

A humanoid upper body system for two-handed manipulation

Christoph Borst, Christian Ott, Thomas Wimböck, Bernhard Brunner, Franziska Zacharias, Berthold Bäuml, Ulrich Hillenbrand, Sami Haddadin, Alin Albu-Schäffer, and Gerd Hirzinger

Institute of Robotics and Mechatronics
German Aerospace Center (DLR)
Oberpfaffenhofen, 82234 Wessling, Germany
Email: {christoph.borst}@dlr.de

Abstract—This video presents a humanoid two-arm system developed as a research platform for studying dexterous two-handed manipulation. The system is based on the modular DLR-Lightweight-Robot-III and the DLR-Hand-II. Two arms and hands are combined with a three degrees-of-freedom movable torso and a visual system to form a *complete* humanoid upper body. The diversity of the system is demonstrated by showing the mechanical design, several control concepts, the application of rapid prototyping and hardware-in-the-loop (HIL) development as well as two-handed manipulation experiments and the integration of path planning capabilities.

I. DESIGN CONSIDERATIONS

The concept of our humanoid two-arm system "Justin"¹ (Fig. 1) is based on the modular 7-DoF DLR-Lightweight-Robot-III (DLR-LWR-III) [1] and the four-fingered DLR-Hand-II [2]. It is designed as a versatile platform for research on two-handed manipulation and service robotics in ordinary human environments. This work extends the manipulation capabilities demonstrated with the Robotler system [3].

For the mechanical design the following requirements have been taken into account: The system should be able to reach objects on the floor as well as objects on a shelf up to a height of about 2 m. It should have an anthropomorphic kinematic configuration for research on bi-manual grasping. The integration of link-side torque sensors in the joints has already proved very useful for the arm and the hand, and therefore was maintained throughout the system. Finally, a sensor head mounted on a 2-DoF pan-tilt-unit was integrated in order to allow for scene analysis based on stereo vision and laser range sensors [4], [5].

In particular, the modular concepts of the DLR-LWR-III and the DLR-Hand-II are exploited by building the two-handed system symmetrically with a right-handed and a left-handed sub-system.

Since in future versions the system will be integrated with a mobile platform, it was designed to be slim enough to pass standard doorways of about 90 cm width. The backward *seated* position allows for a lower center of gravity. This is useful to prevent tipping over in curves despite the overall weight of approximately 45 kg. Mounted on a 60 cm table or platform the torso reaches a *human-like* shoulder height of up

¹The system was named "Justin" because it was finished *just in time* for the *Automatica* fair 2006 in Munich.



Fig. 1. DLR's humanoid upper body system: Justin.

to 150 cm. Table I gives an overview of the 43 actuated DoF [6]. In the video, the mobility of the robot and its workspace are demonstrated.

Subsystem	Torso	Arms	Hands	Head & Neck	Σ
DoF	3	2 x 7	2 x 12	2	43

TABLE I
SYSTEM OVERVIEW

II. CONTROL DESIGN

The control of the humanoid manipulator is very challenging due to the large number of degrees of freedom and the resulting redundancy. Using joint-level control complex planning algorithms would be needed to accomplish given tasks. For intuitive operation and hence short development times, high-level control interfaces are needed. Even more important, for many tasks it is desirable to define an impedance behavior in task space. Therefore, flexible control laws are used that implement impedances on joint-level, on end-effector-level, and on object-level. The controllers are based on the well-known compliance control law and combine several suitable potential functions [6], [7].

The performance of the controllers is demonstrated by several experiments:

- Gravity-compensated mode showing coupling stiffness between the arms which can be moved freely in space.
- Three soccer balls are manipulated using the same control law as above.
- Emptying of a trash bin. A trash bin is picked up with both hands, moved around the workspace, and emptied. A *compatible* combination of coupling stiffness and world stiffness for the arms is selected. Human interaction during task execution is presented as well.
- Unscrewing of a can. The vision system based on [5] locates the can that is then opened using both hands. For the unscrewing of the can, an object-level control law that maps onto the hand as well as onto the arm is employed [7].
- Motion of a box and human interaction. The pose of the box is commanded on object-level. Note that the control law maps onto the whole kinematic structure including fingers, arms, and torso to hold the box.

In order to ensure safe physical human-robot interaction the disturbance observer suggested in [8] has been integrated. It is based only on the proprioceptive capabilities of the two-arm system and provides a filtered version of the external torque. This torque estimation is used as a scaling of time increments in the trajectory generation and allows the user to push the robot intuitively back and forth along its desired trajectory as demonstrated in the video.

