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From Robots to Robot Assistants

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Abstract

Conventional robots find their limitation if the task execution requires a level of perception, dexterity and decision making which cannot be met technically in a cost-effective or a robust way. However, 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 a manual workplace. Thus, robot assistants can be thought to be clever helpers in manufacturing environments (manufacturing assistant) as well as in services (home and care assistant). Key components and methods supporting these next generation robot systems are currently under intense investigation. In parallel, first scenarios of cost-effectively co-operating workers with manufacturing assistants are within two to three year's reach from now. In this paper, key issues in the evolution from robots to robot assistants will be addressed and a typical scenario for a mid-term realisation will be given.

1. Introduction

The concept of the manufacturing assistant can be placed within a general context of architectures of automation systems depending on variable certainty of product lifetime and production volume, see figure 1.

- Classical manufacturing lines can be planned and operated effectively if key-parameters such as product life time and volume are a priori known. Based upon technological feasibility and cost for each operation an appropriate degree of automation can be determined which is reflected in the layout of the production facility regarding automated lines and areas of manual workplaces.
- Pre-configured robot work cells produced in medium numbers at low cost for standard manufacturing processes such as welding, deburring, sorting, palletising etc. may even be cost-effective when operated below a full capacity while peaks can be tolerated [2].
- Flexibility in terms of changing products may be

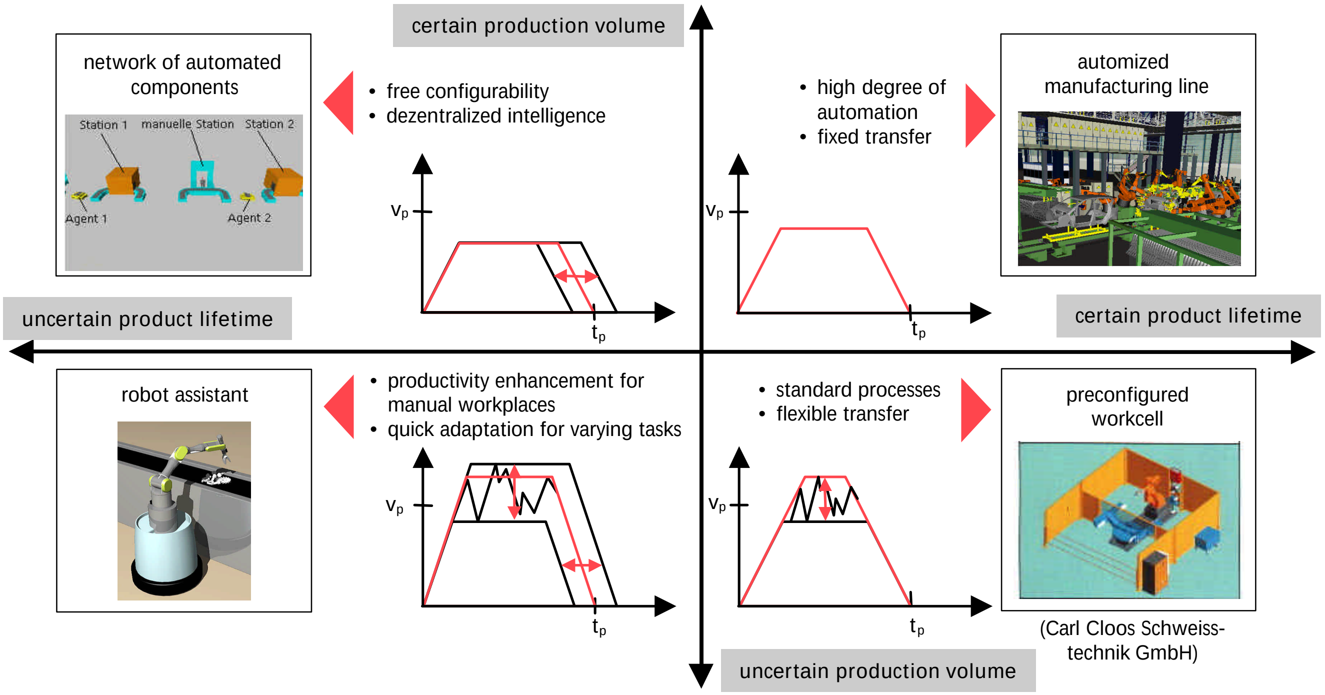

Figure 1: Architectures of automated systems depending on variable uncertainty of product lifetime and production volume [1]

achieved by re-structuring the production into a network of quickly configurable work-stations which are flexibly connected [3]. This results in decentralised architectures of production systems reflected in modern paradigms like Holonic Manufacturing (HMS) or bionic manufacturing systems.

