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Human – Robot Interfacing by the Aid of Cognition Based Interaction

Aarne Halme
Helsinki University of Technology
Finland

1. Introduction

There are two challenging technological steps for robots in their way from factories to among people. The first to be taken is to obtain fluent mobility in unstructured, changing environments, and the second is to obtain the capability for intelligent communication with humans together with a fast, effective learning/adaptation to new work tasks. The first step has almost been taken today. The rapid development of sensor technology – especially inertial sensors and laser scanners – with constantly increasing processing power, which allows heavy image processing and techniques for simultaneous localization and mapping (SLAM), have made it possible to allow slowly moving robots to enter in the same areas with humans. However, if we compare the present capability of robots to animals, like our pets in homes, it can be said without no doubt that improvements are still possible and desirable.

The second step is still far away. Traditional industrial robots are mechanically capable to change a tool and perform different work tasks, but due to the nature of factory work need for reprogramming is relatively minor and therefore interactive communication with the user and continuous learning are not needed. The most sophisticated programming methods allow task design, testing, and programming off-line in a simulation tool without any contact to the robot itself. Today's commercial mobile service robots, like vacuum cleaners and lawn mowers, are limited to a single task by their mechanical construction. A multi-task service robot needs both mechanical flexibility and a high level of "intelligence" in order to carry out and learn several different tasks in continuous interaction with the user. Instead of being a "multi-tool" the robot should be capable of using different kinds of tools designed for humans. Due to fast development in mechatronics, hardware is not any more the main problem although the prices can be high. The bottlenecks are the human – robot interface (HRI) and the robot intelligence, which are strongly limiting both the information transfer from the user to the robot as well as the learning of new tasks.

Despite huge efforts in AI and robotics research, the word "intelligence" has to be written today in quotes. Researchers have not been able to either model or imitate the complex functions of human brains or the human communication, thus today's robots hardly have either the creativity or the capacity to think.

The main requirement for a service robot HRI is to provide easy humanlike interaction, which on the one hand does not load the user too much and on the other hand is effective in the sense that the robot can be kept in useful work as much as possible. Note that learning of new tasks is not counted as useful work! The interface should be natural for human cognition and based on speech and gestures in communication. Because the robot cognition and learning capabilities are still very limited the interface should be optimized between these limits by dividing the cognitive tasks between the human brains and robot "intelligence" in an appropriate way.

The user effort needed for interactive use of robotic machines varies much. Teleoperators need much user effort, because the user controls them directly. Single tasks service robots, like autonomous vacuum cleaners, do not demand too much effort, but complexity and effort needed increase rabidly when general purpose machines are put to work. Figure 1 illustrates this situation. The essential question in the development of next generation intelligent service robots is the complexity of their use. Because being just machines for serving human needs, they are not well designed if they need lot effort either for the preparation of a work or monitoring it.

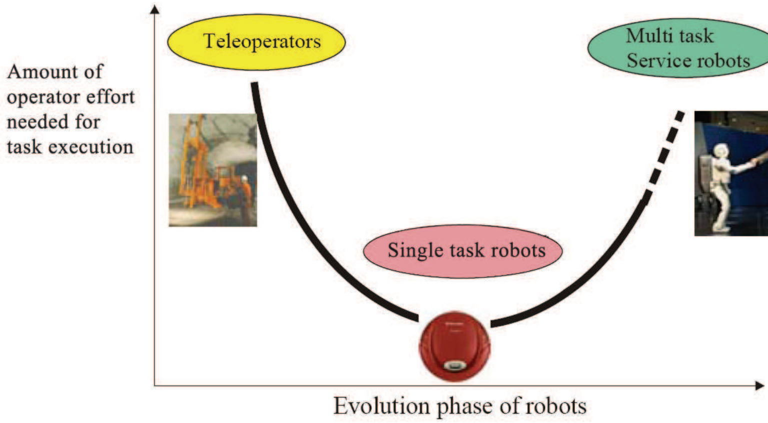

Fig. 1. Illustration of the amount of operator effort needed for task execution during different phases of robot evolution

2. The problem of getting service robots to work efficiently

It is quite clear today that without noticeable progress in the matter, the effort needed for operation of multi-tasking service robots will be even higher than in the case of classical teleoperators, because more data is needed to define the details of the work. The classical teleoperators have evolved greatly since the 1950's and today have reached a high standard of development especially through the development of tele-existence methods and technologies (Tachi, 1999). Teleoperators may be classified into four classes (Fong and Thorpe, 2001) due to their complexity, sensoring, and the operator supervision status, but altogether the way these systems are predicted to develop, they will lead to user information loads too large to be practical as a human-robot interface concept for interactive service robots. Thus new concepts are needed.

