INTEGRATION OF VISION IN AUTONOMOUS MOBILE ROBOTICS

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ABSTRACT

An architecture for integrating various vision devices in an autonomous agent is presented and demonstrated in the case of vision-based navigation in autonomous mobile robotics. The architecture is based on the behavioural approach. Applying this approach to vision results in a collection of vision-based behaviours that perform just simple tasks when considered isolated but are much more capable when working in co-operation. In the presented work, an experimental behavioural architecture was applied to vision by developing a large number and variety of vision devices and behaviours. Shown to be successful in robot navigation tasks, we believe the behavioural architecture to be relevant also for other complex vision-based applications involving real-world and real-time interactions.

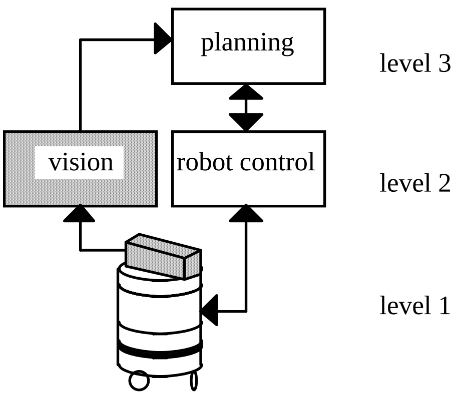

Figure 1: Signal to symbol approach

INTRODUCTION

We need vision for improving robots working in unstructured and changing environments like factories, bookstores, supermarkets, all places where robots require strong interaction capabilities to coping with humans or mastering a changing environment. Using multiple vision devices improves the potential sensing capabilities of the agent but its effective capabilities remain often fairly limited due to the difficulty to integrate them.

In the past, the problem of integrating vision and control was approached according to a number of basic paradigms like scene understanding, sensor fusion, geometrical or topological modelling [5]. Among difficulties met with them, let us mention high complexity leading to slow, unfeasible methods and high noise sensitivity leading to inconsistencies. Moreover, all these paradigms suffer from the interpretation gap between symbol and signal. Figure 1 is a typical architecture derived from these paradigms which use vision to derive the symbols to be plugged into the symbolic planner.

The behavioural approach for the design of autonomous agents follows another paradigm. On one hand and by contrast to the methods above, sensing and acting are tightly bound in behavioural units. On the other hand, the robot activity goes on by successive activation of appropriate behaviours that constitute the basic functionality of the task.

The behavioural approach brings a number of conceptual improvements [1].

Integration of vision and mobile robotics according to the behavioural approach has been proposed and presented previously. However, most systems so far make use of only a rather limited number of sensors and behaviours [2][5]. The architecture we developed and we present in

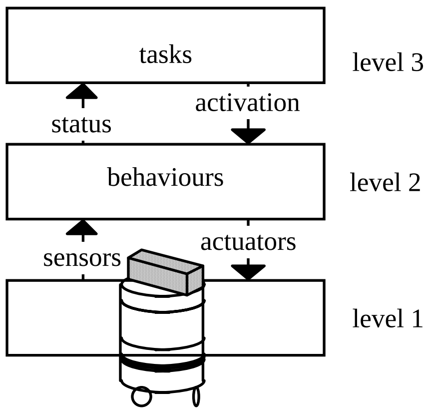

Figure 2: Behavioural approach

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this paper applies to a large number of possible vision devices and behaviours. It illustrates how vision components integrate it well.

Following a general presentation of the behavioural architecture, the next sections are devoted to a description of the design steps necessary to integrate vision in this architecture. The examples apply to autonomous mobile robotics. Finally, we present MANO, the Mobile Autonomous NOmadic robot developed in our lab according to above principles.

HYBRID BEHAVIOURAL ARCHITECTURE

The behavioural approach is based on the existence of individual behaviours and on the coordination of these behaviours. It states: autonomy emerges from the co-operative work of various behaviours [1].

