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Field Test of a Navigation System: Autonomous Cleaning in Supermarkets

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1 Abstract

Siemens has developed a prototype of an autonomous navigation system for mobile service robots. Its suitability for tough everyday operation has been successfully demonstrated since August 1996 with cleaning machines in chain store supermarkets of Albert Heijn B.V. in the Netherlands. Here, HEFTER CLEANTECH (HCT) cleaning robots are being used in cooperation with the cleaning specialist RTB.

2 Introduction

Renowned institutes credit the market for service robots with excellent chances for the future. The first applications that are expected to appear in this market are transport in public buildings and autonomous cleaning in the commercial sector. The common enabling technology for these two applications is autonomous navigation in everyday indoor environments, and the corresponding navigation system is a key component in these robots.

The application that Siemens selected for the first extended field tests is autonomous cleaning. The requirements in this specific application are very challenging:

- Completely unchanged ordinary supermarkets, especially no artificial beacons of any kind to support the navigation.
- Robots to be operated by untrained supermarket personnel.
- Cleaning during usual business hours, i.e. while customers are around.

Based on Siemens' research in autonomous mobile robots and experience in industrial automation solutions, a navigation system matching the above requirements has been developed, with the prototypes ready for field testing after only three months of development.

This prototype development and the ongoing field test phase are done in cooperation with four partners: the supermarket chain Albert Heijn B.V., the cleaning specialist RTB, both of the Netherlands, and the cleaning machine manufacturer HCT and Siemens AG of Germany. Two machines are in operation in Albert Heijn supermarkets in the Netherlands: the first since August 1996 in Haarlem, the second since February 1997 in Purmerend.

3 Cleaning Machine and Navigation System

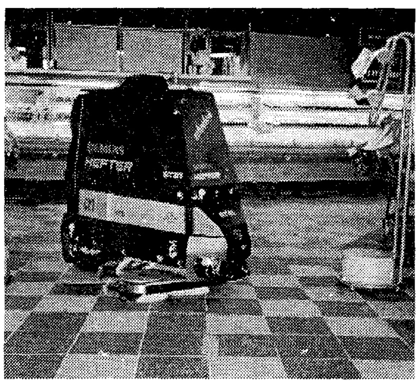

Fig. 1: Autonomous Cleaning Robot

The cleaning robot (Fig. 1) has been composed of an ordinary cleaning machine made by Hefter Cleantech and of the navigation system provided by Siemens.

One special feature of the cleaning machine is the retractable wing (at the front right of the machine) that allows to get close to obstacle contours in cleaning, and that can be extended and retracted as needed.

This cleaning machine has been equipped with a processor and several peripheral controllers, with sensors and with navigation algorithms to convert it to an autonomous robot. The sensor systems comprise a 2-dimensional laser scanner with a very high safety standard, a fiber optical gyroscope and an ultrasonic sensor system (Fig. 2). On the cleaning machine, the sonar transducers are mounted essentially in two horizontal layers in a very deliberate fashion in order to provide a

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high degree of 3D-coverage.

Safety (in a strict sense) relies mainly on the laser scanner and a couple of tactile switches and bumpers. Violation of the scanner's protection field or contact with the switches or bumpers cause the machine to stop immediately.

The main features of the behavior of the robot are

- Obstacle detection and mapping of the local environment,
- Dexterous local maneuvering around obstacles,
- Localization without any installation,
- Plan execution.

Obstacle detection is based on the ultrasonic sensor system, the laser scanner or both of them, depending on the configuration of the hardware. A local grid is used to accumulate and fuse the sensor readings.

Reactive local maneuvering uses the steer angle field approach [1]. In a 50ms loop, the grid map is evaluated and free steer angles are determined. Among these, an appropriate angle is selected depending on the current state of the machine. This allows the robot to move in a very flexible and dexterous manner, closely (in fact within a distance of a few centimeters) to obstacles. This is a strict necessity in environments as crowded as supermarkets - otherwise the robot would not move at all most of the time!

No installation (beacons or other „artificial" landmarks) is needed for the localization. Features like walls, corners or cylinders are used as „natural" landmarks in the localization module [2] which can also rely on ultrasonic sensor data, laser scanner readings or on both.

The nominal cleaning program is coded in a sequence of intermediate configurations together with the respective status of the cleaning aggregates (brushes, wing, water pump, turbine).

A flexible obstacle avoidance behavior is implemented:

If the deviation is considered to be small, the robot goes round the obstacle. Otherwise, if the obstacle is too big, the robot stops moving and cleaning, and waits for the path to get clear. In case the environment is fully crowded and hence the path remains blocked, the system branches to an exception handling guiding the robot to an appropriate clear configuration „nearby".

In case the robot is definitely trapped over some period of time, the robot calls for an operator's help. The operator may then release the robot which subsequently is able to continue its program. Other trouble situations which cause the robot to stop executing the program are e.g. hardware errors, lack of fresh water or low battery voltage.

