Benchmarking dexterous dual-arm/hand robotic manipulation

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Extended Abstract

Introduction

DEXMART is a European large-scale integrating project (IP) funded in the Seventh Framework Programme. The acronym stands for *DEXterous and autonomous dual-arm/hand robotic manipulation with sMART sensory-motor skills: A bridge from natural to artificial cognition*. The project is focused on artificial systems reproducing smart sensory-motor human skills, which operate in unstructured real-world environments. The emphasis is on manipulation capabilities achieved by dexterous and autonomous, and also human aware dual arm/hand robotic systems. The challenge is to allow a dual-arm robot including two multi-fingered redundant hands to grasp and manipulate the same objects used by human beings. The objects shall be allowed to have different shape, dimension, and weight.

As compared to research and development on humanoid robots in Asia, the focus in Europe is rather on useful service tasks than pure social entertainment. Applications of robot companions range from a helper in family homes to executing tasks in offices, public environments and in professional services. Another important application area is the assistance to elderly and mobility-impaired persons that could be helped to achieve some independence from full time caring personnel. For this scenario the robot has to reach almost the same manipulation skills as a human being. The realisation of a truly dexterous and autonomous dual-arm/hand manipulation system is still an open research issue: bimanual manipulation is such a complex task combining different strategies, constraints, goals, advanced sensing and actuating technologies, requiring new concepts and design of artificial cognitive systems.

In this context the question is raised how to measure and evaluate the progress of one's own research and how to compare the results with others. This is especially difficult if one wishes to evaluate the performance of real, physical, intelligent robot systems interacting with the real world.

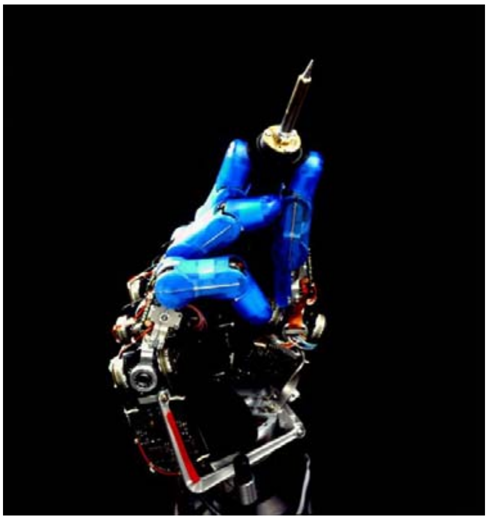


Figure 1 One arm/hand grasping

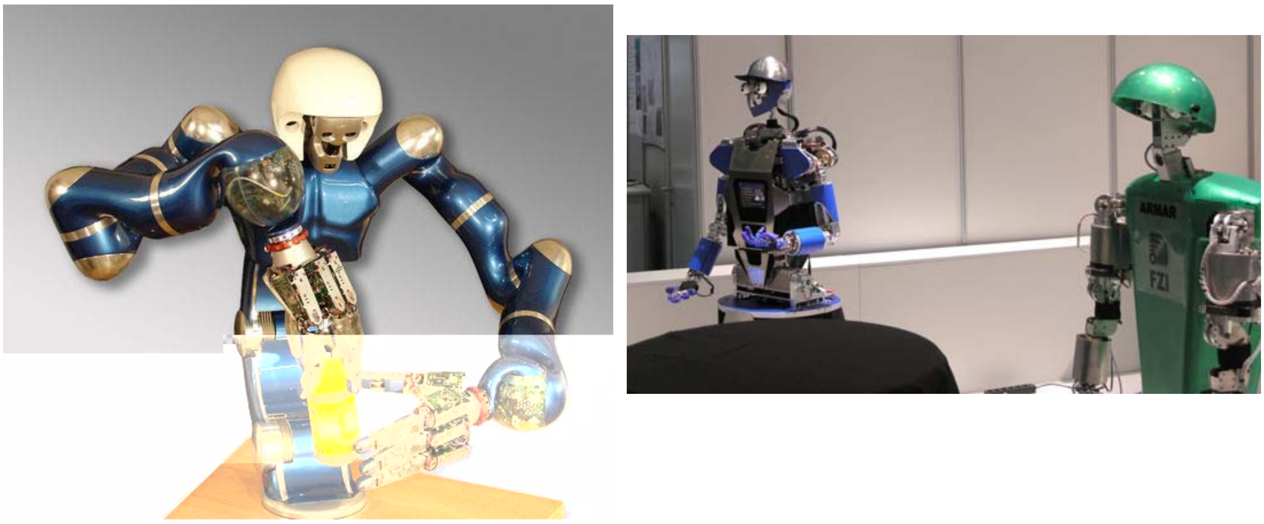
Robot grasps an object

In order to exemplify the difficulty to evaluate the performance we take a closer look to the details that influence the success of this “simple” robot activity. Obviously there are multiple factors. The following non exhaustive list refers to some of these factors:

