

## Reference ID

### MAN-MACHINE-INTERACTION AND CO-OPERATION FOR MOBILE AND ASSISTING ROBOTS

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#### ABSTRACT

In this contribution we present three robot assistants built at the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA): The production assistant rob@work assists workers doing fetch and carry tasks and participates in manual arc welding. The robotic home assistant Care-O-bot<sup>®</sup> II supports elderly and handicapped people in their living environment. The cooperation work station team@work enables a worker to co-operate with the robot in a common workspace.

Beside the hardware architecture of the system, emphasis is placed on the manner of co-operation between man and robot. Furthermore the needed sensor system and motion control is described.

#### INTRODUCTION

Until today the "partnership" between humans and machine opposes a not eliminated lack: the machine misses a "minimum intelligence" enabling a "co-operation" at all.

The interaction with assistance systems and in particular with artificial mechatronic assistants represents one of the large technical challenges for the next decades. This co-operation and interaction manifest themselves not only in the dialog between humans and machine, but also in the autonomous or part-autonomous practice of forces by the machine on the common work space or on humans. Humans are thus not only addressee of information, but possibly also the target of physical forces. This aspect lends its own quality to the man-machine-interaction. In particular the interaction between humans and machine, who are able to move independently and to change their or its environments physically, involves not only perception and communication, but also planning and co-ordination both mutual and common movements and actions.

The central scientific questions, raised by the interaction and co-operation of humans and machine in form of an autonomous or part-autonomous robot assistant, are examined in three different applications:

#### *Interactive assistant in manufacturing: production assistant*

In many manufacturing processes humans cannot be supported so far or only by high-specialised machines. The use of robots is still limited to little complex functions like precise, fast, but always similar movements. Automated guided vehicles are still too inflexible regarding modification of the task and of the environment. Their interactions with humans are limited to stopping/power-off in case of threatening collision. Due to the lack of intelligence in today's systems, in particular regarding to their interaction abilities, humans are still employed for monotonous and/or exhausting activities, which can be dangerous to health in extreme cases.

Regarding the increase of productivity and humanisation of workstations a new quality in the improvement of manufacturing processes can be obtained by mobile assistance systems, also called production assistants. They complete the tasks in interaction with humans; they do not replace humans, but support them. Humans take on setting, monitoring and instruction tasks. In cases, in which the machine does not "know" how to go on, the human will intervene for guidance and further instructions. Humans and machines are partners in the work-participating manufacturing process.

An example for this kind of production assistant is the robot assistant rob@work.

#### *Interactive assistant for household and maintenance*

Future technical systems offer support in the daily life as well as guidance to selfinitiative. Visions assume that we all will use intelligent anthropomorphic assistance systems as mass products in our daily surroundings for multiple activities. These systems with multimedia interface, handling lever and grip arm fulfil all requests to technologically and economically fastidious mass products with substantial mid- to long-term market potential. First exemplary represented system concepts acknowledge this.

The assistant for household and maintenance is to enable a handicapped user to execute a number of elementary activities

without other assistance. The robot assistant will be inserted predominantly into existing domestic environments with small technical modifications and used by untrained or handicapped persons. The direct contact to humans as well as the demand for situation-suitable reaction and adaptability of the system are in the focal point.

The Fraunhofer IPA has developed a second robot assistant called Care-O-bot II that fits in this category.

**Interactive assistant for assembly tasks**

Especially the small appliances industry (electrical tools, household appliances) feel the pressure of the market to decrease costs and to increase varieties. This leads to a situation in production that is characterised by

- Small and varying production batches
- Small and varying quantities
- Many product variants
- Complex production processes
- Short product lifecycles

The required flexibility cannot be achieved by the existing automation solutions due to their product specific layout. Thus these products are manually assembled in spite of high labour costs. Nevertheless automation offers the highest rationalisation potential, even under the difficult circumstances. Efforts are being made to enable human and robots to work together in the same workspace.

At the Fraunhofer IPA a robot cell called team@work has been developed, where man and robot can share one assembly task.