Intuitively it is clear that such concepts must utilize the superior cognition and reasoning capacity of human brains allowing fusing of different perception information and making conclusions on the basis of insufficient information. This means that controlling the robot must be based mainly on semantic or symbolic information instead of copying motions or following numeric models, which is the case even in teleoperation commanded in task level. The problem is how to get the exchange of information in such a way that the robot "understand orders" and actively interacts while performing them rather than follow them slavishly. Only in this way is there a possibility of keeping the user load within acceptable limits. The ultimate goal is to let the robots do skilled work, thought at first by the user, but gradually learned by the robot as an independent performance (Halme & all, 2006). By skilled work we mean here work tasks, which are individual in the sense that they need sensing and detail planning each time when executing, although the general plan how to do them has been already taught to the robot. Most of the work tasks in our living environment are such one because of inherent disorder and changes that occur without warning.

3. Interfacing with cooperative robots – the concept of common spatial awareness (CSA)

The approach to be considered in the following is based on the idea that as much as possible of the information needed to make the robot to perform a work task is given in symbolic or schematic form instead of numeric data. The environment itself should be utilized when possible. The human user can create relatively easily such information when using his/her cognition in the work place. The cognitive capacity of the robot is programmed so that transferring the user's will to the robot happens mostly in the form of dialogue, which makes sure that the task is uniquely defined and can be executed by the robot's internal commanding system. The dialogue is based on concepts and objects in a virtual world called Common Spatial Awareness, CSA. The CSA is a model of the working environment, which both entities can understand in the same way through their own cognition system. The detailed meaning of CSA will be explained later, but it is good to note that we use the term "awareness" here in a different meaning than psychologists, who often include feelings and imagination in this concept. In our pragmatic awareness concept the physical working place is the place, where both the human user and the robot try to be "as present as possible". The human user might be also tele-present there, but the robot is supposed to be physically present.

The CSA concept allow to divide the perception, cognition, planning and execution processes between the user and robot brains in a way that utilizes the strong features of both of them. Humans are usually good in cognition i.e. process their perception data in conceptual level and "understand" the environment. In the same way they are good in planning actions when only poor or partial data is available. Their perception is, however, not so good in many cases if compared to available machine perception. Robots can have a very accurate and sensitive perception, a good geometrical navigation system and they can repeat things untiringly in a same way. An optimal division of tasks in human-robot cooperation is to let the human to take care of the challenging (for the robot) cognition and planning tasks and to let the robot do perception and the actual physical tasks following so high autonomy as possible. Asking advice is a normal communication when human do cooperative work and it is also a useful tool in human – robot cooperation to avoid too complex control architectures in robots.

The CSA is not a uniquely defined virtual world, but rather a concept that can be realized in several ways depending on the application. The concept is illustrated in Fig. 2. The CSA describes those details of the working environments, which are necessary to communicate successfully tasks – in this case gardening tasks – to the robot. It includes both geometrical

and other information, which are able to be understood in the same way by human user and the robot. The fact that the information is spatially related is important, because all work tasks are spatial at least in some extent. In the gardening case the corresponding CSA could include a rough geometrical map of the garden, spatial information about planting, mobility restrictions, etc. Not all information needs to be fixed into a virtual model, but some can be also in the real environment as signs or tags readable to the robot. In such cases the CSA is not only a virtual world, but rather a combination of virtual and real worlds.
It is very important that the CSA can be constructed flexibly, quickly if needed and using different type initial data. The condition where the robot is to be used can vary from having almost zero apriori data (e.g. when the robot and user enter a new unmapped place) to data rich environment (e.g. user's well mapped home yard). In all cases the robot should be able to start working after a relative short initialization time, otherwise it is not considered as a useful tool. The underlying idea is to use very simple basic structure of CSA, which can be refined along the robot mission or if the robot is used repeatedly in the same environment. The case considered in the next chapters illustrates this idea.

Fig. 2. Common Spatial Awareness CSA describes those details of the working environments, which are necessary to communicate successfully tasks – in this case gardening tasks – to the robot.

