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ARCHITECTURE OF AN EXPERIMENTAL VISION-BASED ROBOT NAVIGATION SYSTEM

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ABSTRACT

This paper is a contribution to the investigation of the behavioural approach in robot vision. It describes the architecture and current implementation of a vision-based navigation system for autonomous mobile robots. The robot navigation system is inspired by the behavioural approach and consists of an environment of unix workstations and mobile robots equipped with various vision devices. Main features of the architecture are a pool of highly independent behavioural processes, a control and communication schema centred on a blackboard, a virtual robot interface and a planning unit. Beyond the intrinsic features of the strict behavioural approach, the architecture offers a virtual robot interface and network-wide development and execution capabilities. The paper describes the architecture and gives the status of the current implementation.

1. Introduction

The traditional AI and behavioural approaches lead to different methodologies for building mobile robots [Broo86]. The traditional AI approach decomposes the intelligence in functional processing blocks whose combination provides overall system behaviour. To get any behaviour at all, it is necessary to combine together many modules; improvement of the system proceeds by improving the individual function modules. In contrast, the behavioural approach bases its intelligence on individual behaviours whose coexistence and co-operation let more complex behaviours emerge. Here, each module generates behaviour and improvement of the competence of the system is obtained by adding new modules to the system.

Many experiences were performed these last years with behavioural systems that are usually described either in terms of system control or neurocomputing. Despite many successful applications, it must be concluded that the complexity of the behaviours that have emerged so far does not reach the point we expect for typical tasks in mobile robotics. This leads to the search of concepts and systems which combine behavioural systems with more traditional planning systems [TaLa92][Tor93].

In order to investigate this last approach and in order to fulfil the condition for a physically grounded approach , we started to develop a first experimental robot navigation system using the subsumption architecture [Broo90]. The result is MARS, which is using a dedicated message passing communication scheme and is running on a network of personal computers [GaMu91] [Fac92]. MARS showed the usefulness of this approach for further investigations but was a poor tool, mainly because of the dedicated communication scheme and inflexible development environment.

What was needed was a newer MArs, using a more flexible unix environment, a simple communication scheme and a more powerful NOmad robot: the concept of MANO was born.

In the following , we will present MANO, an architecture of an experimental vision-based robot navigation system. Section 2 describes the architecture for the behavioural approach. Section 3 describes MANO's architecture and section 4 its implementation.

2. Behaviours that solve the robot's task

Robot task and environment

The mobile robot is located in a building, moving horizontally on flat ground. Walls and different obstacles make up its environment. The robot must fulfill tasks like carrying letters or stowing chairs in a room. The robot is further autonomous, which means that it is capable to perform its task in an unpredictable environment.

Behavioural approach

The behavioural approach is inspired to some extend by the animal world [Mori88]. According to it, a robot task results from a sequence of stereotyped actions we call behaviours. The set of behaviours a robot can perform characterises itself in terms of its capabilities to interact with the environment. The behaviour itself is an action that is started by a stimulus and that exists as long as this stimulus exists.

Behavioural architecture

The architecture we propose combines behaviours and planning (fig 1). Behaviours are thought to handle in interaction with the sensed environment. Planning is thought to handle in interaction with some model representation of the environment, typically in form of a map.

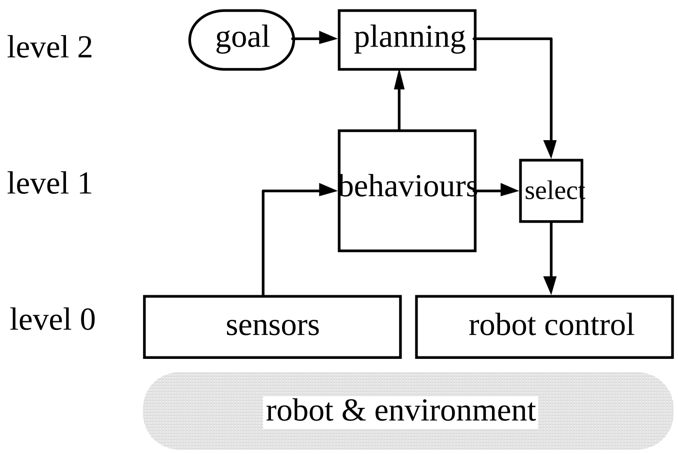

Fig. 1 Principe of the behavioural mobile robot navigation system

Usually, several behaviours can be activated simultaneously. Fully independent behaviours will run concurrently while behaviours which share some common resources are incompatible and exclude one another. Among several behaviours competing for a common resource, a single one can be selected. One such selection concerns the behaviour giving the robot control and is shown in figure 1. The selection is performed according to a decision scheme dictated by the planner [GRM92].

