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Chapter 1

Executive Summary

Deliverable 5.3.2 deals with the demonstrations in the context of WP5.3. It shows the execution of tightly coupled cooperative tasks, where cooperation takes place between two arms, two robots, or a robot and a human. It also shows the adaptation of the learned behaviour that take place in contact with the environment. Further, it shows how cooperative tasks are supported by resource-aware active visual perception. The deliverable is tightly connected to the research conducted in WP4.1 and also benefits from the theoretical work on motor representations conducted in WP2.2. Demonstrations are shown on the KIT and JSI robot platforms. Some of the applied approaches are described in deliverable **D2.2.1**.

The deliverable consist of videos demonstrating

- tightly-coupled physical interaction for cooperative manipulation tasks and movement adaptation when contact with the environment occurs, and
- cooperative perception supporting coupled manipulation tasks.

Chapter 2

Description of Results

2.1 Tightly-Coupled Physical Interaction

Tightly coupled cooperative task execution and adaptation of movements that take place in contact with the environment can be addressed with similar methods. The proposed approach is described in deliverable **D2.2.1**. In the first part of video **CoupledDMPs-LWR.mov** and in video **EnvironmentDMPs-Armar.mov** we show the adaptation of a movement encoded by a DMP that causes unexpected contact with the environment. Contact with the environment is crucial for many robotic tasks. It needs to be safe for both the robot and the environment, which consequently means that the forces should be kept low. We applied the algorithm described in deliverable **D2.2.1**, Section 2.4, to minimize the force upon impact with a table. The movement was repeated several times and adapted to minimize the contact force. The resulting forces are clearly reduced with each epoch, as shown in video **CoupledDMPs-LWR.mov**. Note that here it is crucial that the DMP was modulated with the measured force already in the first epoch, otherwise the resulting forces would be far greater and could damage the robot. The algorithm can be applied to produce a desired force of contact, as it is shown in the latter part of video **CoupledDMPs-LWR.mov**. The same experiment was performed both with Kuka LWR arm (see Fig. 2.1) and with Armar-III humanoid robot.

We applied a similar algorithm to couple two independently executed robot arm trajectories. One full sinusoidal wave was performed by the left robot arm, while the right arm was trained to move along a

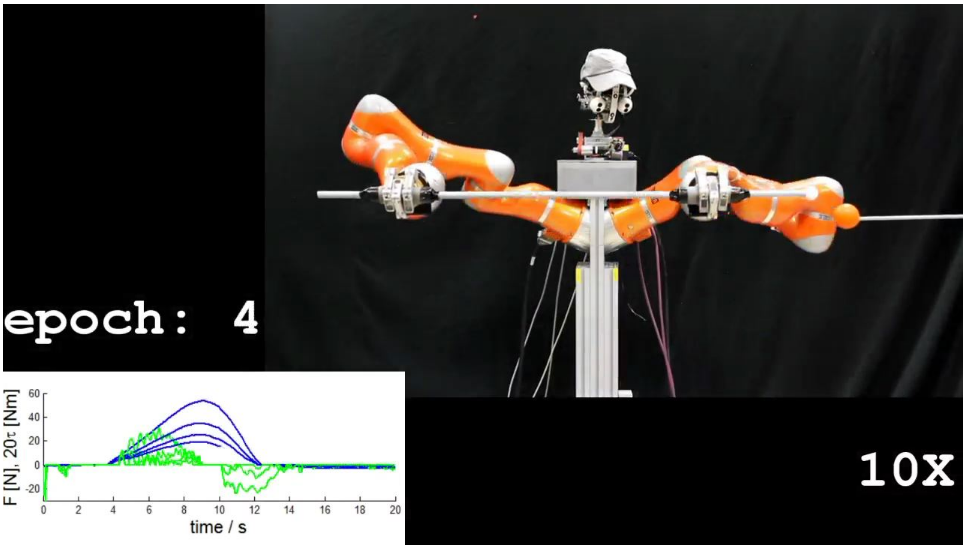

Figure 2.1: The lifting movements of the two arms were trained independently of each other. They are synchronised using force feedback and the adaptation technique described in deliverable **D2.2.1**. As the left arm avoids the obstacle, the avoidance movement is also transferred to the right arm. There is no central planning involved in the execution.

straight line. A stick was held by both hands. Different arm trajectories gave rise to a force acting on the hands. The second part of video **CoupledDMPs-LWR.mov** shows how right arm motion adapts to the left arm motion to minimize the force acting on the two hands. It also demonstrates successful obstacle avoidance. A similar experiment is shown in video **BimanualDMPs-Armar.mov**. Here the two arms movements were trained to move upwards with different velocities. The box was put between the two arms and lifted. The task was to keep the force between the two arms constant, but this is only possible if their movement is synchronized. The video shows that the proposed coupling algorithm successfully synchronizes the right arm movement to the left arm movement, causing both arm to move upwards in unison.

