Chapter 10
Classifying Human Hand Use and the Activities of Daily Living

Aaron M. Dollar

Abstract Humans use their hands for a large variety of tasks during daily life. In this chapter, a discussion of human hand use is presented, including classification schemes for grasping and manipulation behaviors. First, a simple classification of the Activities of Daily Living (ADLs) is presented, providing some structure to a terminology that is typically used in an ad hoc manner. Next, an overview of work related to classifications and taxonomies of static grasp types is presented, followed by a study investigating the frequency of use of various grasp types by a housekeeper and machinist. Finally, a taxonomy classifying hand-based manipulation is presented, providing a hand-centric and motion-centric categorization of hand use. These descriptions and classifications of hand use should prove useful to researchers interested in robotic manipulation, prosthetics, rehabilitation, and biomechanics.

Keywords Grasping · Manipulation · Activities of daily living · Robotics · Taxonomy

1 Introduction

Due to the complexity of the human hand and the immense variability in tasks that we use our hands for on a day-to-day basis, there has long been a desire for classification schemes to categorize these activities and the hand postures/movements

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A. M. Dollar (✉)
Department of Mechanical Engineering and Materials Science, Yale University,
New Haven CT 06511, USA
e-mail: aaron.dollar@yale.edu

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utilized in executing them. Initially, this interest was primarily centered in fields such as biomechanics, hand surgery, and rehabilitation [1–4]. With the advent of robotics into manufacturing tasks, the study of hand function received new life as researchers began to investigate human hands in order to shed light on the design and control of robotic end effectors.

In this chapter, I describe a few classification schemes related to hand use in everyday environments and tasks that should be useful to researchers interested in human manipulation, hand biomechanics, prosthesis and robotic end-effector design, and rehabilitation. In Sect. 2, I present a simple sub-classification of the Activities of Daily Living (ADLs) [5, 6] for the application of robotics in human environments, putting forth a standard categorization that allows robotic tasks to be discussed in terms of the analogous human tasks and their hierarchal classifications. While this is by no means an exhaustive classification, it does provide some structure to terminology that is primarily used in an ad hoc manner.

In Sect. 3, I briefly review the fairly deep literature related to grasp classification, with sub-categorizations according to the static placement of the fingers during power and precision grasps (instead of the movements of the fingers and hand during manipulation movements). This short section is followed by a description of a preliminary experimental examination (Sect. 4) of the frequency with which various grasp types are used in daily tasks, focusing on two subjects: a housemaid and a machinist. For each of these subjects, 4 h of video from a head-mounted camera is analyzed to determine how frequent each grasp type is used and for how long. For each subject, on the order of three thousand distinct grasp changes are observed over the 4 h period, a statistic indicative of the variability and frequency of hand use in human living.

Finally, in Sect. 5, I present a classification of hand and finger motions during in-hand manipulation tasks, focusing on the nature of the motion of the hand/fingers as well as contact with external objects. This taxonomy is hand- and movement-centric in nature (as opposed to object- and force-centric, for instance), and is some of the first extensive work on a topic that is sure to receive more attention as robotic and prosthetic hands become more dexterous.

In order to keep the tone of this chapter as an overview of hand classification, many of the details are not presented in substantial depth. Instead, the reader is asked to refer to the original publications [7–9] for a more extensive description of related work, details on experimental methodology, or in-depth description of the classifications presented here.

2 Activities of Daily Living

Many fields related to occupational therapy, rehabilitation, and gerontology use the term "ADLs" in evaluating the ability of a patient to perform self-maintenance and other daily tasks crucial for unassisted living [5, 6, 10–14]. The term is generally used broadly and qualitatively. Many different sub-categories of the ADLs have

Table 1 Activities of daily living

Domestic activities of daily living (DADLs)	
DADL1	Food preparation
DADL2	Housekeeping
DADL3	Laundry
DADL4	Telephone/computer/technology use
DADL5	Office tasks/writing
DADL6	Hobby/sport
Extradomestic activities of daily living (EADLs)	
EADL1	Transportation/driving
EADL2	Shopping
EADL3	Employment-related tasks/tool use
Physical self-maintenance (PSM)	
PSM1	Feeding/medicating
PSM2	Toileting
PSM3	Bathing
PSM4	Dressing
PSM5	Grooming
PSM6	Ambulation/transfer

been proposed to classify an individual's level of independence, including Physical Self-Maintenance (PSM) [10], ADLs [5], Instrumental Activities of Daily Living (IADLs) [12, 13], and mobility [12], among others. These categorizations of the ADLs were primarily developed to be used by a physician or occupational therapist to assist evaluation of human performance in daily tasks and determine, for instance, whether admission into a nursing home is justified for an elderly or disabled person.

