Robotic Home Assistant Care-O-bot® 3 - Product Vision and Innovation Platform

Birgit Graf, Ulrich Reiser, Martin Hägele, Kathrin Mauz, and Peter Klein

Abstract— **The development of a mobile robot to assist people in their home is a long term goal of Fraunhofer IPA. As a vision of a future household product, the latest prototype, Care-O-bot® 3, is equipped with the latest industrial state-of-the art hardware components and offers all modern multi-media and interaction equipment as well as most advanced sensors and control. Care-O-bot® 3 has been presented to the public on several occasions where it distributed drinks to the visitors of trade fairs and events. Current developments aim at applying the robot in an eldercare facility in order to support the personnel in their daily tasks.**

I. Introduction

INSPIRED by movies and television series, people have for a long time been dreaming of intelligent robots accompanying them in their daily lives and taking over unpopular and strenuous tasks. Such robots would not only be an enormous help to support the independence of elderly and handicapped people. Similar to domestic appliances, entertainment and IT systems they could contribute to enrich everybody's daily life.

The development of such a mobile robot able to assist persons in their home is a long term goal of Fraunhofer IPA. In order to meet this goal, three generations of Care-O-bot® prototypes have been developed so far: Care-O-bot® I was built more than 10 years ago: in 1998 – when the idea of building robots for applications outside of industrial environments was still new [11]. It consists of a mobile platform with a touch screen, able to navigate autonomously and safely in indoor environments, communicate with or guide people. Three robots based on the same hardware platform and control software as Care-O-bot® I were installed in March 2000 for constant operation in the "Museum für Kommunikation Berlin" where they autonomously move among the visitors, communicate to and interact with them [3].

Care-O-bot® II (Fig. 1, middle), built in 2002, is additionally equipped with a manipulator arm, adjustable walking supporters, a tilting sensor head containing two cameras and a laser scanner [4]. The manipulator arm, developed specifically for the robot, provides the possibility of handling typical objects in a home environment. A hand-held control panel is used for instructing and supervising the robot. In addition to the mobility functions already solved in Care-O-bot® I, the second prototype was able to execute simple manipulation tasks autonomously and could be used as an intelligent walking support.

Some major difficulties made it impossible to further proceed with the Care-O-bot® II platform towards long term installations in public and home environments: First of all, the platform was too big and the differential drive system not flexible enough to navigate in narrow home environments. Even more crucial was the concept of interacting and passing objects to and from human users with the robotic arm. By tilting its sensor head and recording the corresponding laser scanner data, Care-O-bot® II was able to generate a 3-dimensional image of the environment and plan collision free arm motions accordingly. However, as taking the 3-D scan took some time and was only executed once, the robot was not able to react dynamically to changes in the environment taking place after the 3-D scan had been taken. Therefore, a more suitable concept for safely passing objects to and from humans was required and was one of the main targets when designing the next Care-O-bot® generation.

Care-O-bot® 3 was built in 2008 and is equipped with the latest state-of-the-art industrial components including omnidirectional drives, a 7 DOF redundant manipulator, a three finger gripper and a flexible interaction tray that can be used to safely pass objects between the human and the robot. Its moveable sensor head contains range and image sensors enabling autonomous object learning and detection and 3-D supervision of the environment in real time. Care-O-bot® 3 was designed according to an overall concept suitable for a product vision, combining technological aspects with a compact and user friendly design.

Fig. 1. Care-O-bot® I, II and 3

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II. CARE-O-BOT® 3 HARDWARE

A. Safe Human-Robot Interaction

The primary interface between Care-O-bot® 3 and the user consists of a tray attached to the front of the robot, which carries objects for exchange between the human and the robot. The tray includes a touch screen and retracts automatically when not in use.

The basic concept developed was to define two sides of the robot (Fig. 2): One side is called the ‘working side’ and is located at the back of the robot away from the user. This is where all technical devices like manipulators and sensors which can not be hidden and need direct access to the environment are mounted. The other side is called the ‘serving side’ which is where all physical human-robot interaction takes place. The concept behind using the tray to interact with the user is to reduce possible users’ fears of mechanical parts by having smooth surfaces and a likable appearance [8]. On the technical side, it is much easier to ensure collision free interaction with the static tray than with a robotic arm moving freely in 3-D-space. As the locations where the robot autonomously grasps objects, e.g. in the kitchen, can be supervised by stationary sensors, moving the arm in the vicinity of humans can be avoided.

