Robot Assistants at Manual Workplaces: Effective Co-operation and Safety Aspects

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ABSTRACT

A safe and flexible co-operation between robot and operator may be a promising way to achieve better productivity at the manual workplace. Thus, robot assistants can be thought to be clever helpers in manufacturing environments for fetch and carry jobs, assembly, handling, machining, measuring etc. Key components and methods supporting these next generation robot systems are currently under intense investigation and it is expected that first scenarios of workers co-operating with manufacturing assistants for selected tasks are within three to five year's reach from now. In this paper, key issues in the evolution from robots to robot assistants will be addressed and typical scenarios for mid-term realizations will be given. Fundamental requirements regarding intuitive programming lead to advanced control architectures which incorporate multi-modal man-machine-interfaces and automatic task planning.

Keywords Man-Machine-Interaction, Robot Assistant, Safety, Manufacturing Scenarios, Task Planning, Robot Programming.

1 INTRODUCTION

Future manufacturing scenarios will be subjected to ever higher flexibility induced by uncertain production volumes as well as uncertain product lifetime [1]. Similarly, industrial automation will face new challenges responding to flexibility requirements originating from:

- Prototyping processes applied to serial productions
- Geometrically variable work pieces or products
- Functionally variable products (based on modules or "platforms").

Flexible automation solutions will increasingly depend on robot technology. However, conventional robots find their limitations if the task execution requires a level of perception, dexterity and reasoning which cannot be met technically in a cost-effective or robust way. Within the otherwise manual task execution less demanding subtasks may still be carried out automatically. A safe and flexible co-operation between robot and operator may be a promising way to achieve better productivity at the most flexible work system: the manual workplace. Thus, robot assistants can be thought to be clever helpers in manufacturing environments providing assistance at handling, transporting, machining and assembly tasks. The robot assistant can be mobile or stationary depending on the workspace to be covered. A viable definition has not been worked out yet.

Increased performance at decreasing costs of robot systems produce a shift in reaching a break-even between manual and robot-based manufacturing cost, see figure 1.

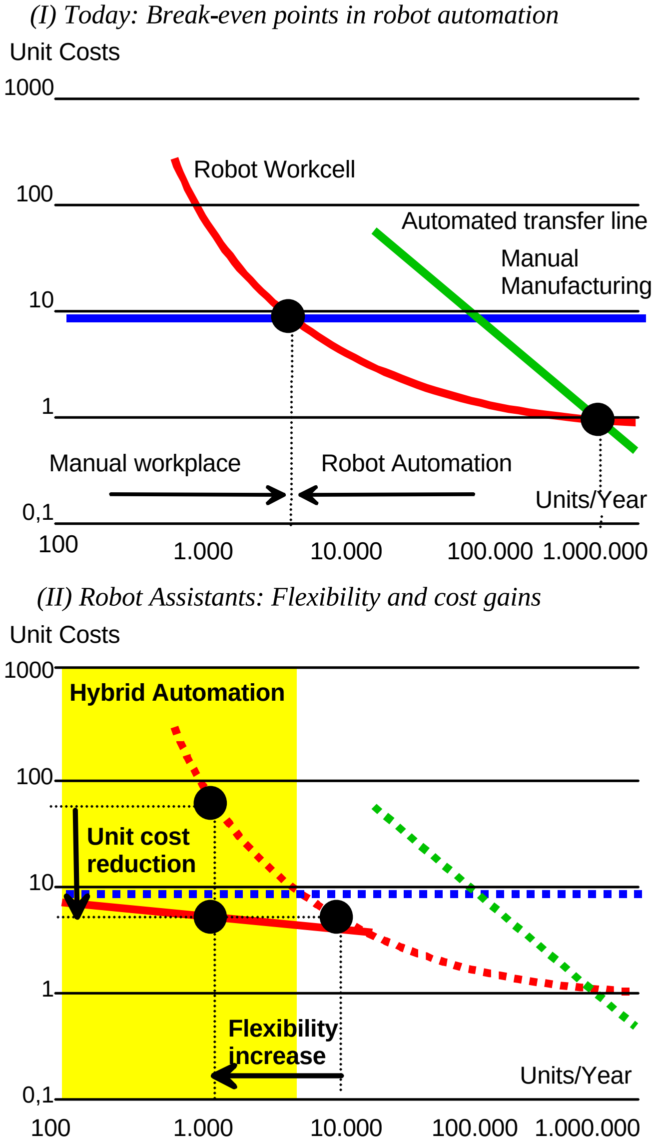


Figure 1: Reduction of robot system costs compared to labor cost (above) and assumed cost potentials of future hybrid automation (below).