Table 1 presents a new sub-classification of ADLs (drawn primarily from [11, 14]) designed for use with the application of robotics in domestic and work environments. These sub-categories are deemed "Domestic Activities of Daily Living (DADLs)", "Extradomestic Activities of Daily Living (EADLs)", and "PSM". In prior work, we discussed a variety of "Objects of Daily Living," putting forth a collection of objects identified as important from a number of sources related to prosthetics, rehabilitation, and robotics [7].

The first and cardinal category, "DADLs," contains subtasks spanning those regularly performed in human living environments. The majority of efforts related to assistive robotics focus on tasks in this category, particularly in Housekeeping and Food Preparation [15–17]. Typical approaches for assistance in this area consist as devices not intended to be utilized for tasks outside of this category. Exceptions, however, include work related to robotic wheelchairs and wheelchair-mounted manipulator arms (e.g. [18, 19]), which are frequently used outside of the home.

The second category, "EADLs," contains activities and tasks performed primarily outside of the home. Note that housekeeping activities, technology use, and office tasks are classified primarily as DADLs, even though they are often performed as employment-related tasks. Aside from wheelchairs and related technologies, robotics applications for these areas include driver assists (e.g. [20]) and cooperative robots for manufacturing tasks (e.g. [21, 22]).

Assistance with tasks related to the final category, "PSM," is one of the most important areas of need in assisted-living and hospital environments. However, this application generally requires physical contact between the robot and human and is sufficiently challenging such that many tasks will not likely be tractable in the near future. Exceptions include Feeding/Medicating, which have been assisted by wheel-chair mounted arms, as well as robotic orthoses [23] and prosthetics (e.g. [24]) for assistance during Ambulation/Transfer.

3 Human Grasp Classification

The first major attempt to organize human grasping behavior into distinct categories was by Schlesinger in 1919, which categorized grasps into six types: cylindrical, tip, hook, palmar, spherical, and lateral [2]. These grasps are primarily defined by the object that the hand interacts with. However, human grasps are often less dictated by size and shape of the object, but more by the tasks that need to be accomplished. In 1956, Napier suggested a scheme that would divide grasps into power and precision grasps [1]. Unfortunately not all the grasps fell cleanly into either of these two categories, with the lateral pinch in particular serving both power and precision functions.

In studying the grasps required for manufacturing tasks, Cutkosky in 1989 provided a much more comprehensive and detailed organization of human grasps (Fig. 1) [25]. This taxonomy was acquired through a set of observational surveys on professional machinists and is essentially an integration of the previous work done by Schlesinger and Napier. The taxonomy tree is organized such that it is first divided into power and precision grasps from left to right, and by task and geometry detail (precision) down the tree. A small number of successive taxonomies, built primarily from the Cutkosky taxonomy, have been proposed since (a comprehensive overview can be found in [26]).

A recent effort has resulted in what the author views as the most complete grasp taxonomy to date (Fig. 2) [26]. In this work, grasp types are organized primarily according to power, precision, and intermediate types, with sub-categorizations according to thumb position (abducted or adducted), and finger/palm contact type (palm, finger pad, and finger side). This work identifies 33 independent grasp types, which includes the 16 grasps from Cutkosky's taxonomy [25].