- Performance of the robot arm: The numbers of DoFs, size of workspace, kinematic structure and the positioning accuracy have a direct impact on the performance of the arm.
- Performance of the hand: The numbers of (articulated) fingers, their DoFs and the kinematic structure of the hand have a direct impact on the grasping performance itself. The more fingers the more robust is the grip but also the more difficult is the control.
- Are the robots and hands equipped with sensors? i.e. internal or external F/T-Sensors, artificial skins, … Sensor information provide feedback to the system and also to the robot and hand control system. Sensor data will increase the robustness but also the control efforts.
- (Sensor-based) Control of robot, hand, robot and hand, robot and hand and mobile platform. Are these components closely or loosely coupled?
- Planning systems: Even this simple task requires some planning capabilities. Does the system have a (collision free) path-planner and a grasp planner?
- Is the task executed in a static or a dynamic environment. The latter will induce a much higher complexity.
- Grasping an object requires some perceptive capabilities. The robot/hand has to know the location and shape of the object. The performance of the perception will heavily depend on the used sensor systems:
    - Mono, stereo camera
    - 3D sensors i.e. PMD, Swiss Ranger, …
    - Coverage
    - Lightening conditions
    - …
- When the robot is grasping the object it interacts with the real world. So the object’s size, weight, shape (compact, lengthy, (a)symmetrical), and form (solid, soft) has a direct impact on the grasp.

In DEXMART one focus is on bimanual grasping. So if one is using a dual arm/hand robot grasping an object there will be additional chances for a successful operation. The system has additional redundancies. I.e. the robot may grasp the object with the left hand/arm or the right hand/arm or even with two hands/arms. It may use all fingers or just a minimum set or something in-between. Generally spoken, there is an almost unlimited number of components (hardware, software, environment) which influence the success of the task “grasping an object”.

A further focus in DEXMART is going beyond “grasping” towards dual-arm/hand “manipulation”. This increases the number and complexity of the topics listed above. The problem space and the grade of difficulty seems to explode.



Justin humanoid manipulator (DLR) ARMAR 2 and 3 - Karlsruhe humanoid robots (FZI)

Figure 2: Two arm/hand robot systems

If one wants to measure or evaluate the performance of bimanual manipulation tasks, two opposing approaches can be applied in principle:

1. Evaluate the performance of system as a whole
2. Evaluate the single components of the system

Both approaches have pros and cons. The first approach is the simplest one as you just run the system and measure binary success or failure. The drawback is the performance of the entire system is not better than the performance of the worst component of the robot system, which one doesn’t know. But it is then known that the system is really able to perform the task. The second approach requires very much effort to measure the performance of all the involved components. Then you have a detailed knowledge on the strength and weakness of the system. However the interaction of the components to build a uniform robotic system is not measured and success of a task cannot be guaranteed.

The term “benchmark” is defined as a standardized problem or test that serves as a basis for evaluation or comparison. So both approaches can be taken into account. A bimanual grasping benchmark should be designed in such a way that it can be applied for different robots and hands. A practical solution could be an extensive multi-layered benchmark, which addresses all or at least the most important relevant performance indicators. Ideally a reasonable task can be performed if the component tests are executed in sequence.

Capability of manipulation

DEXMART is focused among others on the capability of manipulation. For the development of an appropriate benchmark, we decided to start with an analysis on the important aspects for bimanual manipulation.

Cutkosky and Howe have specified a well known grasp taxonomy for a single hand grasp. The grasp hierarchy offers a classification scheme for typical grasps occurring in manufacturing tasks. The taxonomy only covers single handed grasps and does not regard temporal aspects. Dynamic Grasps are also considered and a classification of one handed dexterous dynamic manipulation was developed e.g. rolling an object between fingers, shifting an object in the hand.

