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In today's hospital applications, service robots are mainly focused on single robots specialized to perform a well-defined task. These specialist robots support a restricted number of capabilities, need to get maintained separately and each robot provides its own specialized user interface. However, with the ongoing technological development, robots become able to cover more and more areas in the service field. The research project IWARD follows an approach to develop a robot system supporting various functionalities of current and future services for hospitals. To integrate several robots doing the various tasks a team concept has been developed that enables high efficient use of the robot resources and is adaptable to dynamical shifts of requirements in a hospital. The control of the robot team however is not restricted to technical staff: a single, intuitive interface provides low barrier access for all health care personal.

In IWARD many robots work together in a team to achieve an optimized task planning and scheduling. Since IWARD robots need to be capable to perform various different applications, they are developed following a modular design. The robots can get equipped with dedicated modules providing sensory and actors for a certain application. E.g. a cleaning module helps maintaining the hygienic standard. Having robots working in a hospital, safety and reliability are features of superior importance. This requires IWARD robots operating failsafe in any conditions, which includes the potential breakdown of any device of the system. For this reason it is not acceptable to have a centralized remote control of the robots. So, IWARD robots establish a team of full qualified self organizing robots. This means not only to have distributed plan-

ning and scheduling, but also to share a common model based on distributed perception assembly.

This paper introduces into the concept of IWARD with a special focus on the benefits of cooperative robot teams performing in a hospital.

Keywords:

IWARD, Robot, Service Robotic, Hospital Robots, Co-operative Robots, Modular Robots

## 1 INTRODUCTION

The domain of service robotics is a very fast evolving area. Development on service robotics is strongly supported by the European Commission as well as by national governments. Especially in the field of service robotics in the hospital sector, service robots have been developed for several years and first commercial solutions are available already. Until now, most of these hospital service robots have been single robots, developed for a specified purpose with very restricted capabilities. This leads to expensive systems that can hardly be afforded in greater quantities by hospitals. To program these robots the hospital staff needs to get special training. And there is no or only

# Cooperative Robot Teams Performing in a Hospital

poor integration of several robots into the hospital business.

IWARD ('Intelligent Robot Swarm for Attendance, Recognition, Cleaning and Delivery') concept introduces two new solutions to improve service robotics in hospitals:

1. Service robots acting as a team
2. Modular design of the robots

The co-operative approach provides a fully integrated robot system. All robots of IWARD system obey to the team and share their perceptions and information gathered with the robot collective. This way, decisions like 'which robot should do what' are solved by the system and transparent to the user. The co-operative approach enables the integration of different user interfaces for different tasks into one unique hu-

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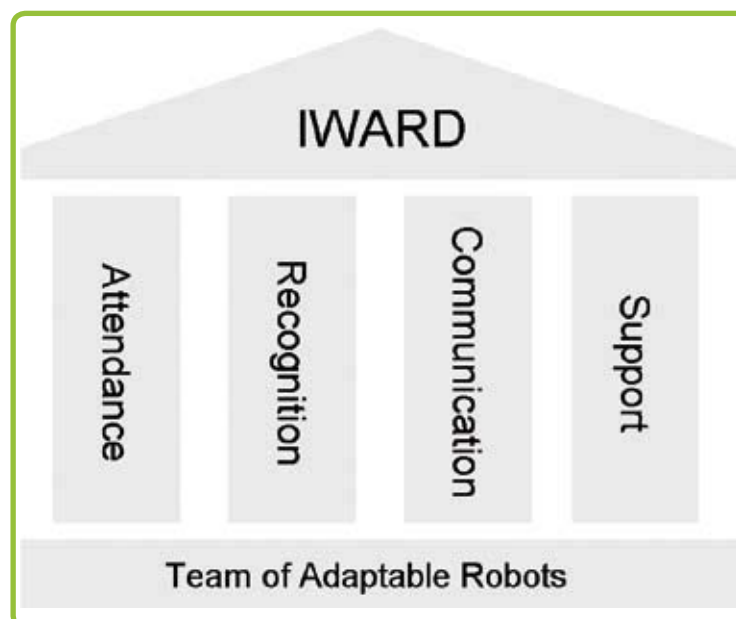


Figure 1:  
Concept of the IWARD approach

man robot interface that gives full control on the operations of the system.