4 Grasp Frequency in Household and Machine Shop Tasks

Though there have been a number of efforts focused on classifying types of human grasps, no previous studies have examined the frequency of these grasps as they

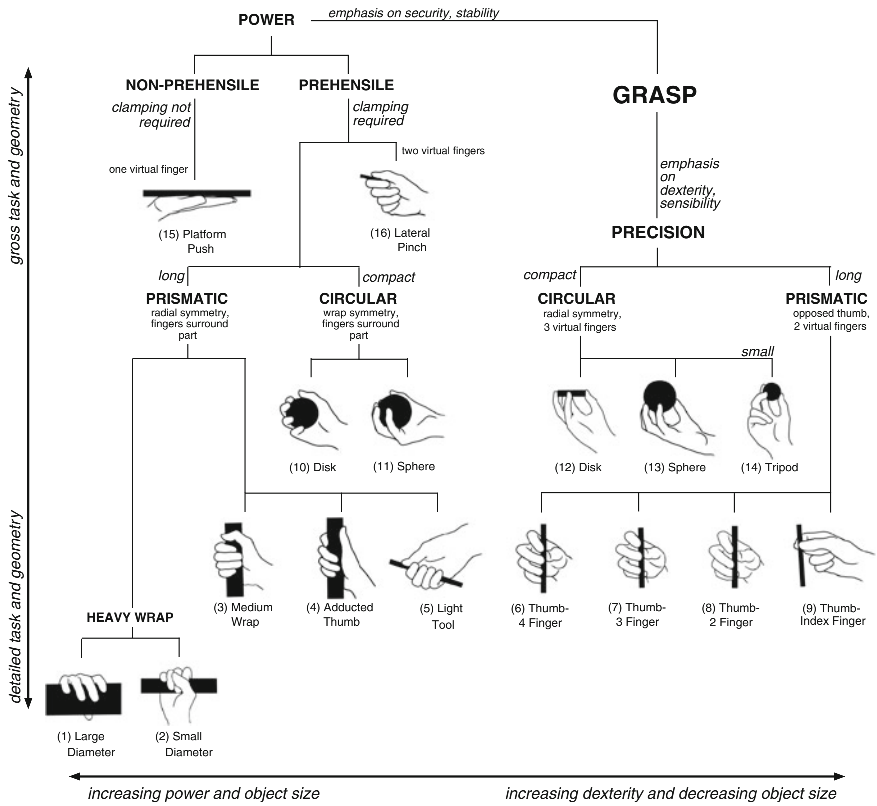

Fig. 1 Cutkosky grasp taxonomy. Adapted from [25]

are used in various settings. The frequency data is important as it will further clarify the relationship between task requirements and the various grasp types. Furthermore, it might serve to establish a sort of "prioritization" of grasp types according to the most frequently used in the examined daily activities. This is important to motivate the practical robotic and prosthetic hand design tradeoffs between complexity and performance. We begin by describing the experimental methodology, including details on the subjects used, apparatus, and protocol. We then present the results for two subjects, a professional housekeeper and a professional machinist, identifying the frequency of grasp type use for each. The complete version of this study is presented in [8].

