

INTELLIGENT TECHNIQUES FOR COGNITIVE MOBILE ROBOTS

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Abstract: Mobile and/or autonomous robots represent a widely approached research subject. The most common problems associated to all the types of mobile robots refers to the spatial orientation system and to the mathematical models. Additionally, many difficulties are generated taking into consideration practical aspects of implementation, but the technology evolution made possible to develop smaller sized robots and to provide them with greater autonomy. Most of the existent mobile robots are wheeled ones, easy to build, but not always easy to control. They are not at all purpose convenient, but could avoid obstacles, without being able to climb them. For an evolution in more complex configuration spaces, worm-like robots were also developed. Control strategies for such robots should have more or less embedded intelligence.

Keywords: autonomy, mobile robots, intelligent control, artificial neural networks, fuzzy control

1. INTRODUCTION

The evolution of mobile robots and their application in different fields – including the domestic area – imposes increasing the autonomy level of such devices. The operation an autonomous mobile robot in a real world unstructured environment requires taking into consideration multiple aspects. The control strategy must be selected in order to operate under conditions of imprecision and uncertainty (prior knowledge about the environment is, in general, incomplete, uncertain and approximate, perceptually acquired information is also typically noisy and incomplete).

In these unpredictable evolutions of the environment the autonomy of mobile robots could be obtained by increasing the level of intelligence of the controller. In the structure of the control system new functions must be incorporated in order to give to the robots the possibility to search the goals by adapting on the unpredictable environment.

The control strategy of the mobile robots must be based on reactive and goal-achieving procedures, which includes the perception, learning, planning and behavior generation phases. These new kinds of functions could be implemented by using intelligent techniques into the autonomous control system.

The architecture of an autonomous control system includes the execution level, the coordination level and the strategic level. Each level in this architecture has more or less incorporated “intelligence”. The distribution of the intelligent tasks on different levels is realized taking into account the “IPDI PRINCIPLE” (Increasing Precision, Decreasing Intelligence).

This paper analysis the possibility to implement the different attributes of the intelligent systems, like: perception, learning, reasoning, communication, planning and behavior generation. The autonomy of the mobile robot is obtained by including into the control system the intelligent techniques like artificial neural

networks and fuzzy control systems. An intelligent mobile robot is an embedded real-time system with real abilities to move and to accomplish its objectives and overall performance in connection to a dynamic and unpredictable environment. The mobile robot behaves like an intelligent agent, which incorporates the mechatronic part as an interface to the environment. Therefore, when an agent acts, it interacts with its environment because it is situated in this environment and realizes the perception of the environment. The evolution of the mobile robot is defined by its behavior in the specified environment, taking into consideration the task it has to fulfil. Only the simultaneous description of the agent (mobile robot), of the task and of the environment completely defines the agent (the agent – task – environment triangle) (Dragoicea, 2003).

In order to fulfil complex tasks into complex environments, the mobile robot must be able to operate autonomously, that means to be able to move in its environment, to adapt to the changes of the environment, to learn from experience, to modify its behavior and to build internal representations of the surrounding world that may be used in the decision making process. In this case the intelligent mobile robot can be seen as a mechatronic structure that can operate autonomously into undefined environments. We identify the main four module of an intelligent system (introduced by James S. Albus) as being the sensory processing module, the world modeling module, the value judgement module and the behavior generation module.

This paper tries to make a synthetic description of the evolution of the intelligent mobile robot control structures taking into consideration the behavior generation based approaches and different architectures of autonomous control systems.

2. COGNITIVE BEHAVIOR OF MOBILE ROBOTS

Recent results imposed by neurophysiology, ethology and cognitive psychology displayed new methodologies to transfer animal behavior models towards intelligent robots, therefore helping to formalize certain aspects of biologic behavior. By analyzing the way in which living creatures fulfil specific actions (analyzing the "inputs" and the "outputs" of their behavior) modalities of organizing intelligence can be defined.