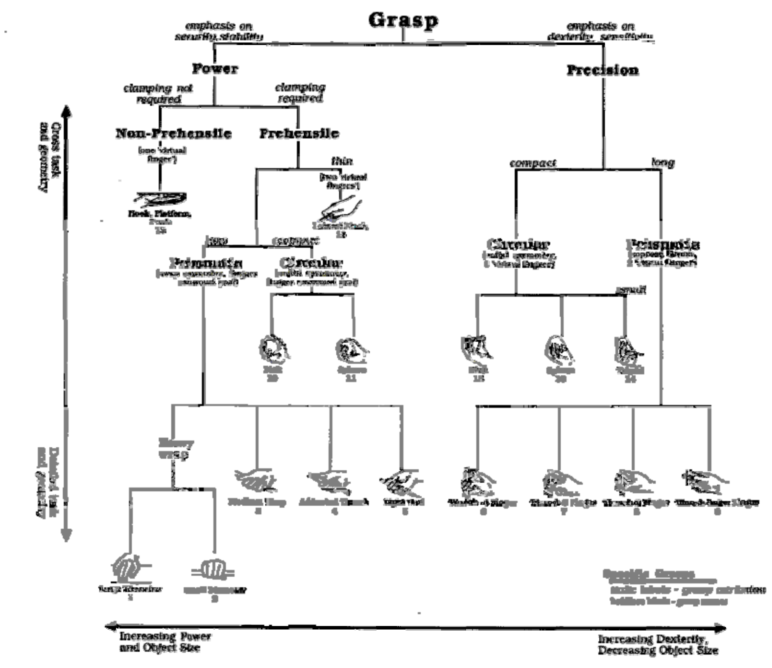


Figure 3 Cutkosky’s Grasp Hierarchy

In DEXMART, we decided to develop a bimanual grasp taxonomy similar to the single hand grasp taxonomy by Cutkosky and Howe. The taxonomy is envisioned to cover all dual handed operations. The analysis will help to identify benchmarks that cover most of the relevant issues. If it is not possible to find one convincing benchmark covering all aspects of the taxonomy a set of benchmarks should be defined.

Guiard 1987 is investigating the roles of two hands for the human. He categorizes the human everyday manual activities in three classes:

1. Some obviously asymmetric activities can be termed as unimanual (e.g., dart throwing, or brushing one's teeth);
2. activities are also markedly asymmetric but bimanual (think of differentiated bimanual activities such as opening a bottle or dealing cards);
3. There are activities that must be termed bimanual and symmetric, as the two hands play essentially the same role (e.g. lifting a large object). They are further subdivided by temporal aspects: a) In phase, e.g. weight lifting; b) Phase shifted, e.g. alternating turning of a screw; c) Asynchronous.

Another classification of the bimanual activities is based on the kinematics: a) Parallel, e.g. weight lifting; b) Orthogonal, e.g. two different objects; c) Serial, e.g. swinging a bat.

Bimanual grasp taxonomy

Some design guidelines are regarded for the bimanual grasp taxonomy. The first can be summarized as “form follows function” like propose by Napier and also Cutkosky and Howe:

- Human grasping and manipulation is goal directed. The performed action is directed by the results the human wants to achieve.
- For the definition of a bimanual grasp taxonomy prototypical manipulation tasks have to be identified which differ in their function and in their “execution behaviour”.

Hereby the following aspects of function and form are of special interest in DEXMART:

- Function: Profile of applied forces, compliance profile, start and stop conditions
- Form: Arm configuration – Hand configuration
  Grasp Shape – Power vs. Precision Grasp
- How do kinematic constraints affect the arm configuration?
- Temporal aspects at least what is the start and the end condition

The latter two bullets are not address by Cutkosky. The second design guideline addresses the technical aspects

- Form – Function
  - Application of small / large forces influence the grasp shape (Power Grasp vs. Precision Grasp)
  - Size of the objects influence the hand/arm configuration
  - Compliance of the objects (soft or rigid) influence the configuration
- Control
  - Different grasp and manipulation tasks might require different control schemes for properly executing the task.
  - Same grasp and manipulation tasks might be properly executed by different control schemes.

Same grasp and manipulation tasks might be executed in different order. Explore parallelism of execution with right and left hand

Moving/solving Rubicks Cube

Pouring water into a glass

Balancing a box

Opening of a screw cap

Inserting a battery into a drilling machine

Empty a trash bin

Figure 4 Sample Manipulations

Figure 4 shows some sample manipulation activities, which are the basis for the first version of the bimanual grasp taxonomy in DEXMART.

