Experiments on Grasp Acquisition

Thomas Wimböck*, Berthold Bäuml*, Jeff Trinkle† and Gerd Hirzinger*
*Institute of Robotics and Mechatronics, German Aerospace Center (DLR), Germany, Email: thomas.wimboeck@dlr.de
† CS Robotics Lab, Rensselaer Polytechnic Institute (RPI), USA

***Abstract*— Grasping and manipulation skills are key aspects for service robots. We present our initial work on the dynamic grasp acquisition (DGA) problem, which is characterized by a large relative velocity between the palm of the hand and the object at the time the fingers begin closing to form the grasp. These kinds of problems are particularly demanding for the hardware and software systems, and so were chosen to help us explore the limits of DLR's humanoid robot, Justin. We conducted two types of DGA experiments: catching a tossed ball and "snatching" an object at rest on a table. The experimental set-ups are discussed and relevant performance measures for these DGA tasks are proposed.**

I. INTRODUCTION

We present initial work on dynamic grasp acquisition (DGA) tasks, which, due to the required speed of execution, poses significant challenges to robotic systems. By the term *dynamic grasp acquisition*, we imply that the relative velocity between the wrist and the object is not zero while the fingers are approaching and grasping the object. The success of this type of grasping can be facilitated by dynamic behavior of the manipulator. In the case of catching a ball an optimization is used. In this way the maximum performance of the robotic system is reached to accomplish a medium-complexity task with known *playing rules*, that is, to catch a ball that is thrown within a specified range in the workspace of the robot. At DLR this application was used to push the robot to the limits of its performance to help identify mechatronic subsystems that should be improved.

Two experimental set-ups are presented and performance measures for the given tasks are proposed: first, catching a thrown ball, and second, "snatching" an object from a table.

II. DYNAMIC GRASP ACQUISITION: BALL CATCHING

Catching a thrown ball with a hand requires very good coordination of the hardware, control, planning and visual sensing to obtain the necessary precision in space and time. Because of this, ball catching has been used for almost 20 years now as a challenging benchmark to develop and test key robotics technologies [1]–[6]. In all these works the general set-up is similar: a stereo vision system tracks the ball and predicts its trajectory, then the time of interception and the hand's pose at this time is determined. Next, the robot configuration to reach the catch pose is computed and finally a path that brings the robot from its start configuration to the desired catch configuration is generated.

In this section we present a ball-catching set-up, which contains two major contributions. First, we use a dexterous multipurpose four-fingered hand (DLR Hand-II [7]) to grasp the ball. This is challenging for the hardware and controllers, because the hand has to be able to close fast enough and has to be robust enough, so that the impact of the ball does not damage the highly complex mechatronic device. Moreover, this is also challenging for the planning algorithms for the arm movements, because the position and orientation of the hand relative to the ball trajectory has to be very precisely determined, to ensure that the ball does not hit (and damage) the fingers in a disadvantageous configuration. The second new aspect is that instead of using separate steps for catch point selection, catch configuration computation and path computation, we present an unified approach, which incorporates all three steps in a single nonlinear optimization problem. Note that in this work we focus on the proposal of performance measures for this application while the details on the implementation and the results can be found in [8].

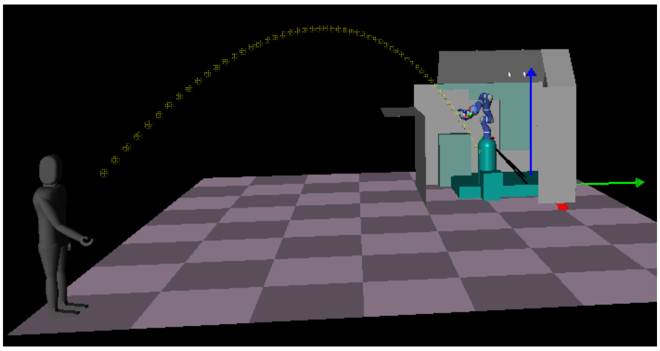

Fig. 1. Overall geometrical set-up (each tile of the floor is 1m x 1m). The ball is thrown by a human from a distance of about 5m toward the robot with a speed of about 7m/s, resulting in a flight time of about 1s.