Following biologic evidences, the specific way to organize adaptation and communication

functions at the control level assures that the mobile robot is capable (figure 1):

- to communicate in an intelligent way with its environment and with other robots;
- to react in hostile environments and to adapt to a variable evolution context through learning and behavior generation;
- to communicate by natural language, being flexible in the decisional process;
- to integrate an informatic system with multiple facilities dedicated to the intelligent agents and to communicate in an intelligent way with the mechatronic structure;
- to assure the hardware and software reconfiguration facility.

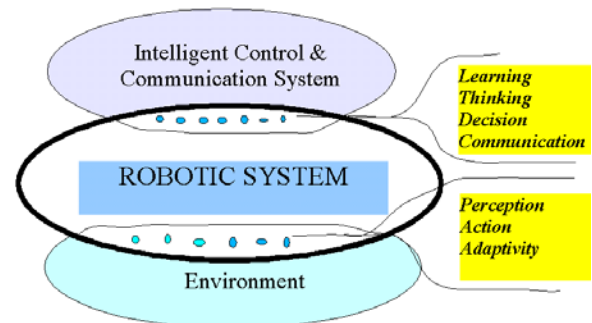


Figure 1 Control system for mobile robots - adaptation and communication functions

Therefore, the integration of advanced environment perception and communication devices into mechatronic structures facilitates the development of strongly associative information systems with high level of intelligence.

Perception, action, adaptivity, learning as well as *decision making* are possible by integrating specific intelligent control techniques like artificial neural networks, fuzzy logic, genetic algorithms or synergetic combinations of them. *Perception, action, adaptivity, learning* and *decision making* are characteristics of living organisms, therefore this should be the starting point for gathering insights regarding this biological functions. Today AI roboticists often turn to biological sciences being that animals can provide existence proofs of different aspects of intelligence.

By focusing on the way living creatures "do" something roboticists can gain insights into how to organize "intelligence". Following the biological traces, inside the control system of a mobile robot intelligence can be organized in a

deliberative, reactive or hybrid deliberative / reactive way.

The most suitable way to implement a reactive control system for mobile robot control is by using *behaviors*. The *behavior-based approach for reactive control* reduces the cost of building and maintaining internal representations of the environment. The agent is considered as an inseparable part of its environment; and there is a relationship between the agent and the environment that governs the behavior of the agent. The agent can retain its relationship to the environment by using a set of behaviors each of which maintains a mapping from sensory information to some control parameters for actuators. Thus, the representation internal to the agent can be compacted to the minimum necessary for the agent to retain its ability to react to some stimuli from the environment for the sake of survival.

As shown in figure 2, the minimum representation required in this approach consists of two parts: sensory situations representing stimuli, and situation to reaction mapping.

A behavior may have several sensory situations (see figure 2), a set of actions and a mapping between the two sets. There may be several reactions in execution at the same time in a behavior-based controller.

The action executed in the actuators may contain the overall, or a part of the, effect of the actions resulting from behaviour programs. By using the exteroceptive sensors, the agent acquires a model of the workspace as it is at the moment when the task must be performed.

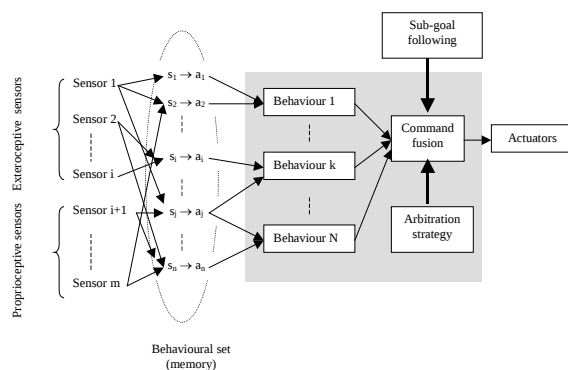


Figure 2 Building a behavior-based controller for reactive navigation

Typically, the sensory situations to which a behaviour can react are limited. Only a portion of the information supplied by all sensors triggers a behaviour, and all the behaviours that are triggered may react differently. The reactions of all behaviours together contribute to the action finally executed in the actuators. A

mechanism is needed to mediate all reactions suggested by behaviours that respond to the current sensory input and to formulate one action to the actuators.

