for direct and complete measurement of contact forces in whole-hand or enveloping grasps are still not available. Current force sensors are subject to hardware failures (e.g., broken connections), require frequent calibration (e.g., even when the temperature in the room changes), are difficult to mount over the entire surface of the hand, and are expensive. It may be possible in some situations to use vision to compensate, but vision brings along with it a variety of problems with overcoming occlusion, calibration, and so on.

  We are currently pursuing research that will allow us to use available sensing technology and learned knowledge to accurately estimate the quality of a grasp. The information which may be available to
Figure 4: If we examine bimanual tasks that arise during everyday activities, we see that the non-dominant hand (the left hand of the human subject in these pictures) often acts as a jig – its role is often simply to provide support to an object, container, or tool. Images such as these suggest that a relatively simple device may be sufficient to play a similar role in robotic two-handed manipulation tasks.
us (depending on hand design) includes the following:

- Simple contact switches distributed liberally over the surface of the hand. The state of these sensors indicates which parts of the hand are in contact with the object.
- Position sensors at the joints of the hand. The actual joint position gives us the current shape of the hand and locations of contacts between hand and object. The difference between the commanded joint positions and the actual joint positions gives us some information about contact forces between hand and object.
- In-line tendon tension sensors (when available) give us further information useful for estimating contact forces.
- Knowledge of the control algorithm in use provides further information which can be used to predict forces at the contact points from position errors.
- Learned mappings from sensor information to grasp quality for common grasps allow us to calibrate our estimates and make them more accurate.
- Active testing performed by the dominant hand allows us to test our estimates by using the dominant hand to apply disturbances to the object grasped with the non-dominant hand.

Once grasp quality can be accurately estimated, we will consider how to best adjust grasps for improved quality. In other words, we would like to have good algorithms for adjusting the grasp in response to initial contact or other sensor information in order to achieve a higher quality final grasp.

In our human subjects experiments, we observe many such strategies. Upon initial contact, a person will reorient the hand to align it to the main axis of the object, translate their hand to center the object in the grasp, and adjust relative finger positions, for example. In some cases, the fingers may be completely released from the object, and the hand configuration will be adjusted so that the fingers can be wrapped around the object more tightly.

It is obvious that when individuals grasp and manipulate objects, they are gathering sensor information that allows them to better estimate how to successfully grasp the object. In fact, a variety of research has been performed in this area, as researchers have proposed algorithms for haptic exploration or force based control algorithms to localize, identify, or securely grasp an object.

We propose investigating the use of an improved grasp quality measure as outlined above, along with knowledge of typical human grasp adjustment strategies, to develop algorithms for robust, reliable grasp adjustment for robot hands.

We will begin by collecting a large database of grasp corrections through human subjects experiments. To ensure that sufficiently large corrective actions are observed, we will perform grasping in situations where the object to be grasped is hidden from the subject’s view. To the extent possible, contact force information will be collected as part of this database. Two-handed grasping will be explored in addition to single handed grasping (i.e., where the object is placed by one hand into the other hand).

Our hypothesis is that, given knowledge of the object to be grasped, or at least of its general family (e.g., glasses and mugs), corrective actions can be easily determined from the sensors available on the robot hand. For example, consider attempting to close the hand over the top of an object such as the cup shown in Figure 1. The way in which the hand begins to conform to the object will very quickly indicate whether the hand must move forward, back, left, or right, for example, in order to center the cup in the grasp.

It may seem difficult to collect a sufficiently large space of examples, given that grasps vary over object location, object shape and size, grasp type, and hand posture. However, there is reason to
believe that the space of interest is actually quite low-dimensional (e.g., [27]). Analysis of our collected database will very quickly tell us whether the proposal of using sensors currently available on robotic hands to determine corrective strategies is feasible, and if not, give us a testbed for examining alternative sensing configurations that are also possible given the current state of available sensing hardware.

Our expected result from this portion of the project is local policies for grasp adjustment to achieve a successful grasp in the absence of precise force sensing or visual feedback.

- Task Transfer for Cooperative Two-Handed Manipulation Tasks

In past research, we have had success in transferring one-handed grasping and manipulation tasks from human demonstrations to robot examples (see Figures 7, 6, and 9). These transfers from human demonstrations to robot execution have relied on planning motions with similar force profiles [19, 17], grasps with similar hand shape [14, 13], and grasping controllers with similar dynamic behavior [20]. We propose to expand our capabilities along two dimensions: first, to extend these algorithms to two-handed manipulation tasks, and second, to develop algorithms for direct user interaction and annotation, which will allow us to build a database of knowledge to make this process of task transfer more automatic.

