Surface Covering Algorithms for Semiautonomous Vacuum Cleaner

KRZYSZTOF SKRZYPCZYK
Department of Automatic Control
Silesian University of Technology
Akademicka 16, 44-100 Gliwice
POLAND
krzysztof.skrzypczyk@polsl.pl

AGNIESZKA PIERONCZYK
School of Engineering, Design and Technology
University of Bradford
Richmond Road, Bradford BD7 1DP
UNITED KINGDOM
agatpi@gmail.com

Abstract: The work is focused on creation of algorithms for housekeeping hovering robot. The project's aim was to design and implement algorithms of movement of autonomous (or semiautonomous) vacuum cleaner, that would be able to work inside of a flat, but not free of obstacles workspaces. In the paper several proposed algorithms of surface covering are discussed. The two algorithms were selected as the most appropriate and presented in this work. Experimental validation of efficiency of the proposed approach were done and the results of the validation are discussed in the paper.

Key-Words: - Mobile robotics, semiautonomous systems, vacuum cleaners, surface covering

1 Introduction

Domestic robots are robots which are used in homesteads. This group of robots is intended to perform tasks such as housekeeping as well as, serving as educational and entertainment robots. Despite of the fact, that the area of domestic robotics is much less funded than for example the military robotics – it has still been growing and developing rapidly, simultaneously increasing the level of human comfort and life. With reference to human kind history, people have always been looking for simplifications and improvements that would made their life easier. Housekeeping devices, especially domestic robots generate wide range of possibilities to achieve this goal. The issue is relatively up to date matter, specially nowadays – when robotics is so popular and creation of its applications became less expensive than any time before. The status that housekeeping robots can obtain in the future, can be compared to the status of all others domestic devices (e.g. oven, fridge, hairdryer) which are nowadays omnipresent at our homes, and create basics of each home's equipment. That can be done only if their performance, utility and prices would be optimized to accomplish a satisfactory trade off. As a matter of fact, the thesis is focused on this area of robotics – namely, housekeeping hovering robot. The project's aim was to design and implement an algorithm of movement of autonomous (or semiautonomous) vacuum cleaner, that would be able to work inside of a flat, but not free of obstacles workspaces. According to this, objectives of the project have been focused on the surface covering and its time consumption, as a consequence of different ways of robot's translocation.

The history of all robots which application was based on the vacuum cleaners cannot be fully ordered. The cause of it is that most robots were created by the commercial companies, which official secrets have not allowed to catalog all created prototypes. Fortunately most of hovering robots, which have been sold on market till now, had been somehow described or at least mentioned in wide range of articles and websites. That gave a possibility to make the historical outline of those robots.

First mentioned, was a prototype of the first sold on market robotic vacuum cleaner called trilobite [5], manufactured by the Swedish corporation Electrolux was available for purchase in 2001.

One year later, in 2002 the first generation of the most wide known, *the Roomba* [1] robotic floor cleaners has been on sale. Nevertheless, to date second and third generations of that robot have been produced. At once, with each generation new improvements were obtained. To begin with better brushes and larger dust bins, finishing with new algorithms of cleaning.

As was previously stated, design and implementation of a robotic vacuum cleaner is the very present issue. What is more, according to documentation and articles which addresses this group of devices – their algorithms should still be enhanced in order to obtain more immune for environment's disturbances and more efficient system.

2 Problem Statement

The work is focused on creation of algorithms for housekeeping hovering robot. As it was stated before – the project's aim was to design and implement algorithms of movement of autonomous (or semiautonomous) vacuum cleaner, that would be able to work inside of a flat, but not free of obstacles workspaces. Although mechanical aspect of the project has been qualified to consider only different types of a testbed robots, environmental perception and physical characteristics have given some additional constraints influencing simultaneously on the project's final output. Those constraints have been taken into account in the project planning and during algorithms evaluation process. Taking aforementioned remarks into account, main objectives are as follows:

- Selection of the project's well suited testbed robot, taking into account its mechanical features and their influence on robot's movement and environment perception

- Evaluation of two algorithms that would implement two different approaches

- Comparison of developed algorithms, taking into account their efficiency in surface covering and its time consumption.

include your paper in the Proceedings. When citing references in the text of the abstract, type the corresponding number in square brackets as shown at the end of this sentence [1].

