MORPHA: Communication and Interaction with Intelligent, Anthropomorphic Robot Assistants

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Abstract

Robot systems, which are employed outside traditional manufacturing applications, so-called service robots or robot assistants, have by far not reached the economic potential of industrial robots yet. There are several factors, which explain this circumstance. Operating robots in unmodified natural environments inhabited by human beings imposes requirements on the robots, which are incomparably higher than the demands made on the capabilities of industrial robots. These requirements concern the robots' sensory perception capabilities, their mobility and dexterity, and their task planning, reasoning and decision making capabilities. The technology available today meets these demands only to a very limited extend. A limiting factor is also the lack of interfaces, which allow a human-friendly, intuitive, and versatile communication and interaction with the robots. Such interfaces are essential for efficiently programming and instructing the robots, which is in turn a prerequisite for an effective and flexible use of robot assistants. To develop human machine interfaces, which allow a human-friendly, intuitive communication and interaction with robot assistants is the goal of the *Leitprojekt MORPHA*.

1. Introduction

1.1. The Core Idea

The central idea of the MORPHA project is to equip intelligent robot assistants with powerful and versatile mechanisms, which enable these robots to communicate, interact, and collaborate with human users in a natural and intuitive way. These mechanisms shall facilitate intuitive teaching, programming and commanding of robot assistants and enable them to execute demanding and complex tasks under the control of and in collaboration with the human user.

As robot assistants are expected to act, behave and communicate in a "human-like" way, these mechanisms have to take into account both the shape and mobility of the human body, and the performance and versatility of the human senses.

The communication between human and robot shall be human-friendly and involve all human senses and communication channels, such as natural speech, vision and understanding of visual (gesture, mimic) visual communication, for example, through gestures and mimic, or the sensing and understanding of forces (haptics).

By providing building blocks for a human-friendly, “human-like” communication between a human and a robot MORPHA will pave the way for novel assistive systems in production as well as in domestic environment. This includes robot assistants for manipulation, assembly or transportation tasks in production environments, for cleaning task in domestic as well as in public environments and intelligent assistive systems for elderly, sick, or disabled people.

1.2. The MORPHA Consortium

The MORPHA consortium consists of sixteen academic and industrial partners. The project is lead by Delmia GmbH (formerly Delta Industrieinformatik) a subsidiary of Dassault Systems, France. GPS Gesellschaft für Produktiossystem supports Delmia and is in charge of the project coordination and administrative functions. The two partners DaimlerChrysler and Siemens have taken the responsibility for the two scenarios *The Manufacturing Assistant* and *The Robot Assistant for Housekeeping and Home Care,* described in the following sections. These two scenarios represent one of three columns of the MORPHA project. The scenarios are linked through five major basic research topics representing the second column of MORPHA: *Channels of Men Machine Communication, Scene Analysis and Interpretation, Learning and Adaptation, Coordinated Motion Planning and Task Planning, Safety.* Research and development on these topics is coordinated by the partners DLR, Ruhr-Univ. of Bochum, Univ. of Karlsruhe, FAW Ulm, and Fraunhofer IPA, respectively. The third column of MORPHA is the development of a number of prototypes, which allow an evaluation and a fast exploitation of R&D results in applications of economic interest. An example is the development of prototypes of new human-friendly, intuitive programming and teaching devices for industrial robots. The development of prototypes and applications is the primary interest of the industrial partners, Astrium, Amtec, Delmia, Graphikon, Kuka Roboter, Reis Robotics, Propack Data, Zoller+Fröhlich, ZN.

2. Interaction and Communication with Anthropomorphic Robot Assistants: An Overview over the MORPHA project

2.1 Scenarios

The collaboration and co-existence between a human and a robot assistant and the inherent problems with respect to communication, interaction, and collaboration will be studied in two scenarios:

The Manufacturing Assistant

The use of mobile robot assistants in manufacturing environments (manufacturing assistants) will lead to significant improvements of industrial production processes, particularly in terms of increased productivity and humanization of the work place. Robot assistants in manufacturing will accomplish tasks through close interaction with people, thus supporting human workers, not replacing them. The human worker is responsible for the command, supervisory, and instructional functions, while the robot assistant will carry out boring, repetitive and strenuous operations. In cases where the robot does not know how to proceed, the human worker will intervene to provide guidance and additional instruction. Robot and human worker are, therefore, partners in joint manufacturing processes. Typical tasks in manufacturing applications are taking out parts from containers, the transportation of parts to machining stations or assembly work cells, and the assistance with the assembly.

