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CONTROL AND NAVIGATION OF MOBILE ROBOTS IN SAFETY AND FIRE PROTECTION

This paper presents the actual situation of mobile robots (MRs) application in the field of safety and fire protection. At the beginning are described the basic structures and subsystems of each MR, reasons for their applications and some design examples of mobile robots applied for safety and fire protection. The second part of this paper presents several different conceptions of MR control systems with respect to dangerous applications. The last part of this paper is oriented on the methods of MR navigation and path planning. This part is related with maps and localization problem and describes why it is necessary to have a map in MR control system. There are presented some basic map types with their advantages and disadvantages.

1. Introduction

Generally, the mobile robot is a complicated mechatronic cognitive system consisting of many subsystems with different levels of complexity. The most distinguished characteristic mark of mobile robots is their locomotion in space. The problem of design process of a mobile robot integrates the knowledge from many science fields as cybernetics, automation, mechanical engineering, electronics, informatics, artificial intelligence and bionics. Selection of appropriate navigation method in workspace is one of the fundamental problems, which is solved by the design process of all autonomous mobile robots (AMR).

The reasons for mobile robot application:
- safety – 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.

The application of mobile robots in natural disasters, various rescue operations and fires can help increase the efficiency and safety of rescue work. It can reduce the risk that people have now to undergo during similar actions. The minimization of risk for human in danger environment is also the reason why the researchers around the world deal with development in the field of mobile robotics. In this paper we want to describe some problems associated with the application of mobile robots under these very specific and hard conditions.

AMRs contain several subsystems:
- mechanical subsystem (locomotion subsystem) – undercarriage,
- sensoric subsystem – internal and external sensors,
- control subsystem – control of all subsystems of AMR,
- communication subsystem – data transfer and communication with operator.

2. Application of mobile robots in fire protection

One of the authors had within practical Erasmus training the chance to participate in the project oriented on development of a mobile robot named Guardian (Fig. 1a). This robot is designed for firefighters and developed by the company Robotnik Automation (Valencia, Spain). The main task was to run real time Linux on embedded PC together with drive subsystem. The second task was implementation of a laser range finder to the SLAM (Simultaneous Localization and Mapping) algorithm. Another subject of development was the system enabling to automatically follow a walking firefighter without teleoperation. The new Guardian is a high mobility robot with modular architecture. It is able to integrate several sensors – indoor/outdoor laser, cameras, microphones, stereohead, GPS, IMU (Inertial Measurement Unit) and actuators for modular robot arms, tilting camera, etc. The robot weighs 75 kg and its load capacity is approximately 50 kg. Guardian is an all-terrain vehicle, able of climbing up and down steps thanks to the hybrid undercarriage (combination of wheels and belts). The robot is small enough to be transported in a conventional car boot and light enough to be loaded into a lift. The mobility and high speed of the robot allows it to rapidly access to buildings.

Guardian is controlled by embedded PC with operational system Linux Real Time. On this platform the Player/Stage is running thus enabling the navigation of the robot through the corridors inside the buildings and also building its own map of environment. The system WiFi/WiMan is used for the communication

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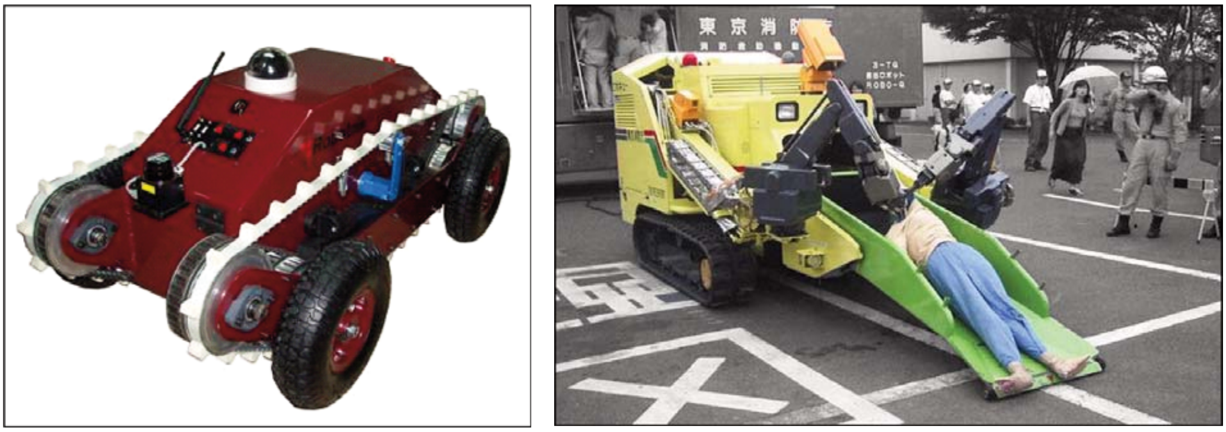


a) b)