III. SOFTWARE ARCHITECTURE

In order to test different concepts either on the control level or on higher levels of abstraction in a flexible manner, a new software architecture, the aRD-concept ("agile Robot Development"), was developed at our institute [9]. The aRD-concept is a flexible, pragmatic and distributed software concept designed to support the development of complex mechatronic and robotic systems. It gives easy access to scalable computing performance and is based on the abstract view of a robotic system as a decentral 'net of calculation blocks and communication links'. Using this concept, the classical, predominately monolithic control structure is dissolved into a fine-grained net of communicating modules. The individual modules can be run distributed on multiple processors. Even the execution across computer borders under strict real-time conditions is possible. The video shows how a simple application is programmed, transferred to the real robot and tested using our rapid prototyping environment (e. g. Matlab/Simulink, RTLab, and robot visualization).

IV. PERCEPTION, PATH PLANNING AND TASK-ORIENTED PROGRAMMING

The aRD software architecture enables the representation of control concepts as skills. With our task-oriented programming (TOP), the successor of the MARCO framework [10], the robot is commanded on a high level of abstraction by combining these skills to form complex tasks. Pick and Place operations as well as simple manipulation tasks such as unscrewing a can are intuitively represented and commanded.

Being designed for service robot tasks, Justin operates in the same environment as humans. In this context, perception of the current scene and task adaption are mandatory. Multiple objects can be recognized by computing robust pose statistics from stereo data points [5]. In the video, the task is to reach a tea can and to grasp it. Based on the current scene, goal positions that are beneficial for a path planner can be autonomously computed using the approach presented in [11]. A path planner [12] is connected to the task-oriented programming software using aRD and computes a path to the goal taking into account all obstacles in the scene. The path execution is then initiated and supervised by the TOP.

REFERENCES

- [1] G. Hirzinger, N. Sporer, A. Albu-Schäffer, M. Hähle, R. Krenn, A. Pascucci, and M. Schedl, "DLR's torque-controlled light weight robot III - are we reaching the technological limits now?" in *IEEE International Conference on Robotics and Automation*, 2002, pp. 1710–1716.
- [2] J. Butterfaß, M. Grebenstein, H. Liu, and G. Hirzinger, "DLR-Hand II: Next generation of a dextrous robot hand," in *IEEE International Conference on Robotics and Automation*, 2001.
- [3] U. Hillenbrand, Ch. Ott, B. Brunner, C. Borst, and G. Hirzinger, "Towards service robots for the human environment: the robotler," in *Mechatronics and Robotics (MECHROB)*, 2004, pp. 1497–1502.
- [4] M. Suppa, S. Kielhöfer, J. Langwald, F. Hacker, K. Strobl, and G. Hirzinger, "The 3d-modeller: A multi-purpose vision platform," in *accepted for ICRA 2007*.
- [5] U. Hillenbrand, "Consistent parameter clustering: Definition and analysis," in *Pattern Recognition Letters, to be published*.
- [6] Ch. Ott, O. Eiberger, W. Friedl, B. Bäuml, U. Hillenbrand, Ch. Borst, A. Albu-Schäffer, B. Brunner, H. Hirschmüller, S. Kielhöfer, R. Konietzke, M. Suppa, T. Wimböck, F. Zacharias, and G. Hirzinger, "A humanoid two-arm system for dexterous manipulation," in *IEEE-RAS International Conference on Humanoid Robots*, Genova/Italy, 2006, pp. 276–283.
- [7] T. Wimböck, Ch. Ott, and G. Hirzinger, "Impedance behaviors for two-handed manipulation: Design and experiments," in *accepted for ICRA 2007*.
- [8] A. D. Luca, A. Albu-Schäffer, S. Haddadin, and G. Hirzinger, "Collision Detection and Safe Reaction with the DLR-III Lightweight Manipulator Arm," *IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 1623–1630, 2006.
- [9] B. Bäuml and G. Hirzinger, "Agile robot development (ard): A pragmatic approach to robotic software," in *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2006, pp. 3741–3748.
- [10] B. Brunner, K. Landzettel, G. Schreiber, B. Steinmetz, and G. Hirzinger, "A universal task level ground control and programming system for space robot applications - the MARCO concept and it's application to the ETS VII project," in *Proc. of the 5th iSAIRAS International Symposium on Artificial Intelligence, Robotics, and Automation in Space*, 1999, pp. 507–514.
- [11] F. Zacharias, C. Borst, and G. Hirzinger, "Bridging the gap between path planning and task planning," in *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2006, pp. 4490–4495.
- [12] B. Baginski, "Motion planning for manipulators with many degrees of freedom - the bb-method," Ph.D. dissertation, TU Muenchen, August 1998.