Figure 1: Manufacturing Assistant (a design study)

Real, complex factory environments are characterized by frequent changes, by varying positions of transport containers, by parts of differing forms and weights in the containers, and by the use of various machining tools. Accomplishing a task sequence requires a maximum of flexibility. This flexibility can only be achieved by instructing the robot assistant in an interactive teaching and learning process where the human worker is responsible for

- familiarizing the robot assistant with the manufacturing environment by showing it around and naming selected places, thereby having the robot learn a model of the surroundings; this model will be later used by the robot for navigation through the environment while carrying out such things as transportation tasks;
- showing the robot objects like transportation containers, parts, or machine tools, so that the robot is able to generate internal representations of those objects. Demonstrating specific motion behaviors and maneuvers to the robot assistant, teaching it sensor-based locomotion and manipulation capabilities (skills). A typical example is docking to a transport container and grasping some parts.
- demonstrating complex sequences of operations from which the robot can extract and generalize appropriate task plans.
- teaching the robot assistant how to cooperate with the user in an appropriate manner. This includes the robot's taking into account the behavior of the human worker and his or her intentions (if they can be identified) in its own behavior and plans.

The Robot Assistant for Housekeeping and Home Care

The scenario of house keeping and home care robot assistants focuses on the employment of assistive robot systems in everyday domestic settings. There are different motivating factors for the employment of robots in the home. On the one side, comfort factors and a changing societal framework favor the employment of man-made personnel. On the other side, an increasing number of households include inhabitants that require physical support in day-to-day life due to sickness or age. Robot systems will work directly with people in this area, thus placing a central importance on making interactions between people and machines as natural as possible.

The robot assistant in the home should work together with the user to perform simple housework. In addition to fetch-and-carry duties, this includes tasks such as setting the table or performing basic cleaning. The robot assistant will have to be able to move through the various rooms of the home without colliding with furniture or people.

Figure 2: Robot Assistant for Housekeeping (design study)

Human interaction with the robot assistance system will have as its purpose the commanding and teaching of the robot, but it also offers interesting possibilities of augmenting the performance of the entire system. So far, robot systems have only been able to deal with the high complexity and the wide variability of everyday surroundings to a limited extent. This complexity and variability place high demands on the robot's intelligence and autonomy, demands that cannot be fully satisfied given the current state of the technology. The capability to interact with a human user offers the robot system the possibility of making use of human guidance and support to expand its initial competencies. The prerequisite for this, however, is that the communication between robot and user be to some extent natural, so that it will not be considered a burden by the user.

2.2 Basic Research Topics

The two scenarios *Manufacturing Assistant* and *Robot Assistant for Housekeeping and Home Care* stand for a large variety of applications for robot assistants. The basic problems and mechanisms of collaborative and interactive problem solving and task execution by the "team" robot-human, however, are independent of the specific application considered. In the following we identify five basic research topics which are common not only to the above but to a large number of applications.

Channels of Human-Machine Communication

The goal of effective interaction between user and robot assistant makes it essential to provide a number of broadly utilizable and potentially redundant communication channels. The integration of classic interfaces, like graphical input-output devices, with newer types of interfaces such as speech and visual interfaces, tactile sensors, and force/torque sensors, is indispensable for the task. At the same time, the robot assistant must be able to differentiate between the user's communication and the dynamics resulting from the manipulation function itself.

Scene Analysis and Situation Assessment

A mandatory precondition for efficient cooperation is a reliable perception and understanding of the structure of the environment and its dynamics. The robot must be able to analyze and interpret events in the surrounding world in order to react appropriately. Furthermore the robot needs to develop an understanding of its task and the context within which it has to solve it.