4. Case WorkPartner

The research platform WorkPartner, shown in Fig. 3, is a humanoid service robot, which is designed for light outdoor tasks, like property maintenance, gardening or watching (Halme & all, 2003). The robot was designed as a multi-purpose service robot, which can carry on many different tasks. As the partner to the user it should be capable of performing tasks either alone or in cooperation with its master. In Fig. 3 WorkPartner is cleaning snow on a yard – a very common task in Finland in winter time. The colored beacon shown side of the robot is a part of the user interface equipment by the aid of which he/she can easily crop the area to be cleaned.
Skills for new tasks are initially taught interactively by the operator in the form of state diagrams, which include motion and perception control actions necessary to perform the

task. Design of the user interface has been done so that most of the interaction can be done (not ought to be done) with human like conversation by speech and gestures to minimize the wearable operator hardware. Different interface devices have also been developed to help the mutual understanding between robot and operator, especially in teaching and teleoperation situations.

Fig. 3. WorkPartner service robot cleaning snow from the yard

Although the WorkPartner robot is used here as a reference example, it should be noticed that many of the ideas and results presented are generic in nature and do not depend on the specific robot. Almost any mobile service robot with manipulation capability and with similar subsystem infrastructure could be used as the test robot as well.

4.1 Human-robot interface (HRI) equipment

The main functions of WorkPartner's HRI are

- communication with the robot in all modes of operation
- task supervision, assistance and collaboration
- task definition/teaching
- direct teleoperation
- environment understanding through common awareness
- information management in the home-base (Internet server)

The HRI consists of three main hardware components: operator hardware, robot hardware and home base. The home base component provides additional computing power and a connection to external databases (internet).

The core of the operator hardware is a portable PC including multimodal control interfaces, a map interface and a wireless connection to interface devices as illustrated in Fig. 4 - 5. The whole hardware is wearable and designed in such a way that the user can move easily in the same environment with the robot. The hardware is relatively versatile because it is designed not only for normal commanding and supervision, but also for teaching and teleoperation. Due to the nature of the work these functions might be needed without knowing it beforehand, so it is practical to make the whole system wearable at the same time. In certain cases, however, it is appropriate that the user can control the robot without wearing any operator hardware. Commanding by speech and gestures from close distances is used for this purpose.

The important interface components on board of the robot are camera, laser pointer, microphone, loudspeaker, head LEDs, and the arms. Besides for working, the arms can also be used for communicating in a dialogue mode, like a human uses his/her hands. The communication network with the operator and the home-base server is based on WLAN.

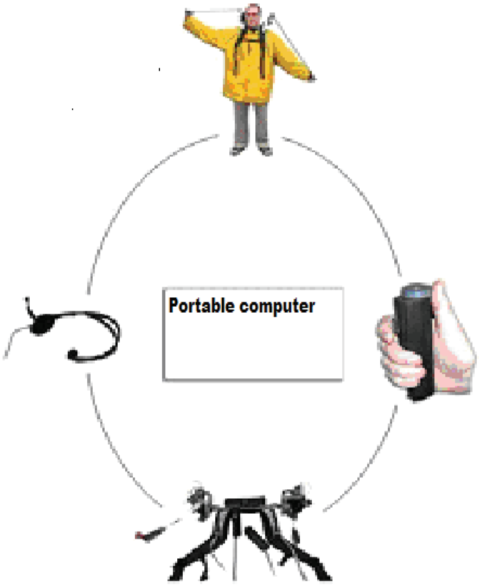

Fig. 4. User wearable hardware including "reins" (see also Fig. 9) and acceleration sensors for transmitting hand and body motions, and microphone connected to portable computer.

Fig. 5. Robot head includes camera, laser pointer and five LEDs.

4.2 Principle of interaction

The core of WorkPartner's interaction and cognition system is a software the main parts of which are the interpreter, planner, manager, and internal executable language (see Fig. 6). The *interpreter* takes care of the communication and receives the commands/information from the user. Information can be spoken commands, gestures, or data from any interface equipment. The data from interface devices and detected gestures are unambiguous and can be forwarded to the manager. Spoken commands are broken into primitives and the syntax of the command sentence is checked. If the syntax is accepted and all the other parameters of the command - such as the objects and their locations - are known, the command is transferred to the *manager*. In the event of shortcomings in the command, the interpreter starts asking questions from the user until the information needed to plan the mission is complete.

