A Mobile Robot Platform for Assistance and Entertainment

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ABSTRACT

Based on the successful hardware and software architecture of Care-O-bot™ (Schaeffer et al., 1999) a new generation of mobile robots has recently been designed at Fraunhofer Institute of Manufacturing Engineering and Automation (IPA). The 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. In this article the hardware platform of the robots and their features such as navigation and communication skills, their 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. The robots have been running in this museum daily since March 25th 2000 without noteworthy problems.

Keywords: Mobile Robot, Museum Robots, Self Localization, Obstacle Avoidance, Communication

HARDWARE PLATFORM

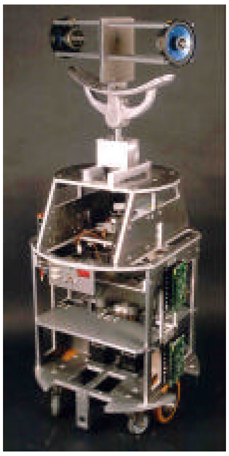 

Fig. 1 Basic platform and “fully dressed” museum robot (© Museumsstiftung Post und Kommunikation)

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. Its range is 180 degrees and its scan distance reaches up to 15 meters. It conducts a scan approximately every 30 milliseconds at about 15 centimetres above the ground with a resolution of 0.5 degrees. The laser scanner is used for self localization, navigation, and obstacle detection.

Additional safety sensors are a bumper at the bottom of the robots as well as several infrared sensors integrated in the bumper and facing upwards. These sensors are used to detect obstacles above the scanning level of the laser scanner. A magnetic sensor which is placed on the bottom side of each robot can detect magnetic bands which are buried in the ground. Such magnetic bands can for example be used as a boundary of the robots operating area. An emergency stop button is placed on either side of each robot.

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.

SOFTWARE ARCHITECTURE

The control software for the mobile robots is based on the object oriented ‘Realtime Framework’ (Traub et al., 1999) and the software library ‘Robotics Toolbox’. This software package, developed at Fraunhofer IPA, facilitates the integration of reusable software components in application specific control systems with the support of a framework and specific design patterns. The software components of the ‘Robotics Toolbox’ are reusable functional units. Each unit either encapsulates algorithms, controls sensors or drives actuators. Following this strategy software can be developed by analogy to electronic circuit development, where application specific circuit layouts are printed on boards which are then equipped with prefabricated electronic components.