In the behavioural context, planning acts on the system by allowing behaviours to run or not, and by acting on the decision scheme used for the selection of one among the competing behaviours. It does so in a context sensitive manner.

Vision-based behaviours

Vision-based behaviours are characterised by the fact that their stimulus is a visual pattern called sign pattern. It is this sign pattern that triggers the behaviour and maintains the behaviour active as long as it exists.

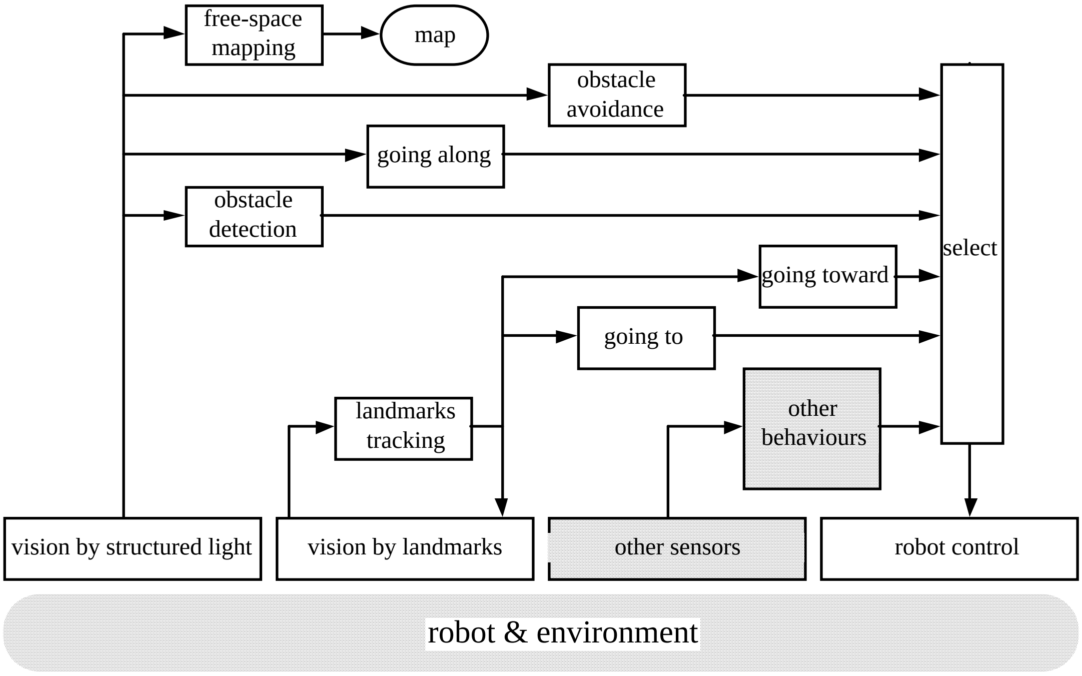

Fig. 2 Vision-based behaviours

The vision systems we use are described in [HuMa89] [Fac92] [HMFT92]. Their current behavioural description is shown in figure 2 where we recognise the following vision-based behaviours: *going towards, going to, going along, obstacle avoidance, obstacle detection, landmark following and mapping*. This set of behaviours allows basic capabilities for vision-based navigation.

The behaviours found in this basic set consist of several types. Most of them act in the feedback loop across the environment and fall therefore in the category of external behaviours according to our definition. There is only one internal behaviour –*free-space mapping*– which builds up an internal representation of the environment.

3. MANO's architecture

MANO is the name of the experimental vision-based robot navigation system. In the following, we describe the requirements it has to fulfil and the architecture selected for its implementation.

