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A Navigation System and Task Planning in a Mobile Robot for Inspection

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1. Introduction

An autonomous inspection robot can be designed to operate in a wide range of industrial, military, police, scientific, domestic and educational applications. The robot described in this project work, is a low-cost vehicle that is intended for research purposes, but with a few changes in some of its components it can be used for real-life tasks. The general idea in the creation of this robot is to use the advantages of the modular design. Different ready standard modules are combined in order to construct the whole system. The designer has to select the most appropriate components and to make the connections among them. He has to organize their communication in order to achieve their proper work and also the proper work of the robot system as a whole. Each component affects greatly the performance of the system and that is why the selection of the sub-units is very important, but it also should be done according to the imposed set of constraints, such as price (Fig. 1). The designer must also ensure the good communication between the operator and the robot.

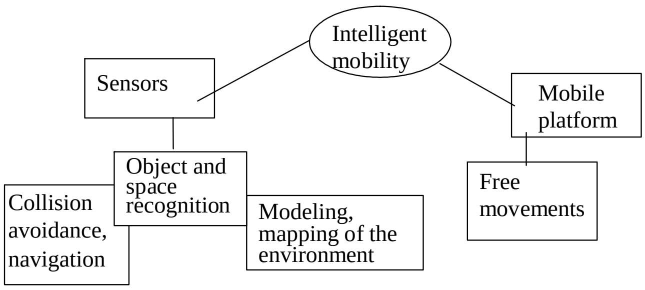

Fig. 1. Components supporting intelligent mobility

2. Navigation system

The navigation of a mobile robot comprises localization, motion control, motion planning and collision avoidance. Its task is also the online real-time re-planning of trajectories in the case of obstacles blocking the pre-planned path or another unexpected event occurring.

Inherent in any navigation scheme is the desire to reach a destination without getting lost or crashing into anything. A higher-level process, called a task planner, specifies the destination and any constraints on the course, such as time.

Many problems have to be solved before robots can match the sophisticated navigation abilities of people. Most mobile robot algorithms abort, when they encounter situations that make the navigation difficult [2].

Set simply, the navigation problem is to find a path from start (S) to goal (G) and traverse it without collision. The relationship between the three subtasks – mapping and modeling of the environment; path planning and selection; path traversal and collision avoidance – into which the navigation problem is decomposed, is shown in Fig. 2.

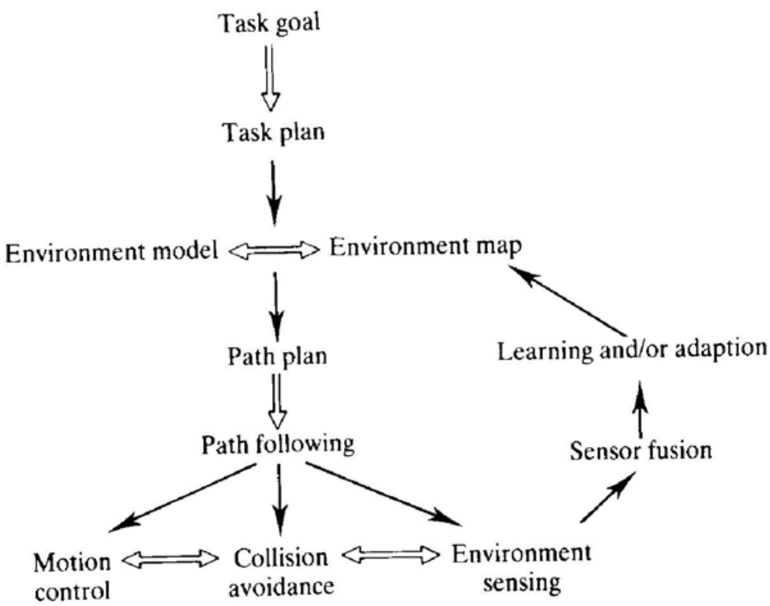

Fig. 2. Mobile robot control hierarchy, showing information flow

Environmental perception. Being autonomous or partly autonomous-guided systems, the mobile robots need to move in an unstructured environment without having a prior knowledge about it. In order to provide this autonomy, there is a need of sensor-based navigation. A reliable sensor system is the key feature for the perception of the environment. The basic configuration of each mobile robot has its integrated sensors. Depending on the requirements of the task some sensors may be superior to others.

