rob@work: Robot Assistant in Industrial Environments

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Abstract

In this contribution we present a robot assistant consisting of a mobile platform and a manipulator to support manual workplaces in production environments. We propose a general definition of robot assistants. Two applications for the robot assistant rob@work are described – the assembly of hydraulic pumps and the assistance of manual gas metal arc welding (GMAW). A description of the hardware and software architecture, the man-machine-interface, the task-planner and the path-planning of the robot assistant is given.

1 Motivation

Small lot sizes, unpredictable production timelines and volumes and increasing cost pressure are raising the area of conflict between flexibility and automation. A possible solution to this problem is the application of robot assistants.

Robot assistance supports manual workplaces that are the most flexible work systems, by division of labour between robot and worker. The sensory skill, 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. In areas like assembly or welding, where many tasks are carried out manually, robot assistants lead to an increased competitiveness.

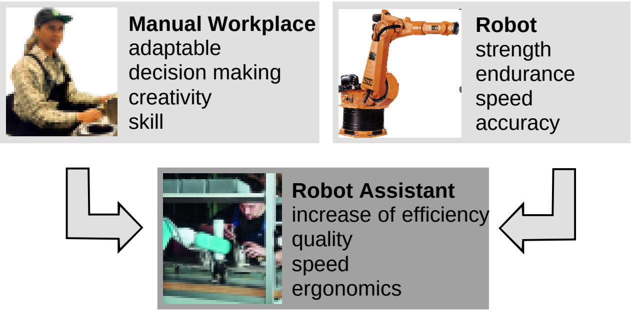

Figure 1. Motivation for robot assistants.

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 will fetch and carry objects, support in grasping, holding and lifting objects and assists in complex production processes like welding or bonding.

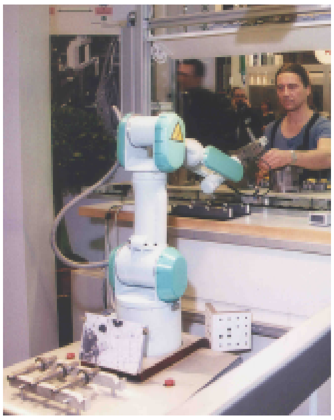

Figure 2. robot assistant rob@work at Hannover Trade Fair

The flexible and situational task sharing between worker and robot is a vital element of the "human centered automation". rob@work is part of the realisation of this idea.

In the chapters below following topics will be discussed:

- Definition of robot assistants
- Robot assistance to assembly of hydraulic pumps
- Robot assistance to manual arc welding

2 Definition of Robot Assistants

We have analysed existing technical assisting devices to determine significant characteristics and to find a definition of robot assistants.

Collaborative robots or cobots [6] invented by Edward Colgate, are mechanical devices that provide guidance through the use of servomotors, while a human operator provides motive power. Cobots are used for the assembly of car doors and for the set-up of a virtual surface used to constrain and guide the workers motion.

Balancer [7] provide a power assisting for handling of heavy objects and provide virtual boundaries and prevent overtravel through the use of sensors.

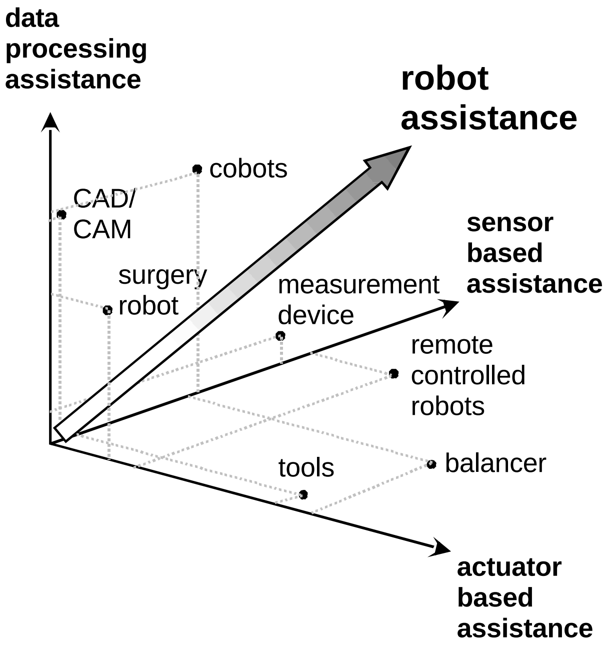

Figure 3. Influence factors on robot assistance

Surgery robots [8] provide force assistance and eliminate trembling and inaccuracy of the surgeon. Patient data, like radiograms etc. are presented to the surgeon.