Fig. 1 Mobile robots applied for rescue systems
a – Guardian (Robotnik Automation, Spain) [4], b – Robo-Q (Tokyo Fire Department, Japan) [5]

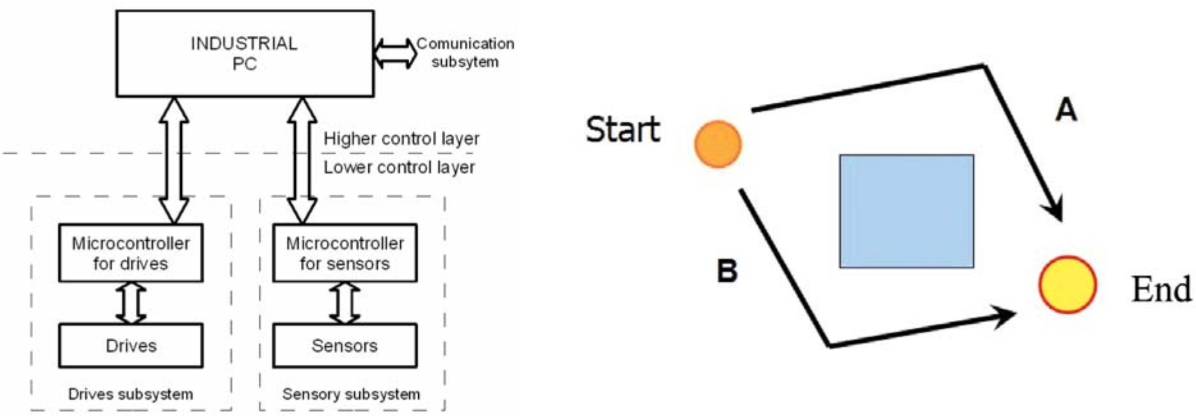
with the operator. As an optional device the system can be applied for manipulation with objects by two independent arms.

Another example of the mobile robot for the rescue systems is the Robo-Q used in firefighting (Fig. 1b). Now, it is working for the Tokyo Fire Department. This robot uses its arms to identify and pick up any people who might have passed out from the smoke and fumes generated by fires. The practical side of this robot is that firemen no longer have to run into thick smoke or chemical fumes to perform the rescue.

3. Control systems for mobile robots for application in fire protection

The control system of the mobile robot together with a control program is one of the most important parts of the mobile robot. Hardware of the control system should be able to retrieve information from the sensoric 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. It is necessary to take into account the planned usage of the mobile robot during the selection of a suitable type of a control system – if it is a mobile robot for indoor or for outdoor environment. This leads to requirements for operating temperature, humidity and vibrations. Another requirement, which affects the concept of the control system, is also the question what the control system will monitor and handle (drives, sensors, communication with operator) – all within relatively small periods. The autonomy of the mobile robot significantly affects the final configuration of the control system where there are several possibilities. Roughly speaking, the mobile robot control system can be based on the a personal computer, industrial computer (IPC – Industrial PC) or on a microcontroller.

The control system based on a standard personal computer is not very suitable for mobile robots applied in safety and fire protection. These applications require the control system with some special characteristics (resistance to high temperature, humidity and vibrations). All of these requirements and some others can be



a) b)

Fig. 2 The basic scheme of control system for AMR (a) and path planning (b) met using the control system based on IPC or based on the microcontroller.

Control system based on microcontroller can be developed exactly for concrete application. We can set up the number of inputs, outputs, communication interfaces, etc. Also the final size of the control system can be smaller than in case of IPC. It is necessary to use a special container for the control system. The microcontroller is not the best solution for a control system with high computing power requirements, but it is good to combine the microcontroller with IPC.

Control system based on combined architecture can provide us with advantages from both industrial PC and microcontroller (Fig. 2a). The lower control layer can control only some processes, for example, a drive subsystem or sensoric subsystem. In case of the drive subsystem, it is necessary to drive motors depending on information from the higher control level. It means to compute the parameters for a motor driver with feedback from incremental sensors using PID (Proportional Integral Derivate) algorithm which gives us higher control accuracy. The sensor subsystem based on a microcontroller processes data from sensors. The higher layer of control system then does not have to use computing power on those tasks and can work, for example, on the path planning and map building.

The navigation of AMR focuses on the three basic tasks (three key questions) which the control system of mobile robot has to solve (Fig. 2b) [3]:

- Where am I?
- Where am I going?
- How do I get there?