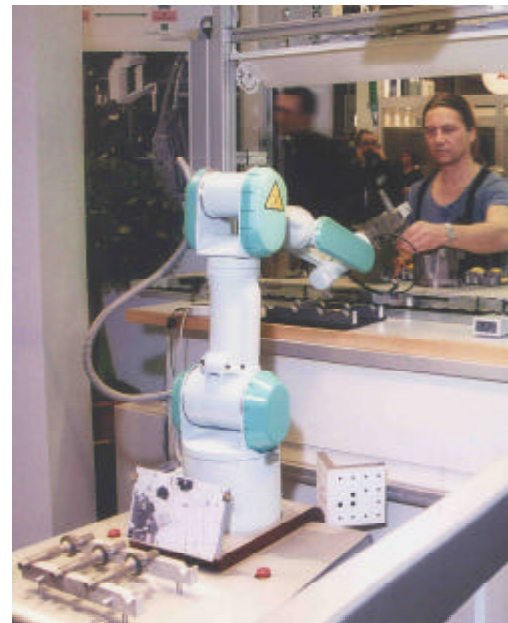
**ROBOT ASSISTANT ROB@WORK**

Robot assistance supports manual workplaces, the most flexible “work systems”, by distribution of labour between robot and worker. The sensory skills, the knowledge and the skilfulness of the worker are combined with the advantages of the robot (e.g. strength, endurance, speed, accuracy) to an enhanced work system (Figure 1). In areas like assembly or welding, where many tasks are carried out manually, robot assistants lead to increased competitiveness.



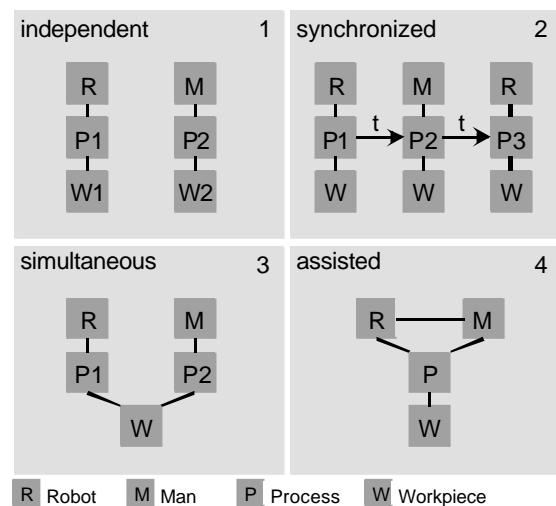
**Figure 1.** Motivation for robot assistants

The robot assistant rob@work stands for a vision of an easy to use intelligent helper for manual work places. Through the combination of a mobile and automatic navigating platform with a manipulator, rob@work fetches and carries objects, supports in grasping, holding and lifting objects and assists in complex production processes like welding or bonding.



**Figure 2.** Robot assistant rob@work at Hannover Trade Fair

Four types of co-operation between man and robot assistant are defined (Figure 3). The first type of co-operation is defined as independent operation. Worker and robot operate independently on different work pieces. This is the standard case for today’s industrial robots. A smooth transition represents the synchronised co-operation (2). Worker and robot operate consecutively on one work piece. They are still separated, even though this workplace could be designed more efficiently [SPINGLER02].

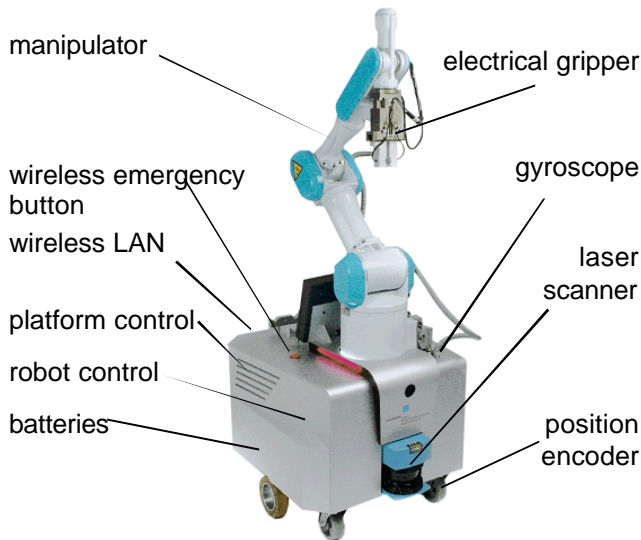


**Figure 3.** Different types of human robot co-operation

The next step toward co-operation is the operation on a common work piece (3). Robot and worker do not have physical contact. Closest co-operation occurs, if not only the same work piece is machined, but also the process is done by robot and worker together (4). This assisted co-operation applies to rob@work for the assistance of manual arc welding (see below).