We define a behaviour as an independent stereotyped action that is maintained by a specific perceived stimulus. Examples of robot navigation behaviours are *Wander around* or *Go along* . Each behaviour is activated by a stimulus. The overall agent behaviour emerges from the coordination of the various active behaviours.

The behavioural approach is of special interest for building agents which interact strongly with their environment by sensing.

Figure 2 illustrates the basics of a the behavioural architecture which derives from this approach. We recognise a structure organised in three levels of abstraction:

- Level 1: physical
- Level 2: behavioural
- Level 3: cognitive

Level 1 includes all devices for acting on the robot and for sensing the environment.

Level 2 is the heart of the architecture and implements the behaviours as independent modules.

Level 3 includes units which implement the tasks to be performed by the agent. The units proceed by activation/deactivation of the behaviours. Units can be built according to very different principles [6].

In the frame of this paper, we select the principle of a task described by a state machine whose transitions are controlled by a status vector and each state gives rise to an activation vector. Status and activation vectors refer to the signals from and to the behaviours respectively (figure 2). Therefore, each unit is an automaton. Because of this combination of behaviours and tasks expressed as state machines we call the architecture hybrid.

The described behavioural architecture provides advantages by its intrinsic features like concurrency of several behaviours, simplicity of design, abstraction hierarchy, time response hierarchy, a physically grounded system [1].

VISION IN THE BEHAVIOURAL ARCHITECTURE

The integration of vision in the behavioural architecture requires operations at all three levels: defining vision devices at level 1, defining vision-based behaviours at level 2 and, at level 3, defining the tasks in term of behaviours, making best use of the visual behaviours available. Let us consider the three levels successively.

At level one, defining vision devices consists merely in selecting a number of vision devices needed or useful for the application. Vision devices that have been considered so far in our investigations belong to active and passive vision, landmark vision, laser range imaging, sonar and infrared ranging.

At level two and of central concern is the definition of vision-based behaviours. Each behaviour is defined and developed as a widely autonomous unit responsible for a stereotyped action the robot performs under the control of a stimulus. In vision-based behaviours the stimulus is a visual pattern. Upon detection the stimulus initiates a robot action and maintains it as long as it exists, building up a control loop with feedback across the environment.

The sorts of behaviours to be implemented are selected according to sensor capabilities and application requirements. Typical behaviours considered for vision-based navigation are: *Going towards, Going along right, Obstacle avoidance, Obstacle detection, Landmark following, Wander around, Homing, Self-positioning*, etc.

Finally, tasks the robot has to perform are defined at level three. Each task is packaged in a unit. Typical tasks considered so far are: exploration, navigation, postman task, tidying up chairs in a room [6][8].

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LEVEL 1: PHYSICAL

At this level we define a number of vision devices that we mount onto the mobile robot in order to improve its performances.

We selected various vision devices [4]:

- *Laser range sensor*

This measurement device uses the principle of triangulation to measure the distance of objects in the robot environment. The specific range sensor we use applies triangulation between a plane of light and the line of sight relative to a pixel of the camera. The plane of light of the laser intersects with the environment in a profile line which geometry is finally obtained.

- *Passive vision*

This is classical vision involving a video camera and a video processor that performs standard image processing and recognition.

- *Landmark vision system*

This active vision system uses a light source coupled to a video camera to enhance the detection of reflecting landmarks distributed in the environment. The bright landmarks are detected, labelled and tracked in a dedicated Transputer system that produces the time sequence of labelled landmarks at an approximate rate of 15 Hz.

- *IR sensor*

The IR sensor basically measures light emitted initially by a neighbouring infrared diode and back reflected by the environment. A short distance is detected when the intensity overpasses a given threshold. IR sensors are use for close-range distance measurements (0.3 - 1.2 m)

- *Sonar*

Sonars use the time-of-flight of a back reflected acoustic signal to measure the distance to the environment in front of the sonar. Sonars are used for medium range distance measurement (1-6 m)

Not all of the sensing devices above are purely visual in essence and sonar are definitely not. Nevertheless, as all of them perform similar contact-free measurements of the environment, we consider them all, indistinctly from each other.