A problem of existing service robots is: they are only produced in small numbers and therefore are very expensive. These robots are specialized on performing a single mission, e.g. like transportation of medicines. IWARD provides a solution for this by introducing a new modular design. It consists of an inexpensive base platform that is able to mount one or several modules. While the base platform only provides sensory for safe navigation and operation in the hospital environment, a module contains the technology needed for performing certain tasks. For example a module, consisting of a delivery box, enables a robot to perform delivery tasks. Benefit of this modular design is the flexibility in the robot configuration. The configuration can be adapted to the specific requirements of a hospital and also according to the actual requirements at runtime.

For mid-size service robots performing in a hospital, four fields of user requirements have been recognised: Attendance, Recognition, Communication and Support (Figure 1).

Monitoring the hospital wards, the IWARD system provides Attendance for the patients. This expands on the recognition of situation provided by the recognition column. Attendance enables the system to react on unusual situations, like patients lying on the floor, lost objects etc.

Recognition: camera equipped mobile robots are able to detect objects, persons and situations.

Communication provides a direct link between patient and staff. Camera equipped robots deliver pictures and video information from the concerned patient. Together with the Attendance, each robot is able to open a channel to the ward crew which shortens reaction time and reduces human error.

Support: The robots provide modules for assist in cleaning, guidance and transportation tasks. The cleaning modules help to maintain high hygiene levels. The hospital staff will be also supported in guidance tasks. Robots equipped with a guidance module are enabled to guide patients to a location specified (e.g. the X-Ray room). The transportation module assists in the transfer of medicine, documents (such as medical records or x-rays) between hospital departments and areas. Due to the sensitive nature of such documents a security system is employed to ensure that only authorized people can get access to the transported objects.

### 1.1 Co-ordinating a Team of Robots

Concerning the coordination of IWARD robots, two aspects need to be taken into account: One is the users view on IWARD system. Having robots in a hospital, full control on robot operation and safety are mandatory requirements. Therefore it is important to provide the user with an easy-to-use interface for controlling the robots activities. On the other hand, to benefit from the cooperative approach, it is the responsibility of the system to take care of task allocation and robot configuration. So, the second aspect of coordination is about AI solutions for operation strategies of robot teams.

### 1.2 User Interface

Users of IWARD have been identified as nurses, doctors and auxiliaries. Additionally, patients and visitors are also users within some scenarios, but since they are not allowed to control robots in terms of giving orders they will not be taken into account concerning the robot coordination.

The typical users (nurses, doctors and auxiliaries) share a common property: they are all steadily changing their location within



Figure 2:  
IWARD Terminal  
Interface



Figure 3:  
IWARD PDA inter-  
face (prototype).