A further challenge consist in a continuous cost reduction by means of "hybrid automation" in which a cost-effective co-operation of human worker and robot assistant takes place.

Key components and methods supporting these next generation robot systems are currently under intense investigation. In parallel, first scenarios of co-operating workers with manufacturing assistants are within three to five year's reach from now. In this paper, key issues of robot assistants will be addressed and typical scenarios for mid-term realizations will be given. Primary technical challenges such as active safety devices for monitoring the workers motion relative to the robot motion as well as the operation of robot assistants through intuitive man-machine-interfaces will be addressed.

2 STATE OF THE ART AND TRENDS IN ROBOT ASSISTANTS

Robotic assistants provide physical or informational assistance to the worker. They can be viewed as evolutions of industrial robots and have been under investigation for some time [2]. A wide spectrum of robot systems with direct exposure to humans, sometimes with direct interaction have already been suggested in the past.

In 1984 MORO (MObiler ROboter) was introduced as a robot arm installed on a mobile platform navigating freely in the shop floor delivering and handling tools and work pieces [3]. High system costs prevented its industrial use at that time. KAMRO represented an ambitious extension of this concept. With two servo-driven arms on an omni-directional mobile base the system could execute human skills and dexterity for a wide variety of tasks [4].

Several specialist robot solutions have been worked out where worker and robot perform side by side executing complementary tasks according to the classical industrial engineering rule "men are better at - machines are better at...". The COBOT was suggested to provide assistance to the human operator by setting up virtual surfaces to constrain and guide motions when handling or placing objects [5].

Advanced robot assistants were presented by Khatib [6]. A platform mounted arm is designed to supplement the physical capabilities of a human operator, providing an "extra pair of hands" that can move a load in response to forces he/she exerts.

Assistive systems in homes have been proposed by Engelberger (Elderly Care Giver), Dario (MOVAID), and Schraft (Care-O-bot) all of which are aimed at supporting a mobility impaired person's life in a natural home setting [7-9]. This assistance is expressed by guiding a person, performing autonomously fetch-and-carry tasks or executing jobs such as preparing a simple meal.

The Denso company suggested a concept where a mobile robot arm can be rapidly deployed at conventional assembly lines to add capacity to the assembly worker as the production throughput increases [1].

Currently the MORPHA project funded by the German Federal Ministry of Education and Research (BMBF) comprising 16 partners from both research organizations and industry aims at robot assistants with powerful and versatile mechanisms to communicate, interact and collaborate with users in a natural and intuitive way [10]. Two scenarios demonstrate the technical developments, systems integration and contribute to first field experience [11]:

- Manufacturing Assistant (coordinated by DaimlerChrysler AG) [12] and
- Robot Assistants for Housekeeping and Home Care (coordinated by Siemens AG).

Man-machine-interaction has been addressed by numerous researchers and is viewed as a prime research topic by the robotics community [13].

More general approaches focus on humanoid robots which mimic human mobility and skills so that they can cope with complex tasks in unaltered environments both at the shop floor or at homes [14].

A cooperative task execution between worker and robot assistant has to produce an overall benefit over other competing manual or automated solutions. Given the slowly evolving key components and techniques required for a robot assistant to communicate and interact in a "human-like way" intermediate application scenarios can be suggested as cornerstones along the evolution to the fully assistive functionality:

- Mobile robot arm for delivery operations in shop floors such as machine tool loading
- Mobile robot arm for flexible handling tasks in laboratory automation
- Active balancers for handling and assembly as precision or force augmentation for the worker
- Cooperative assembly cells where the robot offers in addition to standard tasks a "helping hand" in terms of work-piece positioning or parts and tools presentation, see the team@work-concept [15].
- Dependable mobile robot assistants for co-operative tasks as suggested by the rob@work concept.

Independent of the scenario robot assistants have to be embedded into competitive manufacturing environments. In order to achieve productivity, cost-effectiveness and acceptance of the work system "man-machine" advanced industrial engineering methods have to consider aspects of:

- Balancing environmental adjustments against autonomy requirements of the robot assistant
- Access and use of existing data or knowledge for tasks planning and execution
- Effectiveness of the interaction between worker and robot assistant (ergonomics)
- Cost models of cooperative task execution
- Worker qualification and training
- Compatibility with industrial safety and liability regulations.