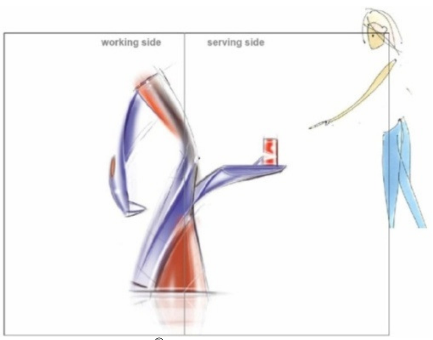

Fig. 2. Care-O-bot® 3 interaction concept

Using these described interaction concept, Care-O-bot® 3 enables the safe executing of fetch and carry tasks and thus provides the potential to operate a mobile, manipulating robot safely in public environments.

B. Mobility and Manipulation

Care-O-bot® 3 is driven by four wheels. Each wheel’s orientation and rotational speed can be set individually. This omnidirectional drive system enables advanced movements and simplifies complete kinematic chain (platform-manipulator-gripper) control. The wheeled drive was preferred to legged locomotion because of safety (no risk of falling) and stability during manipulation. The base also includes the Li-ion battery pack for the robot, laser scanners and a PC for navigation tasks. The size of the base is mainly determined by the required battery space. Nevertheless, the maximal footprint of the robot is approx. 600 mm and the height of the base is approx. 340 mm.

The torso sits on the base and supports the sensor carrier, manipulator and tray. It contains most of the electronics and PCs necessary for robot control. The base and torso together have a height of 770 mm.

The manipulator is based on the Schunk LWA3, a 7-degrees-of-freedom (DOF) light-weight arm. It has been extended by 120 mm to increase the work area so that the gripper can reach the floor, but also a kitchen cupboard. The arm is connected to a 7-DOF Schunk Dexterous-Hand with tactile sensors in its finger making advanced gripping possible. Special attention was paid to the mounting of the arm on the robot torso. The result is based on simulations for finding the ideal work space covering the robot’s tray, the floor and area directly behind the robot following the ‘two sides’ concept developed. Since the manipulator has a hollow shaft no external cables are needed.

The sensor head carries high-resolution firewire stereo-vision cameras and 3-D time of flight cameras, enabling the robot to identify, to locate and to track objects and people in 3-D. These sensors are mounted on a 4 DOF positioning unit allowing the robot to direct its sensors to any area of interest.

Fig. 3 shows Care-O-bot® 3 without covers and gives an overview of the single hardware components.

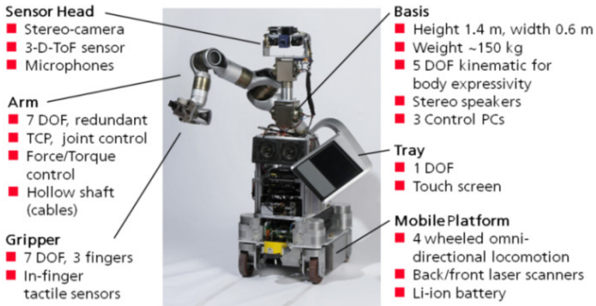

Fig. 3. Care-O-bot® 3 Hardware Components

III. FETCH AND CARRY TASK EXECUTION

The dependable execution of fetch and carry tasks provides the basis for a large number of assistive tasks in home environments. They require the dependable execution of the following key technologies: safe navigation among humans, object learning and detection, and object manipulation. The solutions implemented and used on Care-O-bot® 3 will now be described in further detail.

A. Navigation

In order to plan its actions, the mobile robot should know its current location at any time. The localization of Care-O-bot® 3 is based on two principles. Firstly, the current position and orientation of the vehicle is estimated by coupled navigation and mathematical integration of the travelled route. Where exclusive use is made of odometric information, however, small errors are unavoidable and these add up over time. Therefore, additional use is made of environment sensors, specifically the laser scanners attached to the front and rear of the robot, in order to detect significant environment features such as walls or poles. These features are checked against their reference positions, which are stored in a global environment map. Finally, the position of the robot is calculated in relation to the detected environment features.

Path planning allows a mobile robot to find a continuous trajectory from a given start configuration to a target configuration [6]. The previously learned environment map is used as the basis for planning, the planner taking into consideration both the geometry and kinematics of the vehicle and optimizing the path accordingly. This means that – given a suitable design of the vehicle – it is possible safely to negotiate even extremely narrow passages. Depending on the vehicle's operating environment, it is possible to choose between different planners.