To answer these questions the robot has to [3]:

- have a model of the environment (given or autonomously built),
- perceive and analyze the environment,
- find its position within the environment,
- plan and execute the movement,

4. Navigation and path planning of mobile robots

The 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 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.

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 is used whilst for the task "Coordinated movement between two points of environment" (for known environment) the global navigation is used. For complex solution of mobile robots movements control both navigation methods are therefore used (Fig. 3).

For exploring the surrounding environment the system of proximity sensors is the most commonly used. Tactile sensors are used only as a backup safety element to activate the emergency stop. Proximity detecting of obstacles may be principally based on image sensors handlers or distance measuring sensors (optical and ultrasonic). Only the combination of different processing methods and the application of various types of sensors can increase the quality of output information.

Local navigation

Local navigation is based on execution of elementary steps providing a collision-free robots path within the environment. The movement is executed without considering the global "End" position (Fig. 2b). For the local navigation data from different kinds of sensors (optical, ultrasonic) are used, most frequently in the form of the information about obstacles presence or absence in assumed course.

Global navigation

Global navigation is the control of mobile robots movement between the entered global "Start" and "End" position. In comparison with local navigation, in the case of global navigation the importance of end position is markedly greater. The basic task in

Basic functions and basic types of mobile robots' navigation Table 1.

Navigation strategies	Methods of sensors' data processing	Representation of environment	Type of environment	Level of path planning
Global navigation – strategic level *(Environment exploration)*	Environment modeling	Topological, hybrid or multilayer maps (Voronoi diagram)	Known	Planning of the path between several places
Global navigation – tactic level *(Environment exploration)*	Environment modeling	Metric or topological maps (Potential fields)	Known	Finding the path between two points
Local navigation *(Course planning)*	Localization and obstacles avoidance	Metric maps (Occupation grid)	Unknown	Course planning
Reactive control *(Obstacles avoidance)*	Obstacles avoidance	—	Unknown	—

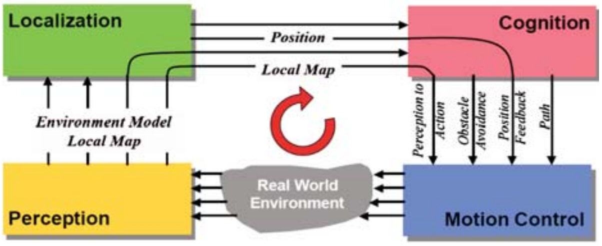


Fig. 3 Activities of mobile robot control system [8]

this case is the determination of a global path. This kind of navigation is called "the planning".

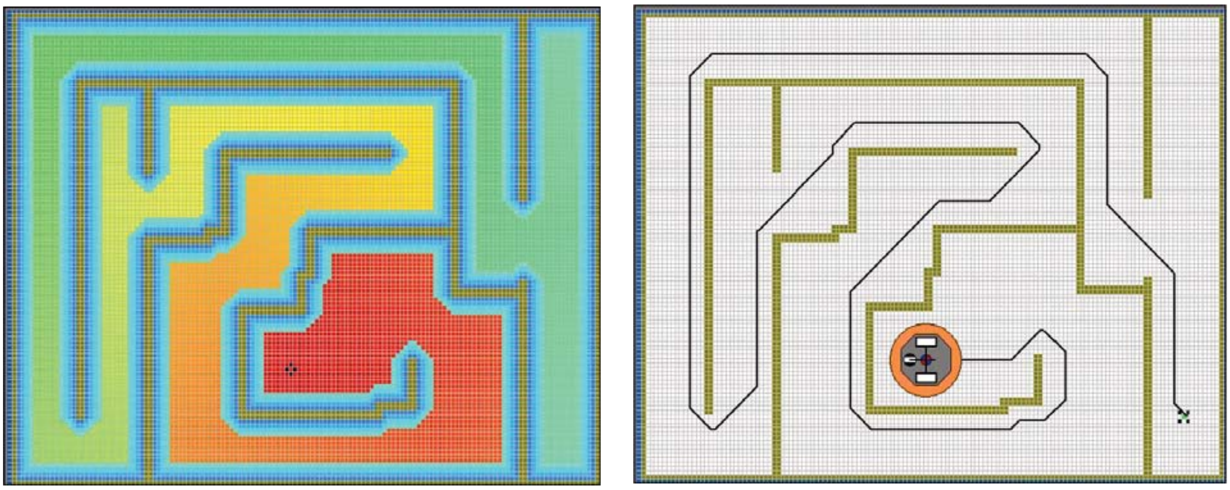
The tactic level of global navigation (the path planning) is often solved with the method of potential fields (Fig. 4), which is based on the principle of cooperation of so-called attractive and repulsive fields (or forces). Generally, the metric maps are applied for generating these fields. Specific selection is dependent on the map size, type of obstacles, etc. [2, 3, 6].