**Hardware Architecture**

The robot assistant rob@work, developed by Fraunhofer IPA, consists of a 7-DOF-manipulator and a non-holonomic platform [GENROB01, HELMS02].



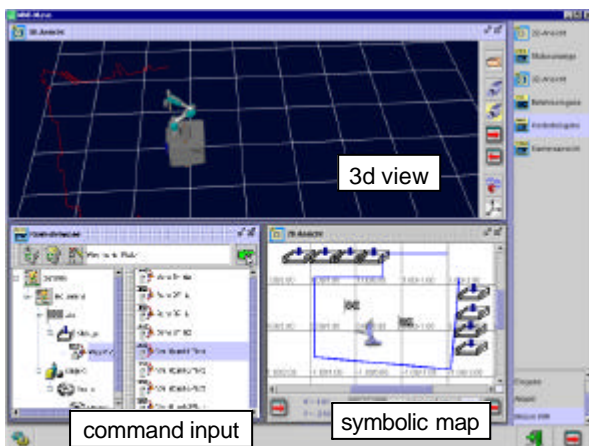
**Figure 4.** Hardware architecture of rob@work

The robot assistant is connected to the man-machine-interface over a wireless LAN and has a wireless emergency stop. The platform contains the platform control, the robot control and a car battery-like power supply, enabling the system to operate 12 hours.

The position of the platform is determined with position encoders at the wheels and a gyroscope measuring the orientation. This is assisted by a laser scanner also needed for safety and navigation.

**Man-Machine-Interface**

An important module of the robot assistant is the man-machine-interface. The component has to combine several different input types (speech, gestures, command selection, etc.) and output mechanisms (3D world model, sensor information, planned action, etc.). For this reason a special software architecture for robot operation has been built. A desktop-like surface presents different possibilities to load different in- and output modules.



**Figure 5.** Man Machine Interface (Screenshot)

Communication between these modules and the robot system has been realised with the communication technology CORBA. A central service to broke and manage data channels enables the simple replacement and extension of in- and output modules. It is also possible to connect more than one user interface to the robot system.

A component to fuse and separate information has been developed. The information of the input modules is semantically merged and sent to the CORBA interface. The separation module distributes incoming information to the involved output modules.

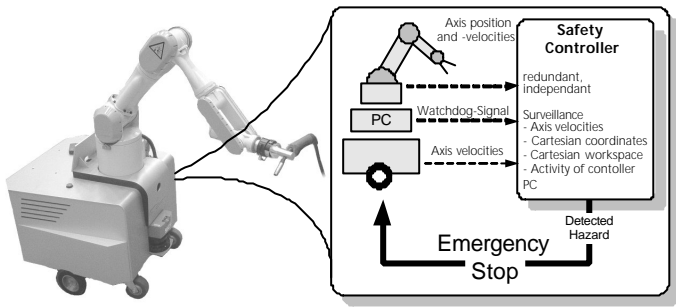
**Safety Considerations**

The safety of mobile manipulators is an important aspect of the idea of robot assistants. The following section shows our approach toward a safe robot assistant. Figure 1 shows a part of a risk analysis [EN1050]. Possible hazards are evaluated by a Risk-Category before ( $RC_1$ ) and after ( $RC_2$ ) an executed action. The Risk-Category consists of an estimation of the probability of occurrence, the possibility of avoidance and the severity of injury.

Hazard	$RC_1$	Action	$RC_2$
Collision platform-environment by malfunction of component	3	Detection and shut off of system (safety controller)	1
Collision manipulator-man by malfunction of element	3	Detection and shut off of system (safety controller) Limited velocities	1
Loss of workpiece	1	Limited velocities Limited weight of workpieces	1
Fall of stairs	3	Limitation of workspace through magnetic band	1
Collision manipulator-man during normal operation	2	Sensor surveillance Acoustic warnings Limited velocities	2

**Figure 6.** Risk assessment of fetch and carry task: major risks [MEYER03]

As seen in Figure 6 one of the actions to increase the safety of the robot assistant is the installation of a safety controller. Such a safety controller (SC) is currently being developed at Fraunhofer IPA and is shown in Figure 7. The SC is integrated in the emergency stop circuit of the system. The SC monitors important system values like axis values and velocities of the manipulator and the mobile platform, life signal from the controller hardware. Solutions for SCs for industrial robots meet Safety Class 3 [EN954] and are currently being implemented for several types of manipulators [ADAMS03].