Teaching, Learning, and Adaptation

Providing effective assistance requires the robot to have its own intelligence. Using predefined functions, this is achievable only in a limited way. It is thus essential that the robot assistant be capable of learning and receiving instructions on various levels of abstraction. This includes programming of single movements, matching of pre-defined, generic capabilities (also called skills) and finally teaching of complete task sequences (macro-skills). At the same time, the system should be able to evaluate the consequences of actions based on its own experience and utilize the results of this evaluation for the purposes of adapting and improving its knowledge. Such evaluations can be learned or imparted by the user through appropriate information channels.

Motion Planning and Coordination, Interactive Task Planning

The collaboration between a human being and a machine that can independently move and act represents a form of interaction that is based not only on communication and exchange of information, but also involves motion and action. These motions and actions of the two agents, human and machine, must be planned, coordinated, and, if need be, adapted reciprocally. We distinguish between three types of motion planning and coordination: motion which involves direct physical contact between human and machine, motion without direct contact, and finally, coordinated planning and execution of action sequences involving motion and manipulation.

Safety / Maintenance / Diagnoses

The employment of robot systems, which are to work directly with people, naturally places highest demands on system safety, reliability, and maintainability. 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.

3. Advances in Robot-Human Interaction and Communication

In the following we briefly present some of the advances in robot-human interaction and communication, which have been achieved by the MORPHA consortium recently.

Towards Interactive Learning for Manufacturing Assistants (DaimlerChrysler AG)

In [1], Stopp et al. present an approach for interactive learning for robotic assistants in manufacturing. The aim of this research is to develop robots that can assist, co-exist with, and be taught by humans, and which can easily be instructed how to either perform tasks autonomously or in co-operation with humans. Apart from developing the "standard" mobile robot capabilities such as landmark recognition, path planning, obstacle avoidance etc. research effort has been aimed at the development of learning capabilities that will allow the user to quickly and intuitively teach the robot new environments, new objects, new skills, and new tasks. For learning the environment, they have chosen to teach the initial environment model using human guidance for focusing attention and acceleration of the learning procedure. The idea is to lead the Manufacturing Assistant around in the relevant part of the factory using a few simple but robust gestures. The goal is not to explicitly teach the robot all features of the environment but to show where it should itself generate its environment model. For interactively learning objects the general idea is to let the operator point out the relevant objects/features either directly in the world, e.g. by using a laser-pointer or in a graphical interface showing the relevant sensor data. Figure 3 shows the current development state of the Manufacturing Assistant at DaimlerChrysler Research in Berlin and how it is teached to grasp objects from a conveyer belt using a gripper camera. With this method, developed together with Graphikon GmbH, the user simply places the relevant objects under the camera a few times. The object is pointed out in the image and at the end a grasping position is defined. This is quite intuitive and has been proven to work very reliably under real world conditions.

Figure 3: Manufacturing Assistant at DaimlerChrysler: Interactive Object Learning

Man-Machine Interaction for Robot Applications in Everyday Environments (Siemens AG)

In [2] von Wichert and Lawitzky discuss the use of tactile sensors as a means for interaction with future service robots, that will solve problems in direct and active cooperation with their users. They present two types of tactile sensors for interaction purposes: an *artificial skin* and a *tactile gripper*. Both types are implemented on the test platform *MobMan*:

- The artificial skin covers the whole arm and parts of MobMan's body. The skin sensors measure the strength (force) and location of surface contacts. The user can move the arm by pushing. The integrated arm and platform control systems additionally allows the user to move the whole robot this way. This can be used to move the robot into desired positions. Because of the 13 degrees of freedom (arm and mobile platform) this is much more convenient than any form of joystick or mouse control. Such interaction is especially well suited for teaching arm/robot poses and motions.

- A tactile gripper measuring external (object) and internal (grasp) forces and moments. While these sensors are designed, to be used for manipulation tasks, they can also serve as input devices for man-robot interaction. Figure 4 shows a situation where the robot is instructed to grasp a bottle. The ambiguity of the environment (several bottles are present) forces the robot to acquire additional information from the user. Instead of complex dialog or keyboard input the user simply grabs the arm (this is detected by means of the gripper sensors) and pushes the robot into a grasping position in front of the desired bottle. From there the robot can continue to pursue its task and autonomously pick up the bottle.