The *manager* forwards the interpreted command to the *planner*, which plans execution of the task as a set of subtasks The planner writes the plan automatically in the form of *internal executable language* (ILMR) (Kauppi, 2003), which controls the different subsystems of the robot during execution. ILMR is a XML type language acting as an intermediate link from the user, an intelligent planner, or a HRI to a robot's actions and behaviors. It provides ready features containing sequential and concurrent task execution and response to exceptions.

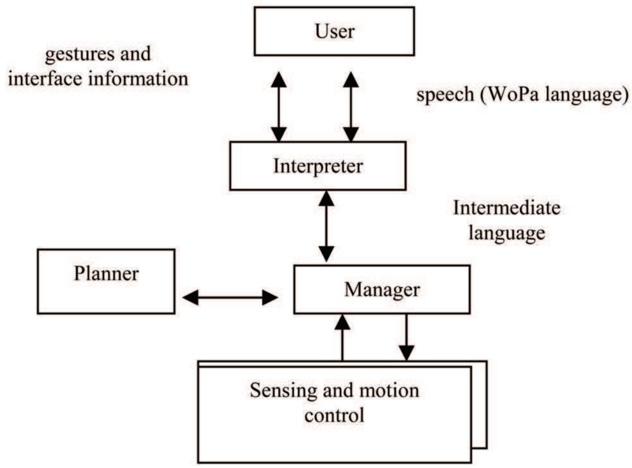

Fig. 6. Interaction principle of WorkPartner

The use of ILMR makes the software development much easier and has an important role when implementing learning capabilities for the robot. The following lines illustrates intermediate language commands

```
obsavoid(on)
speed(0.4)
createpath(myroute,1,1,5,1,5,10,8,13,15,20)
followpath(myroute)
sign1a=findtarget( camera,sign)
```

Due to the poor performance of the commercial speech processing software and the limited speech processing capabilities on board of the robot, the commanding language between

the user and the robot is formulated currently very strictly and the vocabulary is minimized. Language is based on commands starting with an imperative. For example **"Partner, bring box from hall"**. Command processing is executed interactively. The questions to the user are formulated so that they can be answered with one or a maximum of two words. "Partner" is the prefix that starts the command, "bring" is an action verb (go somewhere, take something and bring it back), "box" is an object and "hall" is a location attribute. The object "box" may be a unique object in the common presence or it may be one of the many boxes. In the latter case the robot asks more information. Anyway, the name indicates also form of the object, which is important for gripping process. "Hall" is a known location in common presence, but the location of "box" inside it may be not known. If not, it may be given by the operator by using a more specific definition (e.g. "near door") or the robot may start searching the hall to find the object.
To make actions like above possible a CSA model was developed supporting human task planning and the simple command language. The model is designed to be used in outdoor environment due to the robot design, but many of the principles are generic and applicable to other type of environments, too. The main ideas are explained and illustrated in the next chapters.

5. Spatial awareness in practice – constructing the CSA

In order to cooperate, the operator and robot must have similar understanding of the environment – at least of those elements of it, which are interesting in their mutual division of work. WorkPartner has a set of traditional robotic navigation tools (GPS, dead-reckoning and laser-based map matching), which it uses depending on the present situation. The pose (position and heading) in a fixed world coordinate system is known all the time. Therefore the spatial cognition of the robot can be related in its simplest way to a 2D map with fixed local coordinates and an object database that represents different properties of the environment or tasks to be performed in it. This combination of the map and objects can be visualized together as an occupancy grid to the robot and an object-oriented topographic type of map to the operator.
Making such a map is, however, not a straightforward matter, because connecting sematic information with the geometric one is not a simple task. Humans do not perceive the environment as numerical coordinates, but they can perceive and understand it well without this information. An essential feature in human shaping of the environment is entirety instead of details. Details are considered only after focusing attention to certain aspects motivated by a planned or on-going action. Coordinates are, however, natural for robots. A general problem is how to make both entities to understand the world with semantic information in a similar way. A classical approach to this problem would be to let the robot to recognize objects named by the user using a camera or other perception sensors, and put them on the common map. As well known, the difficulty of this approach is the automatic recognition of objects, which limits strongly utilization of such virtual world as the "common presence". What is meant by an object can be quite a general concept, not only a physical object, but also an abstract object illustrating future actions, like a hole to be drilled. On the other hand, if we allow human interaction the problem can be mostly overcame by letting the user recognize the objects and place them on the map by indicating them to the robot in a way it understands. There are many ways to do this. If the user has geometrically correct map available and he/she knows the position the object can be just be