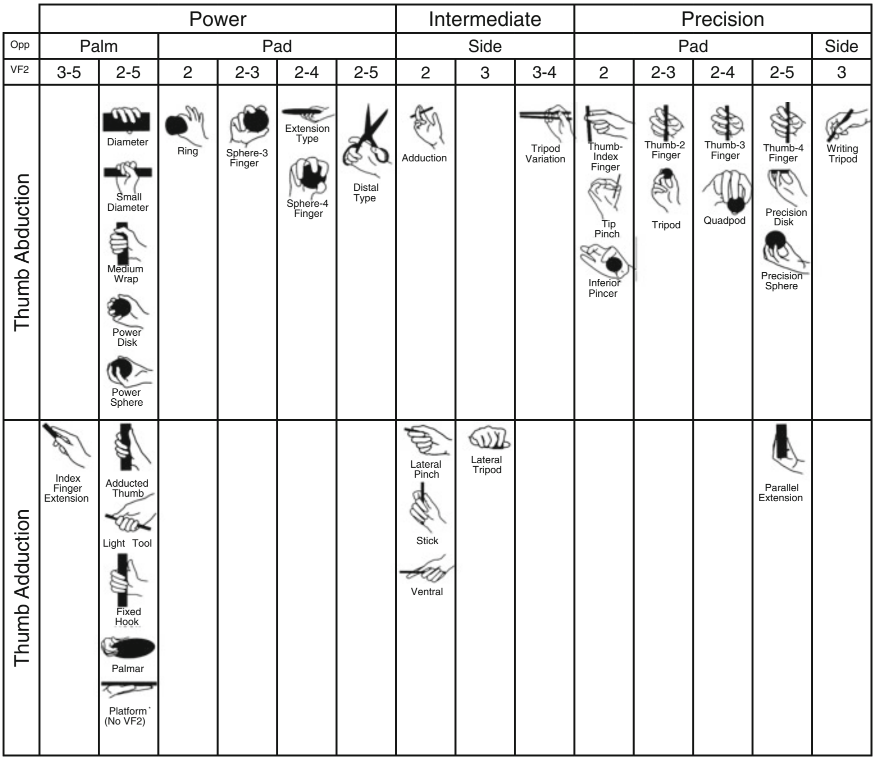

Fig. 2 Modified Feix grasp taxonomy [26]. Note that a few names are used from the Cutkosky taxonomy, such as for the thumb-n finger grasps. The platform grasp from the Cutkosky taxonomy is shown, although it does not have a second virtual finger

4.1 Experimental Procedure and Apparatus

Two subjects participated in the study presented in this section. The first, a 41 year old right-handed male, was a professional machinist who had worked in his profession for more than 20 years. The second, a 30 year old right-handed female, was a full-time house maid who had been working in that capacity for over 5 years. Neither subject had any injury or disability that would alter their grasping and manipulation ability from what would be expected as typical for their profession.

A total of at least 4 h of hand usage was analyzed for each subject, over multiple days. The days and times of recording were carefully chosen according to the subject's feedback such that there would be a wide range of tasks representative of the span of the job requirements performed throughout the total 4 h. Therefore, days and times for which the subject was performing a small number of tasks repetitively were not included.

The video hardware consisted of a tube camera with a wide-angle fisheye lens (2.5 mm, ~140° field of view) attached to a three-band head strap taken from a hiker's lamp. This setup allows the camera to rest on the subject's head without being intrusive or uncomfortable. The camera is connected to a mini digital video recorder and an external battery pack. Both the receiver and battery pack are worn in the back pocket of the subject. The setup is able to acquire video of sufficient quality for manual grasp classification. The overhead view was chosen after informal testing showed this to be the most useful for our purposes as it shows the entire workspace of both left and right arms in front of the body as well as enough of the surroundings to give the context of the grasps in addition to the grasp itself.

4.2 Results

The results below show the analysis of 4 h of video for each of the two subjects—house maid and machinist. During the 4 h analyzed, the subjects were performing a wide range of tasks associated with the regular demands of their profession. All data was manually recorded by a researcher trained in human grasp classification. The researcher went through the video and when the user changed their grasp (either acquiring a new object or releasing an existing object), the grasp type (according to the Cutkosky [25] and Feix taxonomies [25]), object and task being performed, and the time stamp associated with the change was recorded. Only the right (dominant) hand was examined in the present study. Approximately 2,500 and 2,000 grasp changes were made during the 4 h period by the house maid and machinist, respectively. The complete results can be found in [8].

Figure 3 shows the frequency data from the house maid (left) and machinist (right), with labels for all grasp types occurring at least 2 % of the time. Grasps followed by numbers in parentheses correspond to those identified in the Cutkosky taxonomy (Fig. 1) [25]. Unnumbered grasp types are labeled according to the terminology utilized in [26]. Figure 4 shows sample screen captures for the three most common grasps utilized by the house maid (top–medium wrap, index finger extension, and power sphere) and machinist (bottom–lateral pinch, light tool, and tripod) during the 4 h analyzed.

4.3 Discussion

From the results summarized in Fig. 3, it can be seen that only a small number of grasp types comprise the majority of those used. For the house maid, nearly 80 % of the time was spent utilizing six grasp types: medium wrap, index finger extension,

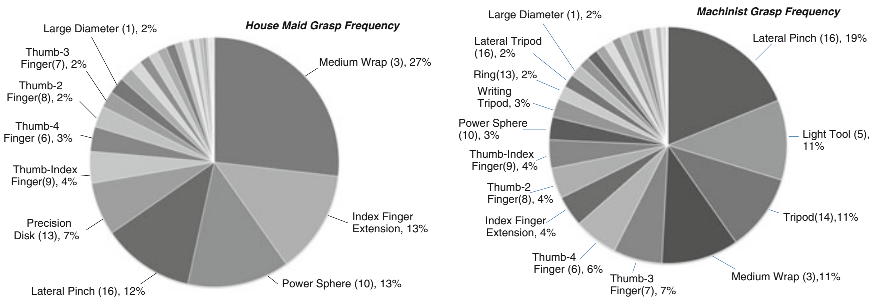

Fig. 3 Grasp frequency results for the House Maid (*left*) and Machinist (*right*), showing 4 h of work. Grasps occurring less than 2 % of the time are not labeled. The 'no grasp' case is not shown here