Figure 4: *MobMan* receiving tactile help in an ambiguous situation

Touch: The Direct Type of Human Interaction with a Redundant Service Robot (DLR)

Mobile service robots will share their workspaces with humans, e.g. in offices or households. Thus a direct contact between man and machine is inevitably. For safety reasons it is necessary, that the robot is able to sense any touch over is entire arm. The DLR's robotic lab has developed a robot with kinematics and sensory feedback capabilities similar to the human arm [3]. A main feature is the ability to perform compliant manipulation in contact with an unknown environment.

Touch can be interpreted by the robot in different ways depending on its current task context. When the robot is performing a planned task and is detecting unexpected forces on its arm, this can be interpreted as an unforeseen collision. It will react using sophisticated collision avoidance mechanisms to eliminate the sensed forces and torques.

A collision, however, can also be a deliberate touch by the user. As both share their workspace, in some situations the human can feel a threat if the robot comes to close to him. A natural human reaction could be, that the user pushes the arm away to get clearance. In such situations the arm will react by an evasiveness motion of the touched links while remaining the orientation of the TCP, if necessary.

Figure 5: The DLR arm sensing touch.

Motion coordination of a Human and a Robot in a Crowded Environment (FAW Ulm)

Prassler et al. [4] developed an approach to coordinating the motion of a human with a mobile robot moving in a populated, continuously changing natural environment. The test application, which is considered, is a wheelchair accompanying a person through the concourse of a railway station moving side by side with the person. In healthcare and rehabilitation scenarios this addresses a rather important issue. Pushing and maneuvering a carriage such as a wheelchair or a hospital bed, exposes the back of the pushing person to significant strain often resulting in severe long-term back problems. Having a wheelchair, which could autonomously accompany a person side by side through a natural public environment, could eliminate this problem.

The approach is based on a method for motion planning amongst moving obstacles, which is known as *Velocity Obstacle* approach. This method is extended by a method for tracking a virtual target, which allows one to vary the robot's heading and velocity with the locomotion of the accompanied person and the state of the surrounding environment.

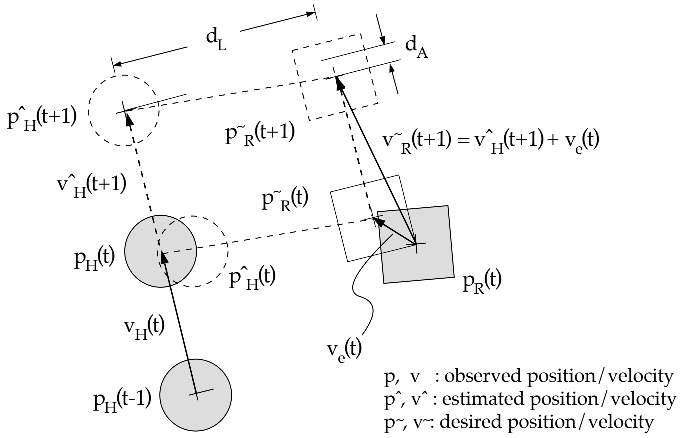


Figure 6: Accompanying behavior based on tracking a virtual moving target.

From Robots to Robot Assistants (Fraunhofer IPA)

Robot assistants represent a generalization of industrial robots characterized by their advanced level of interaction and their ability to cope with partially structured or unstructured environments. They are increasingly suited for their environment and close the gap between full automation and manual workplaces by effectively co-operating with the worker during handling, transporting, machining and assembly tasks.

To underline this statement, Haegele et al. [5] introduce a prototype scenario currently being implemented at Fraunhofer IPA. This scenario deals with the assembly of hydraulic motors.

Within MORPHA basic methods and components are investigated which result from basic functional requirements given by a household and home assistant:

- Fetch and carry of selected objects
- Support in grasping, lifting and holding of objects
- Guide and support the mobility impaired user when, for instance, getting up from bed or walking to the bathroom
- Give access to infotainment or household systems

For an intuitive use of the robot assistant as a walking aid, the motion control system has been adapted so that the non-holonomic kinematic system consisting of platform and guided person moves along ergonomically compatible trajectories. This principle is currently being extended to the full kinematic arrangement of both platform and robot arm for safe physical man-machine-interaction.