placed on the map. The robot is not necessarily needed in this operation. Alternatively, when moving together with the robot he/she points the object in a way, which enables the robot to put it on the map. WorkPartner robot has two such pointing devices available, one is the laser pointer in its turning head and the other is “sceptre”, which is a stick with colored head used by the user (see Figure 11 below). A third way is to relate a new object to an already known object, e.g. “close to object A”, in which case the known object is used as a rough position reference.

It is important to keep the top level representation of CSA as simple as possible to allow human capability of shaping entirety work optimally. As mentioned before, this is done in a natural way by dropping out details until they are needed. One approach for this is a “box-world”, where the objects with approximately known location are represented on the global map by “boxes” or “ mini – worlds” inside which they exist. The boxes carry the names of the objects shown to the user so that he/she can outline the world both graphically and conceptually. The data base is object oriented so that details of the objects, their form, orientation, etc., can be obtained by clicking the corresponding boxes on the map. The principle is the same used in modern object based digital maps. Not all objects, however, are in boxes. Such objects exist in the database, but have no physical location (or the present location is not known). The objects may exist also without identity, say “ball”, in which case it refers to all ball objects in the common presence before identifying more.

The underlying idea when using the CSA is to get an easy to human way to transfer the task related information between the user and the robot. In the “box-world” outlined above the essential information for the user is usually related to the boxes and their mutual relations to the world. For the robot the “box-world” is only the navigation world. Tasks usually require entering “inside boxes” to find detail information needed in execution. Robot perception is supposed to be able to find and recognize the object when it is close to the corresponding box. Task execution can then continue in an autonomous mode using robot’s own perception or in cooperative mode, where the user helps using his/her perception. For the user the “box-world” can be represented in several ways graphically, augmented with a real picture from the environment or just as the real world, where positions are marked with signs, lines etc.

The methods to create a new CSA should be easy, quick, and reliable. Using existing may not be practical, because their validity may be a problem, and even if valid, fixing the local co-ordinate system in the right way and positioning the objects might take much time and effort. Using 3D- or 2D- laser scanners for mapping is a potential method, which is shortly described in the following.

Fig. 7 represents a laser range camera view from a parking place in the Helsinki University of Technology campus. Ranges are color coded and objects, like cars, building walls, etc. are easily recognizable for human cognition. In the next picture the user has cropped a car by mouse forming a box around it. He/she can immediate transfer this information to the presence model by giving a name (like “my car”) for the box. If the object “my car” is needed during a mission of the robot – e.g. when commanding to wash it - the robot knows that it can be found inside that box in the presence model (provided of course that it has not been moved). The box may include the accurate model of the car as illustrated in the last picture in Fig. 7. Such information has usually no use for the user when commanding the robot, but the robot may need it when doing its job (e.g. washing the car).

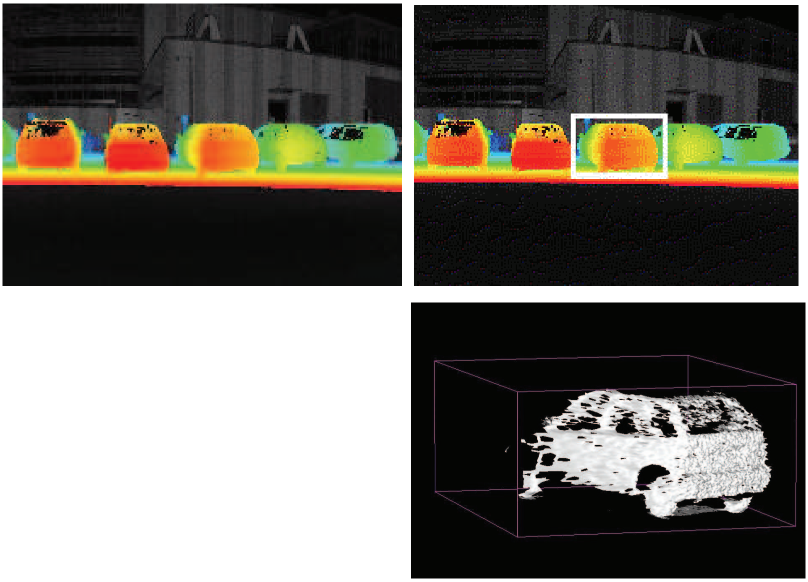

Fig. 7. Building up CSA “box-world” using 3D-range laser camera.