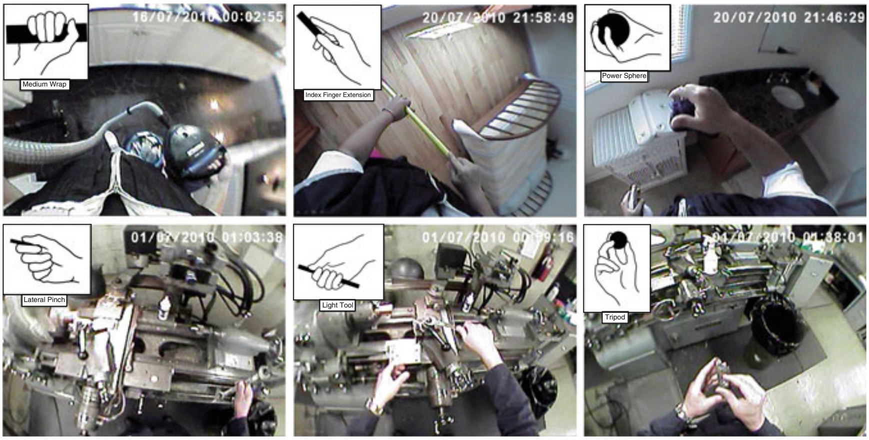

Fig. 4 Video stills from the House Maid (*top*) and Machinist (*bottom*) experiments showing the three most commonly-used grasps and example tasks performed using them

power sphere, lateral pinch, precision disk, and thumb-index finger. Nearly 80 % of the machinist's time grasping utilized nine grasps: lateral pinch, light tool, tripod, medium wrap, thumb-3, thumb-4, index finger extension, thumb-2, and thumb-index. Note that all 16 grasps identified in [25] occurred in both subjects' data, with the 'power disk' occurring least. However, two grasps frequently utilized by the subjects (index finger extension and writing tripod, >3 % for both subjects) are not represented in the Cutkosky taxonomy. It is also interesting to note that the house maid primarily used power grasps while the machinist used a balance of both. Furthermore, the machinist switched grasps more often (∼2,500 in 4 h vs. ∼2,000).

One particularly interesting question that was raised during our analysis related to how to classify grasps of non-rigid objects. The house maid in particular often used a rag or other cloth to wipe down surfaces for cleaning. We have classified these grasps primarily as ‘power sphere’, based on the observation that the subject utilized all five fingers in the grasp. However, a new subset of grasp types for compliant objects might be developed.

While 4 h is a fairly large amount of grasping data (>2,000 grasps per subject), these results will, of course, change to some extent based upon the specific subject being examined. Future work will involve completing the 8 h of video analysis for these two subjects, as well as investigating grasp behavior for additional professions that may be of interest to robotics, such as food preparation, machine maintenance, and others.

5 Human Manipulation Classification

This section presents a taxonomy for detailed classification of human and anthropomorphic manipulation behavior. This hand-centric, motion-centric taxonomy differentiates tasks based on criteria such as object contact, prehension, and the nature of object motion relative to a hand frame. A sub-classification of the most dexterous categories, within-hand manipulation, is also presented, based on the principal axis of object rotation or translation in the hand frame. Principles for categorizing complex, multi-faceted tasks are also presented, along with illustrative examples. Although illustrated with human hands, the taxonomy can easily be applied to any robot manipulator or end-effector. (Note that a more extensive version of this section can be found in [9].)