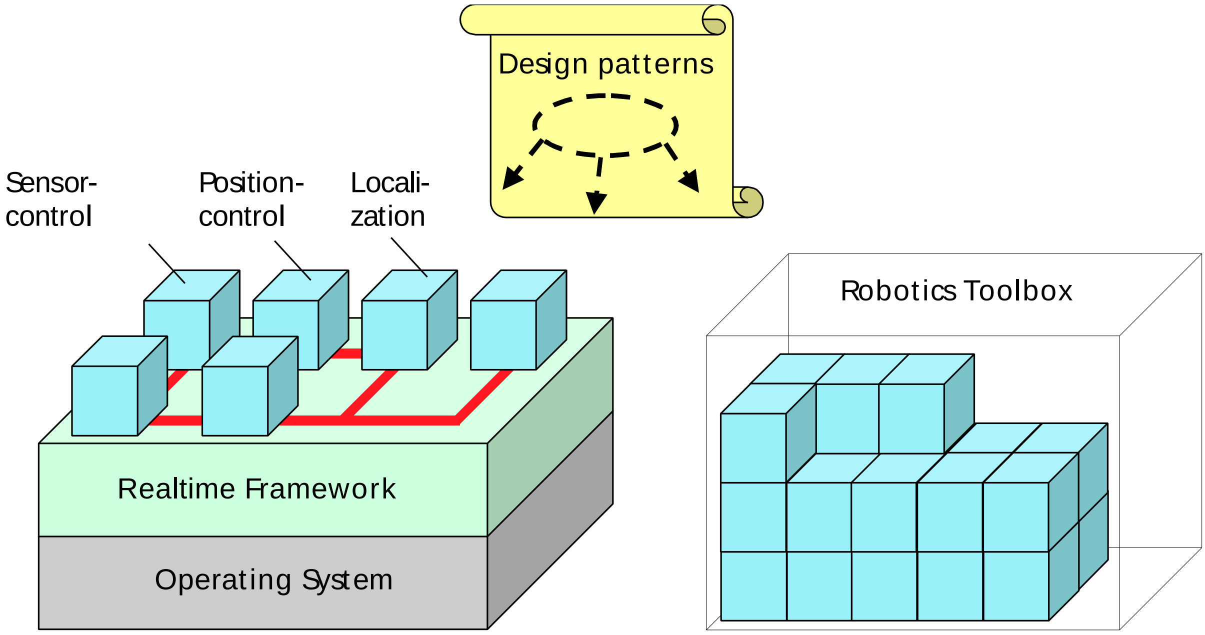

Fig. 2 Architecture of the Control Software

In figure 2 the ‘Realtime Framework’ represents the board. It ensures the structural connection between the components (automatic initialization/deinitialization, non local error handling, ...). In addition to that the framework represents a facade for operating system functions. Thus it becomes relatively easy to run the control software on a different operating system. 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 provides abstraction mechanisms for uniform control of different I/O interfaces (e.g. CAN-Bus).

Like the connections in electronic circuits, the data flow between the single components of the 'Robotics Toolbox' can be determined individually, depending on the given application. This becomes possible, because of the use of specifically developed design patterns, which prevent semantic dependencies between the individual components. Thus each component can be reused in a very flexible way.

The design patterns are reusable micro-architectures for the integration of 'Realtime Framework' components, the 'Realtime Framework' itself and application specific program parts. Their use in different applications facilitates the documentation of the software and the communication between different development teams significantly.

ROBOT FEARUTES

Navigation skills

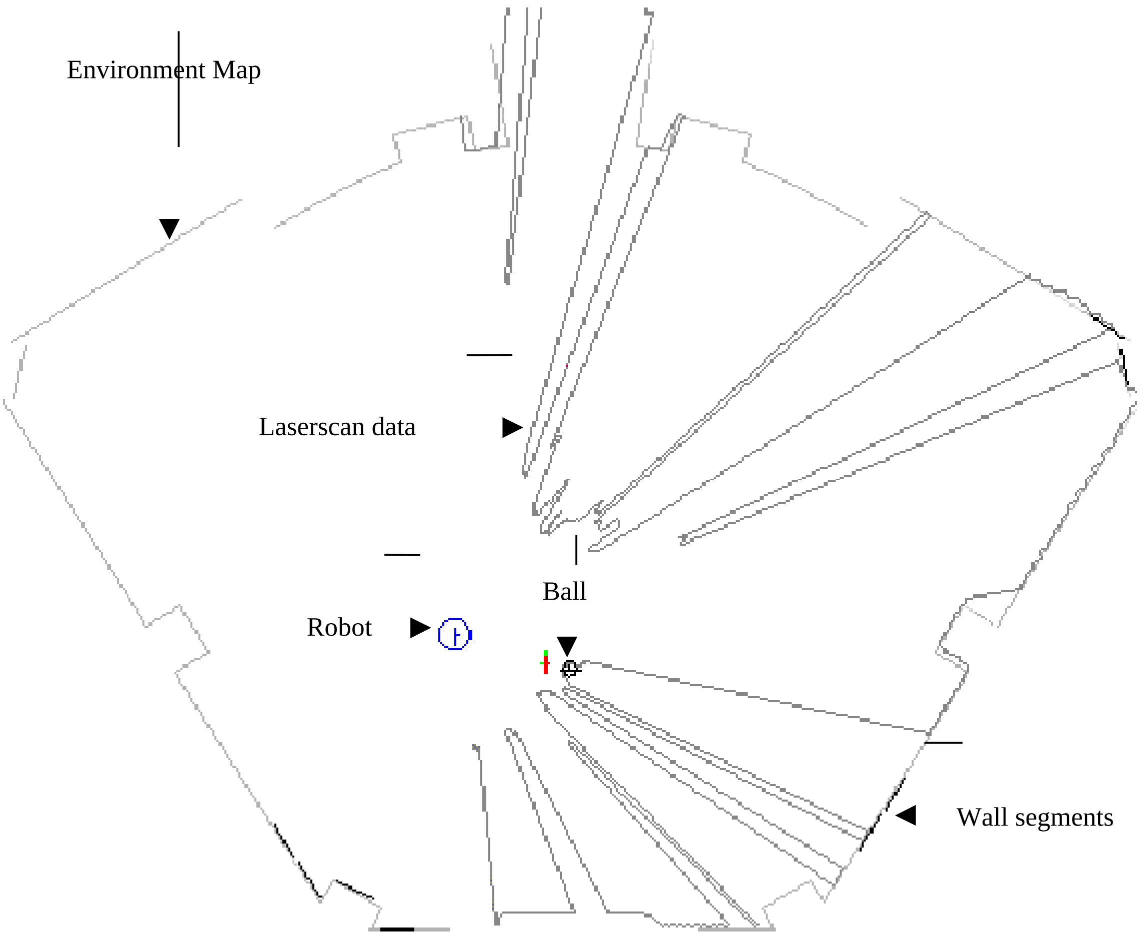

Fig. 3 Screenshot of a robot during operation

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

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 modeled in a map (Fig. 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.