This is a process, where human cognition is used very effectively to create the CSA in a semi-automated way rapidly, reliably and a natural way including only the essential object information. After creation, only a simplified representation of the common presence is usually enough for operational purposes in the HRI.
Mapping of the basic geometry of the CSA can be done by many ways and means. Another possibility is illustrated in Fig. 8. It is a wearable SLAM system, which is based on a personal navigation system and 2D – laser scanner. The personal navigation system (PeNa), developed originally in a European Union PeLoTe project (Saarinen & all, 2004) for use in rescue operations, uses only dead-reckoning instruments, like a stepping odometer and heading gyro, because it is designed to operate without support from beacon systems. The stepping odometer is, however, fused with the laser-based odometer obtained by algorithmic processing of laser range data.

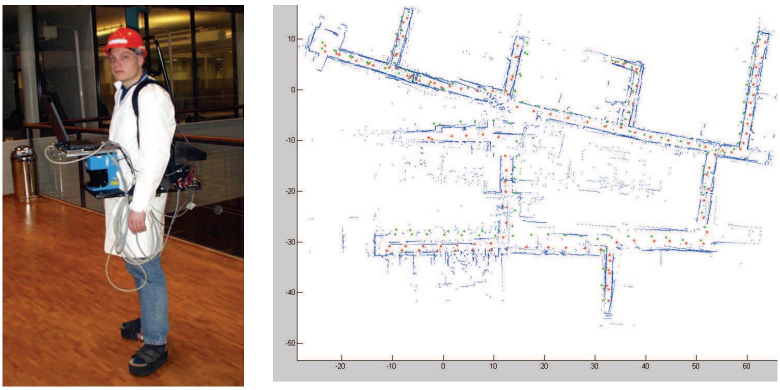

Fig. 8. Personal SLAM system developed in EU PeLoTe project.

Fig. 8 illustrates also the result when mapping of an office corridor environment. The map made by the aid of PeNa is quite correct in proportioning, but the long corridors are slightly bending. The bending effect is due to the dead-reckoning navigation error, mainly caused by gyro drifting and odometric errors. When used as the basic map of a common virtual presence such distortion has no meaning, because a human looks more at the topology of the map when using it and the robot relies on its sensors when moving and working in the environment. Mediating the semantic information between the entities is possible in spite of geometric errors as long as the human entity can understand the main features of the map and their correspondence in the real world.

7. Communication trough the physical environment - devices and means for interaction

When working with a cooperative robot, like WorkPartner, the human user needs effective means to communicate with the robot. When using a CSA model communication utilizes the concepts of this model. From the user point of view the CSA represents the world of robot understanding. From robot's point of view the user is only a special type of object that interacts with it. Interaction can be done directly or indirectly. The direct interaction means that the information goes directly to the awareness of the robot. In the indirect transfer the user leaves some kind of mark and related information to the real environment, where the robot can obtain it when needed. The idea of the common spatial awareness is best utilized when the indirect methods are used as much as possible, because the user uses then maximally his cognition and ability to perceive entireties. The user has then already been able to complete the geometric information with task related conceptual information and the autonomy of the robot actions can be probably increased during the work period. To illustrate this, some of the interaction means developed for WorkPartner robot are explained.

7.1 Direct teleoperation

Direct teleoperation is needed to test and move the robot when an intelligent part of the software cannot take over for one reason or another. This is the primary direct means to interact. In the case of the WorkPartner robot direct teleoperation is used e.g. to teach skilled tasks before they can be done autonomously. Another situation where direct teleoperation is used is when driving the robot from one place to another or testing its functionality. Because of the large number of degree of freedoms the robot has, a joystick alone is not a practical device for teleoperation. A wearable shoulder mounted device, called "Torso controller" was developed (see Fig. 9).

7.2 Gestures

Gestures (and expressions) are very typical and natural way of human communication. They are used both with the speech and without it (Amai et all, 2001; Fong et all, 2000; Heinzmann and Zelinsky, 2001). It is fairly easy to develop a sign language which is simple but rich enough in meaning for interacting with a robot. The problem, as in the case of speech, is reliable recognition of gestures used in the language. In the case of the WorkPartner robot, two different ways to detect gestures have been developed and tested.