**Figure 7.** Architecture of a safety controller for robot assistants [MEYER03]

**Robot Assistance to Assembly of Hydraulic Pumps**

An application that was realised with rob@work is the assembly of hydraulic pumps. Rob@work fetches shafts from their store and carries them to a manual workplace. Figure 5 shows the manual workplace which was the base for the set-up at the Fraunhofer IPA.



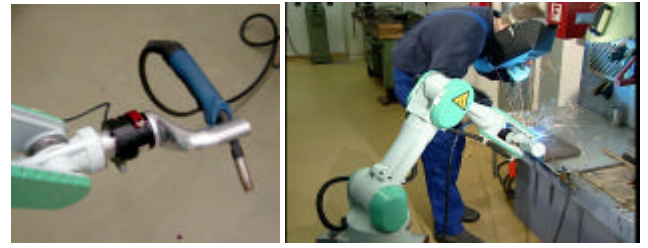
**Figure 8.** Assembly of hydraulic pumps

In order to perform the fetching of objects, a man-machine-interface has been developed and an intelligent task planner has been implemented. These components are described in detail in the next sections.

**Robot Assistance in Manual Arc Welding**

Manual gas metal arc welding is still an important production process. Many areas still exist where welding robots cannot provide the flexibility of human workers. This applies especially to work pieces, which are too large to be handled by standard welding robots. Another problem is the only partially defined work piece geometry and location, without which the robot cannot follow the taught trajectories. Even if this information is known to the robot, the work piece geometry changes due to heat distortion during the welding process, especially in case of multilayer welding. Because of these reasons many advantages of welding robots cannot be realised. This includes in particular repeatable and documentable quality, high precision and high welding speed.

Figure 6 shows rob@work to assist manual arc welding. The task sharing between robot and worker is done as follows: The worker directs the welding torch on the trajectory of the geometrically unknown workpiece. The robot assistant keeps a constant velocity  $v$  and constant welding angles  $\alpha$  and  $\beta$  [HELMS02B].



**Figure 9.** Prototype of robot assistance for manual arc welding

**ROBOTIC HOME ASSISTANT CARE-O-BOT® II**

**Technical challenge**

Technical aids allow elderly and handicapped people to live independently and supported in their private homes for a longer time. As a contribution to these required technological solutions, a demonstrator platform for a mobile home care system – called Care-O-bot® – has been designed and implemented by the Fraunhofer IPA [COB]. Care-O-bot® II is the second prototype of a robotic home assistant, see Figure 8. Its manipulator arm is equipped with a gripper, hand-camera, force-torque-sensor and optical in-finger distance sensors. The tilting head contains two cameras, a laser scanner and speakers. A hand-held panel with touch-screen on the robot’s back is detachable to keep in touch even if the robot moves in a different room.



**Figure 10.** Robotic Home Assistant Care-O-bot® II.

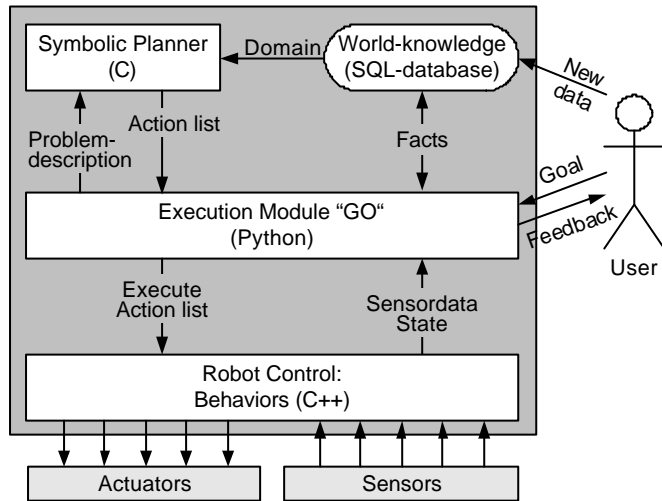
Care-O-bot® II is capable to perform fetch and carry tasks in home environments. From the view of the robot, it has to cope with many different situations and to fulfill complex tasks even in dynamic environments. Furthermore, it must be able to



execute not only one single activity at a time, but several activities concurrently. From the view of the user, the robot has to be easily commanded without the need for the user to learn anything like a programming language. The robot must be safe and dependable.