Remote controlled robots for fire fighting and bomb disposal assist the operator through actuators or manipulators and through the use of appropriate sensors.

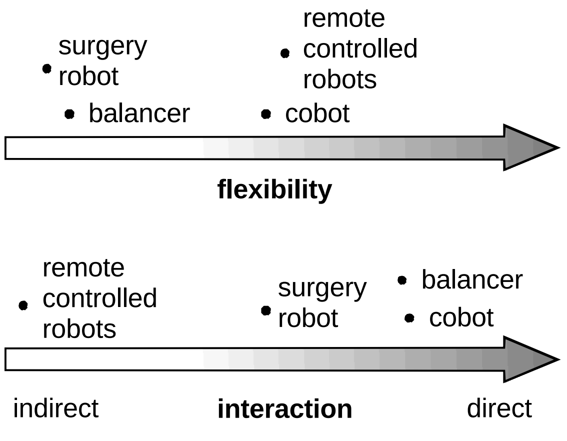

Figure 4. Classification of existing assistants

As shown in figure 3 the described devices provide assistance in a sensor based, actuator based or data processing way. A more or less interactive and flexible co-operation (figure 4) between the human operator and the robot occur.

Therefore we define a robot assistant as a *direct interacting*, *flexible* device, that provides *sensor* based, *actuator* based and *data processing* assistance.

On the basis of the considered assisting devices four types of co-operation were defined (figure 5). 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 consists of the synchronised co-operation. Worker and robot operate consecutively on one work piece. They are still separated, although this workplace can be designed very efficiently [9].

The next step toward co-operation is the operation on a mutual work piece. 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. This assisted co-operation is met for the cobot and balancer mentioned above.

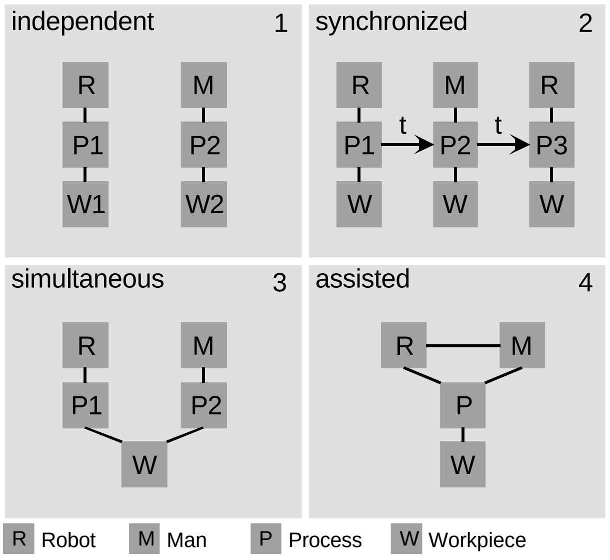

Figure 5. Different types of human robot co-operation

Our approach is to equip a manual workplace in such a way that an assisted workplace evolves.

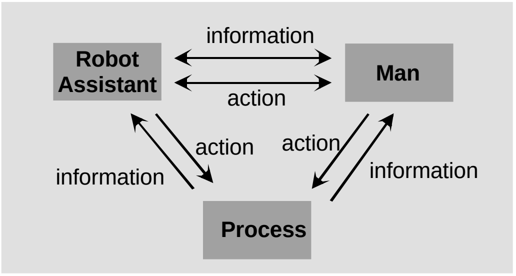

Figure 6. Relationship between man, robot assistant and process

The existing manual process is divided in its elemental functions to identify the potential for co-operation between robot and worker. Certain elemental functions they can be complemented or substituted by a robot using suitable actuators, sensors and/or information processing (figure 6).

3 Robot Assistance to Assembly of Hydraulic Pumps

An application that was realised with rob@work is the assembly of hydraulic pumps. Rob@work fetched shafts from where they were stored and carried them to a manual workplace. Figure 7 shows the manual workplace which was the base for the set-up at our institute.