A number of research questions arise when considering two-handed manipulation tasks that were not present when considering a single hand only, even if the second hand is used primarily for fixturing the object. How do we choose the best grasp for the non-dominant hand? How does the non-dominant hand acquire the object? In some cases the dominant hand may need to grasp the object first and place it in the non-dominant hand. How do we ensure that the grasp is adequate given the uncertainties in contact forces applied to the object by the second hand? What sensing and control algorithms must we use to ensure that the two hands operate in a cooperative way rather than interfering with each other? We have invested considerable attention to improving our pipeline for capturing accurate, subject-specific human hand motion [4, 6, 7]. New challenges will certainly arise in capturing the detailed motion of two hands as we collect data from human subjects experiments. We plan to explore two-handed manipulation activities in a similar philosophy as our previous research, addressing these research challenges as they arise.

Beyond directly extending our previous research to two-handed manipulation activities, we are pursuing how direct user-interaction can improve manipulation performance and add to our understanding of manipulation tasks. We are currently developing user interfaces for directly altering the progress of a running simulation or execution of a grasping algorithm [12]. Whereas teleoperation allows a user to directly control every detail of a motion, our interface allows a user to reach in and change only those aspects of the motion that need to be altered (e.g., the wrist orientation, the configuration of one of the fingers, or the overall grasping force). We are also developing tools that allow the user to annotate what is important about a grasping task (e.g., important contact locations, dominant contact forces, important task outcomes). This database will make it easier to accurately transfer tasks from human examples to proper robot execution in the face of varying object geometries and uncertainties in the environment and variation in the importance of different aspects of task performance from task to task.

3.2 Reduced Degree-of-Freedom Hand Design

If we examine the images in Figure 4, we can see that the non-dominant hand (the left hand in this case) takes on a relatively limited number of shapes and is required to perform a relatively limited number of
motions. The range of operation is much less than the full set of possible shapes and motions that could be achieved with the hand, and the fingers almost always move in a highly coupled manner. This apparent tendency of people to make use of a quite low degree-of-freedom workspace has been observed by a number of researchers, including those in the neuroscience community (e.g., [27]). The idea has even been applied to the development of reduced degree-of-freedom robotic hands (e.g., [3]).

We have a shared goal with this previous work: to identify a hand design with appropriately coupled degrees of freedom for simplified control, inexpensive manufacture, and effective operation. What distinguishes our research from previous work, however, is our approach. Instead of simply considering synergies in observed motion (e.g., the first few principle components of observed hand motion), we will evaluate proposed designs based on their performance in simulated and actual manipulation tasks taken from a large test suite of everyday activities such as those shown in Figure 4. Potential designs will be evaluated based on their performance on this suite of activities.

The design space will be optimized along the following dimensions:

- **Joint positions and joint axis orientations.** In previous work [4, 6, 7], we have found that even small changes in joint position and joint axis orientation for the kinematic model of a hand can have a significant effect on grasping capabilities and hand appearance. We will optimize these parameters to best achieve our suite of manipulation tasks while making use of user feedback to retain a humanlike appearance to the resulting designs.

- **Coupling of joint degrees-of-freedom.** We will identify the optimal coupling between joints for various target degrees-of-freedom (e.g., for 6, 12, or 24 degrees-of-freedom design). Unlike in previous approaches, the optimal couplings will be based on actual task performance rather than on a linear model formed from observed data.

- **Palm design.** In previous research, we have found palm geometry to be critically important for forming robust grasps [20]. We will explore a variety of palm designs, with material for the palm to range over a design space (e.g., from a material such as silicone to a thin silicone layer over foam padding). We will also explore adding degrees-of-freedom to the palm, optimizing over joint placement and number of joints to be added. The intent is to capture some of the ability of the human hand to conform to objects with the thick pads of tissue and muscle found on the human palm (e.g., the thenar eminence and hypothenar eminence).

- **Controller design.** At a later stage of the research, we will investigate variations on controller design. As each potential hand design will be evaluated based on ability to perform manipulation tasks, the manipulation simulator which tests this capability will be a critical element of the optimization process. The manipulation simulator can make use of a variety of controllers, which will mimic the controllers used in actual task execution on the robot. One part of the design process will explore alternative controller designs.