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 fig. 3). The robot then drives to a computed intercepting position.

Preplanned navigation: If the robot is supposed to move to a certain target position it will plan the shortest path to this position while taking its environment into account (Latombe, 1996). The path planning algorithm uses the same map like the self localization module as a representation of its environment.

Obstacle Avoidance

In each of the navigation modes of the robot, even in the preplanned mode, there exists the danger that it collides with a dynamic or unmodelled obstacle. Two methods have been implemented in order to prevent the robots from running into such obstacles. Both use the 2D laser scanner for detecting the distance to obstacles around a robot.

Collision detection: This safety function is used to avoid hitting persons or objects in the path of the robots. It directly influences the driving speed of the vehicle. Getting closer to an obstacle the robots gradually reduce their speed until they come to a complete stop. This function also works without failure if a robots task is to play with a ball. In this case collision must not stop the robot if it wants to hit the ball, but only if there is any obstacle between it and the ball (e.g. a visitor sets its foot between ball and robot).

Obstacle surrounding: In contrast to the path planning module described above this module is not model based. This module uses scanner data not only in the path of the robot but at the maximum surroundings of 180 degrees around the vehicle. After having detected an obstacle on the way to its next target the robot tries to find an intermediate target position along a calculated safety circle around the obstacle (Lumelsky, 1990).

Communication

The communication functions of the 'Realtime Framework' have been uses to connect multiple robots to a control computer by a radio Ethernet. This enables the robots to communicate data – like their current position – to all other robots using a CORBA interface. This communication allows the robots to interact with one another instead of merely reacting to each other's presence. It is further possible to connect a remote computer to the robots – also from far away using an ISDN line. So remote diagnosis or software updates of the robots in the museum in Berlin can be done directly from Fraunhofer IPA in Stuttgart.

Handling

The robots are specially designed to be used by inexperienced personnel. A small joystick is the only device necessary to set the robots in operation and to shut them down again. After a robot has been switched on an operator can use the joystick to run the robot in the different startup 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.

Safety concept

The robots possess several safety sensors, functions and features. The safety sensors are mainly hardware backup systems ensuring that the robots do not do any harm to visitors or themselves, even if the software or the main sensors fail.

Operating area: In normal operation the robots' software ensures, that the robots do not leave their designated operating area. Since the robots continuously knows their current position it will not move beyond the borders of their operating area. The operating area is defined in an initialization file and can thus easily be adapted to any environment. In addition the operating area of the robot can be limited by a magnetic band that is buried in the ground. If the downward facing magnetic sensor of the robot detects this band it will immediately open the safety relay of the robot and thus stop it. A human has to remove the robot form the band and press a release button before the robot resumes operation.

Collision: As described above the software of the robots ensures, that they do not collide with any humans or obstacles. The bumper of the robot forms a hardware backup system. If the bumper is pressed the robot will be stopped by opening its main relay. The same function is fulfilled by the upward facing infrared sensors if the robot approaches an obstacle which lies above the range of its laser scanner. As soon as neither bumper nor infrared sensors detect a collision any more the robot resumes operation.

MUSEUM APPLICATION

Description

In order to entertain visitors in the recently opened 'Museum für Kommunikation' in Berlin with a new technical attraction, throughout the last year, three mobile robots have been built and programmed by Fraunhofer IPA (Graf et al., 2000a, 2000b).

Fig. 4 Entertainment robots in the “Museum für Kommunikation”, Berlin

(© Museumsstiftung Post und Kommunikation)

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.

Experiences

Since the robots were installed in the museum they traveled more that 1000 kilometers they. 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 fulfill 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. It is currently checked, if other emergency concepts do also fulfill all safety regulations. One of these concepts could be, that the emergency stop can be released by the visitors without the usage of a key.
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

CONCLUSIONS AND OUTLOOK

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

Thus development and improvements are going on at Fraunhofer IPA. A new Care-O-bot™ platform will soon be build, including a manipulator arm to perform handling tasks.

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