One way is to use the camera head of the robot to track the operator, who uses a colored jacket as illustrated in Fig. 10. A colored jacket is used for two purposes, first to mark the user and secondly to facilitate the gesture recognition. The gestures are recognized by a feature extraction algorithm, which first extracts the jacket color from the picture. This method works fairly well within short distances and in moderate illumination conditions. Another method is to use the torso controller explained above. Hand gestures can be recognized on the bases of the wrist positions. This method is not limited by the distance to the robot, but the controller is needed. Using camera based recognition allows communication with the robot without any wearable equipment.

Fig. 9. Torso controller

Fig. 10. Use of gestures in commanding. Gestures are recognized by the robot's camera head, which tracks the colored jacket of the user.

Rich enough sign language can be constructed in most cases by the aid of simple static gestures, but by adding dynamic features to the gestures the language can be made more natural to use. Dynamic features are included in most sign languages used in human to human communication.

7.3 Pointing interfaces

Pointing is an important part of human communication. The purpose is to relate certain special objects with semantic or symbolic information or to give for an object a spatial meaning. Humans naturally use their hands for pointing but also technical means like pointers when the "line of the hand" is not accurate enough. In the case of human to robot communication there are several ways pointing can be realized. Pointing can be done through the virtual CSA by using a normal computer interface provided the accuracy obtained is good enough and spatial association with the object can be done easily (like in Fig. 7).

When pointing in the real environment a pointing device may be used. The main problem with handheld pointing devices, like laser pointers, is how to bring the pointed location to the CSA geometry, usually defined in a local coordinate system. In the case of the WorkPartner robot this problem has been solved by using the robot itself as the reference point. The navigation system of the robot knows all the time the robot pose, i.e. 2-D position and heading angle, in the local coordinate system. Two different systems are in use. In one of them the user uses the laser range finder assembled in the other eye of the camera head on same optical axes as the camera. The user points through the camera image by teleoperating the camera head. The pointed locations can be transferred to the robot base coordinate system immediately and then to the common presence coordinate system if needed. Objects up to 10-15 m distances can be pointed.

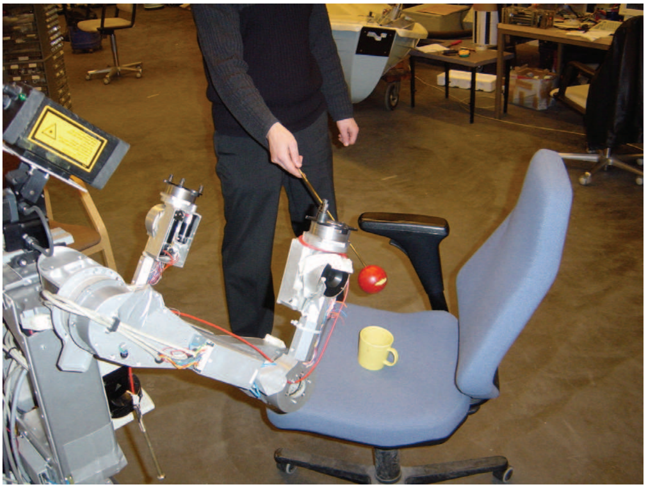

Fig. 11. Use of "scepter" for pointing.

The other system is called "scepter". As illustrated in Fig. 11, the scepter is a stick with a colored ball at the tip. The visual perception with color tracking follows the tip and measures the coordinates from the image when the operator indicates that the position is right. This system is applicable within close distances only, but it does not require any active devices be with the operator. In the picture the user directs the robots sight to the coffee cup when e.g. naming it as an object in CSA. The same principle is applied when the user uses himself as the pointer. By tracking the colored jacket of the user the robot can measure his/her position and also follow him/her when moving. For example by letting the robot record the trajectory of the motion the user can show the way to travel in a work task at the same time as he/she evaluates if the road is passable.