Distributed execution of behaviours leads to fast decisions making, so the agent can react to sensory input quickly. Each behaviour fully implements a control policy for one specific sub-task, like following a path, avoiding sensed obstacles, or crossing a door. The *arbitration strategy* decides which behaviours should be activated depending on the current goal and on the environmental aspects. Several behaviours may be concurrently activated: in these cases, some form of *command fusion* (or a *combinator*) is needed to combine the results from these behaviours into one effector command. Many proposals in the autonomous robotics literature adhere to this scheme, but differ in the emphasis put on each part.

In order to encode the behavioral response that the stimulus should generate, a functional mapping from the stimulus plane to the motor plane should be created. Therefore, a behavior can be expressed as a triple $(S, R, \mathcal{F})$, where S means the domain of all interpretable stimuli, R represents the range of possible responses, and $\mathcal{F}$ represents the mapping $\mathcal{F}: S \rightarrow R$.

S - The stimulus domain

S consists of the domain of all perceivable stimuli from the environment. The strength of the input stimuli will determine whether or not to respond and the magnitude of the response.

Each stimulus can have a particular type, depending on how it was obtained. Figure 2 distinguishes between data received from proprioceptive sensors and exteroceptive sensors, therefore different processing techniques are involved in extracting meaningful information (e.g. real valued raw data processing, feature extraction, etc).

Behavior-based robotic systems would start with crisp sensor readings (e.g. numeric values from proximity sensors).

R - Range of responses

The instantaneous response $\mathbf{r} \in \mathcal{R}$ of a behavior-based reactive system can be expressed as a 3-dimensional vector consisting of 3 sub-component vectors. Each of the sub-component vectors encodes the magnitude of the translational and orientational responses:

$$\mathbf{r} = [x \ y \ \theta]$$

where the first two components of $\mathbf{r}$ represent the two translational degrees of freedom (x , y in the two-dimensional cartesian coordinates), and the last components encode only one degree of rotation θ . Because the geometrical aspects of mobile robot mechanical configuration translate (x , y , θ) triple into wheels velocities (V_{left} , V_{right}), the range of possible responses can be easily expressed in terms of actuator control signals (Dragoica, 2000).

$\mathcal{F}$ - The behavioral mapping

For each individual active behavior we can formally establish the mapping between the stimulus domain and the response range that defines a behavioral function $\mathcal{F}$.

$\mathcal{F}$ can be defined arbitrarily, but it must be defined over all relevant stimuli in S . Usually, a specific stimulus threshold, τ , must be exceeded before a response is produced for a specific stimulus, $s \in S$. A value of $\mathbf{r} = [0, 0, 0]$ indicates that no response is required given the current stimulus s .

In this framework, the behavioral mappings, $\mathcal{F}$, of stimuli onto responses fall into two general categories:

- null*: the stimulus produces no motor response;
- discrete*: the stimulus produces a response from a limited set of prescribed choices (all possible responses consists of a predefined cardinal set of actions that the robot can enact, e.g. turn-right, go-straight, stop, travel-at-speed-5, etc). R consists of a bounded set of stereotypical responses enumerated for the stimulus domain S and specified by $\mathcal{F}$.

3. FUZZY BEHAVIOR REACTIVE CONTROL

A fuzzy control system for behavior-based robotic systems would start with crisp sensor readings (e.g. numeric values from proximity sensors), translate them into linguistic classes in the fuzzifier, fire the appropriate rules in the fuzzy inference engine, generating a fuzzy output value, then translate these into a crisp values representing actuator control signals.

Fuzzy logic allows a certain type of discrete encoding of the (situation, reaction) pairs by using rule-based systems. Here $\mathcal{F}$ is represented as a collection of IF - THEN rules that take the general form:

IF antecedent THEN consequent

where the *antecedent* consists of a list of preconditions that must be satisfied in order for the rule to be applicable and the *consequent* contains the motor response. The discrete set of possible responses corresponds to the set of rules in the system. More than one rule may be applicable for any given situation. The strategy used to deal with conflict resolution typically selects one of the potentially many rules to use based on some evaluation function.