Path optimization takes account not only of the environment map, but also current sensor data. This makes it possible to adapt the path to changing parameters, e.g. if a point on the planned path is inaccessible because of a dynamic obstacle, such as a person or piece of furniture. This task is solved using the method of "elastic bands", in which the path is modeled as a rubber band that is wound around detected obstacles and smoothed [9].

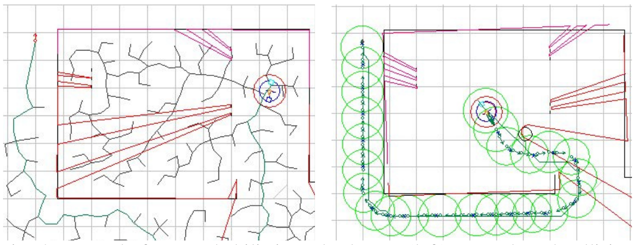

Fig. 4. Example for a probabilistic path planner (left), smooth and collision free path leading around an obstacle after path modification with elastic bands (right).

This component controls the smooth and efficient movement of the vehicle along the planned path. The realized software modules allow the control of a variety of vehicle kinematics from simple differential drives to omnidirectional wheels.

The control system for Care-O-bot® 3 is split in three hierarchical levels: The first level is the trajectory-tracking controller, which keeps the robot on its path. Then follows a controller instance that coordinates the four wheel modules and a third instance for each individual wheel module. The representation of the robots motion state is based on reformulating the ICM [1], similar the method proposed by Thuilot, D'Andréa-Novel and Micaelli [13].

B. Object Learning and Detection

In order to grasp an object, the robot must first be able to detect and locate it in the environment. By combining a range imaging sensor [12] with a color camera it is possible to upgrade conventional 2-D recognition processes from traditional grey- and color-image processing into 3-D recognition processes. To achieve this, a special calibration between the sensors is used in order to compute an approximate color image, the pixel coordinate system of which is brought into alignment with that of the depth-image camera. In the resulting "shared image" not only the color value, but also the distance of the respective neighborhood point is known for each pixel in the image (Fig. 5).

The recognition algorithm is based on scale invariant feature transform (SIFT) descriptors that are recorded for each object and fed into a learning algorithm (one-class Support Vector Machine, SVM) [7]. Using the data of the range imaging sensor, specific feature points can be segmented from the background. A region in space is effectively masked out in the color image of the scene using the range measures for the corresponding pixels in the range image.

New objects are taught to the robot by placing them in front of the sensors and by recording the relevant SIFT-key-points for the object [5]. Fig. 6, left displays the teaching of new objects using the proposed range segmentation. The right three images of Fig. 6 illustrate the learning process and resulting representation of an object: Several images of the object are recorded and for each the feature points are detected. In a second step, the feature points of all images are fused into a "feature point cloud" which again can be used to detect and compute the position of the object in a given scene.

Fig. 5. Depth image of a scene (left) and corresponding shared image (right)

Fig. 6. Spatial segmentation for object learning (left), side view of an object, detected feature points and corresponding feature point cloud (right three images)

C. Manipulation

Based on the data from the range imaging sensor and the identified location of the object to be grasped, a collision free trajectory for moving the manipulator to the detected object can be computed. To solve this, the robot and scene are modeled using »oriented bounding boxes« (OBBs) [2]. For the robot a distinction is made between static components (e.g. the robot's torso) and dynamic components (e.g. its manipulators). The dynamic components are mapped by articulated models which are updated with each robot movement. The model of the scene is obtained by generating corresponding OBB models from the point cloud obtained by the range sensor. The obstacle model is used as the basis for online collision monitoring. The algorithm consists of two main phases: determination of potentially colliding objects by a rough distance check based on the velocity vectors of all moving parts, and subsequent elaborate collision tests for all objects in the determined potential colliding sets [10]. Fig. 7, left shows the velocity vectors of a moving arm, Fig. 7 right shows the successful detection of potential collisions.

