Entertainment Robotics: Examples, Key Technologies and Perspectives

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Abstract

Based on the successful hardware and software architecture of Care-O-bot [7] [9], a new generation of mobile robots has been designed at Fraunhofer Institute of Manufacturing Engineering and Automation (IPA). Three robots have been created to communicate with and to entertain visitors in a museum. Their tasks include welcoming visitors, leading a guided tour through the museum or playing with a ball. The robots have been running in this museum daily since March 25th 2000 without noteworthy problems. In this article the hardware platform of the robots and the key technologies for applying mobile robots successfully in public environments such as navigation and communication skills, safety concept, and handling are outlined. Further the underlying control software of the robots is described. Finally the application of the robots at the 'Museum für Kommunikation' in Berlin is presented and perspectives for future installations of mobile entertainment robots are given.

Keywords: Mobile Robots, Museum Robots, Software Architecture, Navigation, Safety.

1 Hardware Platform

Figure 1. Basic platform and "fully dressed" museum robot
(© Museumsstiftung Post und Kommunikation)

Each vehicle is equipped with two driven wheels (differential drive) including shaft encoders for motion tracking. The robots are able to move at a speed of up to 1.2 m/s. Four castor wheels are further used for keeping the robots upright. A gyroscope is integrated in the robot platforms to track their current orientations.

A 2D laser scanner is attached to the front of each robot. The laser scanner is used for self localization, navigation, and obstacle detection.

Additional safety sensors are a bumper at the bottom of the robots and several infrared sensors which are integrated in the bumper facing upwards. These sensors are used to detect obstacles above the scanning level of the laser scanner. Activating one of the safety sensors as well as pressing either of the emergency stop buttons results in an immediate stop. Besides software restricting the allowed operation area, a magnetic sensor facing towards the ground is used as a secondary system to prevent the robots from leaving their assigned area. This area is bounded by a magnetic band lowered in the ground.

Being equipped with several long lasting batteries the robots are able to move independently for up to ten hours without interruption. For daily operation the robots can be recharged over night.

2 Software Architecture

The control software for the mobile robots is based on the object oriented 'Realtime Framework' and the software library 'Robotics Toolbox', both developed at Fraunhofer IPA. The Robotics Toolbox is an extensive software library, which – in several independent packages – contains modules for implementing all necessary service robot control functions. Furthermore, the use of rapid prototyping methods is being supported by adequate simulation and test environments for all modules.

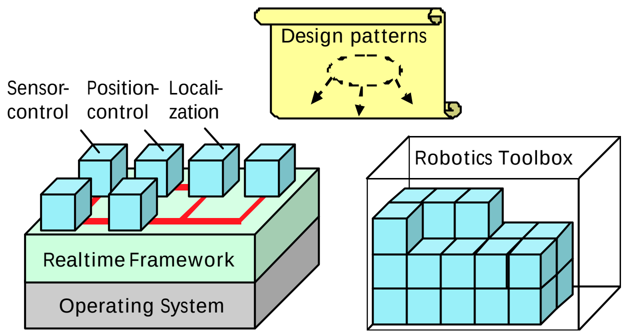

Figure 2. Software Architecture

The Realtime Framework [10] supports the software developer in designing a service robot application. It enables simple and fast integration of single Robotics Toolbox components to an application (Figure 2). The framework provides the structural integration of threads and components (automatic initialisation/deinitialisation, error treatment, etc.). The communication functions of the framework include mechanisms for highly efficient and real-time capable local communication as well as mechanisms for implementation of distributed communication, e.g. for remote diagnosis. The Realtime Framework further presents an abstraction layer for operating system functions and thereby improves the portability of the control software.

3 Robot Features

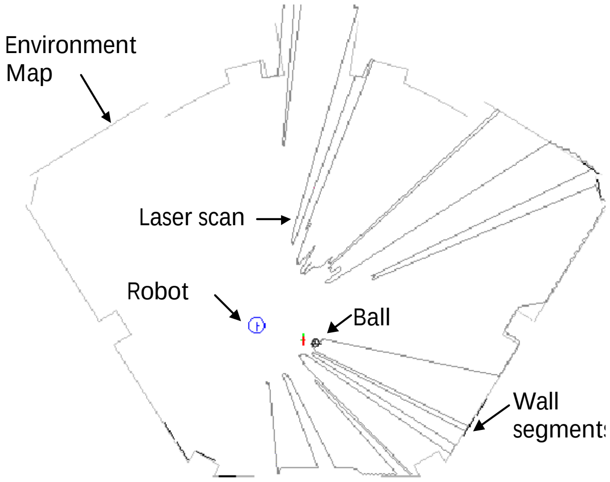

Figure 3. Screenshot of a robot during operation

The following navigation skills have been implemented and tested on the mobile robot platforms:

3.1 Self Localization

Self localization is based on data gained from the wheel encoders (position in x and y) and the gyroscope (robot orientation). However, while using these functions small errors are unavoidable and sum up over time (e.g. 6 degrees of drift per hour for the gyroscope). Therefore the robot's surroundings are modelled in a map (Figure 3). By comparing segments found in the natural environment of the robot (e.g. walls, doors), laser scanner data can be matched to the given map and the robot can correct its position. Information acquired by this method is merged with odometric data using a Kalman filter.

3.2 Robot Motion

Three different types of robot motion planning can be distinguished:

Program controlled navigation: In order to easily specify motion plans for a mobile robot, the "Mobile Vehicle Command Language" (MVCL) has been developed. It allows to write operation programs as simple ASCII files. Operation programs provide the possibility to easily synchronize motion, multimedia and upper axis control commands.

Reactive navigation: In this mode, the current target position for a robot is constantly recalculated in reaction to its environment. Selected objects of a given shape can be detected by the laser scanner (e.g. the ball in Figure 3). The robot then drives to a computed intercepting position.

Preplanned path: If the robot is supposed to move to a certain target position, it will plan the shortest path to this position based on a static map [4].

3.3 Safety concept

One of the most common accidents caused through industrial robots is a person being hit by the robot [1]. For stationary robots the responsibility lies partly with the user – safety measures, as e.g. keeping a certain distance to the robot, must be obeyed. For mobile robots, however, all responsibility lies by the vehicle, therefore the major goal for safe operation should be to prevent a mobile robot from driving into people or from leaving its operation area which might lead to additional incidents as e.g. by a fall down stairs onto people.

For maximum safety a redundant three level safety system has been implemented on Fraunhofer IPA's mobile platforms.

Level one is the laser scanner based collision detection. Whenever an obstacle is detected in the robot's vicinity, the speed of the vehicle is reduced at a degree depending on the distance to the obstacle. If an obstacle or a person gets too close to the vehicle, the robot will stop and wait until the area is clear again.

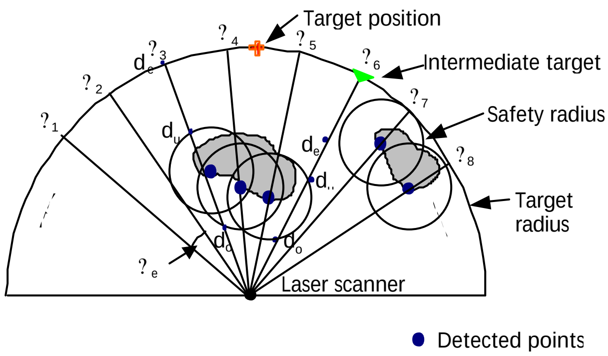

Figure 4. Reactive obstacle avoidance using the "PolarBug" algorithm

The safety module "obstacle detection and surrounding" (Figure 4) is applied in order to avoid unnecessary acceleration and deceleration caused by the collision avoidance. Obstacles detected by the laser scanner are surrounded in advance. The reactive obstacle avoidance algorithm PolarBug [2], based on the VisBug method [6] is being used. This algorithm has been developed especially for obstacle detection with a laser scanner, as well as for fast reaction and navigation in unsteady environments. The major difference to common obstacle avoidance algorithms is the direct processing of the laser scanner data (polar coordinates) which enables a very high efficiency of the algorithm.

Data not only in the planned path of the robot, but all measurements of the laser scanner are evaluated. In case obstacles have been detected between the current position of the robot and a given target, an intermediate position is being calculated which brings the robot around the obstacles as fast as possible. The best free passage is found considering several parameters like e.g. width and depth of passage, deviation of passage from direct line to target and distance of intermediate position to robot and final target position. All relevant factors are joined using a fuzzy logic approach.

Apart from the laser scanner the robot is equipped with a rubber bumper all around the vehicle. Activating the bumper results in an immediate stop. The operation speed of the robot is initially restricted depending on the size of the bumper – so that it can always stop before the bumper is crushed completely. In order to secure the area above the laser scanner, several infrared sensors have been integrated in the bumper facing upwards.