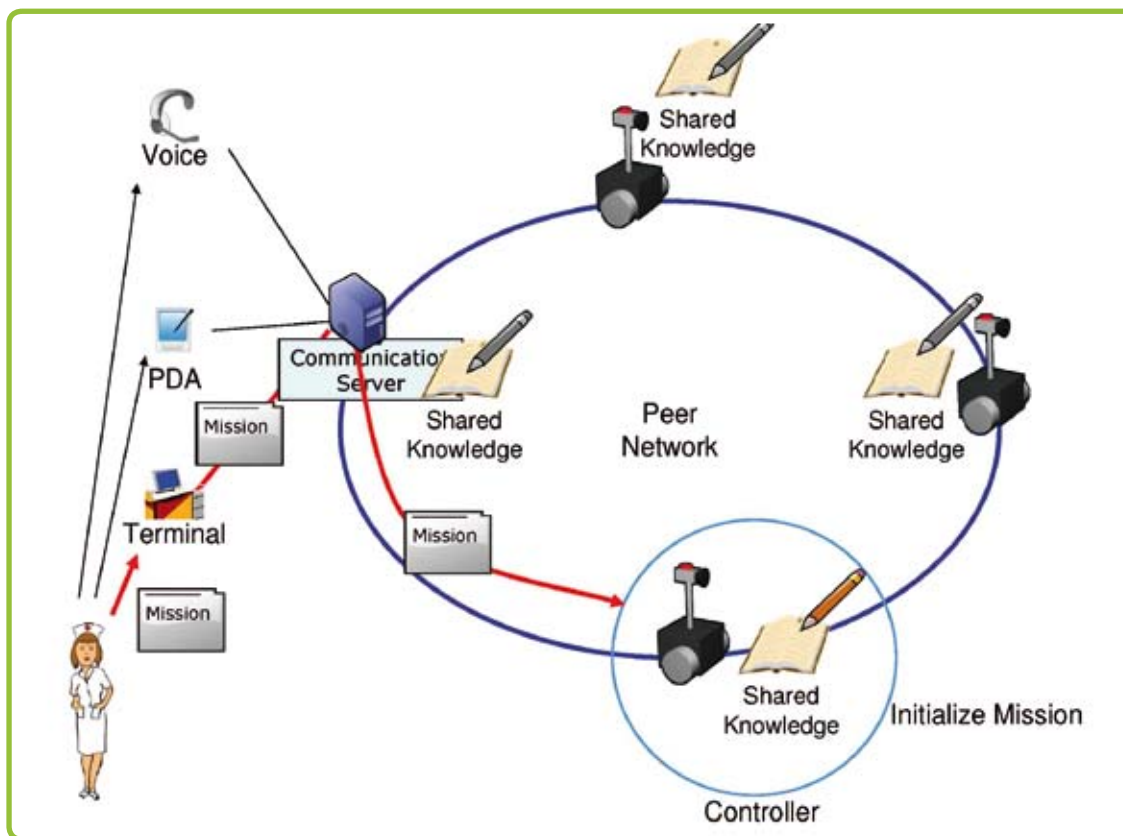


Figure 4:  
Interface using dif-  
ferent modalities.

the ward or hospital. So, it is not feasible to restrict the control interface to a fix computer terminal in an office. For this IWARD introduces different modalities of interaction, to enable the users to find the most suitable communication channel for every situation. Therefore, additional to the terminal interface, it is also possible to use mobile devices (e.g. a PDA) or phones (Speech Interaction) for communication. The robots are equipped with touch screens and sound that can be used for direct Human Robot Interaction (HRI). Even though, this way various interfaces are used, it is the aim of IWARD to provide interfaces that feel unique to the user.

One way to achieve this is to provide a common look and feel for all visual interfaces. But even more important is to have knowledge about current status of the user and the related orders available on all platforms used. This enables the user to decide which modality to use for HRI.

In the case, it is necessary for the robots to notify a certain user

(e.g. because an ordered delivery is available now or an emergency has occurred, etc.) IWARD HRI manager automatically chooses the most appropriate communication channel. For instance, if a user recently used his PDA to communicate with the robots, it is very likely that he can be informed of a delivery of medicine using the same PDA. Additionally, users can define for their profile the modality they wish to get contacted on.

### 1.3 Multi-Robot Operation

In a common understanding (e.g. James McLurkin, CSAIL, MIT) [1,2,3], a robot swarm is a group of multiple robots working together on a single task such as formation, combating forest fire, sea rescue, [...]

Swarm robotics is a new approach to the coordination of multi robot systems which normally consist of large numbers of relatively simple physical robots. The goal of this approach is to study the design of robots such that a desired collective or group behaviour emerges

from the inter-robot interactions and the interactions of the robots with the environment, inspired but not limited by the emergent behaviour observed in social insects, called swarm intelligence.