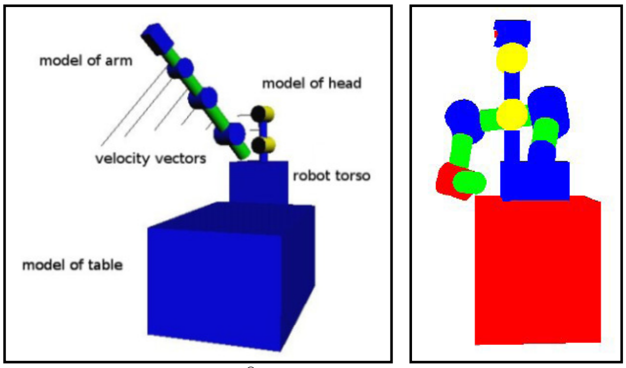

Fig. 7. Model of Care-O-bot® 3 standing in front of a table, lines indicate velocity vectors of moving parts (left). Detection of potential collisions between different parts of the robot illustrated in red color (right).

In the next step, the collision detection algorithm is coupled with a path planner. On the basis of the current robot configuration, the path planner calculates a collision-free path to the target configuration. The entire obstruction model is again used as the basis for the path search, with the result that the determined path is guaranteed to be collision-free with respect to both the robot's itself and also its environment.

IV. Public Presentations of Care-O-bot® 3

After its first public presentation at AUTOMATICA fair in June 2008 in Munich, Care-O-bot® 3 has been displayed successfully at several occasions such as the opening of the Fraunhofer inHaus in Duisburg and the Science Night in Vienna in November 2008. Care-O-bot® 3 showed its abilities to dependably grasp bottles from a shelf, place them on its tray, and hand them to the visitors. In Vienna, more than 100 bottles were passed to the visitors in one night. In March 2009 two Care-O-bot® 3 systems were displayed at CeBIT 2009 in Hannover where they presented themselves and their capabilities to the visitors in a multimedia show.

For the 50th anniversary of Fraunhofer IPA in July 2009, the scenario was further extended. The robot successfully opened a door in order to get to the next room where it grasped a cup from a cup holder and placed it on top of the bottle. Both objects were finally handed to the visitor who had previously ordered one of three available drinks using the integrated touch screen of Care-O-bot® 3 (Fig. 8).

During all public presentations we could observe a strong public interest in the robot, also coupled with significant press coverage. During the different trade fair presentations and the IPA anniversary, visitors of the robot were mainly adults, who not only confirmed their interest in a robotic home support in general but who also appreciated the high technological level of the Care-O-bot® 3 hardware and application software. During the science night presentation in Vienna, a large number of children enjoyed interacting with the robot. Sometimes the kids even struggled with each other in order to be the one receiving the drink from the robot. Among all exhibits of the science night, Care-O-bot® 3 was ranked place four by the visitors who had the possibility to vote for their favorite exhibit by SMS.

As could be observed, Care-O-bot® 3 and the topic of robotic home assistance is attractive for all age groups. Nevertheless, when looking at the demographic development, one of the most urgent application areas of the near future will be the assistance of elderly persons.

V. Application in an Eldercare Facility

The WiMi-Care project aims to implement and test first application scenarios for service robots in an eldercare

Fig. 8. Care-O-bot® 3 executing fetch and carry tasks: order by touch screen, grasp a bottle, pass door, hand bottle and cup to visitors.

facility. Based on an observation of their daily task and a survey conducted with the personnel of the selected eldercare facility, the following observations were made:

The staff described time-consuming routine tasks concerning logistics as a main difficulty. Especially transport-jobs would keep them busy and prevent them from their actual care-work. Besides, carrying heavy load is a health risk for the staff. Another central problem is seen in the adequate supply of the inhabitants with water since elderly people tend not to drink enough. Thus, one of the care workers' most important jobs is to offer drinks to the patients. In addition to providing the elderly with water at a regular basis, it is often necessary to also record the amount of water taken every day in order to induce adequate measures in case an inhabitant has not drunk enough and thus ensure his or her well being. A third difficulty concerns the night shift when the staff is reduced to a minimum. Often one care-worker is responsible for thirty inhabitants at night. The staff reported that there would be a massive overwork in case of emergencies and sometimes even during the day. These results also show that in addition to regular care tasks there is only little time left for entertaining activities with the elderly people or even to motivate them to interact with other inhabitants. As a result some inhabitants stay by themselves and slowly lose their communication capabilities.

Based on to these problems several scenarios for applying mobile service robots in such environments have been worked out. In order to guarantee the usefulness of the application scenarios they were presented to the staff of the facility and all received positive feedback.

