MOBILE ROBOTS AND SIMULATION – AN APPROPRIATE TOOL HOW TO INCREASE THE EFICIENCY OF THEIR APPLICATION IN PRODUCTION SYSTEMS

Gabriela-Veronica STOIANOVICI[1,*], Vladimír BULEJ[2], Adrian GHIONEA[3], Viera POPPEOVÁ[4]

[1] PhD student, Eng. Department of Machines and Production Systems, University Politehnica of Bucharest, Romania
[2] PhD. Researcher Eng. , Department of Automation and Production Systems, University of Zilina, Slovakia
[3]Prof. PhD. Eng. Department of Machines and Production Systems, University Politehnica of Bucharest, Romania
[4] Prof. PhD. Eng., Department of Automation and Production Systems, University of Zilina, Slovakia

Abstract: *This paper presents the basic information about the mobile robots, their application in automated production systems and about simulation of their movement. Nowadays, the application of mobile robots is very frequent and the number of developed robots still grows. They can be found in logistic chains for material handling of flexible manufacturing systems, firefighting, chemical operations, underwater technological operations, etc. The paper describes some methods for solving the mobile robots' navigation in an indoor environment (laboratories, factories, corridors of buildings) and explains in detail the designed solution of global navigation through the potential fields. These potential fields navigate the mobile robot safely along the trajectory between obstacles to the goal position.*

Key words: *mobile robot navigation, simulation, AGV, potential fields, sensors.*

1. INTRODUCTION

During the last period the separate area in robotics called mobile robotics was established and developed. This area is focused on the development of suitable robotic devices, methods, special algorithms and finding their appropriate application in real world. Generally, the mobile robot (MR) is a complicated mechatronic cognitive system consisting of several subsystems with different levels of complexity. The most distinguished characteristic mark of mobile robots is their locomotion in space. The knowledge from many science fields like cybernetics, electronics, informatics, automation, mechanical engineering, artificial intelligence and bionics are integrated [3]. Selection of appropriate navigation method in workspace is one of the fundamental problems solved by the design process of all mobile robots.

The reasons for mobile robots development and their application are different – for example the viewpoint of safety level of processes (the elimination of human contact with danger objects or environment), exploration of unknown terrain, inaccessibility and unavailability (survey by landslides and earthquakes), reliability (elimination of human error from the processes). Increasing of safety level of processes, reliability and continuous growing of production efficiency are also the most important reasons for their application in industry. They can be applied as a main transport system within the factory, they can co-operate with standard industrial robots in robotic cells and they can be used also like cleaning or other kind of service devices. According to their application they have different level of autonomous behavior. In the highest level we can speak about autonomous mobile robots (AMR) or automated guided vehicles (AGV).

AMR contain four basic subsystems:

- mechanical subsystem – undercarriage;
- sensorial subsystem – internal and external sensors;
- control subsystem – control of all subsystems of AMR;
- communication subsystem – data transfer and communication with operator.

2. PROBLEM DESCRIPTION

We have decided to solve some particular problems such as to find suitable methods for robot navigation, design of control system and simulation software able to simulate AMR movement in its known or unknown environment and design testing mobile platform (undercarriage). In this article we have focused mainly on the design of simulation software and suitable navigation methods.

The first step is the definition of requests – what kind of conditions we have and what is needed from the designed AMR. We have selected these [1]:

- simulation of robot movement only in 2D space (floor of factory, corridors, etc.),
- SW applicable for robots on three-flywheels undercarriage with differential control,
- simulation of local navigation,
- simulation of global navigation.

Because we would like to simulate a robot movement in the space, it is necessary to create a mathematical description of each element – mathematical model of robot, mathematical model of sensor and mathematical

* Corresponding author: Splaiul Independentei 313, 060042, *Bucharest, Romania*
Tel.: 0040 21 402 0365;
E-mail addresses: *gabriela.stoianovici@yahoo.com* (G. Stoianovici); *adrianghionea@yahoo.com* (A. Ghionea), *vladimir.bulej@fstroj.uniza.sk* (V. Bulej); *viera.poppeova@fstroj.uniza.sk* (V. Poppeova)

model of space. Simulation software (Figs. 1 and 2) was designed in the programming language *Microsoft Visual Basic* for operation system Windows.