3 ROBOT ASSISTANT *rob@work*

A concept of a mobile robot assistant (rob@work) has been developed at Fraunhofer IPA since 2000, see figure 2. It consists of a light-weight 7 axis manipulator (Mitsubishi PA 10) mounted on a non-holonomic mobile platform. It is connected to a man-machine-interface station via wireless local area network (LAN). The platform contains all energy supplies, lasting for some 12 hours of operation, controls and navigation sensors. The robot arm is equipped with a servo-controlled gripper and an integrated vision system. The platform's navigation capabilities comprise automatic path-planning, automatic obstacle avoidance, precise positioning (within some 10 mm), position-update by natural landmarks (characteristic walls, pillars etc.). The platform is considered safe in public environments following European standards.

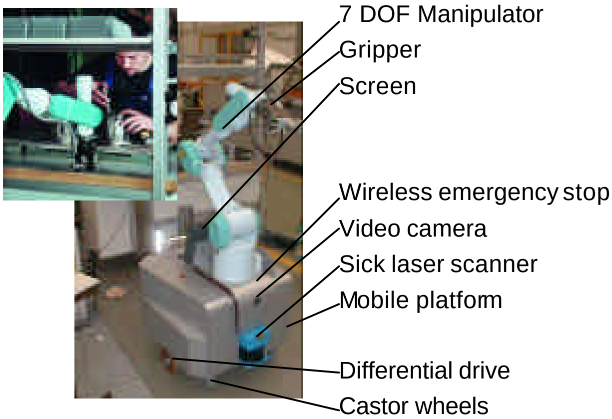


Figure 2: Components of rob@work

Instructing rob@work is based on simultaneous use of natural speech and graphical information imbedded into an overall control system, see figure 3.

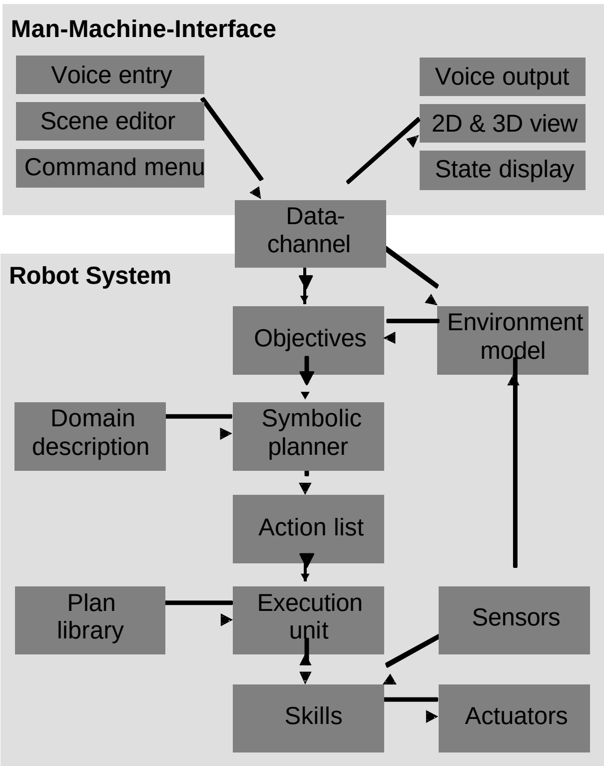


Figure 3: Control architecture of rob@work

From these commands (goals) the symbolic planner proceeds by generating a list of possible actions. The planning process relies on a constantly updated world model that includes available tasks sequences and skills, the current state of both robot and environment. The chosen "FF-planner" [16] uses the Action Description Language (ADL) [17] and the standard "Planning Domain Description Language" (PDDL) of world model data. The plans generated by the symbolic planner are executed by "JAM-Agents" of SRI International, which follows a "Believe, Desired, Intention" (BDI) reasoning model [18, 19].

3.1 Man-Machine Interface

First experiments showed that in average industrial settings, existing natural speech recognition systems still depend on headsets for instruction. The man-machine-interface, figure 4, is characterized by:

- Simultaneous use of various input channels (touch screen or speech)
- Situation-dependent use of the appropriate output-channel
- Communication between the MMI and the robot system by CORBA middleware.

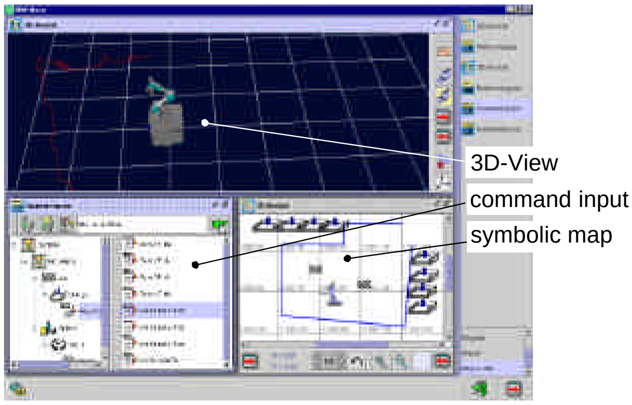


Figure 4: Man-Machine-Interface

3.2 Safety

In the case of physically interacting robot assistants it is obvious that a proven safety is of paramount importance. Despite several considerations no standard procedure or solution catalogue has been provided for the safety conformable design of robot assistants as is the case with industrial robots [20].