- In future manufacturing scenarios requiring highest flexibility may depend on robotic assistants to effectively co-operate with the worker at handling, transporting, machining and assembly tasks. The robot assistant can be mobile or stationary depending on the workspace to be covered [4].

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 2. A further challenge would be a continuous cost reduction by means of “hybrid automation” where a cost-effective co-operation of human worker and robot assistant could be a promising approach.

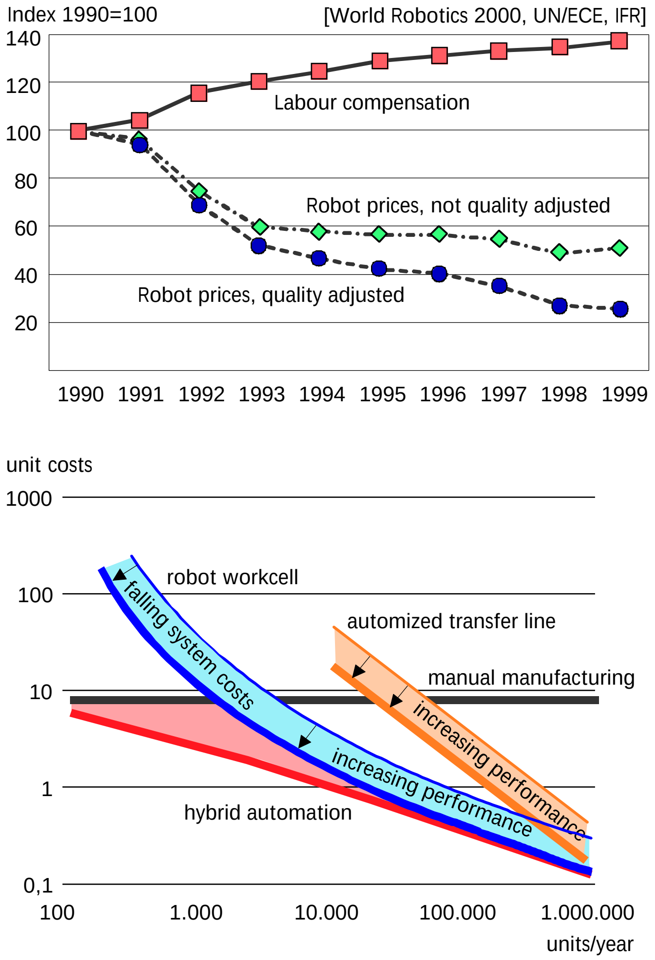

Figure 2: Reduction of robot system cost compared to labour cost (above) and assumed cost potentials of future hybrid automation (below)

Robotic assistants can be viewed as evolutions of industrial and mobile robots and have been under investigation for some time. A wide spectrum of highly kinematic systems with direct exposure to people, sometimes with direct interaction have been suggested:

- In 1984 the MORO (MObililer RObοter) was introduced as a robot arm installed on a mobile platform navigating freely in the shop floor delivering and handling tools and work pieces [5]. High system costs prevented its industrial use at that time.
- The COBOT was suggested to provide assistance to the human operator by setting up virtual surfaces to constrain and guide motion when handling or placing objects [6].
- Advanced robot assistants were presented by Khatib [7]. 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. Also, multiple robot assistants will work co-operatively in moving, and positioning objects under the supervision of the human operator.
- 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 [8-10]. This assistance is expressed by guiding a person, performing autonomously fetch-and-carry tasks or execute jobs such as preparing a simple meal.
- 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 [11].

2. Key-Technologies

In our understanding robot assistants should communicate and interact in a “human-like” way and therefore should take into account both shape and mobility of the human body, the performance and versatility of the human senses as well as the natural operating environments [12], see figure 3.

Robot assistants represent a generalization of industrial robots characterized by their advanced level of interaction and their ability to copy with natural environments both at homes and shop floors.