3. DESIGN OF SIMULATIN SOFTWARE

With respect to the possibility to execute and record the realized trajectory, it is necessary to create suitable mathematical description of mobile robot, movement method and model of environment.

3.1. Mathematical model of MR and its environment

The simulation software is destined for three-flywheel mobile robot with differential control and localization is solving by odometer. Then we must transform the information extracted from two incremental sensors (encoders placed on two drive wheels) to the set of global coordinates (x_{O2RS}, y_{O2RS}) (Fig. 1) [1 and 3].

The meanings of the notations in Fig. 1 are as follows:

[01, *X*, *Y*] – Global coordinate system (GCS) – rigidly connected to the map of environment,
[02, *U*, i] – Local co-ordinate system (LCS) – rigidly connected to the robot,
[02, *R*, i] – Auxiliary co-ordinate system (ACS),
X, *Y*, *x*, *y* – axes of GCS and its generalized co-ordinates,
U, *V*, *u*, *v* – axes of LCS and their generalized co-ordinates,
R, *S*, *r*, *s* – axes of ACS and their generalized co-ordinates,
α – tilted angle of mobile robot (MR) with respect to the GCS,
A – point of interest,
q – positioning vector (with respect to the different co-ordinate systems).

Absolute position (global coordinates) is calculated from the relative position:

$$x = r + x_{O2RS} = (u \cdot \cos\alpha - v \cdot \sin\alpha) + x_{O2RS}, \quad (1)$$

$$y = s + y_{O2RS} = (u \cdot \sin\alpha + v \cdot \cos\alpha) + y_{O2RS}. \quad (2)$$

Backward calculation of relative position from absolute coordinates. Co-ordinates in LCS can be expressed from the system GCS by following equations where the expressions in brackets describe the displacements between both co-ordinate systems:

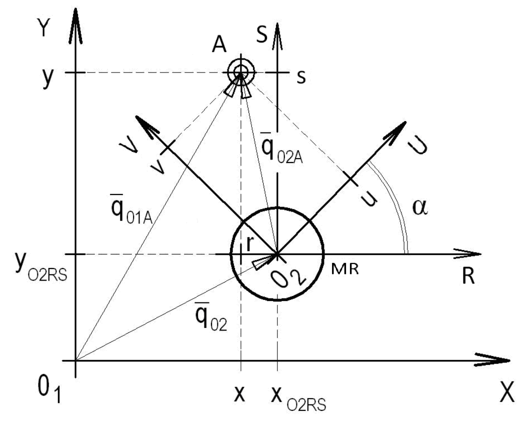

Fig. 1. Mathematical model of mobile robot and its environment.

$$u = r \cdot \cos\alpha + s \cdot \sin\alpha = = (x - x_{O2RS}) \cdot \cos\alpha + (y - y_{O2RS}) \cdot \sin\alpha, \quad (3)$$

$$v = -r \cdot \sin\alpha + s \cdot \cos\alpha = = -(x - x_{O2RS}) \cdot \sin\alpha + (y - y_{O2RS}) \cdot \cos\alpha. \quad (4)$$

3.2. Navigation of mobile robots

In robot navigation in a space with obstacles, the goal is to find a collision – free path of robot from the starting to the target (goal) position.