While the authors were unable to find any extensive classifications that differentiate the full range of human manipulation behaviors from one another, a number of related works should be mentioned. Elliott and Connolly described three general classes of within-hand (intrinsic) manipulation movements: simple synergies, reciprocal synergies, and sequential patterns [27]. In simple synergies, all digits involved move as one unit, such as while pinching or squeezing. In complex synergies, the fingers move together, but the thumb moves independently. In sequential patterns, the digits move independently in a repeatable sequence. Exner’s classification [28] has been used fairly extensively in clinical settings, classifying within-hand manipulation into five categories: palm-to-finger translation, finger-to-palm translation, shift, simple rotation, and complex rotation. Gentile [29] proposes a task classification scheme based on environmental context and function of the action. It differentiates tasks according to whether it is being performed in addition to basic body stability or body transport motions.

A much different but related classification is the taxonomy of haptic disassembly tasks [30], which classifies tasks according to task type and type of force or torque required. The force classification differentiates between tasks where the force is aligned with the motion, such as pressing a button, and those where the force is not aligned, such as sanding a surface. Torque is differentiated by whether the torque axis passes through the grip space, expressing the difference between turning a screwdriver and a steering wheel.

Other work has used the term *manipulation primitives* to describe the steps used in a specific algorithm or by a specific robot, but work by Morris and Haynes [31] describes a more general definition based on motion in six possible degrees of freedom between two rigid bodies. Morrow and Khosla [32] later improved on the notation used and described a general architecture for executing manipulation task primitives based on sensorimotor primitives defined based on a specific robot. These efforts focus on object motions and degrees of freedom and therefore differ substantially from the current hand-centric taxonomy.

5.1 Human Manipulation Classification

Figure 5 presents our manipulation taxonomy (with terms defined in Fig. 6). Note that in creating this classification, we take a hand-centric view of the problem, as opposed to an object-centric view. The taxonomy therefore focuses on what the hand is doing during execution of the manipulation task, rather than how the object being contacted is moving during the task. As a result of this classification, a given movement of an object can be done from multiple locations on the tree (e.g. a low-friction knob could be turned with a single finger as a non-prehensile task, or with multiple fingers as a prehensile task). Object-centric classifications might be made in a manner similar to [32] described above. Note that this is also a motion-centric view of manipulation tasks, as opposed to a force-centric view (such as [30], as described above). However, the two are related by the Jacobian of the manipulator so that motions can occur in directions in which forces can be applied and vice versa. Tasks in which force is applied normal to the major direction of motion (e.g. writing on a board) would be considered two distinct simultaneous tasks, decomposed in a manner outlined in Sect. 5.1.2.

5.1.1 Further Sub-Categorization

Using the existing categorization criteria for the taxonomy, certain further sub-categories might be added depending on the specific application of the taxonomy. For example, for each sub-categorization that includes motion of the object, more specific details of the nature of that motion can be added. These motions might be broken up by rotations or translations about some fixed frame, as is presented for dexterous within hand manipulation in Sect. 5.2, or with regards to how many degrees of freedom in which the object can be actively manipulated in (similar to [32]). Alternatively, some type of classification related to the force, similar to [30], might be made.