Requirements

We ask MANO to fulfill following requirements

a) use the behaviour-based approach

b) offer the capabilities to use a real robot with real world interactions as well as a simulated robot in an artificial environment

c) offer vision capabilities as described above

d) execute in a unix environment, with networking capabilities: behaviours should be able to execute on any node of the network

e) offer monitoring capabilities

f) offer flexibility: changing and adding behavioural modules should be easy

Architecture

The selected architecture for MANO is given in figure 3. We recognise two robots. The first robot is the real robot used in its natural environment: we use a class of mobile robots named Nomadic 200. The second robot is a simulated one which moves in the artificial environment of the simulator. Both robots are made equivalent with respect to the navigation system by the use of the concept of a virtual robot. From the point of view of the navigation system, a simple switch allows to select either the real or the simulated robot.

Behaviours are implemented by modules of which there are an arbitrary number, whereas planning is implemented by a special module which in turn, is unique.

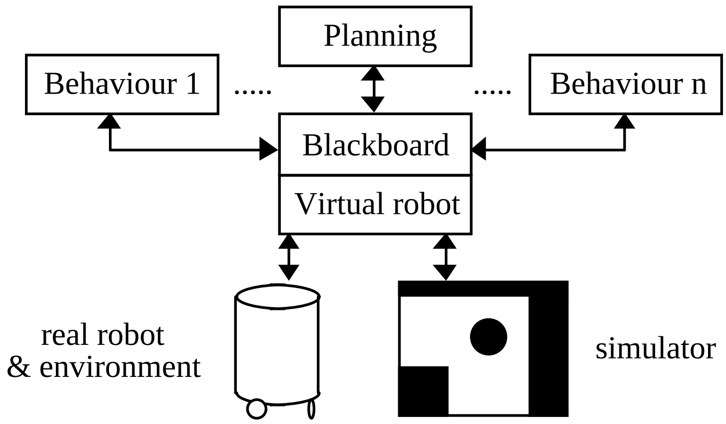

Fig. 3 Architecture of MANO

Communication between all the elements given so far is implemented by the blackboard. It plays a central role in the architecture. Both control and knowledge are handled through it.

Control structure

To explain the basic mechanism of MANO, let us consider its control structure as given in figure 4.

We distinguish control at three different levels. Level 0 considers the interactions between the virtual robot and the environment. There is an up flowing stream of sensed data informing the behaviours about the sensed interactions between robot and environment. There is also the down flowing stream of motion commands for the robot. Obviously, there are two forms, depending whether the real robot or the simulator is activated.

Level 1 is the behavioural level. Behaviours receive sensed data and generate two kinds of ouputs. Each behaviour's stimulus informs the planner about its current internal state which, in its simplest form, can be either stimulated or not stimulated. The second output exists only in the stimulated state of the behaviour and consists of commands to move the robot.

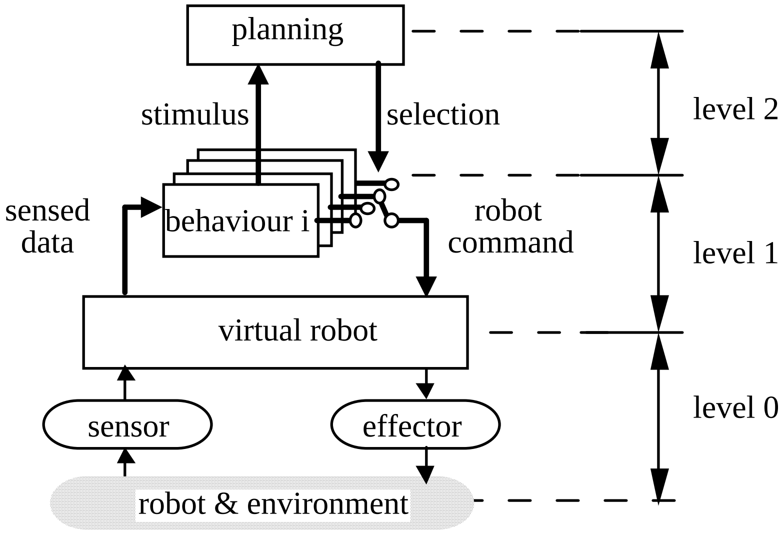

Fig. 4 Control structure of MANO

Signals of level 0 and level 1 form together a closed loop we call the behavioural control loop: at a given instant of time, the robot is controlled by one behaviour which forces the robot into an interaction with its environment. This happens through the perceived stimulus and according to the nature of the behaviour.