For the development of service robots, one usually chooses a combination of different sensors, in order to achieve optimal results in the environmental sensing. First of all, the navigation system needs firmly integrated sensors to each of the actuated wheels or other means of mobility. Generally there are photo-optical encoders coupled to the wheels which give the main control system data for their position and number of turns in some of the rotation directions. Having this information, the control system can follow a certain programmed path.

The second group of firmly integrated sensors are those connected to robot safety. The anti-collision sensors are usually attached to the mechanical bumpers surrounding the mobile platform. They are usually tactile sensors or micro switches built in, or, in the more advanced ones the bumper systems are doubled for safety reasons by ultrasonic or laser ones installed around the robot body.

There is a large variety of sensors, which can be added to the basic ones, thus adapting the robot for some special applications or extending its abilities.

The use of vision to acquire the location of objects requires extensive computing power and robust recognition algorithms. The camera captures a two-dimensional image, from which the vision processing software must extract image features. These features are compared to models of the objects to identify the object of interest and the location to which the robot has to move. The location (position and orientation) of the object relative to the robot, and/or relative to world co-ordinates is then estimated to produce an object location signal.

Sensors are varying from simple ones to the very sophisticated sensory systems, applying the artificial intelligence (AI) principles.

Environmental modelling. The environmental modelling unit processes the sensor data and relates it to the world model, thus building environmental maps. These data and the environmental maps are then used for the motion control of the mobile robot [3].

For precise modelling and perception of the environment it is important to reduce measurement errors and to guarantee an adequate registration of all relevant features in the environment. This is achieved using and evaluating data from different sensors, which should preferably work with different underlying physical principles.

The combination of various sensors data into one plausible stream of sensor data is known as sensor fusion. This fused sensor data is used to build up a world model as reliable and complete as possible.

Nowadays other algorithms use also fuzzy logic or neural network techniques to combine sensor data and to extract relevant features and patterns. The pre-processed data is then used to construct a map or model of the environment, as shown in Fig. 3.

Fig. 3. Environmental perception and modelling

When creating maps there are generally two common representations, the geometric and the topological approach. A geometric map represents objects according to their absolute (Cartesian) geometric relationships. It can be a grid map or a more abstract map, such as a line or polygon map. Often grid maps are used as they have the advantage of requiring less computation than other maps and they are also built up more quickly.

By contrast the topological map is based on recording the geometric relationships between the observed features rather than their absolute position with respect to an arbitrary coordinate frame of reference. The resulting representation takes the form of a graph where the nodes represent the observed features and the edges represent the relationships among these features. Unlike geometric maps, topological maps can be built and maintained without any estimates for the absolute position of the robot.

Navigation. The navigational functions are usually divided into different classes, regarding their complexity.

The most direct coupling of sensors and actions is achieved by reflexes. This is a strong relationship between a sensor stimulus and a reaction of the system with by-passing any higher task planning functions of the robot. Especially critical life support mechanisms are based upon these reflexes. They are basically characterized by a short response time and are difficult to inhibit by higher intelligence functions. They guarantee a safe behavior of the vehicle in emergency and other unexpected situations.

Other more complex mechanisms lead to local navigation schemes. This level is still of higher reactivity and can cope with changes in the environment such as unexpected or even moving obstacles. Its task is also the re-planning of trajectories in case of an obstacle blocking the path or of other sudden events. Since it determines the vehicle path on-line and real-time, it usually cannot guarantee the production of an optimal trajectory.

The most complex mechanism of action is the global navigation, generating paths to goals given by the task-planning unit [4]. The paths generated in that way consider all data provided by the world model and the result is near to optimal movements.

Safety. Classical industrial robots work in an environment that strictly separates the workspace of human beings and robots. On the opposite, service robots are defined to fulfil their tasks in public areas, which are not enclosed or separated. In most cases this implies direct contact between the robot and the people. This contact is not avoidable and it could be even a part of the task specifications. Therefore, the development and design of service robots requires very high levels of safety measures. Service robots have to react to and cope with human behavior, so they have to ensure their harmlessness with respect to the persons staying in the workspace of the robot [5]. Constructive measures in the system design as well as structural and design measures for the workplace of the robot have to be taken, in order that all aspects of person's safety to be satisfied.