3 The Equipment

As a testbed for validation of proposed solution the miniature, laboratory mobile robot Khepera II [2] was used. The Khepera is presented in fig.1. As a matter of fact, that implied also an usage of The MATLAB software, which was required to program the robot. Detailed specification of the Khepera II and is usage in the MATLAB can be found on the www.k-team.com web site. Nevertheless, the robot used in experiments is a complex device and it seems reasonable to highlight its main features. Thus, hardware and software description is presented below in order to introduce some essential knowledge, required for full apprehension of developed algorithms, that are afterwards presented.

Fig.1 The Khepera II robot [2]

The Khepera II is a small, differential wheeled mobile robot, designed as a scientific research and teaching tool at Federal Institute of Technology Lausanne (EPFL) in Switzerland. First of all, the robot is well suited for project's purposes because it renders rapid idea generation, prototyping and evaluation. In its User Manual can be found, that the robot allows also confrontation to the real world of algorithms developed in simulation for trajectory execution, obstacle avoidance, preprocessing of sensory information, hypothesis on behaviors processing [2].

4 The solution

In this section details on two designed surface covering algorithms are presented end discussed. The first is the simple random-walk based one. The second one is more complicated hybrid concept that merges two different approaches – random movement and spiral motion.

4.1 Random walk based algorithm

The first algorithm has been based on the idea of random movement (fig. 2). The robot is moving in forward direction till an obstacle is sensed, then it stops. Next, by comparing sensor readings decides in which direction to turn – left or right. Finally, by generating a random number decides how much to turn. The overriding aspect of this algorithm is a distance between the robot and obstacles. It has been done, by setting into its source code, a distance threshold value. Simply, when the distance is lower than the given threshold value, the robot takes an action in order to omit obstacles. As a result of this, the manner in which robot is moving depends strongly on its surrounding. Despite the fact, that the algorithm assumes ongoing turns from the obstacle (i.e. if obstacle is sensed on the left, it turns right) what may cause stacking in corners, the random turning banishes the issue. All in all, the algorithm fulfills the aim of the work, allowing the robot to move around a room avoiding obstacles. However, its efficiency should be compared with more sophisticated movement manner in order to examine its utility.

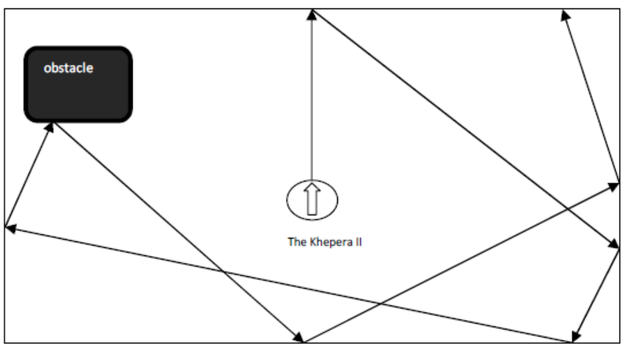

Fig. 2 The visualization of 8 iterations of robot's movement according to random walk based algorithm.

This working mode is presented below in a form of a flow chart (fig.3).

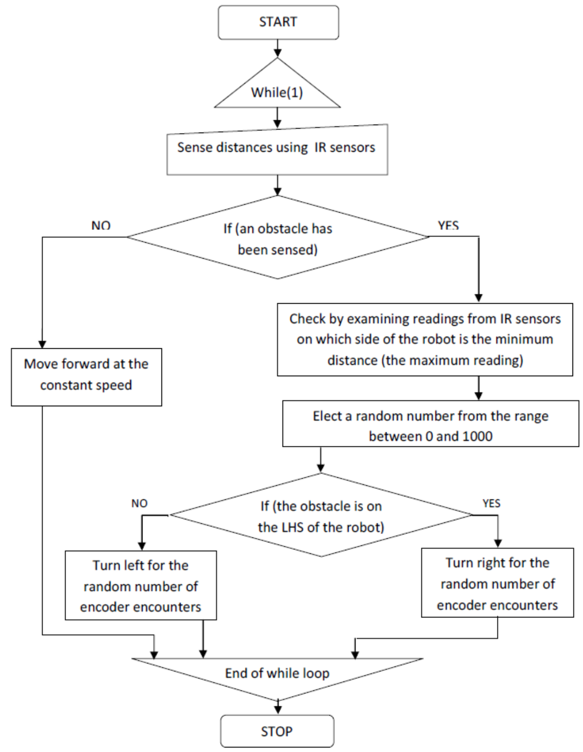

Fig. 3 The flow chart for the random walk based algorithm.