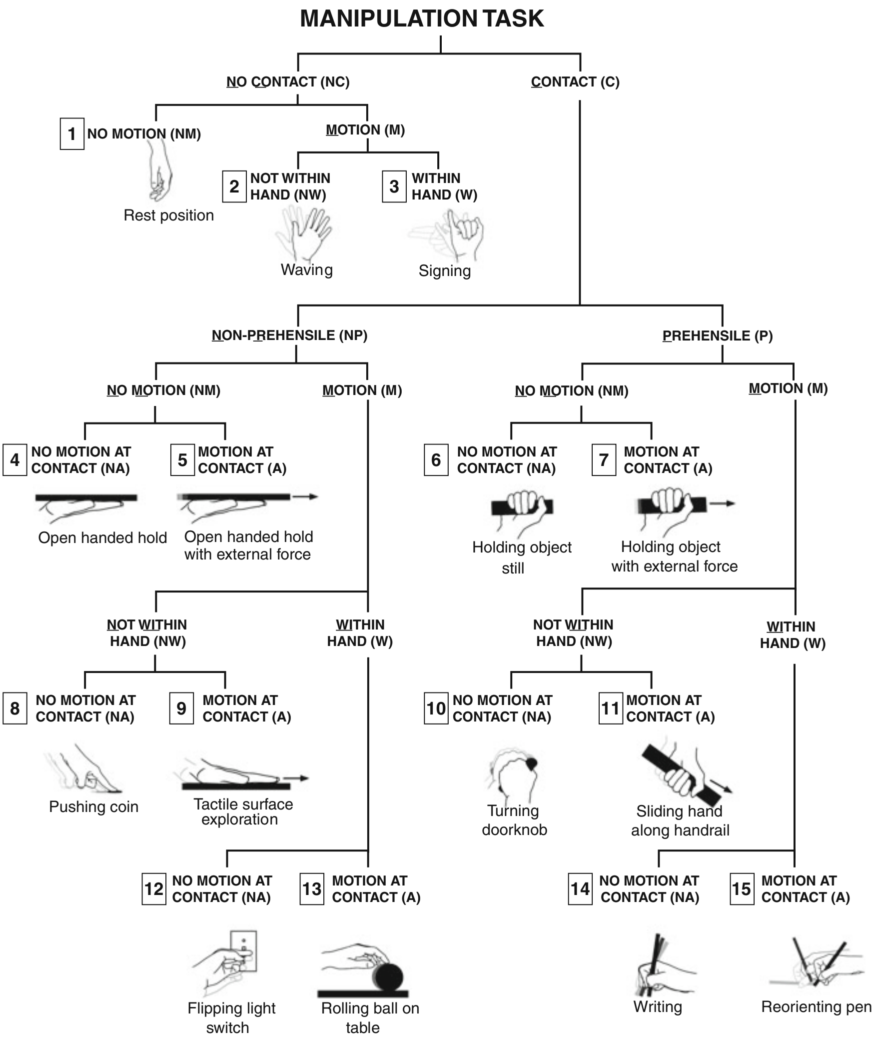

Fig. 5 Manipulation taxonomy. Any type of human or robotic manipulation task can be classified according to this taxonomy regardless of hand morphology. Example tasks are given for each leaf of the tree

5.1.2 Classifying Complex Tasks

The taxonomy above provides a structured way of classifying relatively simple tasks. More complex tasks have less obvious categorizations. There are three major types of complex manipulation tasks that require further discussion as to their categorization: time-separated sequences, simultaneous bi-manual tasks, and simultaneous within-hand tasks.

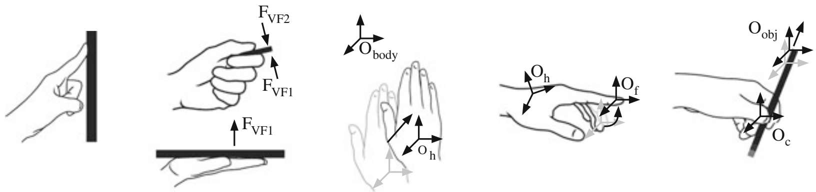

Fig. 6 Explanation of important terms in the manipulation taxonomy

Time-separated motions, such as a long sequence of movements to accomplish an overall goal, should be classified as the sum of the discrete sub-components of the manipulation process. For instance, picking up a pen and writing with it might be decomposed into three sub-tasks: lifting the pen from the table (prehensile/motion/not within hand), rotating the pen into the writing position (prehensile/motion/within hand/motion at contact), and writing with it (prehensile/motion/within hand/no motion at contact).

Bi-manual tasks, where both hands are in use and *required* to perform the task, would be defined by the individual tasks being performed by each hand. Simultaneous use of the hands to perform independent tasks should not be considered ‘bi-manual’.

Tasks where the hand performs two or more simultaneous functions (e.g. pulling a hand drill trigger, thumb-typing on smartphone, using calipers, writing on a chalkboard, etc.) are some of the most dexterous tasks regularly performed. We propose that these types of tasks should be treated as the sum of the distinct sub-tasks being performed. For example, the task of pulling the trigger on a power drill could be categorized as a prehensile, no motion task (grasping and holding the drill handle) combined with a non-prehensile/motion/within hand task (index finger compressing the trigger). Thumb-typing on a cell phone would be similarly considered as the sum of a prehensile, no motion task (holding the phone with the palm and fingers) combined with a non-prehensile/motion/within hand task (thumb pressing the keys). Writing on a chalkboard, where a force is being applied to the board (to maintain contact) and the chalk is being moved along the surface of the board would be considered as the sum of two prehensile/motion/within hand tasks, as applying force to the board and moving the chalk both require actuation in each direction.