A. System Architecture

Figure 1 shows the geometrical set-up,

The visual tracking system, based on stereo cameras (standard PAL with 50Hz half field rate), provides a new prediction of the ball trajectory every 20ms. Over 80% of the thrown balls are tracked successfully , but for each throw the predictions vary while the ball is flying and typically converges to the required precision of less than 2cm and 5ms only about 100ms before the catch time. Therefore, the decision where, when, and in which configuration to optimally catch the ball also has to be continuously adapted. We use a compute cluster with up to 32 CPU cores (Xeon, 2GHz) to solve the planning task (formulated as a nonlinear optimization problem) on-line (taking ¡ 60ms for replanning).

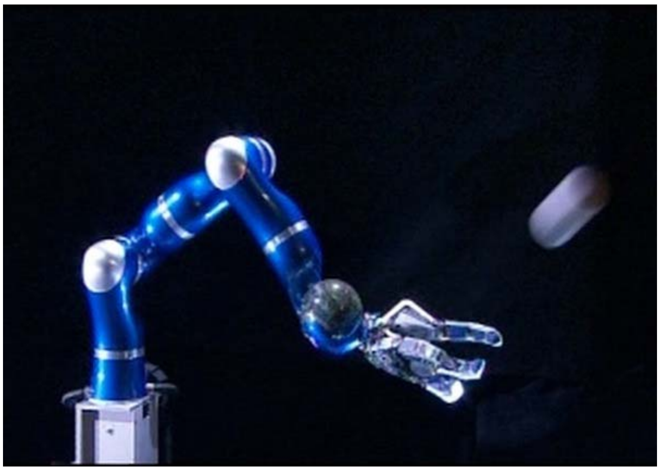

Fig. 2. DLR Hand II mounted on the DLR light-weight robot III (LWR) used to catch flying balls.

The robot system (a subsystem of the humanoid, Justin) is composed of the DLR-LWR-III and the DLR-Hand II (see Fig. 2). The light weight arm has a remarkable load to weight ratio of 1 : 1 with a mass of 14 kg. The torque sensing is used on the one side for interaction with unstructured environments and humans, and on the other side, it is used to damp vibrations of the structure [9]. The hand has four fingers with 3 DOF each, resulting in 12 DOF for the hand. In addition to the position sensors, the link-side torques are measured as well. The control law runs on a Core2Duo, 3GHz with a controller sample time of 1 ms.

B. *Catching Results and Evaluation*

Before executing the experiments on the real hardware the kinematic solutions were verified using a virtual environment in which the computed trajectories were validated. During the experiments three different catching behaviors (i.e. different cost functions) were evaluated. For the analysis of the experiments, we recorded in particular the desired velocity profile, the measured joint velocities and torques. In order to demonstrate the large number of possible catch points, we recorded many experiments and stacked them together. Another important tool that we used to determine the performance was a off-the-shelf high speed camera. Running at 300 frames per second we were then able to see the dynamic ball motion within the hand, and to optimize the finger commands.

The task to catch a ball is well suited to measure the performance of online planning algorithms, since there is a direct relation to the likelihood of a successful catch. The time needed for the first solution for a trajectory and the time for a replanning step are the two crucial values. Secondary, to evaluate the planning algorithm it is interesting to determine how these measures scale with number of degrees of freedom of the robotic system or with the number of obstacles in the robot workspace. Since a trajectory is given to the control system, the interesting measure here is the accumulated tracking error of the arm to position the hand. An interesting measure for the hand are the forces that appear during and after the grasp. The most important value here is the maximum force that appears at the fingers, since large forces can damage the hardware. Furthermore, looking at the product of forces and velocities gives the generated power, which can be integrated over time to compute the overall work. For an even more precise measurement of how much work was spent for the task, the output of the power supply has to be monitored.