Figure 7. Assembly of hydraulic pumps

On order to perform the fetching of objects, a man-machine-interface (MMI) was developed and an intelligent task planer was implemented. These components are described in more detail in the next sections.

3.1 Hardware Architecture

The robot assistant rob@work which was developed by Fraunhofer IPA consists of a 7-DOF-manipulator and a non-holonomic platform.

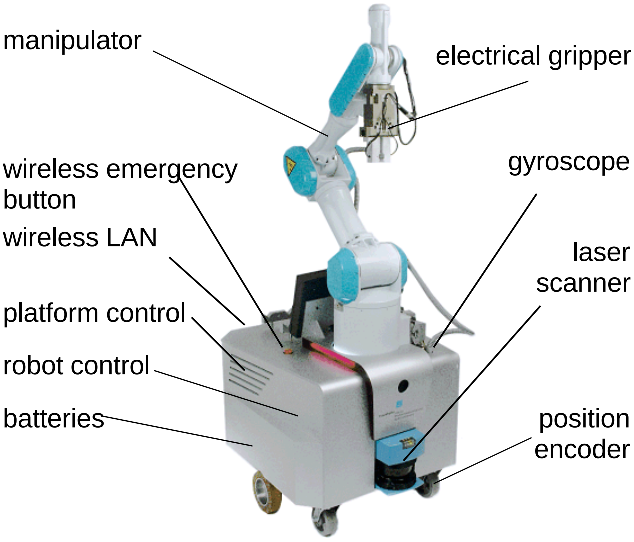

Figure 8. Hardware architecture of rob@work

The robot assistant is connected to the MMI over a wireless LAN and has a wireless panic button. The platform contains the platform control, the robot control and a car battery-like power supply, enabling it to operate 12 hours.

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

3.2 Software Architecture

Effective task execution requires the robot assistant to have its own intelligence. Because of the different tasks it has to perform, it is important that the robot assistant is adaptive to new tasks and easy to instruct. This includes the programming of single movements or process steps, the adaptation of generic skills and the learning of entire series of actions to execute a task. The architecture of rob@work is shown is figure 9.

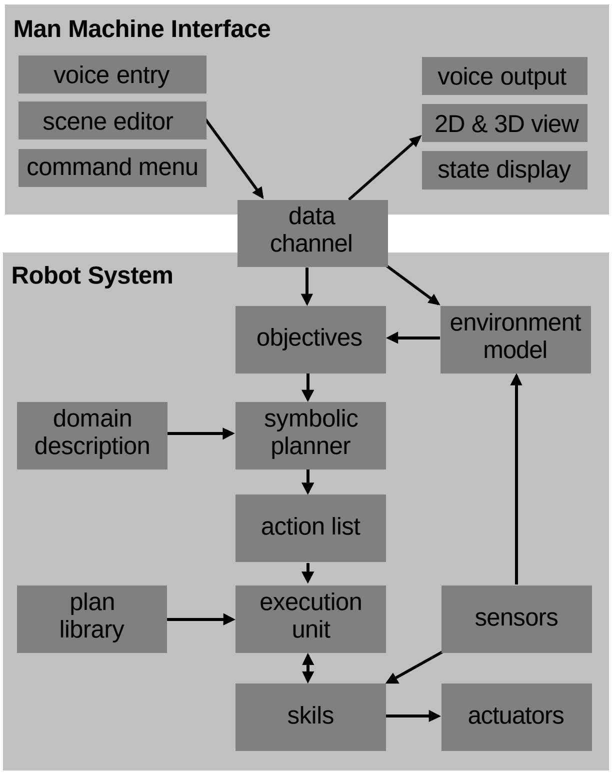

Figure 9. Software architecture of rob@work

The communication between the worker and the robot assistant is done by the man-machine-interface (MMI). The tasks that the robot assistant has to perform are sent to a symbolic planner, which generates a list of all possible actions. The execution unit selects the most appropriate actions and passes them to the robot control. A world model is stored in a database and is constantly updated with new sensoric information. The current state of the task execution is displayed in the MMI.

The world model database contains all necessary information of the environment of the robot assistant. This includes a geometrical map and information about objects, including name, properties (open/closed), relationships (part of, inside of, etc.), geometrical properties (surface, size, etc.), and data to display the object in the MMI.