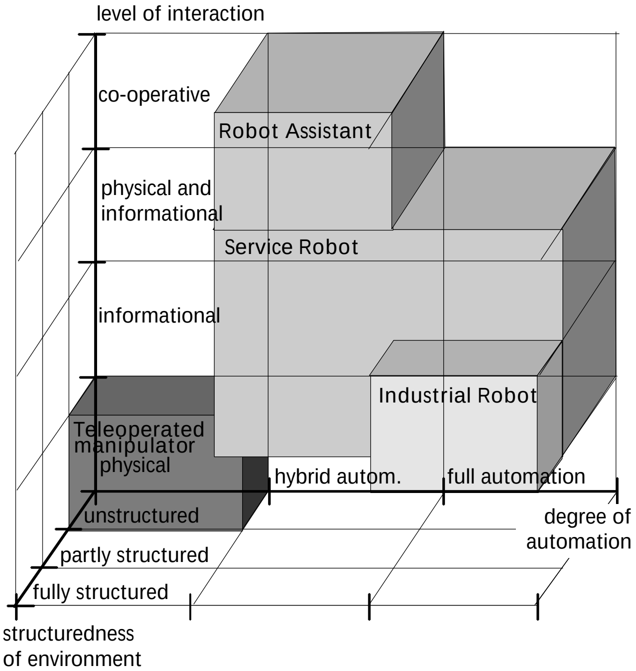

Figure 3: Context of robotic assistants relative to tele-operated manipulators, industrial and service robots

Man-machine-interaction has been addressed by numerous researchers and is viewed as a prime research topic by the robotics community [13]. Currently a large project funded by the German Ministry of Education and Research (bmb+f) comprising 16 partners both from research organizations and industry aims at conducting R&D to equip robot assistants with powerful and versatile mechanisms to communicate, interact and collaborate with users in a natural and intuitive way. From two scenarios

- *Manufacturing Assistant* (co-ordinated by DaimlerChrysler AG) and
- *Robot Assistant for Housekeeping and Home Care* (co-ordinated by Siemens AG)

typical requirements are derived for five key-technologies considered (Figure 4):

- *Channels of Human-Machine Communication*. User and robot assistant should co-operate and safely interact even in complex situations. This implies that the assistant understands the user intent through natural speech, haptic or graphical interfaces.
- *Scene analysis and interpretation*. Effective co-operation depends on the recognition and perception of typical production environments as well as on the understanding of tasks in their context.
- *Learning and self-optimising.* Effective assistance not only requires technical intelligence of the robot but also a knowledge and skill transfer between human and robot. A typical example of learning is programming by demonstration.
- *Motion planning and co-ordination.* During human-machine interaction motions have to be planned and quickly co-ordinated. For motions without physical user contact skills such as avoiding obstacles, approaching a human, presenting objects etc. have to be performed. In the more difficult case of physical contact with the user typical skills would comprise compliant motion, anthropomorphic grasping and manipulation.
- *Safety, Maintenance, Diagnoses.* A suitable safety concept must account for the integrity of the system just as it must account for the integrity of its surroundings. External events affecting the proper function of the system and internal error conditions must be identified and classified according to their inherent risk factors.

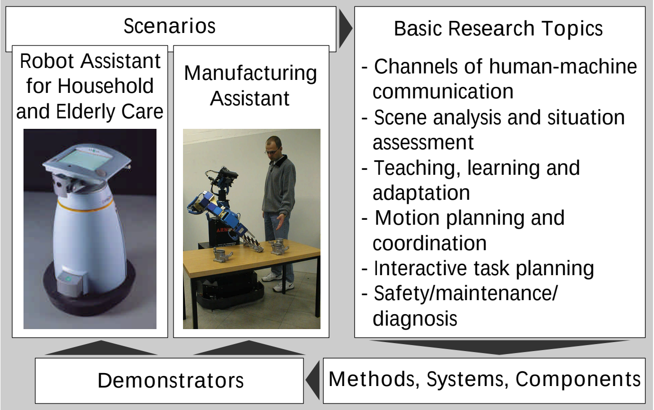

Figure 4: Structure if the research project MORPHA on developing key technologies for man-machine-interaction

3. Man-Machine Interface and Planner

In our work a basic architecture of the man-machine-interface is under the development which should meet the following central requirements:

- Arbitrary and simultaneous use of various input channels (touch screen or speech).
- Situation-dependent use of appropriate output-channel.
- Add-on-component on task planner and root control with tele-operation facility (use of CORBA-middleware).