The planning module at level 3 has access to the behaviour's stimuli and receives the general navigational goal. It controls the selection of adequate behaviours accordingly .

Virtual robot

The virtual robot has following interesting features:

a) virtual inferface
b) real world or simulated mode of operation
c) monitoring of sensors

From the structural point of view, it is divided into two main parts, the vision and non-vision part of the robot, respectively named virtual vision and virtual nomad (fig 5)

Virtual Nomad

It is the commercially available robot Nomad 200 and its simulator [Noma92].

Nomad 200 is a 1 meter tall mobile robot. Its cylinder-shaped body is moved by a three wheels motion system that allows two degrees of freedom: translation and rotation around its vertical axis. Its sensors are arranged symmetrically around the body, each measuring a given sector of the surrounding environment. They are of three different types: 16 sonars, 16 infrared range sensors and 8 tactile sensors.

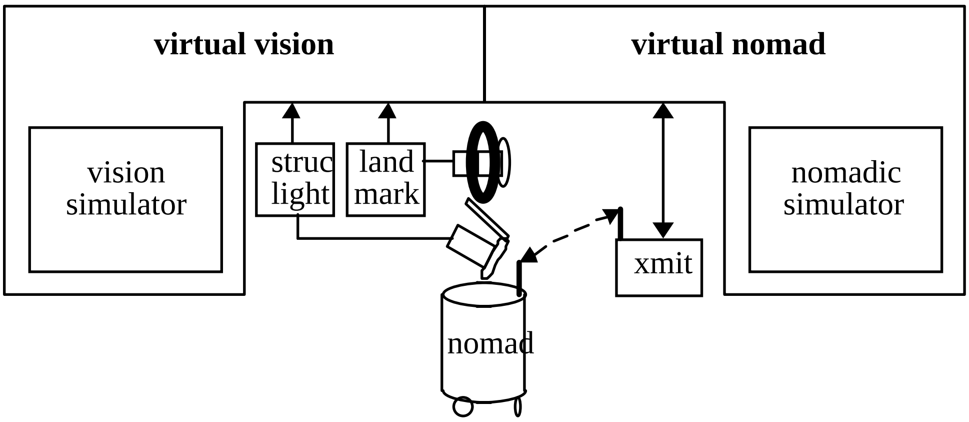

Fig. 5 MANO's virtual robot

The nomadic simulator is the equivalent of Nomad 200 in form of a simulator. It includes an artificial environment described by a 2-D map with polyhedral-shaped obstacles in which the robot is moved according to the motion commands given to the robot. The robot movements and interactions with the environment are simulated and reported as the sensed output. The simulation is either exact or corrupted by adjustable noise.

Virtual vision

It is based on the two vision devices described above as vision by structured light and vision by landmarks. The two devices have been developed both in the real form and in the simulated form.

The real vision devices include cameras mounted on top of the Nomad 200 and dedicated processing units found in external hardware. Vision by structured light delivers the geometrical profile of the environment in front of the robot at a rate of about 10 Hz. Vision by landmarks performs landmark detection and tracking. It delivers the observed position of back lighting landmarks found in the environment at a rate of about 5 Hz.

The vision simulator performs the equivalent functions. It includes an artificial environment described by a 2-D map of obstacles and landmarks. Visual interactions between sensor and environment are simulated according to the sensors models and given as virtual sensed data.

Blackboard and control

The blackboard is the communication channel between the planning, the behaviours and the virtual robot. Information can be exchanged through it simply by writing and reading a given item, each item being referenced by a key. The information found is of two types: control information for the selection of behaviours and knowledge to be exchanged.