The symbolic planner generates an action list, to execute the objectives specified by the worker. rob@work uses the FF-planer [1], which is based on ADL (Action Description Language [2]). The FF-Planner uses the standardised Planning Domain Description Language (PDDL) [3].

The plans generated by the symbolic planner are executed by JAM-agents [4]. JAM is a BDI-Agent architecture (Believe Desire Interion) based on a procedural reasoning system (PSR) of SRI International. The tasks are executed and monitored after the beliefs (maps), desires (objectives) and skills are defined by the symbolic planner and the database.

3.3 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 was built. A desktop-like surface presents different possibilities to load different input- and output modules.

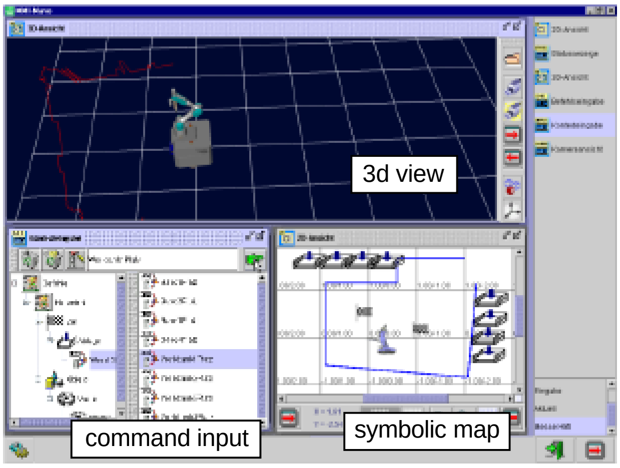

Figure 10. Man Machine Interface (Screenshot)

Communication between these modules and the robot system was 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 was 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.

3.4 3D Sensorics

For a robot assistant interacting with humans it is not sufficient to move its manipulator along preplanned trajectories. For secure and dependable operation, environmental data must be acquired and considered throughout the whole manipulation process. For supervising the manipulation process, rob@work workplace will be equipped with a tilting laser scanner.

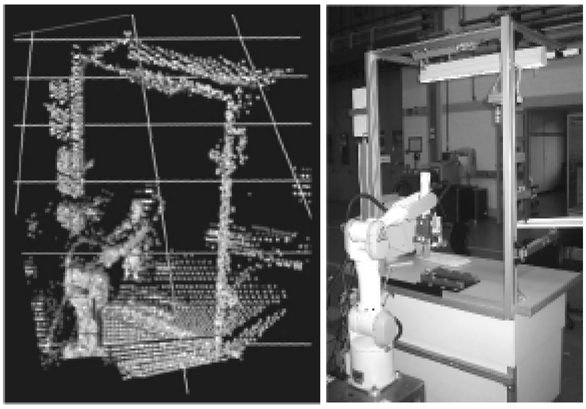

Figure 11. Environmental model acquired with the 3D laser scanner.

The environmental model acquired with the 3D laser scanner consists of a large number of distance values (Figure 11) which can be evaluated to detect obstacles close to the robot arm. A collision free trajectory for the robot manipulator can further be generated based on this data [5]. Some promising first simulation results were already obtained.

3.5 Typical procedure of a command input

A typical procedure of a command input is described below: A common command in our selected scenario (figure 7) is “Get 20 shafts of type xyz”. This command is given to the voice processing of the MMI. It translates the command into a unified format of subject, object, predicate. This information is given to the PDDL-Converter, that converts it into a target state description. In this example “There exist 20 shafts of type xyz on position workplace 1”. This target state description is send to the AI-Planer, that creates a action list subsequently.

For this it requires information form the symbolic database (shafts xyz are on rack 4 is in hall 2) and form the skill list, that lists all the possible action the robot can take. The generated action plan is then executed by the JAM execution unit. This is done in consideration of geometrical data from the environmental map.

4 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 partial defined work piece geometry and location, without which the robot cannot follow the teached 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.