4 Field Test

Two prototype robots have gone into operation for field tests, the first in August 1996, the second in February 1997. The primary goal for these field tests was acquisition of real-world experience with robot technology, especially also with navigation and public acceptance. In fact, due to the very short time available (the robots had to be developed almost from scratch within a few months), some compromises had to be made. For example, the highly desirable development of a really appropriate, extremely robust sonar system was fully out of reach for the prototype generation. And, while on the product system a teach module will be available, for the field tests a simulator has been used to model the environment and to generate the robot's path.

Nevertheless the results of the field tests are convincing. The robots typically cleans the vegetables department two or three times a day during opening hours. Speed is limited to 35 cm/s for acceptance reasons. Many people felt that this (admittedly moderate looking) speed is adequate for environments as cramped and narrow as supermarkets. One full run takes about 25 minutes.

During the (in sum) more than two years of operation, not a single incidence has occurred. The robots behave in such a careful, defensive way that the customers never expressed any concern or feeling of unease with the robot approaching them. Actually, most customers did not take any notice of the robot at all - this came as a real surprise

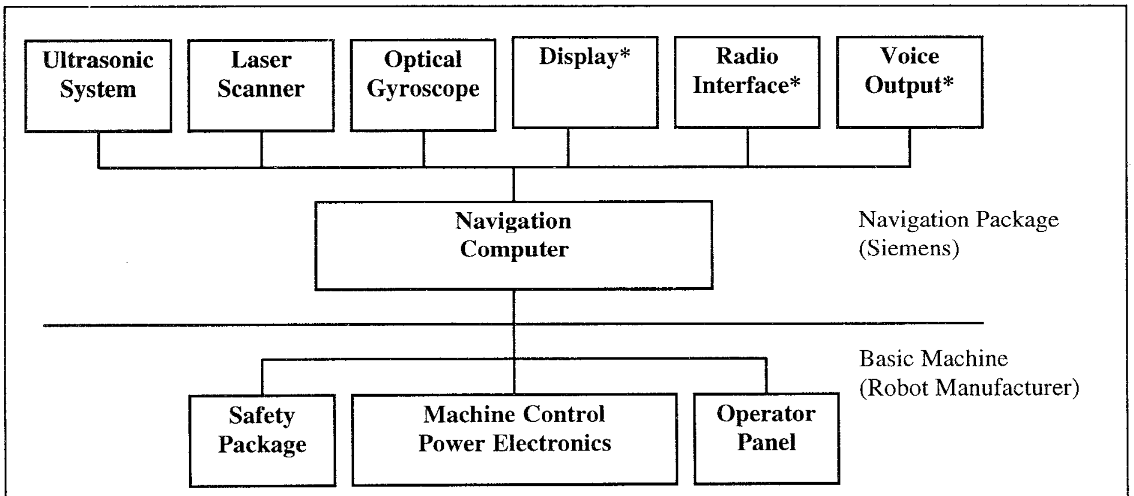

Fig. 2: Architecture

to the developers. No really aggressive acts against the machine were reported.

Speech output and signaling which reveal an idea of the robot's intentions to the people standing in its way proved to be useful features.

In a sense, keeping a high level of agility and reactivity on the one hand and cautious, compliant behavior on the other hand are opposite goals. We feel that a reasonable compromise has been found. A good mixture of heuristics and reactive mechanisms helps the robot to escape from problem situations. But admittedly, in some situations applying deliberative strategies (planners) would have been more efficient.

Of course, providing an interface which is both secure and easy-to-use is a necessity. Keys are used to enable the automatic mode, preventing unauthorized access. Then simply a start button needs to be pressed to make the robot clean the assigned area of the supermarket and then return to the starting position. The supermarket personnel was able to use the robot with only some minutes of instruction.

Cleaning performance was evaluated in the sense of area coverage and by inspection. Though perfect cleaning was not the main objective of this field test, it turned out to be satisfactory to the supermarket management in most cases, in fact in many runs it is close to or even beyond the target level for a product machine.

Environment conditions are very hard for localization: Only very few shelves turned out to be suitable to be used as reliable landmarks. And in general with many people or boxes or trolleys around, visibility of these landmarks is very poor. Nevertheless the localization module maintains an estimate of the robot's position and orientation to a precision of a couple of centimeters and a few degrees. This holds true even if, in the course of obstacle avoidance, the robot deviates substantially (a few meters) from its previous plan.

Service and maintenance are important issues, of course. Availability of the machines turned out to be fairly high over the years (> 95%). For prototype machines a higher level of service demand was expected and conceded. The hardware was initially suspected to be not very robust, especially the PC with its hard disk and the sonar system. Luckily, the service requirements were actually by a factor smaller than expected.

5 Conclusion

The field test proved that the navigation system for service robots has reached a stage of maturity that allows for application on a wide scale. Consequently, work is under way to convert the prototype hardware of the navigation system into a full product. This will include a completely new ultrasonic sensor system featuring highly robust piezo-ceramic transducers and ruggedised processor hardware. The software will be significantly enhanced, including various planners and autonomous mapping and teach-in modules to support the installation.

Acknowledgment

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6 References

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