Navigation strategies can be classified into several groups from the viewpoint of method of sensors' data processing, representation and type of environment and level of path planning. At the bottom there is the pure reactive control oriented only on obstacles avoidance when the nearest space surrounded the robot is scanned. The robot tries to detect all obstacles in front of it and avoid the collision with them. Next level is local navigation which solves also localization. When the robot knows the environment and it has its own map, we can speak about a tactic level of global navigation. In this case the robot can find the path between two points located somewhere in the map. The highest level is often called the strategic level of global navigation. There are many approaches depending on types of obstacles, dimensionality of the space and restrictions for robot movements. Among the most frequently used are road-map methods (visibility graphs, Voronoi diagrams, with structure RRT, case-based reasoning, etc.) and methods based on cell decomposition. A common feature of all these methods is the generating of trajectories composed from line segments [6]. In [4] was developed simple but fast method for real-time localization in static environment based on popular Markov localization which cannot be used in real world application due to computational demands. A PCSM (Pre-computed Scan Matching) localization method for small robots with low memory and low speed processors was developed. Modification of this method to be useable in dynamic environment and incorporation to the SLAM (Simultaneous Localization and Mapping) techniques seems to be a perspective approach to successful navigation in complex environment.

Next we will describe some basic information about map types, because of the fact, that navigation and map types are in very close relation.

3.3. Maps – representation of robots' environment

Industrial environment can be classified as the hard one because of wide range of disturbing elements – dust, electric noise, etc. The connection with the human operator can be lost. In this cases robot should have its own map and also the algorithm described "what must be done" in emergency case. When the robot loses the connection with an operator, the robot should find the right way by itself. Therefore, it is important to choose an appropriate map type which will help the robot to find the right way in this case.

Metric maps. Objects are described by their shape and dimensions. This group is very often represented by raster maps. As an example we can consider the so-called Occupancy grid, Polygonal map or the Quadtree representation. The Occupancy grid looks like a grid where the columns and rows have constant width or height.

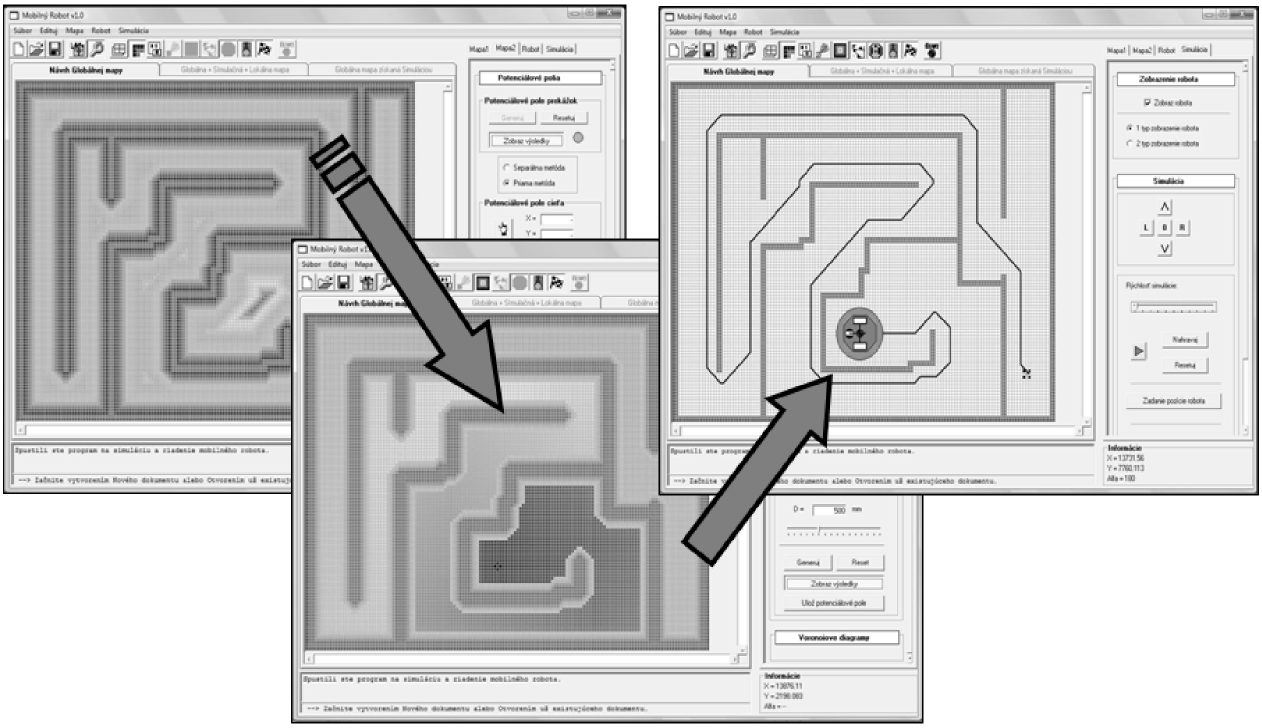

Fig. 2. The method of global navigation solution (tactic level) based on Potential fields application (simulation software *Mobilny Robot V1.0* designed at University of Zilina).