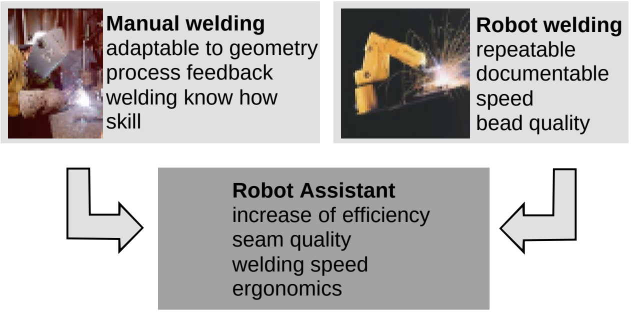

Figure 12. Advantages of man and robot to gas metal arc welding

Even if the robot can be reasonably utilised, a human worker could bring in his advantages. A human worker is able to start welding with no further instruction or teaching, while the teaching of a welding robot can be very time consuming especially for small lot sizes and multiple curved welding trajectories. Another advantage of manual welding is given by the possibility to change important process parameters like current, welding angle, feed rate instantly. This can improve the welding quality.

The placing of welding trajectories in multilayer welding is done in a superior way by a skilled and experienced human worker. This also influences the welding quality and stability.

Multilayer welding of large work pieces was defined to determine the requirements to the welding assistance. The executed manual operation where divided into elemental functions (Figure 13). The determined function where rated with regard to the suitability to be assisted by a robot assistant.

Elemental Function	M	RA	C*	Infl.**
Preparation				
Select welding wire	●	●	2	E
Insert welding wire	●	○	-	
Specify current	●	○	-	
Specify wire feed	●	○	-	
Spot welding				
Clamp work piece	◗	●	4	SQE
1st welding spot	●	○	-	
nth welding spot	●	●	3	SE
Approach welding position				
Position rough 1st layer	●	○	-	
Position rough nth layer	●	●	2	S
Fine positioning	●	◗	-	E
Weld trajectory				
Burner surveillance	●	◗	-	
Control burner distance	◗	●	4	QE
Control feed velocity	◗	●	4	SQE
Control welding angle	◗	●	4	QE
Measure temperature	○	●	4	Q
React to temperature	●	◗	-	
Welding oscillation	◗	●	4	QE
Trim welding wire feed	◗	●	4	

M: Man
RA: Robot assistant
●: Suitable
◗: Partial suitable
○: Not suitable
*: Co-operation type (figure 5)
**: Influence on (S)peed, (Q)uality, (E)rgonomics

Figure 13. Elemental Function of manual arc welding

Based on this evaluation a concept for a robot assist for manual arc welding was generated and is currently realised.

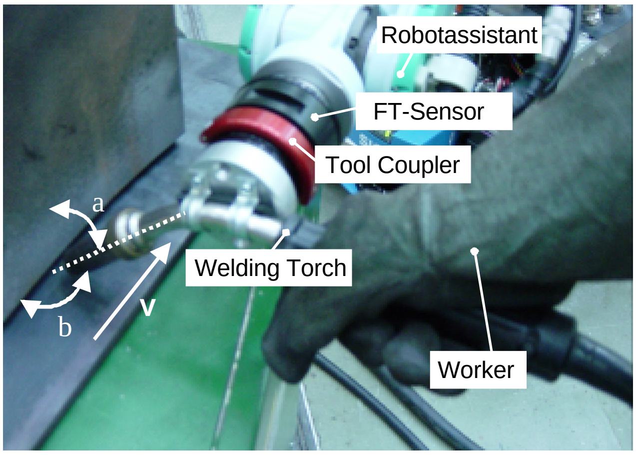

Figure 14. Prototype of robot assistance for manual arc welding

Figure 14 shows a prototype of robot assistance for manual arc welding. The task sharing between robot and worker is done as follow: The worker moves the welding torch on the trajectory of the geometrically unknown workpiece. The robot assistant keeps a constant velocity v and constant welding angles α and β.

5 Outlook

The robot assistant rob@work as well as the presented scenario of assembling hydraulic pumps were realised and presented on the Hannover Trade Fair 2001 and 2002. The concept of a robot assistant for manual arc welding is currently being realised. Rob@work will be equipped with force-torque-sensors to provide assisted trajectory generation and execution of manual arc welding.

6 Summary

We presented the robot assistant rob@work to support manual workplaces in production environments. We described our definition of robot assistants, its hardware and software architecture and its main functions. Furthermore we showed two scenarios: in assembly of hydraulic pumps and robot assistance in manual arc welding.

7 Acknowledgement

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