The starting point should always be a risk assessment to determine the probability and the consequences of a system failure. This process is standardized and well documented from a methodological point of view [21]. Based on the determined safety category adequate components can be selected, procedures and precautions be designed.

When possible simple means such as the reduction of forces or moments exerted by moving parts should be pursued. Several approaches can be distinguished:

- Passively compliant systems [22, 23]
- Monitoring acting torques on the kinematic structure of the assistant [24]
- Actively torque controlled kinematics [25]

- Controlling the robot workspace by sensors and predicting human motions for collision avoidance [26]
- Employing redundancy in safety critical systems (sensors).

Actively and safely monitoring robot workspaces still remains an ambitious research topic due to its dynamic 3D nature. By now it is recognized that computer vision will play a central role as it is the only useful sensor system to track body motions and adapt robot movements within a typical robot working envelope. First results have been reached, of which figure 5 gives a first impression [27].

Figure 5: Monitoring the robot assistant's workspace by visual sensors from the ceiling (above) and the workbench (below), courtesy Fraunhofer IPK and Fraunhofer IWU.

4 SCENARIOS

4.1 Initial Scenario

The prototype scenario, see figure 6, deals with the assembly of hydraulic pumps and can be described in its manual task execution as follows [28]:

- The assembly process is batch oriented. One product is manually assembled on a work bench segment at a time
- One station involves the fitting of a ball bearing under a press
- Preparation of the assembly starts with the worker carrying all required parts from the storage and placing them at their workbench segments
- The worker then moves from segment to segment assembling unit by unit until the batch is finished.

A robot assistant could take over the following steps upon command by the worker at his/her workplace:

- Fetching the assembled parts from the storage and placing them at their segment
- Placing seals and screws on the motor's housing.
- Attaching the name plate.
- Eventually performing simple assembly tasks such as fitting a ball bearing on a shaft.

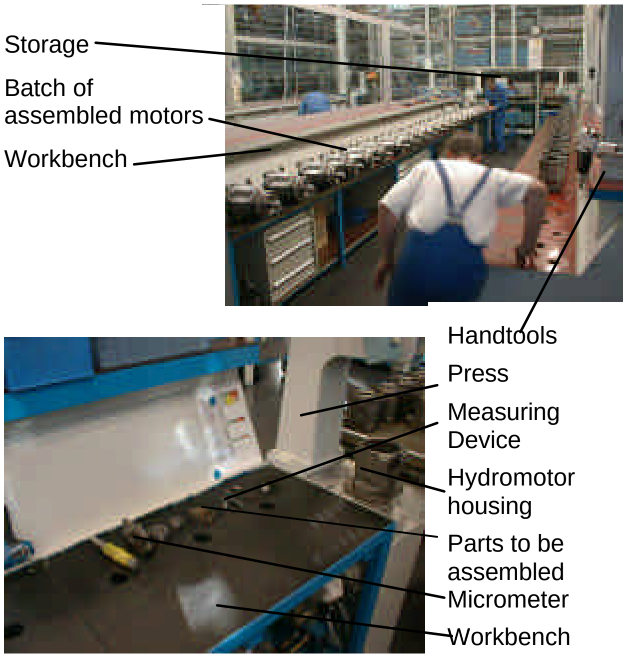


Figure 6: Initial Scenario of rob@work at a workbench with a batch of assembled hydraulic motors (Courtesy Bosch Rexroth Mobile Hydraulics).

4.2 A Class of Manageable Manufacturing Tasks for Robot Assistants

Cooperative task execution in the given scenario still proved to be far from cost-effectiveness and acceptance by the worker as rob@work performed too slowly both in instruction and task execution. However, it is apparent that the immediate success of robot assistants and their further technical developments and application design should focus on real manufacturing scenarios which support the advantages of an assistive robot.