7.4 Using signs and marks in the real environment

One very old mean of indirect communication between humans is by signs or marks left to the environment. The same principle is also applicable in human to robot communication or even robot to robot communication (Kurabayashi et all, 2001). The signs can be passive but also active, so that they indicate their presence and information actively. Good examples of passive signs are traffic signs. Similar signs can also be used to conduct robot tasks in the working area, as illustrated in Fig. 12. The figure presents a hypothetical case, where a user has marked the home yard for a robot that helps in cleaning and carrying things in this environment. By simple color-coded signs it is easy to mark routes to travel, areas forbidden to cross, dangerous areas (like ditches), areas to collect litter, etc.

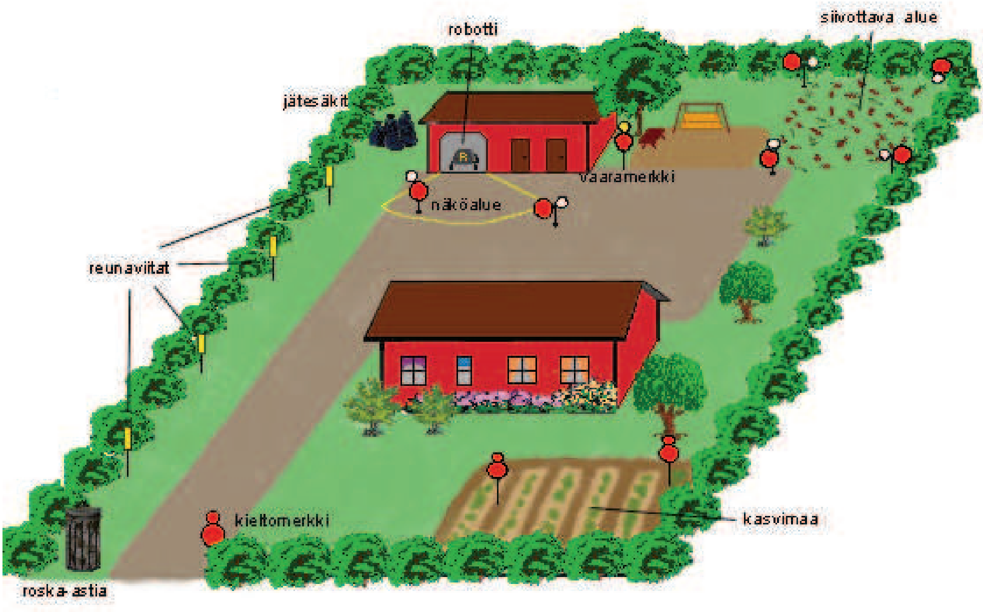

Fig. 12. Illustration how task conducting signs could be used in a home yard

One may of course mark them through the CSA model provided such one is available and accurate enough, but in many cases it is easier to just mark this information in the real environment and allow the robot to read it when close enough.

8. Conclusions and discussion

Communication by the aid of symbolic or semantic information between the user and the robot is essential in effective use of future collaborative service robots. This is possibly the only way to avoid the robots becoming masters for the users as long as the autonomy of the robots can be developed highly enough. Really skilled tasks reaching a sufficient level of autonomy is still far away. This way of building up a new type of HRI technology allows the user the possibility of using his/her superior cognition capacity to load the machine instead of it loads him/her.

The underlying idea in the presentation in this chapter is that this can be realized through ”common spatial awareness”, CSA – a concept of utilizing robot cognition together with human cognition. SCA is a virtual world presentation, which is understood in a similar way by all entities, robots and users, involved in the task. Semantic information related to the task and the real environment can be exchanged trough this world. The essential problems are how to build this world effectively, represent it for the user, and how to associate objects and concepts with it when the real world and /or tasks are changing.

In the presentation the idea behind this has been studied and demonstrated by the aid of the WorkPartner service robot developed at TKK Automation Technology Laboratory. The humanoid-type robot, having a simple command language, and the wearable user interface equipment allow the user to work with the robot in the same outdoor environment. Spatially bound information is essential in cooperative tasks. Various interactive methods and equipment have been developed and demonstrated to bring this information as a functional part of common presence.

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This book consists of 18 chapters about current research results of service robots. Topics covered include various kinds of service robots, development environments, architectures of service robots, Human-Robot Interaction, networks of service robots and basic researches such as SLAM, sensor network, etc. This book has some examples of the research activities on Service Robotics going on around the globe, but many chapters in this book concern advanced research on this area and cover interesting topics. Therefore I hope that all who read this book will find lots of helpful information and be interested in Service Robotics. I am really appreciative of all authors who have invested a great deal of time to write such interesting and high quality chapters.