### System control architecture

Care-O-bot<sup>®</sup> II is equipped with a hybrid control architecture to be able to achieve high-level complex goals, to interact with a complex, often dynamic environment, to be able to ensure the system's own dynamics, to handle uncertainty, and to be reactive to unexpected changes. A description of concept for the architecture is given in [HANS01, TRAUB99]. The basic modules are shown in Figure 9.

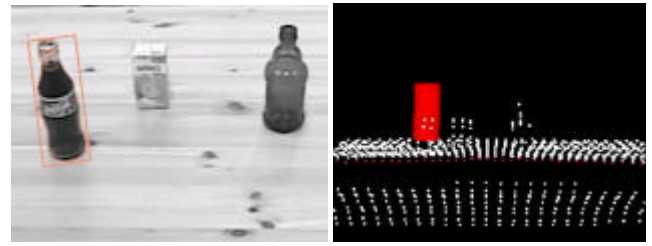


**Figure 11.** Basic modules of the system architecture of Care-O-bot<sup>®</sup> II.

The assistant can be instructed interactively through a man-machine-interface. Each user command is translated in a goal-definition and transferred to an execution module. The execution module triggers a symbolic planner, which calculates with a given domain an action list. The execution module enables or disables behaviours of the robot control to execute these actions step by step. It supervises the triggered behaviours, handles raising exceptions and returns feedback to the user. The behaviours can run sequentially or concurrently. The robot updates its world-knowledge simultaneously to the execution. With the given system architecture, Care-O-bot<sup>®</sup> II is able to plan and execute complex tasks autonomously.

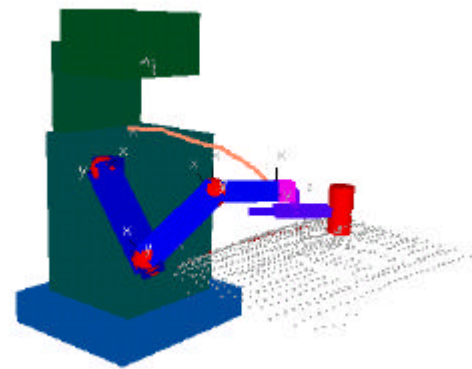
### Grasping

To fetch objects, a method for grasping autonomously based on camera and 3D laser scanner information has been implemented. Reference images of objects are initially taught to the robot. To grasp a previously taught object, the corresponding reference image is loaded and compared to the current image of the camera. By fusing the data from the camera-based object detection and the distance information provided by the scanner, the exact location of the object can be computed. The detection of a bottle is displayed in Figure 10.



**Figure 12.** Detected bottle, object to grasp in the 3D-scan.

Based on the data from the laser scanner, a collision-free trajectory for moving the end effector of the manipulator to the detected object is computed (see Figure 11). The implemented method is based on path planning with Rapidly-Exploring Random Trees and smoothing the calculated path [ROHRMOSER02].



**Figure 13.** Planning a collision free path for grasping an object

### Experimental results

In order to demonstrate the fetch and carry capabilities of Care-O-bot<sup>®</sup> II, a sample home environment at the size of 5 by 5 meters, containing a sofa, table, and two bookshelves, has been set up. Care-O-bot<sup>®</sup> II has a model of this environment in its database. Giving it the command "bring beer to sofa" via the hand-held control panel, the robot performs the desired fetch and carry duty: first it calculates an action list for the desired goal. The goal complexity increases, if the user defines a more complex, nested commands, like "tidy up". Next, the robot moves to a location, where a bottle of beer is standing, takes a picture and tries to detect the desired bottle. If the image-processing fails because of the changing light conditions of the environment or because the number of bottles does not match with the expected number of bottles of the robot's world knowledge, it transfers the image to the user to mark the desired bottle. This interaction is intended to increase the dependability of the complete system.

Once the object to grasp is identified, the robot scans the area and matches the identified image-region with the 3D information. The robot grasps the object with a collision-free trajectory. This method, using camera and 3D information, guarantees robustness against positioning inaccuracy and changing object positions. After lifting the object, the manipulator is moved on a collision-free trajectory to a safe position for

driving. Care-O-bot® II moves to the sofa, faces the person and offers the bottle (see Figure 12). The hand-over is accomplished by using a force-torque sensor in the end effector to detect that the user has grasped.