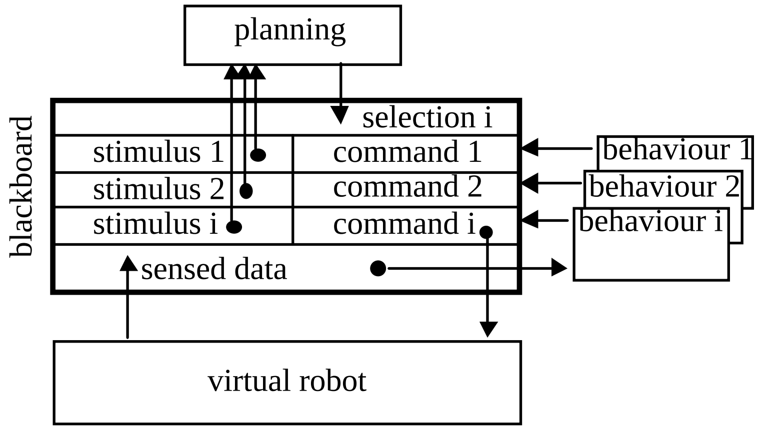

Fig. 6 Selection as an example of control

Figure 6 shows a simplified form of data exchange between planning, behaviours and the virtual robot involving sensed data, commands and selection. The later is a representative for the control mechanism.

4. MANO's implementation

The final implementation of the MANO architecture is shown in figure 7 where the architecture is now shown in term of unix processes. Main features thereof are: the design of each behaviour as an independent process, making it highly autonomous; the use of server processes to implement the virtual nomadic and the blackboard, defining a client-server relation for the interprocess communication channels implemented by sockets. In the unix environment, the MANO blackboard is implemented by the ndbm tool.

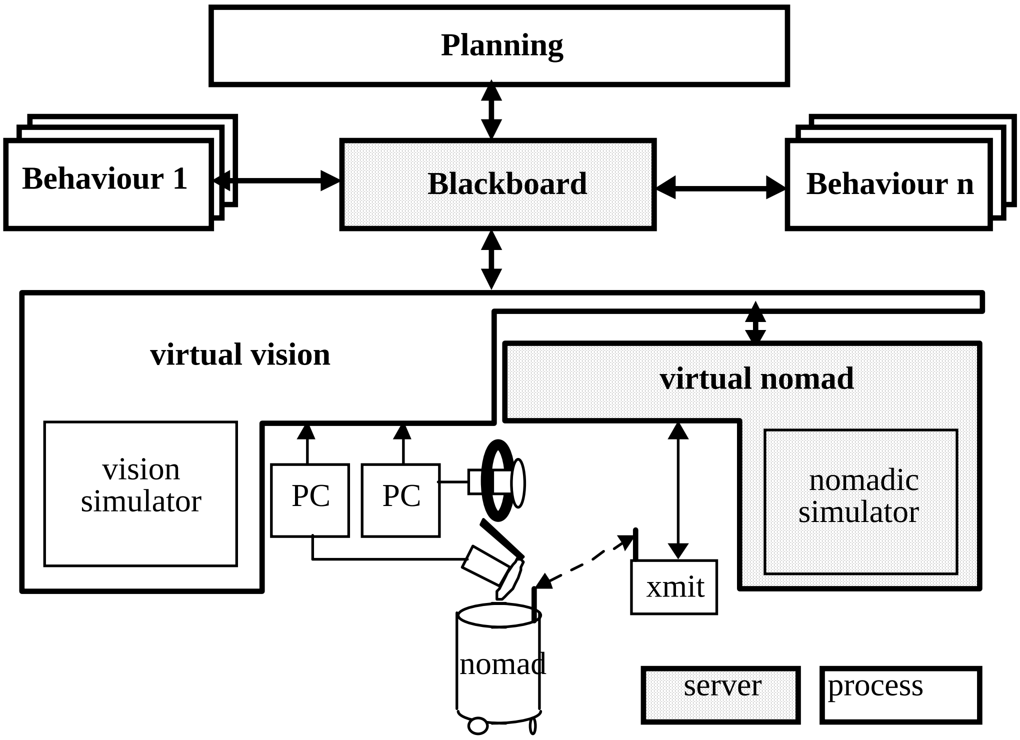

Fig. 7 Architecture and unix processes

MANO has been implemented on a network of Sun workstations. It is now operative in the described form, offering the expected features.

6. Conclusions

In this paper, we presented the architecture and implementation of a vision-based navigation system for autonomous mobile robots. The resulting system named MANO presents a number of advantages, namely as follows.

a) The intrinsic advantages of the behavioural approach: physical grounded bottom-up design, large relational independence of the behaviours, ease of development

b) The virtual robot: equivalent simulation and real-world interface make development and experimentation both easy and fast

c) The network-wide software development and testing capabilities, that allow versatile teamwork

d) The flexibility: open to various forms of behaviours and planning concepts

7. Acknowledgements

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