Each cell can get the status “obstacle” or “free cell” (in mathematical meaning for example 1 or 0). It is easy to build a grid, but there is a problem with huge amount of data hence it is also memory space-consuming.

Memory consumption is probably the most serious problem in the application of raster maps to create the environment model. This problem was solved by many research teams, and also among the first creators of the robot Shakey.

The basic ways to reduce memory consumption are:

- quad tree data structure for metric maps,
- other types of maps (polygonal, topological representation, hybrid map, etc.).

Topological maps. In this case the path between points is described by a graph where the nods represent the rooms or places which are important for the robot movement and the lines represent the path between these places. It leads to a smaller amount of data and smaller requirements for memory space. On the other hand, the description of space is not very precise. To topological maps we can assign the Potential fields and also Voronoi diagrams or Generalized Voronoi diagram (GVD).

Hybrid maps. The basic structure of a workspace is described by a graph but the structure of any node is for more details described by a metric map. The whole structure provides us with the possibility to have an optimized description free of losses of sufficient resolution in important places.

Multilayer map system. Multilayer map system is based on concurrent working with several different map types. Each map is placed in one layer. It means that we have the system of different kinds of data structure and we can transform the structure of data from one layer to another one. Then it is possible to choose the most appropriate map for each task.

3.4. Solution for our simulation software

In our case, the selection of appropriate navigation strategy depends on required level of mobile robots autonomy, on kind of fulfilled tasks and on character and level of environments cognition. For the classical task “Safety browsing of environment” (for unknown environment) the local navigation was selected whilst the global navigation for the task “Coordinated movement between two points of environment” (for known environment). For complex solution of mobile robots movement control both navigation methods are therefore necessary (Fig. 2).

We have selected the simple form of multilayer map system for designed simulation software. For the task of local navigation are used the Occupancy grid (metric map) which is next transformed to the form of Potential fields for the task of global navigation.

The global navigation based on Potential fields can be divided into the several steps. General method is known [1, 2, and 5]: for selected space, a scalar function called the potential is constructed that has a minimum, when the robot is at the goal point, whilst a high value on obstacles. Everywhere else, the function is sloping down toward the goal, so that the robot can reach the goal point from any other point following the negative gradient of the potential [2].

It is more practically, the process of potential fields’ generating, divide to three basic steps, for simplification and for easy modification of goal point [5]:

- Generating of Obstacles Potential field;
- Generating of Goal potential field;
- Generating of Final potential field.

During this process, several errors can happen such as deadlocking of robot in some points or the aborting of generated trajectory. We have proposed one possible solution. The previous method with three steps can be replaced by the potential fields' generation just in two steps. Firstly, the Obstacles potential field is generated and next, on the basis of data extracted from this one, it is generated also the goal and final potential field together (both in the same time). The collision-free path planning (global navigation) of AMR in action space is then based on final potential field, which is constructed by using proper combination of both fields. The method of navigation and environment modeling is shown in Fig. 2.

4. PROTOTYPE OF TESTING UNDERCARRIAGE

The phase of simulation software design was followed by next step – building of first MR prototype usable for testing of designed algorithms (at the beginning just implementation of local navigation).

Hardware of the control system should be able to retrieve information from the sensorial subsystem – in qualitative and also in quantitative meaning. The control program must handle and analyze this information in real time and provide the appropriate reaction of actuators. The mobile robot autonomy significantly affects the final configuration of designed control system where there are several possibilities. Roughly speaking, the mobile robot control system can be based on: personal computer, industrial computer or microcontroller.