- **Sensor capability.** A final part of the design optimization process will explore the needed sensor capability of the hand. Do we need to load the hand with a complete suite of sensors to achieve our goals or are simpler sensors, coupled with clever algorithms sufficient?

### 4 Broader Impact

As mentioned above, broader impact of the proposed activities falls into two main areas: (1) forming a better understanding of human motion itself and (2) implications for prosthetic design for human limb replacement.
A significant portion of our research program is to pursue human subjects studies with the goal of understanding the range of human manipulation strategies available and also understanding as well as possible why people choose to use one strategy and not another. Are they minimizing energy? Choosing a more robust strategy for a high precision task? Exactly how do object weight and task precision influence the choice of strategy. Reference [9] describes some preliminary experiments investigating these questions for prerotation (Figure 9) and additional research to further clarify such questions is underway. We believe that we can only successfully transfer a task from a human demonstration to robot performance if we understand a great deal about why a person chooses to perform a task in a certain way.

Regarding implications for prosthetic design, our proposed robot hand design process will be carefully organized to balance the goals of simplicity in design and ability to achieve a wide range of everyday tasks while functioning as the non-dominant hand. It is our hope that this research will lead to novel prosthetic hand designs that are cost effective, easy to control, attractive in appearance (even when in motion) and sufficiently agile for a wide variety of ordinary daily activities.

5 Management Plan

The hardware aspects of this project, along with software development and integration for the robot controllers will be managed by Garth Zeglin, an experienced senior staff member at Carnegie Mellon University. Garth’s experience and research interests center on developing "minimalist" robot mechanisms which utilize natural dynamics to simplify tasks. His work to date (see Figure 5) has focused on designing dynamic legged machines for studying both hopping and walking. He received a B.S. in mechanical engineering from MIT in 1991, with thesis work on the Uniroo hopping robot. For his doctoral work at the CMU Robotics Institute he worked with H. Benjamin Brown on the Bow Leg Hopping robot. This one-legged machine uses an innovative design for a flexible, efficient leg which combines structure and elasticity in a single spring (now patented). The freely pivoting hip placed above the body mass creates a high degree of passive attitude stability. The Bow String tendon design decouples the actuators from stance forces; this allows low-power actuators to guide the dynamic process and reduces the control demands to one discrete update per hopping cycle. The design exhibits very clean dynamics which can be approximated in closed form, which allows for efficient real-time planning of foot placement sequences to cross simple terrain problems.

Since completing his Ph.D. in 1999, he has shifted to developing walking machines. He was solely responsible for the hardware, software, and electronics development for two bipedal walking machines built...
Figure 6: We have developed an automatic technique to extract grasp controllers from human demonstrations [20]. Our controllers allow us to create physically based simulations of human grasps. The passive properties of the simulated hand are set to closely match those of the human hand so that a user can interact with the running simulation and obtain good results (e.g., to pull a grasped object out of the hand). Active control parameters for achieving the grasp are derived automatically from the human demonstration. Our controller is robust to changes in object geometry, as shown in the figure, and is capable of modulating grasp force to squeeze the object loosely or firmly, for example. Work is now in progress to improve these algorithms for robust robotic grasping in uncertain environments.

for the study of dynamic walking principles. These machines feature direct drive and low-ratio electric actuators to remain highly backdrivable at the hips and knees. This is motivated by McGeer’s work on unpowered walking machines; by allowing the legs to swing freely during recovery, the natural dynamics reduce the mechanical work required to maintain the walking cycle. His collaborative work on the walking control led to an invitation in 2005 to work at TU Delft in Holland on the design of an autonomous electric biped also based on dynamic walking principles. He collaborated on the mechanical design, was responsible for the electronics design, and wrote the initial software infrastructure.

Garth has managed installation, revisions, and software development for the Shadow Hand in our lab for the past two years. He would be responsible for supervising purchase and installation of the robot torso and arms, integrating them into our existing software environment, and designing and building the new robot hand based on our research findings related to human use of the non-dominant hand in two handed manipulation.

6 Results from Prior NSF Support

NSF CCR-0093072 (Pollard)
April 2001 – March 2007
$326,630

CAREER: Quantifying Humanlike Enveloping Grasps
Under NSF support, we have developed techniques for planning grasping and manipulation tasks for robots based on measured human motion and forces [19, 17] (also see Figures 6 and 7), have explored force capabilities of both human and robot fingers [18], and have developed an anatomically based grasp quality measure that has good predictive power for human grasp choice [11, 13] (also see Figure 8). This grant has now expired.
Figure 7: Task transfer: the human demonstration is adapted for implementation on the robot so that expected task forces are no greater than twice those required for the demonstration [17]. More generally, the outcome of this project was an algorithm for identifying families of grasps or manipulation plans that are $X\%$ as good as a human demonstration.

