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

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Abstract. The development of a mobile robot to assist people in their home is a long term goal of Fraunhofer IPA. In order to meet this goal, three generations of a robotic home assistant "Care-O-bot®" have been developed so far. As a vision of a future household product, Care-O-bot® 3 is equipped with the latest industrial state-of-the art hardware components. It offers all modern multimedia and interaction equipment as well as most advanced sensors and control. It is able to navigate among humans, detect and grasp objects and pass them safely to human users using its tray. 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.

Keywords: robotic home assistant, Care-O-bot, product vision, navigation, manipulation, object learning and detection, safe human-robot interaction, fetch and carry tasks.

1 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

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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 accordinag 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

2 Care-O-bot® 3 Hardware

2.1 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.

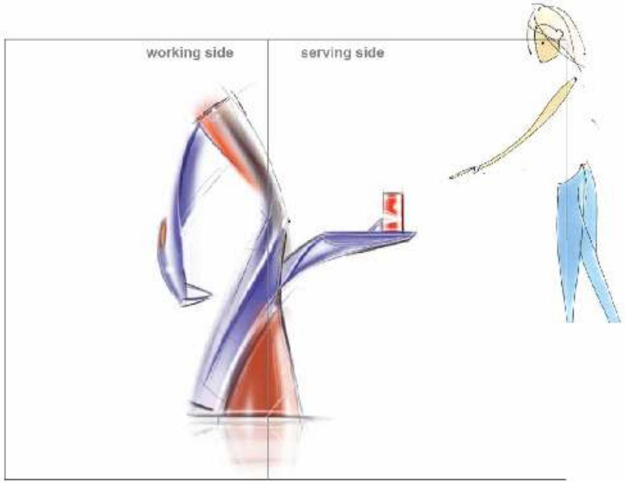

Fig. 2. Care-O-bot® 3 interaction concept

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.

2.2 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 simplifyes 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.

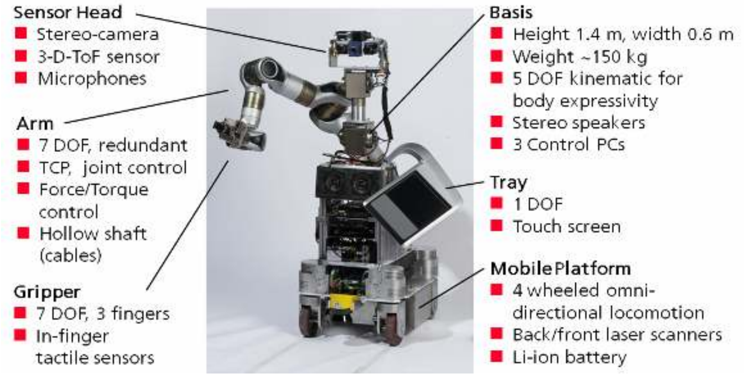

Fig. 3. Care-O-bot® 3 Hardware Components

3 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. Fetch and carry tasks usually consist of the following components:

1. Accept user command
2. Move to target position
3. Locate desired object

4. Grasp object
5. Bring object to user

In order to execute the single steps, the following key technologies need to be solved: 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.

3.1 Navigation

Localization. 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 and Path Modification. 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].

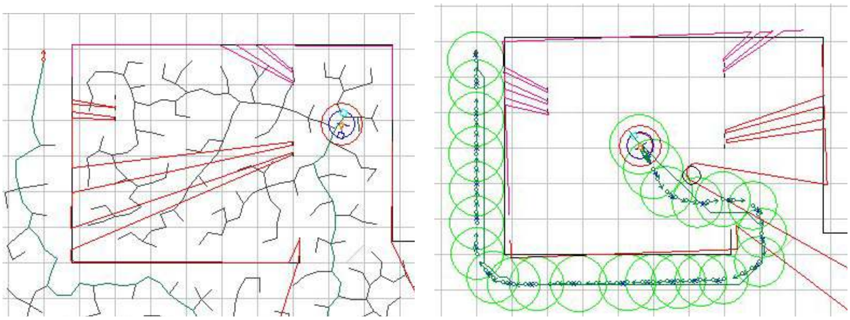

Fig. 4. Example for a probabilistic path planner (left), smooth and collision free path leading around an obstacle after path modification with elastic bands (right)

Motion Control. 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].

3.2 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)

3.3 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 middle and right show the successful detection of potential collisions.

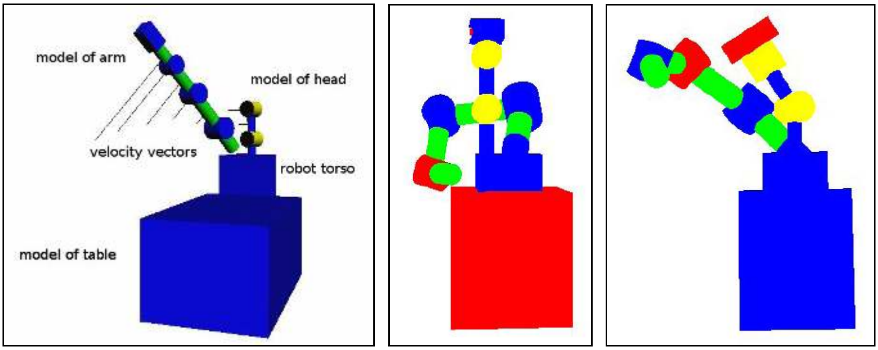

Fig. 7. Model of Care-O-bot® 3 standing in front of a table, lines indicate velocity vectors of moving parts (left). Detection of potential collisions between different parts of the robot illustrated in red color (middle, right).

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.

4 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.

Fig. 8. Care-O-bot® 3 presentations at AUTOMATICA fair (left) and in Vienna (middle, right)

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