**Figure 14.** Care-O-bot® II offers a drink.

Vice versa, the bottle can also be handed-over to the robot and put on a furniture by the robot. When handing-over an object to the robot, the in-finger sensors are used to detect the object and close the gripper. When placing objects on furniture, the location is first analysed with the 3D laser scanner. Once a free position has been detected, a collision free path is planned and the arm moved to this position. The force-torque sensor data are required to detect the point where the object touches the table. The gripper is then opened and the object relieved.

#### COOPERATION WORK STATION TEAM@WORK

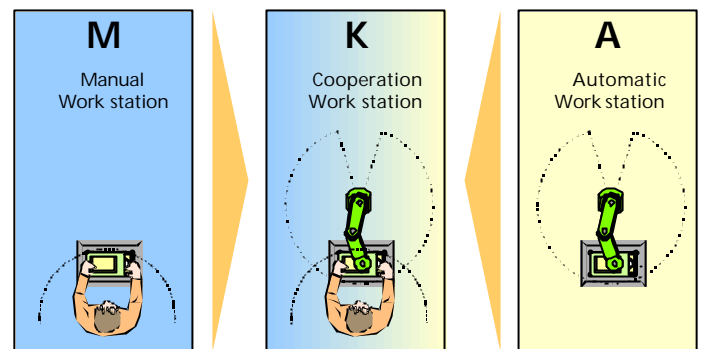
An assembly system should satisfy the following specifications to be best fitted to the mentioned requirements of small appliances industry:

- Production adaptive system (flexible worker employment)
- Product neutral configuration
- Big work content per station
- Possibility of steady rotation of manual and automatic jobs

There are already some trials of assembly systems that offer a steady rotation of manual and automatic jobs to optimally combine the skills of man and robot. These systems have in common a strictly separation of man and robot work stations, due to safety reasons. The flexibility of division of work is reached by the material flow system. This means the product is carried round man and robot work stations in circles, until it is finished. But a costly material handling and material flow control system prevented a widely use of these systems. Consequently it can be assumed that the assembly object is ideally stationary and worker and robot are arranged in that way that both have unrestricted access to the assembly object. Therefore the division of work of man and robot can be absolutely flexibly organised. This results in a system without a strictly separation of man and robot work stations.

#### Direct man robot cooperation

The idea of direct man robot cooperation is to remove the strict separation of man and robot work stations and to combine manual and automatic capabilities in one work station (see Figure 13).



**Figure 15.** Cooperation work station

For the realisation of direct man robot cooperation, two main issues had to be developed. On the one hand a cooperation cell has been developed to optimally utilise the potentials of a direct man robot cooperation. On the other hand an intelligent safety system especially guarantees the human safety, but nevertheless maintains the assembly productivity of the system.

#### Control system

The workspace control system is realised as a flexible distance control. Position, velocity, and acceleration of man and robot are determined and related along the shortest distance. The actual shortest distance is compared with a distance limit that depends on current velocity of man and robot, and constants like the brake and emergency stop performance of the robot. For sensoric detection of man and robot, an image processing system is used that is fixed above the work place.



**Figure 16.** Camera surveillance of the workspace

The demonstration system team@work was installed at the Fraunhofer IPA to demonstrate the idea of a direct man robot cooperation. team@work bases on the principles of a cooperation cell and is exemplarily realised with a configuration of two work stations, one worker and one robot (see Figure 15).



**Figure 17.** Demonstration system team@work

This configuration is best suitable for assembling a sample product „Thermo printer“. The Thermo printer is a print unit of a department store scales that consists of different components like structural and flexible parts and electronic components.

This leads to different demands on handling and joining processes e.g. pressing, screwing and gluing. The Thermo printer represents very good the product spectrum of small appliances, this means small products (workpiece carrier 320 x 320 mm) with many different procedures (>30).

## CONCLUSION

In this contribution we presented three robot assistant systems built at the Fraunhofer Institute for Manufacturing Engineering and Automation: The production assistant rob@work, the robotic home assistant Care-O-bot® II and the cooperation work station team@work.

Beside the representation of the system, the different assistance modes of assistance of the individual robots were described. Furthermore the needed sensor system and motion control were shown.

Open questions and current research topics are the safety issue, the flexibility of the robot assistants and the developments of different strategies of co-operation between man and rob assistant.

## ACKNOWLEDGMENTS

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