The requirements for a service robot, which acts in an environment along with a human being, are that all possible contacts with the person should be harmless as well as all movements should be surveyed and stopped when the robot approaches the person. Safe operation of the robot should be guaranteed even in the case of multiple sensor malfunctions. Another requirement is that the man-machine interface should be of ergonomic design and the operation of the robot should be as simple and self-evident as possible.

3. Task planning

A basic problem in robotics is to resolve specified tasks and commands and plan the resulting motions and sub-tasks. The planning system needs to transform a task-oriented problem into a plan, which describes how the given problem can be solved by the robot. For this transformation a detailed knowledge base and world model have to be available. These models give the robot a description of its environment, and thus enable it to construct the necessary operations needed to fulfill the task. The plan generated in this way contains a sequence of action elements (e.g. movement, picking up items, manipulating items) with assigned resources (e.g. the robot or its gripper). The motion control manager determines the start and destination of a path and plans the course and the necessary actions.

The resulting motions of a robot are called trajectories or paths and consist of a sequence of desired positions, velocities and accelerations at a given point.

The sequence of plan elements is called a task execution sequence. During this planning stage all constraints and restrictions, like closed or impassable areas are considered as well as target times, resources, supplies or the processing of parallel or sequential tasks (Fig. 4.).

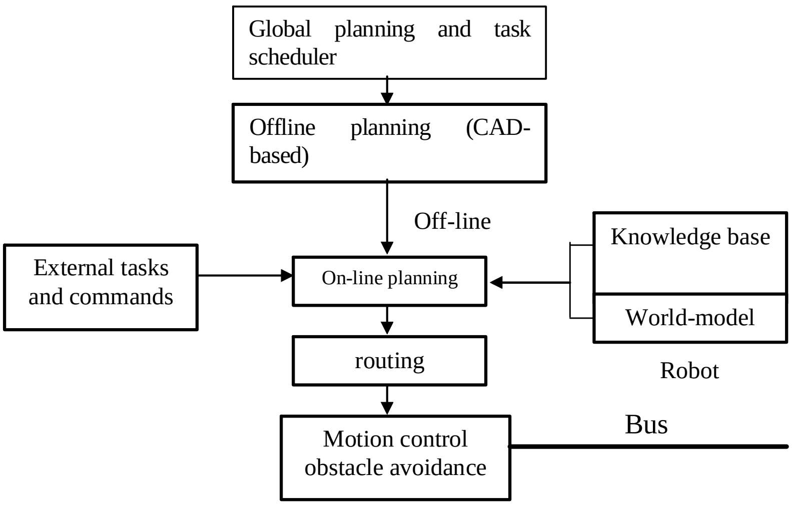

Fig. 4. Task planning of mobile robots

Basic planning paradigm. In 1983 Wilensky has outlined the basic structure of plans from the viewpoints of com-monsense problem solving and natural language understanding. In this paradigm the planner recognizes from the environment that a new situation has arisen which merits a goal.

The planner then retrieves from memory a plan that might be used to achieve this goal, or generates a new trial plan if no existing plan is suitable. This candidate plan is then projected forward (via simulation) to observe the outcome. This outcome is examined to see if there are any conflicts that will arise in achieving other goals if this plan is pursued. If not, this and other candidate plan outcomes are evaluated and the maximum-valued plan is chosen.

The plan, when implemented, will modify the current state of affairs. This impact, together with any other changes in the environment, results in a new world model with new situations that may merit new goals, so that the cyclic process of planning continues. When candidate plans are being considered, if the candidate plan overlaps existing plans for other goals, these overlapping plans may be merged to preserve resources.

A basic problem in planning is that of conflicting goals. The causes of conflicting goals are indicated in Fig. 5. (A preservation goal is a goal to preserve an already existing condition, or a goal not to undo a desirable state or a goal resulting from another plan.)