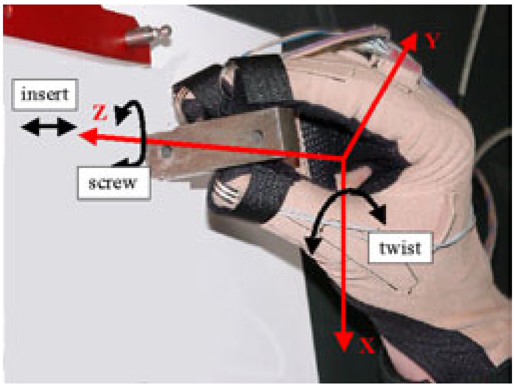
Generating Interactive Robot Behavior: A Mathematical Approach (Ruhr-Univ. Bochum)

When interacting with human beings in a real-world situation, a robot is confronted with a fast changing dynamic environment. As the behavior of both, the human and the robot, change the environment, they can be considered as a coupled dynamical system embedded in a dynamic surrounding. The coupling functions are action and perception, i.e. the sensor output and the effector movement on the robot's side. To capture these dynamic aspects of man-machine-interaction, Steinhage et al. (see [6] as an example) have developed a mathematical framework in which the behavioral state of the robot is represented by a state variable of a dynamical system. The coupled nonlinear differential equations, which model this dynamical system, are designed such that the solution of the equations over time generates the desired robot behavior. The output of the robot's sensor systems serves as parameters on the dynamic equations. The major advantage of this approach is its robustness: as the dynamical system is within a stable state most of the time, sensor noise or fluctuations do not influence the overall behavior. Qualitative changes within the robot's behavior are caused by switching from one stable state to another by inducing a *bifurcation* in the dynamics. To design the dynamical systems, we have developed a number of design rules in the form of a toolbox: to generate elementary behaviors, we use simple *attractor dynamics*, for behavioral organization we employ a specific *neural winner takes all dynamics* and to generate complex behavior we use so-called *neural fields*.

Dynamic Grasp Recognition within the Framework of Programming by Demonstration (Univ. of Karlsruhe)

A extension of a *Programming by Demonstration (PbD) system* is presented in Zöllner et al. [7]. The main goal of *PbD* systems is to allow the inexperienced human user to easily integrate motion and perception skills or complex problem solving strategies. Unfortunately actual *PbD* systems are dealing only with manipulations based on *pick & place* operations. For recognizing fine manipulations like screw moves the question: *"What happens during a grasp?"* has to be answered. In order to do this, finger movements and forces on the fingertips are gathered and analyzed while an object is grasped. This assumes vast sensory employment like a data glove and integrated tactile sensors. Furthermore object and hand tracking using stereo cameras a magnetic field sensor are deployed for detecting object and hand movements.

In [7] it is illustrated how information of tactile sensors is integrated in the segmentation algorithm of the users demonstration. Detecting contact phases between users finger and grasped objects leads to the recognition of dynamic grasps and to a higher reliability of the whole PbD system. The presented approach for the segmentation of dynamic grasps is based on the analysis of force sensor signals. After the segmentation, the dynamic grasps are classified by a time delay approach based on a Support Vector Machine (SVM). A sequence of fifty corresponding finger joint values is used as input for the SVM. With this, the time of one elementary dynamic grasp is about 2 seconds.



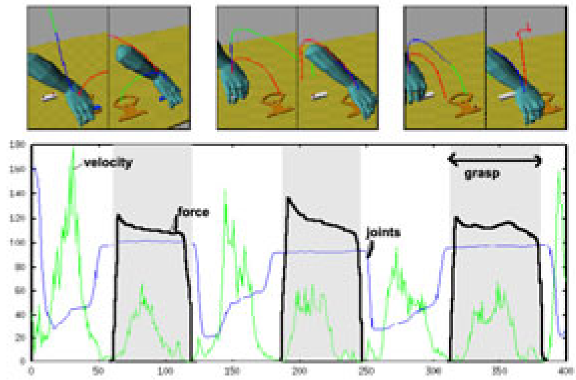


Figure 7a: Data glove with tactile sensors. Figure 9b: Analyzing segments of a demonstration

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