5. Maps and localization

Due to a high level of danger it is necessary to ensure a higher level of the system security. In the buildings on fire a huge problem is with the smoke and dust concentrated inside the closed rooms, so it is difficult to apply the standard method of localization and navigation. Also the connection with the human operator can be lost. Then, it is better when the robot has its own map of environment and also algorithm describing "what it must do" in emergency. When the robot loses the connection with an operator, the robot itself can find the right way. Therefore, it is important to choose an appropriate map type which will help the robot to find the right way in this case.

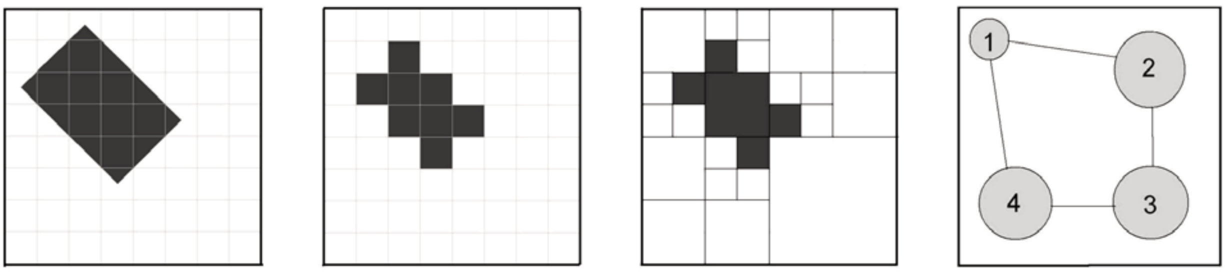
Metric maps

Objects are described by their shape and dimensions. This group is very often represented by raster maps. As an example we can consider so-called Occupancy grid, Polygonal map or the Quadtree representation (Fig. 5). The Occupancy grid looks like a grid where the columns and rows have constant width or height.



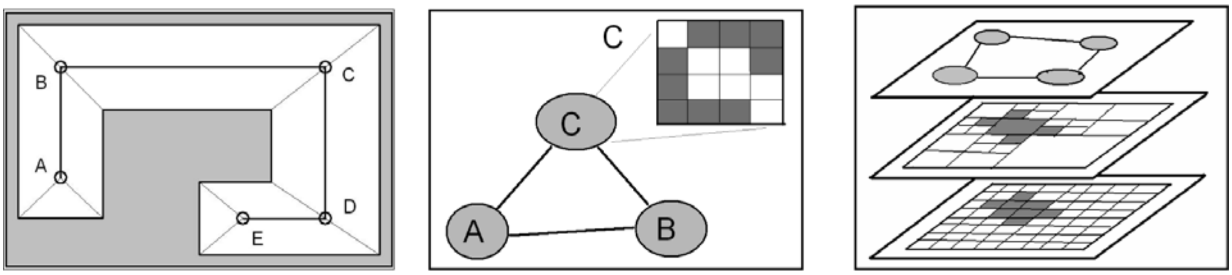
a) b)

Fig. 4 Methodology steps by global navigation - outputs from simulation software designed at authors workplace
a - generated final form of potential field, b - planned path



a) b) c) d)

Fig. 5 Representation of object O in metric (a, b, c) and topological (d) maps
a - object O (in our case "an obstacle"), b - representation of object O in 2D-raster, concretely in Occupancy grid,
c - representation of object O by Quadtree, d - representation of object O in topological map



a) b) c)

Fig. 6 Other map systems for mobile robot path planning
a – transformation of the metric map into the topological map, b – hybrid map system, c – principle of multilayer system

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.

Topological maps

In this case the path between points are 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 (Fig. 6).

6. Conclusion

This paper presents the current situation of mobile robots application in the field of safety and fire protection. Nowadays the application of mobile robots is very often and the number of developed robots still grows. Mobile robots are used especially in the environments, which are dangerous for human. They can be found in firefighting, bomb disposal, chemical operations, underwater operations, etc. Several concrete mobile robots are described in the paper. The second part of this paper presents different conceptions of mobile robot control systems with respect to dangerous application. The control system can be developed as a simple control system based on a microcontroller, but also as a complex control system based on industrial PC combined with PLC and microcontroller. The development of mobile robot control system depends on many factors, e.g. on environment parameters, EMI, required battery running time, computing power, operating range etc.

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