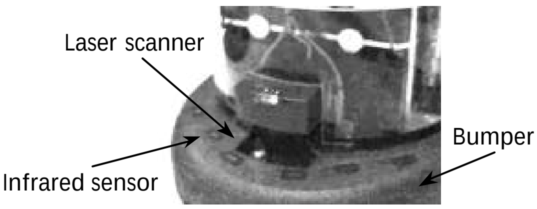

Figure 5. Safety sensors

Thirdly, each robot is equipped with magnetic sensors facing to the ground. They are used as a secondary system to ensure no robot ever leaves its operation area. In the unlikely case of a software failure, by leaving the given operation area and therefore crossing a magnetic band lowered in the ground, an emergency stop will be activated. In addition, each robot is equipped with two emergency stop buttons to deactivate the robots manually.

For applications where the mobile robots move among people in public environments, this safety system has been accepted by the responsible professional association. Furthermore, a CE certification could be acquired for the robots.

3.4 User Interface

Entertainment robots must designed to be used by inexperienced personnel. A joystick with two buttons is the only device necessary to set the robots in operation and to shut them down afterwards. After a robot has been switched on the operator can use the joystick to put the robot in the different start-up modes, such as initial localization and self test. The robot will guide the operator by giving speech output according to its current mode until it starts its default operation mode. For shut down the robot automatically returns to its default rest position before switching itself off.

4 Museum Application

In order to entertain visitors in the recently 'Museum für Kommunikation Berlin' – opened up in March 2000 – with a new technical attraction, three mobile robots have been built and programmed by Fraunhofer IPA [3] [8].

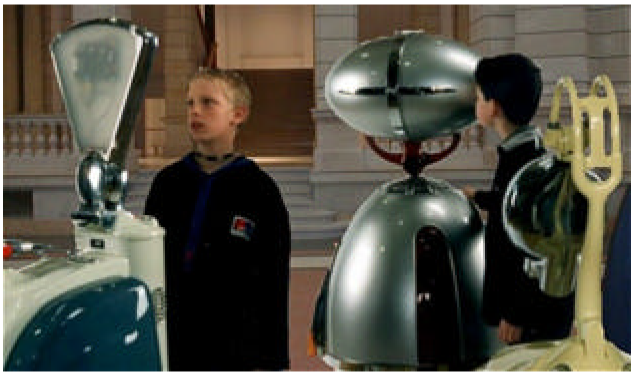

Figure 6. Entertainment robots in the "Museum für Kommunikation" Berlin (© Museumsstiftung Post und Kommunikation)

4.1 Description of Robots

Each robot has a specific character, expressed through its looks and appearance (driving speed, voice etc.). The robots also differ in what information they give to the museum visitors:

The Inciting: This robot acts as an entertainer. It approaches the visitors and welcomes them to the museum. It moves smooth, but determined at a speed of up to 0.4 m/s. Speech output is further underlined by movement of the robot's head. The robot uses its laser scanner to detect visitors. It looks for features like diameter, shape and distance and then uses fuzzy logic to determine which objects in its surrounding are pairs of legs. The robot distinguish between single persons and groups and uses different sets of welcome phrases for each case. An additional feature is that the robot memorizes the position of persons it has already welcomed for a certain time. During that time it will not welcome people at the memorized positions. Thus it is prevented that the robot welcomes a person several times.

The Instructive: Acting as a guide this robot gives tours in the museum. It moves along straight lines at a speed of 0,3 m/s. The instructive gives explanations about the exhibits of the museum. Moving its head up and down symbolizes the robot looking at the object it is currently talking about. Explanations are further underlined by pictures or video sequences shown on the screen of the robot.

The Twiddling: The child in our "robot family" is, according to its character, unable to speak properly and runs around the museum playing with a large ball. This robot moves rather fast at a speed of up to 0.6 m/s and aims at a ball of a specific size as long as it can detect it. Using its laser scanner it detects the ball by its shape and size, similar to the way The Inciting detects people. This robot can switch between three 'moods'. Depending on the situation it is either happy, grumpy or angry. The 'moods' are expressed by different types of sound output. As long as the robot can detect its ball every now and again it is happy and moves constantly towards it. If it cannot detect the ball for a certain time (for example because a visitor lifted it up) it starts to become grumpy and moves around nervously searching for the ball. If it has not found its ball again after an other period of time it will become angry. The robot then stands still and cries until it detects the ball again.