The structure if the man-machine-interface is given in figure 5. Central components are the fusion module which merges the information through the communication channels in and the separation module which relates the output on the adequate channels. Classical speech recognition is used (IBM Voicetype).

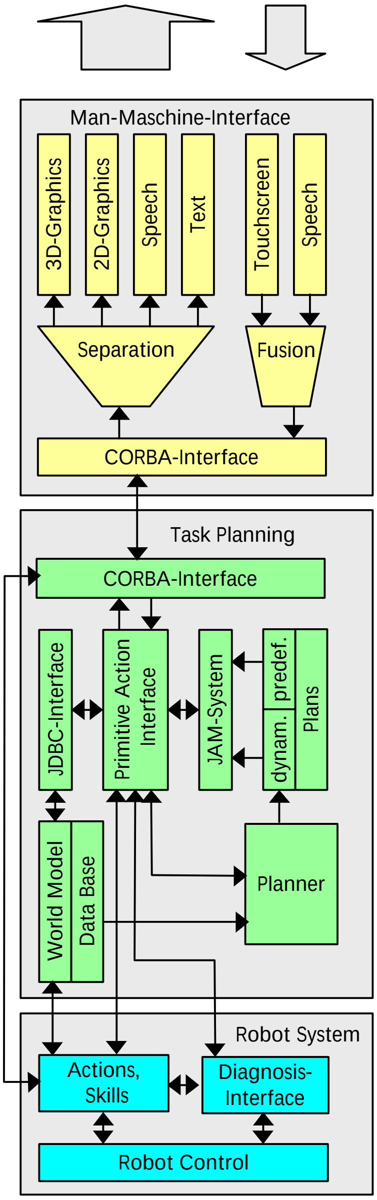

Figure 5: Structure of the man-machine-interface and planner

The task planner should meet the following criteria:

- Support of the classical top-down decomposition.
- Automatic selection among alternative plans according to optimisation criteria.
- Immediate plan modification after changing goals or sub-goals.
- Translation of goals into actions, motion commands and skills which are an encapsulation of motion and sensing.

As the basis for the planner JAM-software was chosen. The package supports both top-down, goal-based reasoning and bottom-up data-driven reasoning. JAM selects goals and plans based on maximal priority [14]. The planner is composed of five primary components (figure 5): a world model, a plan library, an interpreter, an intention structure, and an observer. The world model is a database that represents the beliefs of the planner. The plan library is a collection of plans that the agent can use to achieve its goals. The interpreter is the planner’s "brain" that reasons about what and when the agent should do it. The intention structure is an internal model of the goals and activities the agent currently has and keeps track of progress the agent has made toward accomplishing those goals [15]. Figure 6 shows the example of a task net using the JAM instruction language.

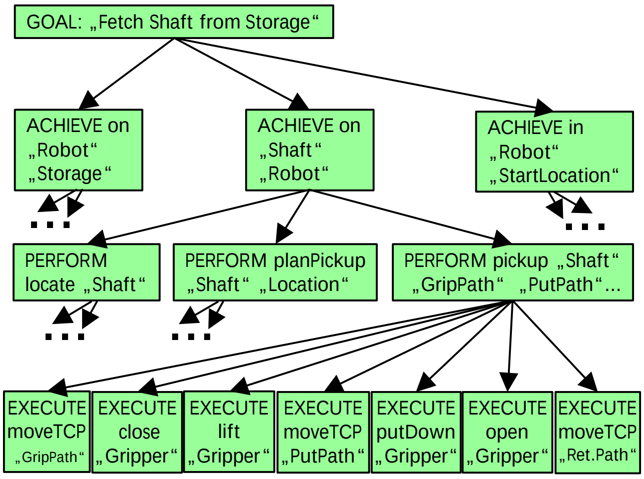

Figure 6: Example of a task net using JAM instructions

4. Safety Aspects

In the case of physically interacting robot assistants it is obvious that a proven safety is of paramount. 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 [16]. However it is stated that approaches exist to arrive at a safety conformable solution for robotic assistants by taking advantage of similar successful solutions from service robot:

- Mobile robots exposed to public environments can be made safety conformable with limited effort (use of category 4 laser scanner or bumper) as is demonstrated with autonomous museum robots [17].
- Service robots such as in the case of automatic refueling comply with stringent safety regulations in fully automatic mode by limiting forces (150 N) and velocities (0.25 m/s) induced by its robot arm.