Swarm robotics emphasizes a large number of robots connected using only local communication. Potential applications include (1.) tasks demanding for extreme miniaturization, and (2.) tasks demanding for extremely cheap designs.

During requirements analysis of the hospital sector, it turned out that several characteristics of a common robot swarm do not comply with the situations and requirements hospitals: (Table 1)

Following this it appears that for swarms of mid-size service robots in a hospital environment a definition divergent from the common understanding of a swarm robotics is needed. It appears that the word swarm is misleading, since it generally is associated to individuals increasing the effectiveness of one mission, where midsize robots capable fulfilling a

Table 1

Standard Robot Swarm	Requirements for Hospital Setting
Working together on a single task	Variety of missions – delivery, cleaning, etc.
Large number of relatively simple physical robots	Fewer number of complex physical robots
Desired collective behaviour emerges from the inter-robot interactions and the interactions with the environment	Self coordinating robots within requirements of health care setting.
Using only local communication	Fail-prove communication is a must.
Tasks that demand for extreme miniaturization	At least mid-size robots required for HRI
Tasks that demand for extremely cheap designs	Affordable robots

Figure 5 : IWARD Robot Team



mission on their own don't benefit from additional robots directly. However, all robots contribute to the superior mission of providing efficient support for services in a hospital. Since this superior mission describes a quite abstract goal, it's not very obvious to accept it as similar functionality as we see ants contributing to support for keeping alive their population.

For these reasons it's been decided to define the co-operative IWARD robots as a "team of robots".

**IWARD Team of Robots**

- › A system of mid-size mobile robots that can be equipped with additional modules
- › Connected through a robust IWARD communication system

- › Coordinated by distributed/hybrid strategies to achieve desired collective behaviours
- › Capable of performing different types of missions in hospital context in order to optimise important performance indicators.

Main objective of the IWARD team of robots is to provide a safe self-coordinated behaviour. This is done by use of a distributed planning, scheduling and decision finding mechanism. To provide a common basis for this technology, robots perception as well as information about their current location and status is shared between all participants.

The IWARD peer system comprises all IWARD robots forming the team of co-operative mobile service robots for hospital environment in IWARD. Each IWARD

robot is represented as peer in the network complemented by further peers as the communication server. The peer system monitors the arrival/removal of robots in the peer network and provides the communication among all peers by WiFi connection.

The robot team behaviour implemented in IWARD is based on a distributed scheduling approach. The team of service robots handles each newly incoming service request (also called mission within the IWARD system) as follows:

1. The mission is transferred to the temporarily team Controller.
2. The mission is spread to all robots connected by the peer network for negotiation; negotiation is done by their individual/local calculation of costs that arise when adding the mission to their current schedule. Major criteria underlying the calculation are the robot's configuration, existing queue of tasks, position, power level as well as start & due time preferences and the importance of the mission.
3. The "cost statements" of all robots are collected by the Controller and the mission is assigned to the robot with the lowest cost offer.

Within the shared knowledge, information relevant for all robots is stored, e.g. the status of a mission; as each robot possesses