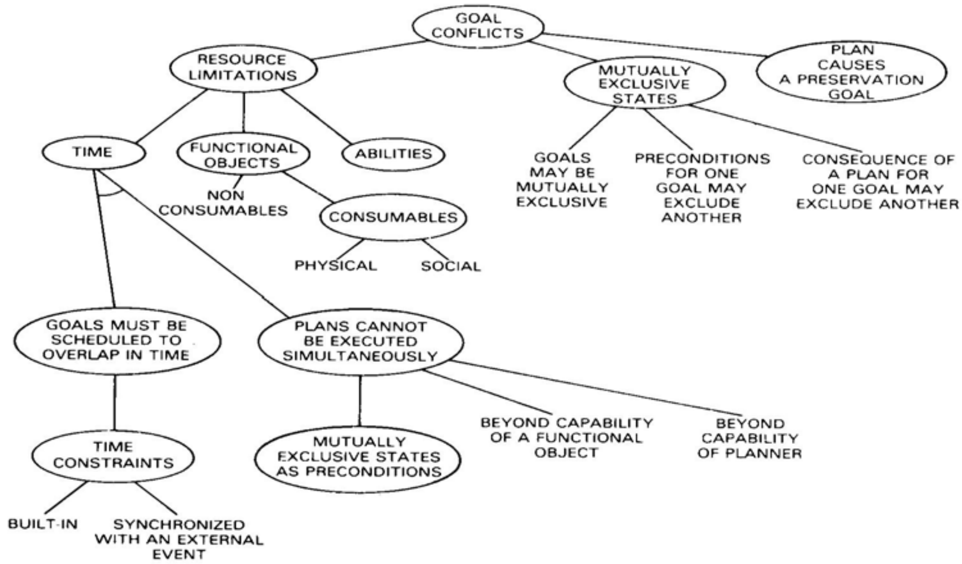

Fig. 5. Nature of goal conflicts

Problems arising from conflicting goals are dealt with re-planning or eliminating the factors causing the goal conflicts. If the goal conflicts cannot be completely resolved, partial fulfilment of goals may be attempted or goals of lesser importance may have to be dropped.

The global strategy is to achieve as many goals as possible, maximize the composite value of the goals achieved, and not waste resources in achieving them.

DEVISER by Vere (1983) is a good example of a planning program designed to deal with conflicting goals resulting from resource and time constraints. Wilensky also discusses “competing goals” that arise in competitive situations. The planning strategies are to:

1. Avoid conflicts
2. Outdo an opponent
3. Hinder an opponent
4. Induce alterations in competitor’s plans

Paradigms for generating plans. The major issue in any planning system is reducing search. The other key issue is how to handle interacting sub-problems. The following paradigms are different approaches to address these issues.

Cohen and Feigenbaum (1982) discuss four distinct approaches to planning:
– non-hierarchical,
– hierarchical,
– script-based (skeletal),
– opportunistic.

The key planning systems that have evolved over the years are based on these approaches. Virtually all plans, both hierarchical and non-hierarchical, have hierarchical sub-goal structures. That is, each goal can be expanded into several sub-goals, which themselves can be further expanded, and so on, until the bottom level consists of operators needed to achieve the lowest-level goals. The distinction between hierarchical and non-hierarchical planners is that "a hierarchical planner generates a hierarchy of representations of a plan, in which the highest is a simplification, or abstraction of the plan and the lowest is a detailed plan, sufficient to solve the problem. In contrast, non-hierarchical planners have only one representation of a plan".

4. Conclusion

There are too many fields of application for mobile robotics – places where locomotion is needed and where the environment is not so simple or is constantly changing. For these applications, the intelligent behavior of the robot has to pass through an understanding of the task and the environment via a global perception and a decision-making process. The ultimate target, which has to be reached in the future, would be a robot that possesses features, resembling those of a human being.

R e f e r e n c e s

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Навигационная система и планирование движения мобильного робота для инспекции

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Описана роботизированная система для инспекции как пример приложении принципа модульности, а также при выполнение експериментов для интеллигентного принятия решений. Программирование удобно для потребителя и вся информация относительно управление робота легко доступна. Представлены планирующая и навигационная системы, обсуждены функции локализации, планирование движении, столкновения.