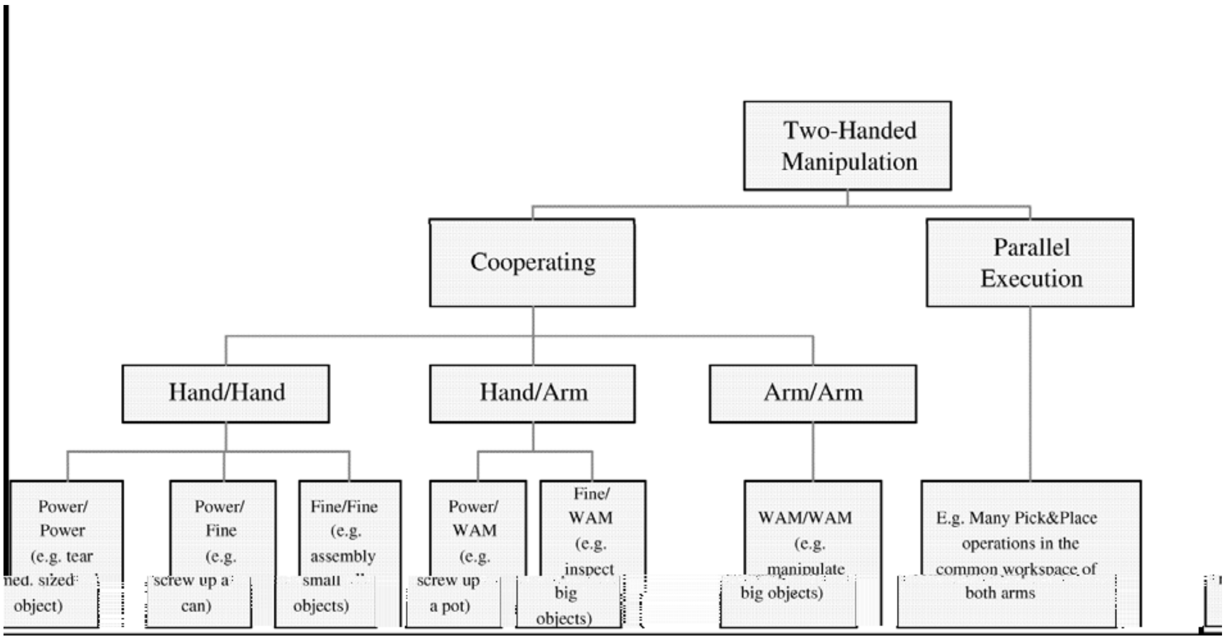


Figure 5 Bimanual Grasp Taxonomy

This taxonomy represents the static case similar to Cutkosky's hierarchy. It is not finalized as some additional aspects are not well covered yet. They address the following topics:

- Temporal conditions / parallel execution of two operations (single hand grasp)
- 2 Force-/ Form-Closed Grasp vs. 1 Dual Handed Force- /Form-Closed Grasp.
- Single handed operation with small support of the second hand.
- Reorient objects with the help of the other hand.

The inclusion of dynamic aspects in the bimanual taxonomy is very difficult and it seems also to be very complex. In DEXMART a first very preliminary structure was developed, which is presented here for the sake of completeness.

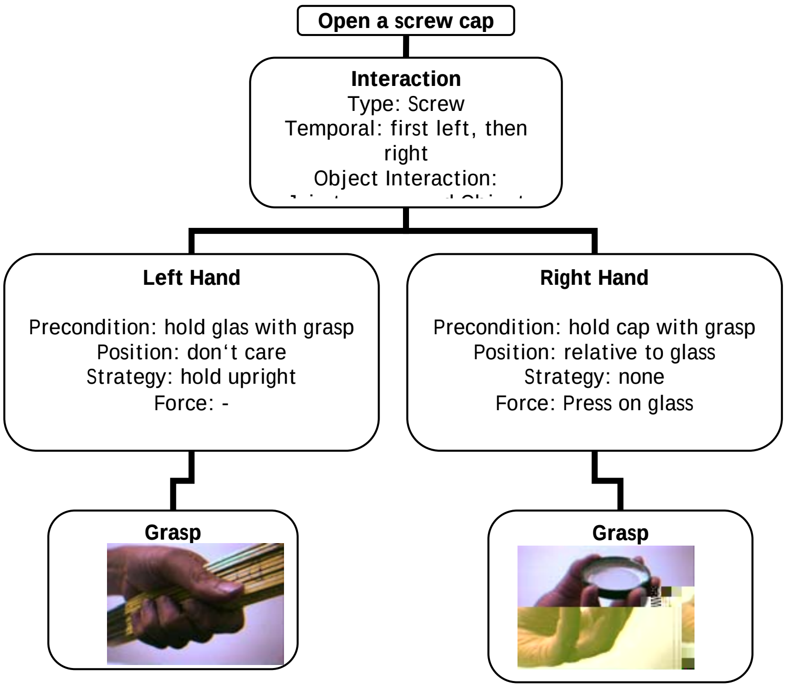


Figure 6 Bimanual manipulation Taxonomy

Based on the taxonomy we will derive a manipulation benchmark. This step is not yet terminated. But according our schedule in DEXMART we will have a first version ready to the Workshop in September.

Remark: Coordination with project partners necessary before publishing the preliminary results in a workshop.

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