4.2 Hybrid algorithm

The second algorithm has been based on the idea of a spiral motion coupled with random turning (fig. 4). First of all, the robot checks if there is enough place to start moving spirally. If yes, the robot convolutes in a RHS direction, increasing a radius from centre point, the till an obstacle is sensed. When the obstacle is sensed, robot stops and compares sensor readings to decide in which direction to turn – left or right. After the decision is made, the robot turns a given direction for a previously allotted angle. Finally, in order to allow itself to begin convoluting, it moves away from the obstacle for a given range.

Invariably, the overriding aspect of the algorithm is a distance between the robot and obstacles. It has been done likewise to algorithm I, by setting into its source code, a distance threshold value, thanks to which an action in order to omit obstacles can be taken. As a result of this, the manner in which robot is moving depends strongly on its surrounding characteristics.

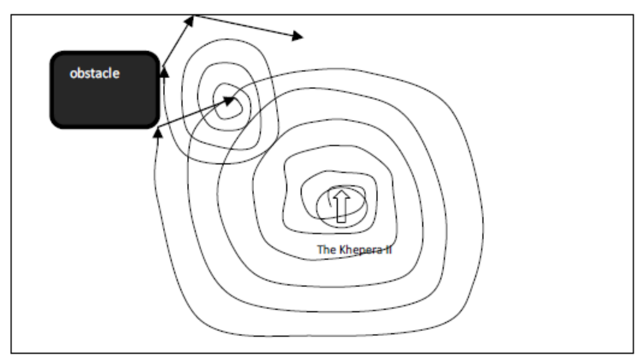

Fig. 4 The visualization of 3 iterations of robot's movement according to algorithm II

The principle how the algorithm works is shown in the form of a simplified flow chart (fig. 5) that gives a full and clear view on properties of the algorithm.

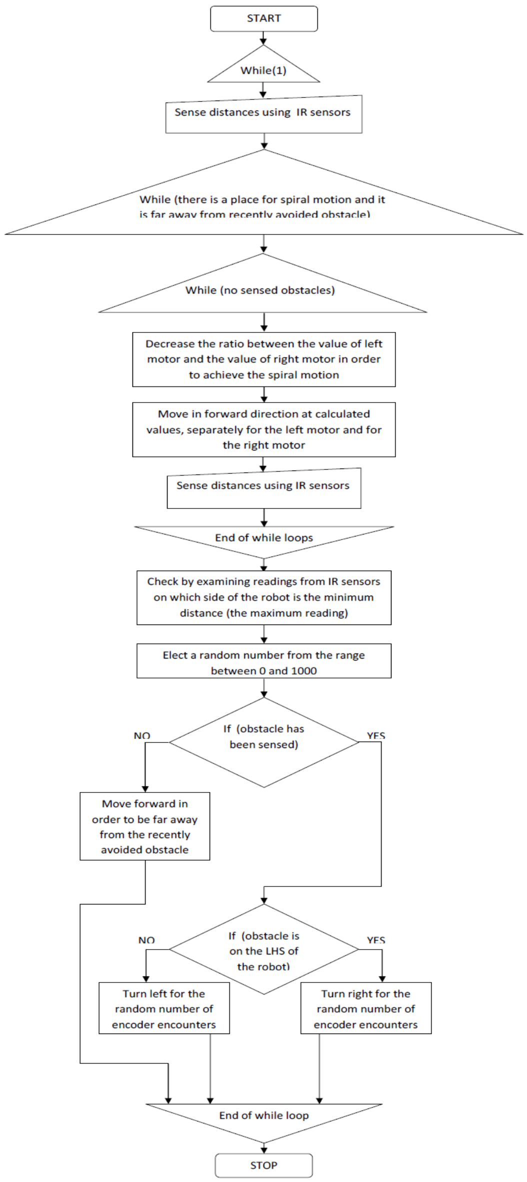

Fig. 5 The flow chart for the hybrid algorithm.