2.2 Cooperative Perception for Coupled Manipulation Tasks

In order to support cooperative tasks, it is necessary to implement methods for active visual perception which are 1) aware of the available resources and 2) able to share these resources with respect to the current cooperative task.

We established such a mechanism, which allows to configure the visual perceptual routines for a given task and employ the available resources with respect to the goal of the task. This mechanism has been demonstrated in a bimanual manipulation task where the goal consists in grasping two objects from a table using both robot arms (see Fig. 2.2). The task execution is supported by visual servoing techniques in order to increase the accuracy of the end-effector positioning. Consequently, the active visual system needs to observer overall four entities, both hands and both objects, in a continuous manipulation task. The spatial distribution of the entities necessitates the selection of appropriate gaze directions in order to allow visual recognition and localization of the entities. For this purpose we introduce a gaze selection mechanism based on a novel saliency measure - the *task acuity* - that allows to include accuracy requirements from the manipulation task in the saliency calculation.

The mechanism to this resource-aware gaze selection mechanism is demonstrated in video **GazeSelectionBimanual.avi**. The video shows the complete processing chain including 1) uncertain object

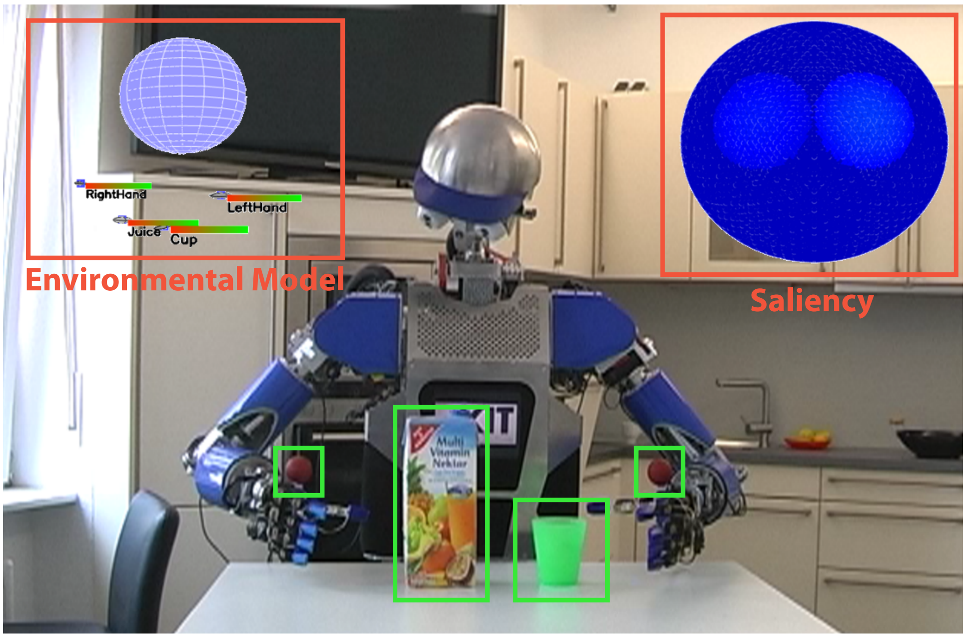

Figure 2.2: Bimanual manipulation necessitates the application of active gaze redirections in order to increase the observable area of the robot cameras. In the course of a bimanual grasping task, overall four objects need to be observed: both robot hands and both objects. In order to solve this gaze selection problem during manipulation we proposed a resource-aware mechanism which allows to include accuracy requirements in the gaze selection mechanism. The recognition results are fused in the environmental model. Based on the remaining uncertainties and the required accuracy of position estimates, the gaze selection mechanism determines gaze directions that guarantee successful task execution.

recognition and localization, 2) fusion in the environmental model, and 3) selection of the most suitable gaze direction based on the task acuity. Using an appropriate task acuity setting of about 10mm yields successful and reliable task execution while higher task acuities result in failure of the execution due to the insufficient accuracy of the position estimate of entities involved in the bimanual task.