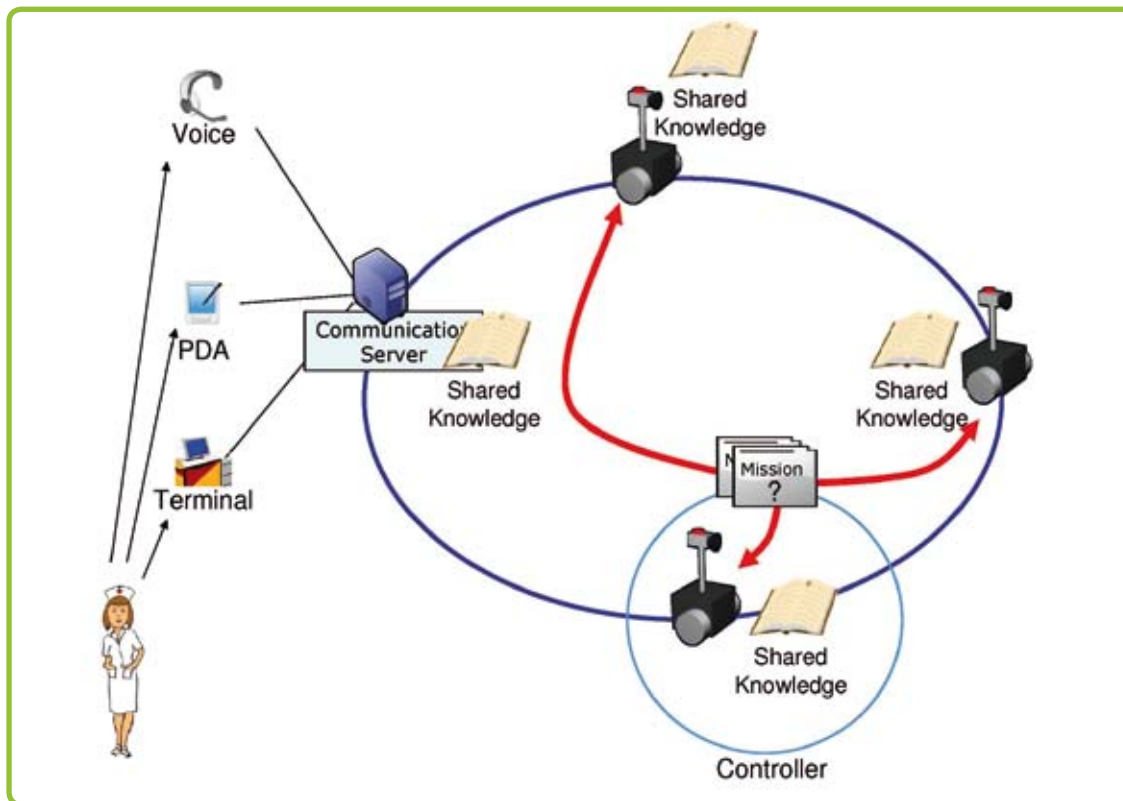


Figure 6:  
Mission Negotiation  
Process

access to a continuously updated copy of the shared knowledge, no data of common interest – in this case connected to the mission negotiation – gets lost.

The role of the Controller can be taken over by any peer of the network at any time. Hence in case of the peer currently being the Controller is failing, the role gets automatically assigned to another peer and further missions can be processed. Interrupted mission negotiation can be continued based on the information stored within the shared knowledge.

Details about the algorithm used for distributed scheduling and planning can be found in several publications [14, 15, 16].

#### 1.4 Safe Operation

Safety and reliability are features of superior importance for IWARD development and testing. So, it is crucial to have the robots operating in a fail-proof manner. This includes a potential breakdown of a robot or other devices attached to the system. Therefore central control of the robots is not ac-

ceptable. Because of this, IWARD establishes a team of full qualified self organizing robots that are able to operate autonomously in the case of network failures or in specified WiFi free areas. Fluent leaving and (re-) joining the network is assured by IWARD peer system. This layer of the network establishes failsafe communication between the robots and at the same time manages the participants of the network. Safe operation also means that the system cares for the robot's power status and assures that missions can be fulfilled by the robot selected. In case a robot detects "low power" during a mission or has other technical problems, the team decides [4] whether it is possible to send another robot to take over the mission or whether a human maintenance service is required to solve the problem. This avoids the situation of having an unnoticed robot lying broken down.