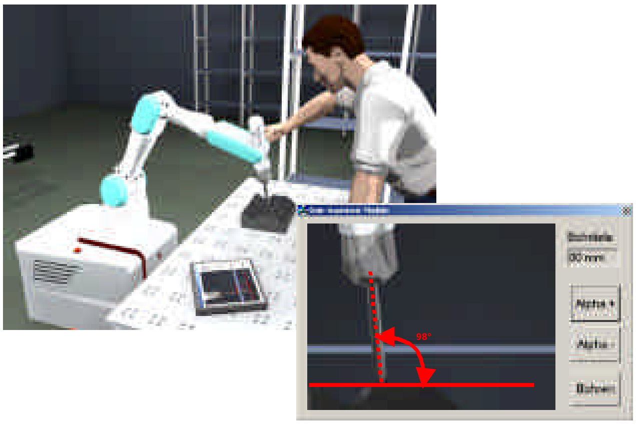
A variety of scenarios are being investigated which suggest an immediate benefit of robot-worker cooperation. There, the class of cooperative tasks considered depends on few additional components and controllable functionality of rob@work:

- Force/torque sensor on the gripper flange for guiding the robot and tactile teaching of trajectories ("play back")
- Changeable tools and gripper for specific tasks
- Easy teaching by indicating goals and trajectories on the workpiece by a laser pointer
- Improved man-machine interface on a detachable web-pad
- Slow motions at limited forces exerted by the robot.

So we focus on using rob@work as an intelligent working aid for a class of specific tasks at the hand for the worker such as welding, 3D scanning, drilling, gluing and positioning workpieces as figure 7 depicts.

“Weld Mate”

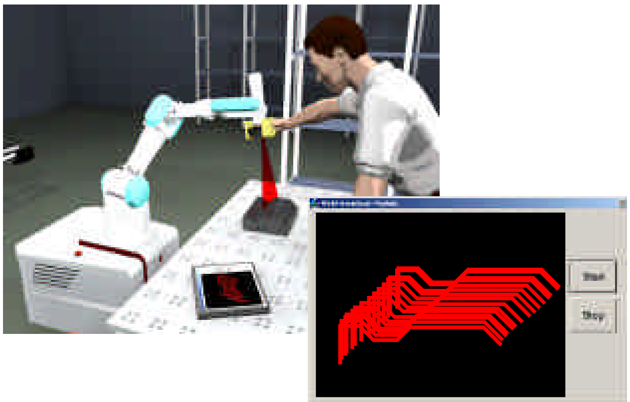
- Attaching welding gun
- Worker determines welding seams by tactile teaching or laser pointing
- Worker starts task execution
- Robot guides tools at constant feed and angle.



“Mobile Scanner”

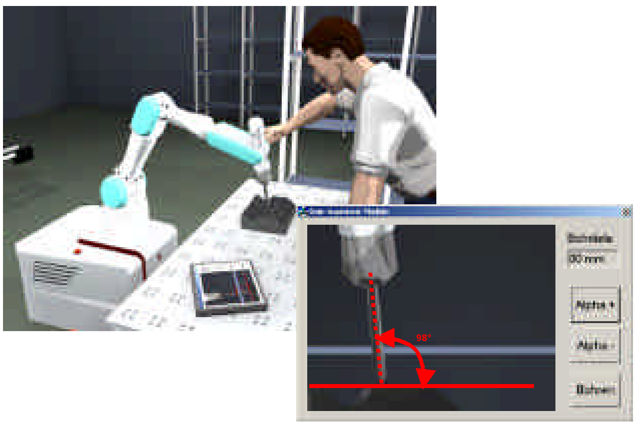
- Attaching scan module
- Worker moves scanner over detection area
- A 3D scan of the workpiece is generated, visualized and stored for further processing

The scanner can be also combined with other tasks.



“Drill Job”

- Attaching drilling tool
- Worker determines approximate drilling position
- Robot positions itself
- Robot guides tool at constant feed and angle.



“Co-Processor”

- Attaching process (i.e. gluing) tool
- Worker teaches approximate motion
- Robot positions itself
- Application of glue.

Figure 7: A class of cooperative manufacturing tasks

5 CONCLUSION

Robot assistants represent a promising evolution to industrial robots. As intelligent manufacturing stands increasingly for the requirements of the flexible and agile production of tomorrow, robots assistants are an important means to access the intelligence of the worker and augment his/her performance at the workplace. Key technologies accounting for a safe and effective man-machine interaction are under intense development.

First simple scenarios already suggest an interesting new aid to achieving better productivity at the manual workplace. As safety guidelines do not cover hybrid working system applications have to be found where task execution still lie within maximum speed and force limits. It is expected that pioneering applications will pave the way to extended safety guidelines and thus facilitate robots working without barriers.

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