Apart from performing their standard tasks, the robots are capable to interact with each other as well as with the museum visitors. So if, for example, a robot gets close to one of the others, it will turn towards it to say hello. If The Instructive detects that visitor obstruct its way it will ask them to step aside. If The Twiddling becomes angry, because it cannot find its ball, The Inciting will come to it and ask the visitors to hand the back to The Twiddling.

4.2 Experiences

Since the robots were installed in the museum they travelled more that 1000 kilometres. During all this time no collisions with either visitors or inventory of the museum occurred. The robots also never left their operating area. Thus the robots did at no time present any danger to the visitors of the museum. They usually fulfil their assigned tasks daily without any trouble.

The robots have been well accepted by the visitors of the museum. Children do especially like the ball playing robot. Even children of about 3 years of age enjoy playing with the robot which is with 1.2 meters substantially higher than the children themselves. This proves, that a intuitive interaction with the robots was achieved by IPA's implementation.

Before they were set into operation the robots have been tested in the museum for 2 months. Due to the extensive tests performed during this time the robots' software is now thoroughly debugged and running without any trouble. The only serious hardware problem that occurred was a broken gear axis. The reason was a failure in the material of a commercial gear axis. After months of daily operation a shaft/grain connection became loose on the ball playing robot. This incident occurred on this particular robot, because this one accelerates and decelerates most frequently. The affected connection was modified on all robots.

An inconvenient observation has been made concerning the way visitors of the museum are using the emergency buttons. They tend to press the emergency buttons of the robots for fun. If a button was hit a member of the museum staff has to put the robot back to operation since a key is needed to release the emergency stop. Due to safety regulations the staff members could not be relieved from this duty up to now.

The experiences in the museum show that the implementation of the Fraunhofer IPA can guarantee the following required constraints:

?? Elimination of any possible danger for the visitors
?? Obstacle detection and avoidance
?? Restriction to a given operating area
?? Robust design for long operation
?? Easy handling for inexperienced personnel
?? Operation for up to 10 hours daily

5 Perspectives

Care-O-bot has been designed as a mobile home care system. Based on this platform a group of mobile entertainment robots has been created. Their installation at the 'Museum für Kommunikation' in Berlin proves, that these robots are suited for every day use. Due to the refined way the robots interact with the visitors they are well accepted by them. The positive attitude the visitors develop to mobile robots paves the way for future systems. However, the underlying technological concept is not limited to the given applications. Further functions could be:

?? "Personal robot" in private homes ("robotic butler"), robot valet
?? Mobil information desk in public areas (shopping malls etc.)
?? Safety guard, night watchman
?? Robot receptionist in office buildings

Figure 7. Care-O-bot II

Thus development and improvements are going on at Fraunhofer IPA. A new Care-O-bot platform has been build, including a manipulator arm to perform handling tasks (Figure 7).

The value of robots in entertainment applications depends on the degree of human-machine interaction which can be used. At the moment, robots behaviour is felt to be rather simple, because communication flow is going in one direction only: Machines like tour guides can bring a lot of visual or audible information to humans by display and audio speakers. On the contrary, it is still not possible to talk to machines so that words are properly recognized, not to mention the problems in analysing words and sentences to extract meaningful information. In the long run, to bring a breakthrough to entertainment robotics in widespread applications, input devices like keyboards, buttons or touch screens have to be replaced by audible communication between human and machine.

Another key technology in future applications is manipulation. Having haptic contact to a robots manipulator/ hand is a real sensation for humans, because this kind of interaction is sensed to be very intimate. It is rather easy to imagine some scenarios where haptic interaction is mo st useful:

?? Promotion robots put some give-away articles to visitors.

?? Mobile robot servants deliver food and drinks to restaurant visitors.

Unfortunately, haptic interaction has to deal with safety issues. A robot arm that can carry a tablet with food and drinks should be designed for a payload of 2 - 4 kg at least. Taking into consideration 6 degrees of freedom and an arm length of approx. 1m, the manipulators weight will come to be in the range of 20 - 30 kg. It is obvious that such an mechanism could do severe damage to humans if drive or controller malfunctions occur. To bring entertainment robot manipulators into application anyway, some effort is done at the moment:

?? Bumpers at the arms hull bring arm motion to a stop when touched

?? Sensors like cameras with image processing analyse the robots workspace to prevent contact of robot arm and humans

?? Sensors like capacitive sensors or ultrasonic recognize approaching objects to the arms workspace

?? Mechanical couplings restrict the torque of robot arm joints to a maximum value

Anyway each solution has its drawbacks, not to mention that there is no guideline to get a certification of the involved institutions at the moment (TÜV and Berufsgenossenschaft in Germany).

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