Considerations on human friendly robot safety stress taking measures from the following fields:

- The starting point should always be a risk assessment to determine the probability and the consequences of a system failure. This process is standardised and well documented [18]. 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 [19].
    - Monitoring acting torques on the kinematic structure of the assistant [20, 21]
    - Actively torque controlled kinematics [7, 22]
- Controlling the robot workspace by sensors and predicting human motions for collision avoidance [23].
- Employing redundancy in safety critical systems (sensors).

We maintain that a safety conformable design for robot assistants can be achieved. However, experience with the design of these systems and their prototype operation in real environments are crucial for their safety evaluation and clearance by safety agencies.

5. Prototype Scenario of a Robotic Assistant

Currently a robot assistant is being taken into operation by Fraunhofer IPA in a realistic scenario. The system is displayed without its cover and interfaces in Figure 7. Emphasis was placed on the most compact shape of the system while maintaining a battery capacity (48 V) of some 8 h under normal operation.

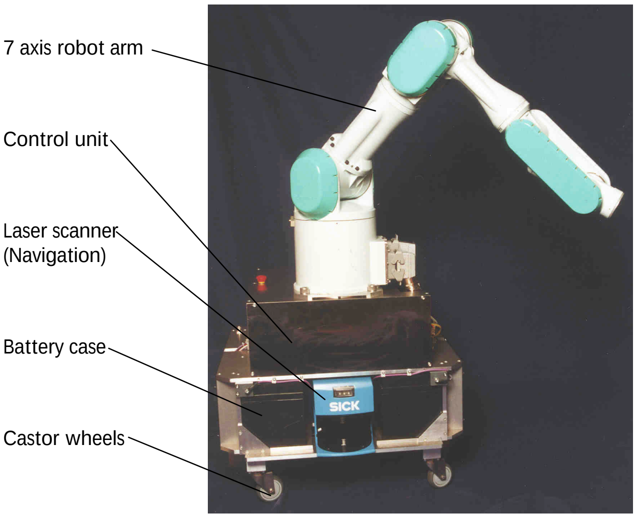

Figure 7: Structure of the robot assistant

The prototype scenario deals with the assembly of hydraulic motors as shown in Figure 8 and can be described in its manual task execution as follows:

- 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 the manual 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.

A reduced prototype version of the system will be at display at the Hannover Trade Fair 2001.

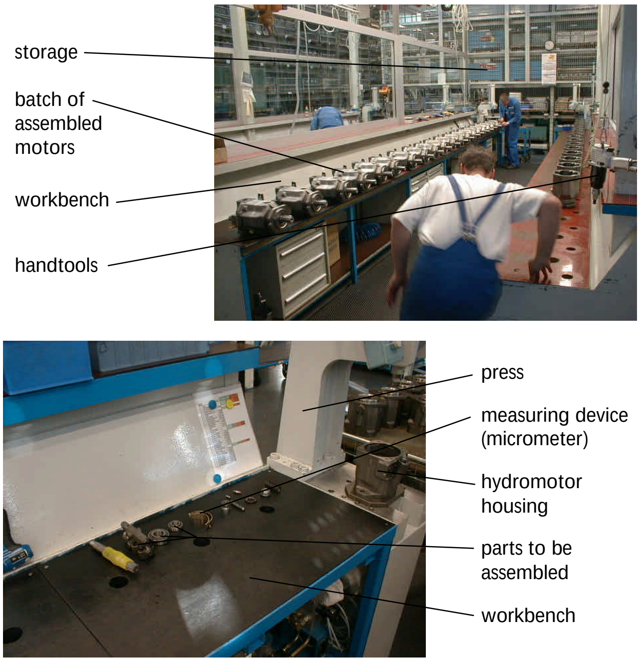

Figure 8: Workbench with a batch of assembled hydraulic motors (above); workplace (below) with parts and tools. (Courtesy Brueninghaus Hydromatik)

6. 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. Their fields of application aim at a variety of possible applications both in manufacturing as well as in services and in home settings. Key technologies accounting for a safe and effective man-machine interaction and are under intense development.

First simple scenarios already suggest an interesting new aid to achieving better productivity at the manual workplace. In any case these scenarios will give most important feedback on the systems further development and practical use.

7. Acknowledgements

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