Figure 3 presents a fuzzy logic control system architecture for elementary behavior implementation that consists of the following parts:

- fuzzifier: it maps a set of crisp sensor readings onto a collection of fuzzy input sets;
- fuzzy rule base: it contains a collection of IF - THEN rules;
- fuzzy inference engine: it maps fuzzy sets onto other fuzzy sets according to the rule base and membership functions;
- defuzzifier: it maps a set of fuzzy output sets onto a set of crisp actuator commands.

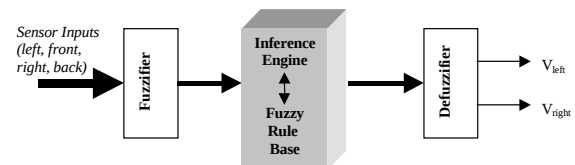


Figure 3 Fuzzy logic control system architecture for behavior implementation

Fuzzy controllers are typically designed to consider one single goal. There are two options if someone wants to consider two (or several) interacting goals.

- First of all, one can write a set of complex rules whose antecedents consider both goals simultaneously. This approach was used for navigating to a target while avoiding obstacles (Skubic, 1993). (Skubic, 1993) used a miniature infrared-based robot, while (Li, 1994) used a simulated sonar-based robot. (Altrok, 1992) used it for a car following a wall-bounded race track while compensating for the skidding and sliding due to the high speed.
- Second, one can write two sets of simple rules, one specific to each goal, and combine their outputs in some way. This approach was used by (Yen, 1995) and (Baxter, 1993) for integrating path tracking

and obstacle avoidance, and by (Maeda, 1995) for integrating vision-based wall following and obstacle avoidance on a Hero 2000 robot.

At present, in most of the current implementations of a reactive based controllers the fuzzy control rules are aggregated within a single rule base and they are processed by a unique fuzzy inference engine, as point 1 mention. In (Dragoiccea, 2003) a new approach allows the possibility to implement simple behaviors in a fuzzy reactive multi-control system. The main advantage of the proposed reactive multi-control strategy based on elementary behaviors is that the arbitration mechanism (i.e. a function of type PLAN) is under user's control, that means it is possible to give more importance to a specific behavior or even rule according to the context in which the robot evolves (i.e. task to be fulfilled and environment conditions).

Different behaviors can be implemented by using this approach, e.g. a position tracking behavior, a wall following behavior, a collision avoidance behavior, etc. The combination of these elementary behaviors by arbitration and command fusion lead to more complex behaviors.

In this approach fuzzy rules of the general form are used:

IF path_cond THEN command1
IF obstacle_cond THEN command2

As an example, table 1 shows practical rules that implement a wall following behavior on our robot test-bed, the mobile robot Khepera:

IF (dist_front_OK $\wedge$ dist_left_far) THEN
 turn_medium_left
IF (dist_front_OK $\wedge$ dist_left_OK) THEN
 turn_smooth_left
IF (dist_front_small $\wedge$ dist_left_medium) THEN
 turn_smooth_right

Table 1 Fuzzy rules for a wall following behavior

A wall following behavior is a tracking control mechanism able to follow any continuous surface at some fixed distance from contact, a feature that is most useful when mapping an unknown environment.

The fuzzy controller that implements this behavior may consist of two controllers, one for right wall following, the second one for left wall

following (figure 4). Therefore, the mobile robot will also be able to enter a corridor and to execute a movement between two walls.

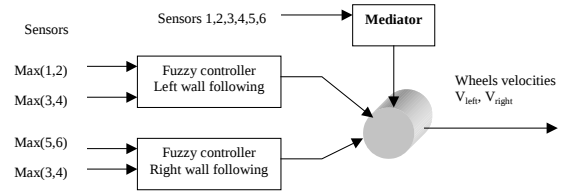


Figure 4 A schematic diagram of the wall following fuzzy hierarchic controller

The inputs for the two fuzzy controllers, as well as for the mediator, is the information received from the distance sensors of the robot (Dumitrache, 2002). The two outputs of the left / right wall following fuzzy controllers are the two wheels velocities, V_{left} and V_{right} .