Figure 8: We have also developed an algorithm to synthesize grasps of unknown objects by matching surface shape features to hand shape features. Offline, the user creates a database of hand poses. Online, a user or a program loads a query—a three-dimensional model of the object to be grasped. The system searches the database to find the hand pose to best match the query. (Left) Representative hand poses for this example are shown in the middle of the figure. The poses displayed are from a grasp of a mouse, a jelly jar, and a lightbulb (left to right). Unacceptable grasps are pruned from consideration and the best grasps are chosen using a quality metric tailored to the desired task. (Right) Clustered results for grasps of a mouthwash bottle using a coke bottle pose.
Figure 9: (Row 1) People consistently use non-prehensile manipulation strategies such as prerotating an object prior to grasping [9]. (Row 2) One reason for the use of this strategy is that prerotation (left) results in a “more comfortable” (lower energy) grasping posture than when prerotation is not permitted (right). (Rows 3 and 4) A second reason is that prerotation (left) allows a standard grasp to be used for many initial configurations of the object, whereas many different grasps must be used when prerotation is not permitted (right). (Rows 5 and 6) Our planner can employ a similar prerotation strategy to decrease energy requirements and to increase the workspace over which a well tuned grasp can be used.
Figure 10: Optimization of human motion. (Top) Results from our reduced complexity formulation of the optimization problem for human motion [10]. (Bottom) We can reduce the dimensionality of the problem by exploring only the subspace of motion represented by a set of captured human motion examples [26].

NSF ECS-0325383 (Pollard, with colleagues)
October 2003 – September 2009
$1,466,666

**ITR: Using Humanoids to Understand Humans**

Under this grant, we are performing human subjects experiments to study human grasping and manipulation activities with a goal toward creating more dexterous robots. In particular, we are exploring non-prehensile manipulation strategies such as that shown in Figure 9 ([9, 8]). Graduate students Jiaxin Fu and Lillian Chang have been partially supported by this grant.

NSF IIS-0205224 (Pollard, with colleagues)
September 2002 – August 2004
$522,000

**ITR: Providing Intuitive Access to Human Motion Databases**

NSF IIS-0326322 (Pollard, with colleagues)
March 2004 – February 2009
$1,406,000

**ITR: Collaborative Research: Indexing, Retrieval, and Use of Large Motion Databases**

Under these related grants, we have performed a series of user studies to characterize user perception of errors in animated ballistic motion [23, 22] to evaluate expected performance of an animated character for a behavior definition provided as a “motion graph” [24, 25], and to develop better algorithms for responsive characters [15]. Also under these grants, we have developed fast techniques for physically based optimization of full-body human motion [10] [26] (also see Figure 10). This work has resulted in five SIGGRAPH publications to date ([23, 10, 26, 15, 16]). Two PhD students (Paul Reitsma and James McCann) have been partially supported by these grants.

NSF CNS-0423546 (Pollard, with Matsuoka)
September 2004 – August 2007
$206,249
RR: Collaborative Research Resources: Learning from Human Hands to Control Dexterous Robot Hands

This equipment grant has been used to acquire the robot hand shown in Figure 1, allowing us to begin to move our research out of simulation and onto robot hardware, as shown in Figure 9.

NSF CCF-0702443 (Pollard)
June 2007 – May 2010
$325,000

CCF: Capturing and Animating the Human Hand: Robust Recovery of Hand-Object Interactions

Under this grant, we are continuing to develop robust algorithms for capturing human hand motions from motion capture data [4, 6, 5, 7]. We are also exploring techniques for direct, interactive control of physically based simulation and optimization of hand motion in close contact with a manipulated object [12]. One student (Lillian Chang) is partially supported by this grant.

7 Education and Mentoring

Many of the research projects described in this proposal are accessible to undergraduates and the prospect of using advanced (and “cool looking”) robotics hardware and pursuing research projects such as dexterous manipulation is inspiring and motivates students who might otherwise not have gotten involved to pursue their own independent research projects. We typically have three or more undergraduates working in the graphics lab, host additional undergraduates during the summers, and expect to continue to support an undergraduate team through REU funding and the Computing Research Association Distributed Mentoring program established for women undergraduates.