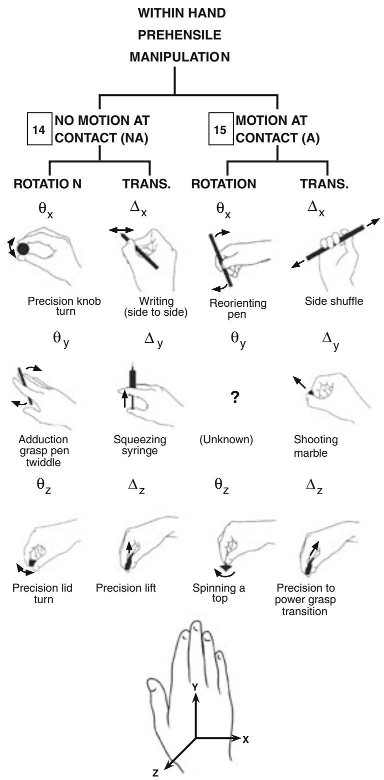

Fig. 7 Dexterous subclassification. Tasks are classified by rotations and translations along hand coordinate axes (*bottom*)

5.2 Dexterous, Within Hand Manipulation

The term "dexterous manipulation" is used frequently in the robotics community, but no widely accepted definition exists. Perhaps the most common use, however, refers to manipulations that would be categorized as prehensile, within hand manipulation according to the taxonomy presented above. Indeed, there is great interest in the field to impart greater dexterity to robotic and prosthetic hands in the form of "within hand" manipulation capability. Figure 7 shows the dexterous manipulation taxonomy. We sub-categorize the movements according to the axis about which the movement is primarily concentrated, with respect to a coordinate frame affixed to the back of the hand. Each movement subcategory ("no motion at contact" and "motion at contact") is therefore expanded to three rotational and three translational movements with respect to this coordinate frame (plus some positional offset).

Due to constraints imposed by hand kinematics, it is unlikely that any movement would precisely align with the fixed coordinate frame axes. Instead, these are intended to be approximate. For movements that are significantly askew from these axes, a linear combination of cardinal movements might be used to describe the task.

Based on the constraints inherent with human hand kinematics, it is difficult to affect dexterous translational movements in the x-direction or rotational movements about the y-axis. Indeed, there are few identifiable common dexterous manipulation tasks for those axes.

5.3 Conclusions and Future Work

This section provides a hand- and motion-centric categorization of human manipulation that might be applied in various ways. For example, the proposed classification scheme might enable better understanding of human hand use by emphasizing hand-centric differences between tasks that might appear similar if only object motion is considered. In some cases, a similar range of object motion might be accomplished through a "not within hand" or "within hand" strategy, with significant differences in the required hand dexterity. This might be used, for example, to help identify hand intensive tasks that a patient recovering from a hand injury should do carefully or sparingly.

The taxonomy might also guide the creation of a set of standard manipulation tasks for each leaf of the tree. This kind of set should include the most frequent tasks that humans perform, and span a wide variety of practical hand motions. Although creating a complete set may be difficult or impossible, even an incomplete set might be a powerful tool for evaluating manipulation performance. This standard set could be used to evaluate a human patient's manipulation ability or chart their progress during use of rehabilitative devices, or to compare the dexterity of robot hands. In either case, performance on the standard task set could be used to assign an overall dexterity score to a hand, providing a structured basis for comparing hand performance.

6 Overall Conclusion

In this chapter I presented an overview of work useful for classifying human hand use. These areas included a very brief overview of high-level tasks in the ADL—an area which would be appropriate for future additional categorization, both at the high level and low level. Next I described various work on grasp taxonomies, which have had a fairly extensive treatment in the literature. Following this, I presented a summary of some results on grasp use during daily activities, categorizing grasp use for 4 h of a professional housekeeper and a professional machinist. Finally, I presented a classification of within-hand, dexterous manipulation, from a hand-centric and motion-centric perspective. While the enormous range of uses of the human hand make it difficult to capture the whole range of function in a succinct format, I believe the work here represents a sufficient means of classification for much of the most important uses. However, there is of course much room for improvement and follow-on to these areas.

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