The mediator for the wall following behavior (see figure 5) realizes a weighting action of the control signal generated by the two fuzzy controllers (for left and right wall following). The weighting strategy will influence one of these two controllers, according to the context in which the robot evolves (i.e. sensors measurements). The inputs to the fuzzy mediator are the values of the left, right and front sensors, and its outputs are the weights for the two fuzzy controllers for left and right wall following.

Therefore, following a more general deliberative / reactive approach, the robot has the possibility to plan (in a deliberative way) the most suitable way to split its global task into subtasks, i.e. to make a mission plan. Then it can determine the suitable behaviors in order to fulfil the subtasks. These behaviors are to be executed in a reactive way, as it was previously mentioned.

4. CONCLUSIONS

Recent advances in cognitive psychology and neurophysiology has led in mobile robotics to an attempt to emulate biology, reproducing the physiology and neural mechanisms. In general, it may not be possible, or even desirable, to duplicate how a biological agent does something. Although "learning from nature" is an old concept, what we can actually learn from biological systems depends very much on the available theories and technologies.

By focusing on the way living creatures "do" something (i.e. analyzing "inputs" and "outputs" of their behavior) roboticists can gain insights into how to organize "intelligence".

Cognitive robotics integrates results from the neuro-sciences and information technologies aiming to develop hardware / software products which "live and grow", i.e incorporating auto-

adaptive and evolving artifacts, based on pure programming.

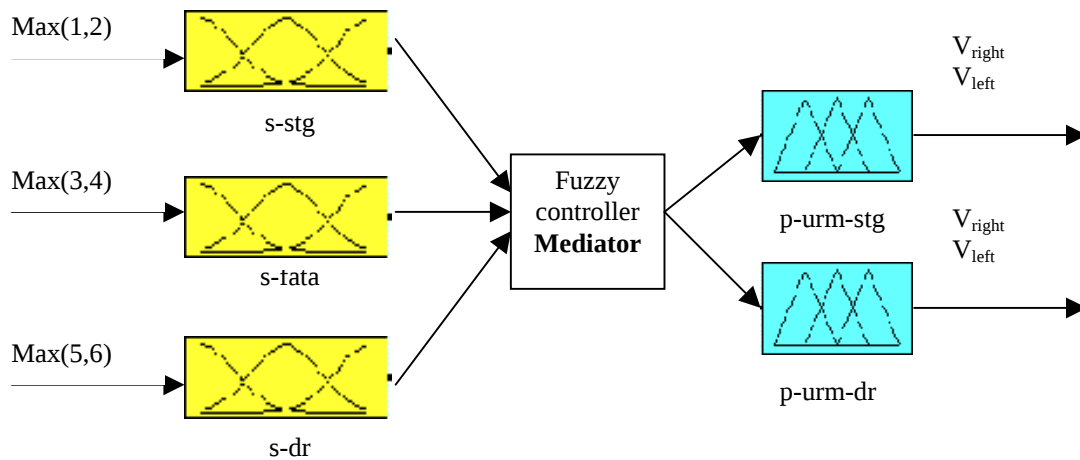


Figure 5 The mediator for the wall following behavior

Finally, as was mentioned and proved by the way in which the test bed for this problem was organized, the jump from the *intelligent robots* to the *cognitive robots* is ensured by the capacity of the latest to symbiotically work together with the human beings for achieving complex objectives, through *communication*. The reciprocal completion and the execution of difficult tasks open a new stage in the development of knowledge and technology.

The cognitive robotics era prefigures into a nearby horizon of time strong correlation with the evolution of the human behavior and cellular intelligence modeling. Building systems based on perception - action activities, including *sensorial*, *cognitive* and *control* aspects which are similar to the *visual*, *hearing*, *olfactory* and *tactile* biological functions, could represent a tangible target in the context of the evolution of the knowledge and information processing.

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