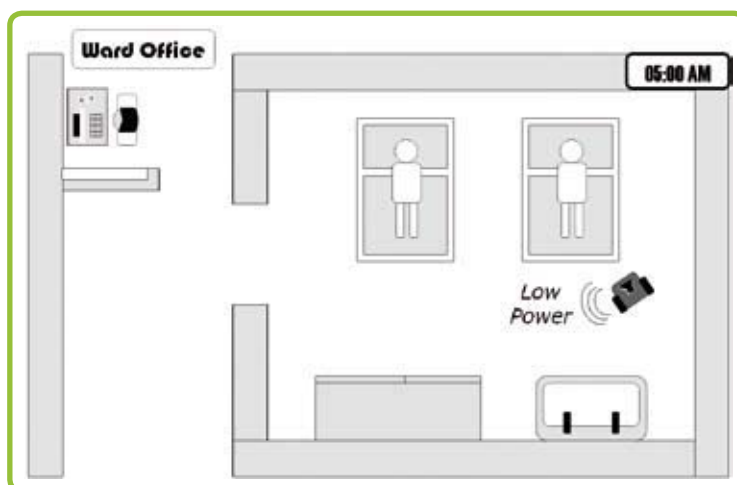
Safe operation in a hospital has many aspects. Even more important than the robot's capability to operate is to assure the safety of the persons located in the robot's

environment. For this, IWARD robots are equipped with a hi-sensitive sonar array that is used for obstacle avoidance, additionally to the robot's laser scanner. In the unlikely case an obstacle could not be detected, an active bumper mounted on the robots base will signal collisions and trigger an emergency stop.

#### 2 MODULAR DESIGN

To provide high level scalability and to enable an adapted configuration of the robots depending on a hospital's requirements, IWARD robots are designed following a modular design. A basic robot platform provides only sensors and actors needed for safe and reliable navigation of the robot. To apply functionality, like cleaning, guidance or delivery, modules need to be mounted on the robots. The attachment and detachment of the modules is implemented by the use of quick-fixture connections. So, the configuration of the robots can be changed very fast and very easily. For the first prototype three hardware modules are supported:

Figure 7 :  
Scenario: Self-coordinating robots.



Cleaning, Delivery and Guidance. But there are many examples for other tasks that could be implemented as IWARD modules.

### 2.1 Cleaning

The cleaning module supports two different cleaning modes: Regular cleaning and spillage cleaning.

For regular cleaning, a location can be indicated that will be cleaned by the robot following a defined schedule. This task normally will be repeated in a specific time period and can be taken into account by the team planning algorithm.

Spillage cleaning is ordered in case a spillage was recognized by a nurse or an auxiliary. Then the IWARD team sends a robot equipped with the cleaning module to the location indicated. This is a typical one-time task that can occur at random.

### 2.2 Delivery

The delivery module includes a delivery box that can be locked and needs authorization to open it. Main application for the first prototype is the delivery of medicine between the pharmacy and the wards.

### 2.3 Guidance

Guidance in a hospital is needed especially by patients and visitors. In the huge buildings of today's hospitals it is a common problem for foreigners to find their way to a certain location. The guidance module enables a robot to guide a person to any place known to the team.

## 3 IMPLEMENTATION & EVALUATION

Within the projects runtime, a robot team consisting of three robots has been developed. A video showing the features of the system can be found at [18]. As a proof of concept, the robot team is able to perform a set of services like Cleaning, Delivery, Guidance, Patrolling and Virtual Consultation. To approve the performance and acceptance of the system, the robots have been tested in simulation and also with health-care professionals (Nurses, Doctors, Auxiliaries ...) in real hospitals in UK and Spain.

At both testing places IWARD received very good ratings from the users. Details about the results can be found in [17] and will be subject of further upcoming publications.

## 4 RELATED WORK

Different mobile service robots for healthcare and hospitals have been developed in the past. They

provide support in taking over pre-defined tasks that regularly need to be done as part of the daily working process.