III. DYNAMIC GRASP ACQUISITION: OBJECT SNATCHING

Object snatching was examined with DLR's humanoid Justin [10]. In most grasping experiments, and what is taught in robotics text books, is that for picking up an object, the end-effector is moved to an approach position, then the fingers are moved to a pre-grasp shape, and then the fingers close around the object. Typically, robot systems pause for about one second at the end of each phase, and motions near the object are executed slowly to avoid accidentally displacing the object. In contrast, the DGA problem is about grasping the object while the palm moves rapidly. In the process, the palm and fingers exert forces on the object causing it to slide, tilt, or roll while the grasp is forming. The advantages of such a coordinated grasping action are that the execution time and energy losses are reduced, and the grasping action is more fluid and natural. The primary drawbacks are impact forces between the object and the hand, and the large computational effort for planning.

A. *Experimental set-up*

In Figure 3 the experimental set-up is presented. Justin is in front of the desk upon which a standard tube part is at rest. The task is to keep moving the arm while grasping the tube and lifting it up in one smooth motion without stops. For the evaluation of the experiments, we recorded the same data as in the previous section. Additionally, we recorded the output of the inertial measurement unit (IMU) mounted in Justin's head, the external torques estimated by an observer (to see the impact forces), and the rigid body trajectory of the object by means of a commercial visual tracking system (see the tracking markers mounted on top of the tube). Note that this latter measurement data is not used as feedback in the grasping controller. It is only recorded for post-processing and analyzing the experiments.

In contrast to the flying ball, the timing of the execution is not given by the task. The interesting measurement to evaluate how well the task is performed is certainly the execution time. The time is taken from the initial configuration to the moment when the arm stopped completely and the object is grasped. A crucial aspect in the DGA problem is that the object was grasped, however, due dynamic effects, the object was moved within the hand. Therefore, for a successful grasp of an object we should measure how much the final object pose relative to the wrist differs from an expected one. An alternative is to measure the grasp quality

Fig. 3. DLR's humanoid Justin in front of a table. The task is to dynamically grasp the tube on the table.

relative to a subsequent task (e.g., object insertion, hand-off, etc.).

REFERENCES

[1] B. Hove and J. Slotine, "Experiments in robotic catching," in *Proceedings of the 1991 American Control Conference*, 1991, pp. 380–385.

[2] W. Hong and J. Slotine, "Experiments in hand-eye coordination using active vision," in *Proceedings of the Fourth International Symposium on Experimental Robotics, ISER95*, 1995.

[3] K. Nishikawa, A. Konno, K. Nagashima, M. Inaba, and H. Inoue, "The humanoid saika that catches a thrown ball," in *Proceedings of the lEEE Intermtional Workshop on Robot and Human Communication*, 1997, pp. 94–99.

[4] U. Frese, B. Bäuml, S. Haidacher, G. Schreiber, I. Schaefer, M. Hähnle, and G. Hirzinger, "Off-the-shelf vision for a robotic ball catcher," in *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2001.

[5] M. Riley and C. G. Atkeson, "Robot catching: Towards engaging human-humanoid interaction," *Autonomous Robots*, vol. 12, pp. 119—128, 2002.

[6] C. Smith and H. I. Christensen, "Using cots to construct a high performance robot arm," in *IEEE International Conference on Robotics and Automation (ICRA)*, 2007.

[7] J. Butterfaß, M. Grebenstein, H. Liu, and G. Hirzinger, "DLR-Hand II: Next generation of a dextrous robot hand," in *Proceedings of the IEEE/RSJ International Conference Robotics and Automation (ICRA)*, 2001, pp. 109–114.

[8] B. Bäuml, T. Wimböck, and G. Hirzinger, "Kinematically optimal catching a flying ball with a hand-arm-system," in *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2010.

[9] A. Albu-Schäffer, O. Eiberger, M. Fuchs, M. Grebenstein, S. Haddadin, Ch. Ott, A. Stemmer, T. Wimböck, S. Wolf, and G. Hirzinger, "Anthropomorphic soft robotics - from torque control to variable intrinsic compliance," in *International Symposium on Robotics Research*, 2009.

[10] C. Borst, T. Wimböck, F. Schmidt, M. Fuchs, B. Brunner, F. Zacharias, P. R. Giordano, R. Konietschke, W. Sepp, S. Fuchs, C. Rink, A. Albu-Schäffer, and G. Hirzinger, "Rollin' justin: Mobile platform with variable base," in *Proceedings of the 2009 IEEE International Conference on Robotics and Automation (ICRA 2009)*, 2009, pp. 1597–1598.