Simple robots without manipulation capabilities can thus be applied to patrol the building at night and report emergencies. They can also be applied for delivery tasks, e.g. to provide emergency equipment to the staff in case an inhabitant of the eldercare facility has been injured or to execute standard transport tasks, e.g. medicine, food, laundry or mail.

Application scenarios for Care-O-bot® 3 were chosen according to the advanced capabilities of the robot. The selected scenarios thus require manipulation or special interaction capabilities that only a robot as complex as Care-O-bot® 3 can provide.

As a first application scenario the delivery of water to the inhabitants of the eldercare facility was chosen. In our scenario the robot will help itself to a cup of water from a water dispenser and fill it up. It will then patrol within a specific area of the building and look for persons. Being able to identify the single inhabitants of the eldercare facility Care-O-bot® 3 is able to offer water to persons who have not yet drunken enough for the day, either by passing the cup through its tray or by placing it to a table next by. Being connected with a database, Care-O-bot® 3 can record to whom a drink has been given.

The second scenario deals with entertaining the inhabitants of the eldercare facility. Using the interactive touch screen of Care-O-bot® 3 inhabitants can select music or fairy tales to be played. The robot here serves as a basis for discussion among the inhabitants. It can additionally be used by the inhabitants to play board games together or against the robot.

VI. Social Impacts

First studies and research results show that a forecast of the future scenario "Care-O-bot® 3 in eldercare facilities" is quite difficult to make. Currently the use and distribution of technology and automation in the (German) healthcare-sector is one of the areas where technology and automation is spread least. In contrast to the medical- and hospital services where machines and computers are quite common – elderly care so far is predominately done without any technical support. A basic question arising from this context is: Will robots be accepted by patients in healthcare facilities? And same as important: Will the care-staff and the silver-agers' families will agree to them?

Many hopes are put into the development of care robots. Robots could help to eleviate the stress and burden of care work by taking on time-consuming, yet routine tasks, and freeing up health care workers to focus on higher-skilled aspects of care provision.

Fig. 9. Care-O-bot® 3 application scenarios: fetching water from a water dispenser, delivering water, and being used as an entertainment platform.

For the patients with acute care needs, robots may lessen their dependence on care workers and contribute to their ability to lead more independent daily lives. Our studies conducted at the eldercare facility have shown that some of those hopes might be fulfilled. In fact there are several tasks which Care-O-bot® 3 could already do or soon be able to achieve the necessary technological development - as presented in chapter V. Especially the lack of well educated staff in the healthcare sector is a growing problem. Automatic solutions for transportation, documentation and other routine tasks would help to reduce the amount of work and thereby be a relief for the service providers. Patients might also benefit from Care-O-bot® 3. The robot can patiently serve drinks and offer activities whenever they want.

The successful development of autonomous mobile-robot-assistants depends significantly on the well-balanced reconcilements of the technically possible and the socially desirable. Indeed everyday transports e.g. laundry, medication and meals are likely to be a very successful scenario. The extensive requirement analysis within a maintenance area confirms this:

"Yes, the scenario with the laundry-transport, I like it."
"Serve meals for example. Yes, I could imagine this."
(Interviews with care workers)

Those positive statements can be generalized for nearly all routine tasks. In contrast the imagination of robots doing *care* work (e.g. feeding, personal hygiene) doesn't find any acceptance at all. There are some worries coming up with the imagination of a care robot future: Both, patients as well as staff are afraid of losing social contacts with one another. In this point of view Care-O-bot® 3 is seen as a competitor. The (sad) conclusion is that most of the attention elderly people in eldercare facilities get is the attention of the staff while doing the care-work. Furthermore the health care workers are afraid of unemployment. These uncertainties have to be considered as quite inconsistent, because they are also aware of their safe job-position regarding the labor market situation.

Nevertheless all of those fears have to be taken seriously if innovations in the field of care services shall be promoted. For the next ten years, high-tech-solutions like Care-O-bot® 3 are likely to have much resentment in the field of eldercare facilities. Within the next generation the situation will surely change.

VII. Conclusions and Current Work

Care-O-bot® 3 has been displayed to the public successfully at several occasions. The task of the robot was to detect and grasp bottles that were then handed to the visitors of the event. Current work focuses on improving and extending this application scenario and to implement and evaluate first application scenarios as described in chapter V to operate the robot in an eldercare facility.

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