One major field of service application in hospitals is the use of autonomous robots for delivery. Some service robots specialised for delivery are exemplary listed below:

- › TUG[5] delivery system from Aethon:

It is currently used in 35 hospitals supporting delivery and tracking tasks of medicine, medical records and supply, specimen, food and laundry amongst others. A delivery box electronically locked ensures that only authorized people get access to the transported contents. An graphical user interface enables human-robot interaction via touch screen or hospital PC. Obstacle detection takes place by using a series of "light whiskers". In case of an obstacle blocking its way, it stops continuing to move after a short while by driving round the object.

- › RoboCart[6] from California Computer Research Inc.:

This cart was developed to transport materials in hospital environment, e.g. specimens or documents. Requesting the RoboCart and sending it to a specific location can be directly communicated to the cart by using a handheld personal controller. This service robot orientates on tapes pre-mounted on the floor which are flexible adaptable to the hospital environment.

- › SpeciMinder[7] from CCSRobotics:

This autonomous robot is specialised to safely transport specimens within healthcare facilities. Hence, a water-tight delivery box protects biological and hygienic risk. Accessing the carrier is restricted to authorised people so that security is ensured. The Speciminder usually patrols between emergency room and laboratory by using a map of the healthcare. However, it can also be manually

ordered to other locations to perform upcoming errands.

- › HelpMate robot from HelpMate Robotics Inc.[8]:

Another trackless delivery supporting service robot for usage in hospitals enabling the transport of medicines, supplies, prepared food, x-ray images mainly deployed in hospitals in the United States and Canada.

Virtual conferences systems are another popular area of application for mobile service robotics. A selection of virtual conferences systems is presented in the following:

- › The Giraffe Video Conferencing robot from Headthere[9]:

This mobile platform (equipped with a 2 mega pixel camera and speakers) provides a video conferencing system also used in hospital environments. The head of the Giraffe robot forms a 14 inch screen fixed at the average human height of approximately 1.8 m showing the conversation partner being logged in to the system remotely. The user (for example a medicine) is able to visit his patient remotely as well as navigating the robot remote-controlled.

- › RP-7 robot[10]:

This remote presence system from InTouch Health Technologies includes an easy-to-use control interface for improving the contact to patients. The real-time video allows for detailed viewing, examination, bedside monitors and equipment. Rapid responding cameras and PTZ head motions provide for quick and effective zoom and auto focus capabilities.

A third upcoming application range of service robots gaining in importance is mobile service robotics developed for assisting elderly people. Examples are:

- › NurseBot project[11]:

Within this project (of the University of Pittsburgh and the Carnegie University), PEARL robot was developed serving as reminder for tasks having to be done in daily life of elderly people. The tele-presence interface (microphone,

speakers and camera) included in the robot also provides a kind of virtual conference system enabling elderly people to have social interaction with relatives or medical staff in spite of often being for themselves the whole day.

- › Cogniron[12]

Cognitive Robot Companion project aimed to develop a robot which serves humans as a companion in daily life. This robot is considered as being able to improve its skills continuously by acquiring new knowledge. The project is focused on human-robot interaction providing the base for social behaviour and communication with humans dependent on the context.

Security robots as the PatrolBot[13] from Mobilerobots provide for example remote video functionality, instant camera zoom, snapshots on demand, a 2-way audio system and moving object detection. Unexpected situations and intruders detected while patrolling could be immediately reported to security staff.

In general, all service robots presented so far are relatively expensive, single robots specialized to a well-defined task. Their usage implies specific training for getting familiar with the system and their specific user interface.

## 5 SUMMARY

IWARD project aims to develop a team of cost-effective robots for hospitals.

The team approach enables unique operation of the system as well as a unique user interface. Very different and flexible configurations of the robot team are supported by the modular design. Hardware that is only used by a certain task can be equipped as needed. This way IWARD can be easily adapted to the specific requirements of hospitals. For evaluation of the IWARD approach, a team of three robots has been developed and tested.

Future research will be done in various areas: E.g. optimization of performance, situation recognition and the development of further modules.

## 6 ACKNOWLEDGMENTS

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