4 Results discussion

During algorithms tests, some ideas were rejected because of the Khepera II limitations. Those limitations came from the imprecise operation and environment perception. Two more interesting and tested algorithms, which were dismissed are presented in a table, together with reasoning of their failure. Nevertheless, more advanced tests were provided for previously described algorithms – I and II – which are namely, random motion and spiral motion algorithms. They have been tested if they are operating properly, what means that they fulfilled aim and all assumed objectives. All provided tests helped in speed and proximity sensors calibration. Finally, when proper work manners for both algorithms were obtained, their outputs gave appropriate and satisfactory results – for infinite period of time, the free from obstacles area of the workspace would be almost fully covered and obstacles would be avoided. However, it has to be mentioned that black or very reflective objects would not be avoided due to sensors insensitivity for that kinds of materials. At the same time, the prominent issue of all objectives was algorithm efficiency. The efficiency was seen as area coverage in time. Taking into account sensors and motors constraints it had been very important to keep illumination levels and initial conditions as similar as possible for each type of test. That assured the most applicable results from each simulation. Owing the fact that both algorithms involved random movement, their outputs were highly unpredictable. Nevertheless, based on numerous tests, following efficiencies for operation time equals 1 minute have been achieved (table 1).

Workspace dimensions: 400x500 mm; no obstacles	
Random Motion	Spiral Motion
1114 cm²	1430 cm²
Workspace dimensions: 800x500 mm; no obstacles	
Random Motion	Spiral Motion
1850 cm ²	2034 cm²
Workspace dimensions: 800x500x100 mm; one obstacle: 100 cm²	
Random Motion	Spiral Motion
1532 cm²	1296 cm²
Workspace dimensions: 800x500x100 mm; five obstacles sum: 150 cm²	
Random Motion	Spiral Motion
870 cm²	540 cm²

Table 1 Comparison of the efficiency of the two presented surface covering algorithms.

As it can be observed spiral motion algorithm has better efficiency coefficient for grater workspace dimensions and smaller number of obstacles. What is more, its efficiency depends strongly from the initial point. The best results were obtained for initial point being in the middle of the workspace, what allowed the robot to convolute with greater radius. On the other hand, when the initial point is closer to the workspace's boundaries, or when the workspace area is filled with obstacles – the random motion algorithm accomplishes better efficiency results than the spiral motion. To sum up, both algorithms that had been developed for the robotic version of a vacuum cleaner, have been checked and they worked properly. Regardless of the fact that their efficiencies varied within environmental changes, their empirically derived efficiencies were still satisfactory.

5 Conclusion

The aim of this work was to design and implement algorithms of movement of autonomous (or semiautonomous) vacuum cleaner, that would be able to work inside of a flat, but not free of obstacles workspaces, have yet to be compared with the achieved outcome. Unquestionably, developed algorithms fulfilled this goal. They have a number of features that allows the robot to interact with its environment in order to perform the task. Both algorithms' programs for the Khepera II enabled the aim of the project to be realized. What is more, the main objectives for the project were based on analysis of developed algorithms, their limitations and efficiencies. The Khepera II returned appropriate response with respect to both programs, keeping a distance to objects, as well as to the area coverage. The robot has not stacked accidently at any of the workspace recesses. As it has been mentioned before, although mechanical aspect of the project has been qualified to consider only different types of a testbed robots, environmental perception and physical characteristics have given some additional constraints influencing simultaneously on the project's final output. Those constraints together with project's output have been deeply analyzed and resulted in proposals for future developments.

Acknowledgements

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References:

[1] iRobot Roomba, *The official polish iRobot Roomba webpage* Available: http://roomba.pl/

[2] K-Team, *Khepera II User Manual*, 1.1 version, Switzerland, page 11, 2002

[3] F.G. Martin, *Robotic Explorations A Hands-On Introduction to Engineering*, 1st ed. New Jersey, United States of America: Tom Robbins, 2001.

[4] P. J. McKerrow, *Introduction to Robotics,* 1st ed. Singapore: Addison-Wesley Publishing Company, 1991.

[5] Trilobite (2010), *Robotyka – The official Electrolux's Trilobite webpage* Available: http://www.electrolux.pl/node37.aspx?categoryid=6681

[6] I. R. Urlich, F. Monada, J. Nicoud, Autonomous vacuum cleaner. Available: ftp://lamiftp.epfl.ch/khepera/papers/ulrich_RAS96.
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