The control system based on a standard personal computer is not very suitable for mobile robots applied in a factory. This kind of applications requires the control system with some special characteristics (resistance to different temperature, humidity, dust and vibrations, electric noise, etc.). All of these requirements and some others can be met using the control system based on IPC or based on the microcontroller. We have decided to build it on the microcontroller ATMEL MEGA 16 [7].

For exploring the surrounding environment the system of proximity sensors is the most common. Tactile sensors are used only as a backup safety element to activate the emergency stop. Only the combination of different processing methods and the application of various types of sensors can increase the quality of output information.

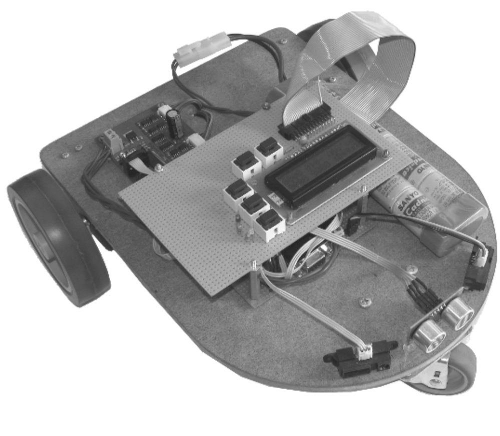

Fig. 3. First prototype of undercarriage for testing of designed algorithms and its behavior [7].

We have selected two types of sensors for the application in our testing undercarriage. The first type is the set of optical sensors used for detecting of any nearest obstacles in both sides of robot. In the middle the second type is mounted – one ultrasound proximity sensor which is used for measuring of the distance to the obstacles located in front of MR. The real prototype is shown in Fig. 3.The same behavior model should be created also in simulation software through the mathematical description of selected sensors.

5. CONCLUSIONS

Nowadays, the application of mobile robots is very often used and them number is still growing because of their high autonomous behavior that can respond easily to new demands (quick changeover, variable orders, reconfigurable design, flexible layout) developed by actual assembly systems.

The main task which should be done is the design of navigation methods and also the design of control system. Potential fields can relatively easy and reliably used for the tasks of mobile robots' global navigation – navigation in known environment. The method based on reactive control is for local navigation easily applicable. In simulation software, which is developed at University of Zilina, we deal with testing both of these methods. We were come to conclusion that the modified method of potential fields' generating process is more effectively. The combination of more methods is shown as the best way to solving of mobile robots' global navigation.

After the testing of every components and software the second prototype can be applied in industrial environment (material transport within the factory, etc.).

ACKNOWLEDGEMENTS: This paper was made under the support of Slovak grant agency VEGA – project No: 1/0207/10.

The work has been partial funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection, POSDRU/88/1.5/S/61178.

REFERENCES

[1] V. Bulej, *Návrh simulačných programov pre mobilné a paralelné roboty* (The design of simulation software for mobile and parallel robots), PhD Thesis, University of Zilina, Zilina, Slovakia, 2007.

[2] J. Vőrős, *Mobile robot path planning using quadtree-base potential fields*. AT&P Journal PLUS, No. 6, 2005

[3] B. Siciliano, L. Sciavicco, L. Villani, *Robotics: Modelling, Planning And Control*, Springer, 2011.

[4] S. Věchet, J. Krejsa, *Mobile Robots Localization and Path Planning*, Tomáš Březina (Ed.), pp. 149−156, University of Technology, Brno, Czech Republic, 2006.

[5] J. Uríček, et al., *Application of Potential Fields for Mobile Robots Path Planning*, TMT 2007, Tunisia, September 2007, Hammamet.

[6] M. Šeda, T. Březina, *Geometric Robot Motion Strategies*, Tomáš Březina, (Ed.), pp. 197−202, Brno University of Technology, Brno, Czech Republic, 2006.

[7] J. Mátik, *Návrh riadiaceho systému pre mobilné a paralelné roboty* (The design of control system for mobile and parallel robots), PhD Thesis, University of Zilina, Zilina, Slovakia, 2008.