Figures 3 and 4 illustrate the Mobile Autonomous Nomad (MANO) together with its visual sensors. It is composed of the commercially available Nomad 200 [7] and selected vision devices mounted on top of it.

Nomad 200 is a vertical cylinder-shaped mobile robot that can be moved on the ground by controlling its translational and rotational speed. The upper robot body can be rotated around its vertical central axis which allows to orient the robot sensors in any arbitrary orientation.

Two laser-range sensors are mounted on top of the robot. One, located in front of the robot, has a horizontal laser light plane and measures a horizontal profile of the environment. The second laser range sensor is located in the back and has its main axis oriented towards the ground, measuring the geometric profile of the environment behind the robot.

In addition, two video cameras are mounted on the robot top, together with active lighting. The devices can be used for passive vision devices or, together with the illumination and back reflecting landmarks distributed in the robot environment, for landmark vision.

A belt of 16 sonars surrounds the robot, delivering the sonar range field 360 degrees around the robot. At the bottom, there is a similar belt of 16 IR sensors.

LEVEL 2: BEHAVIOURAL

This second level is best described by the set of

Figure 3: Visual sensors of MANO
Figure 4: MANO

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behaviours it includes. We considered following vision-based behaviours.

- *Obstacle detection and stop*

The behaviour stops the robot and is activated when obstacles are found in front of the robot. The stimulus is from range sensing: specific shapes of the range profile are interpreted as obstacles.

- *Wander around*

Moves the robot straight ahead and changes the direction only when an obstacle is detected in front of it. The new direction is such that the new move is away from the obstacle. Here, an obstacle is a configuration of radial range field detected by the infrared sensors.

- *Go towards*

Moves the robot towards a landmark. When several landmarks are visible, the move is towards the landmark just ahead of the robot. The behaviour is no longer stimulated when the landmark is near to the robot. In this behaviour, landmarks are visible spots, detected, labelled and tracked by the landmark vision system.

- *Go along*

Moves the robot along extended obstacles like walls, keeping a constant distance to them. This behaviour comes in several flavours depending on the sensing device used for its implementation and the preferred wall following direction. Regarding the implementation, a first one is based on the radial range profile from infrared, the other comes from an interpretation of the laser range profile.

- *Go along left, Go along right*

This behaviours are specialised forms of *Go along*. Whereas any direction of following is possible with *Go along*, these two new forms have forced following directions.

- *Obstacle detection and turn*

This behaviour turns the robot in the direction of the nearest space without obstacles. It is stimulated by obstacles located in front of the robot and detected by given shapes of the laser range profile.

- *Position estimation*

The behaviour is stimulated by observed landmarks. It finds the relative position of the robot with respect to a set of three known landmarks.

- *Push box*

This behaviour is stimulated by an object near to the robot. It moves the robot towards this object and upon collision, continues its move by pushing the object straight ahead. The robot's moves are controlled to keep the object on the straight line. Here, object detection for moving toward it and for controlling the pushing is based on radial range field detected by the infrared sensors.

- *Homing*

On activation, it moves the robot to a fixed location and orientation with respect to specific visual patterns. It comes in several flavours depending on the vision device being used [3]. It is stimulated on detection of two appropriate landmarks, on given configurations of the laser ranger and upon detection of specific visual patterns in the passive video image.

- *Free-space mapping*

Keeps track of the geometry of the environment as observed when the robot is moving. This is done by reporting successively the laser range profiles into a map.

LEVEL 3: COGNITIVE

At this level, tasks are designed by the system developer and expressed as state machines. Best use of available visual behaviours is aimed at.

To describe the cognitive level, we present an example of a task that makes use of some of the developed visual behaviours: Tidying Up Chairs (figure 5).

The purpose of the task is to tidying up chairs in a room with the mobile robot. Notice that this task raises several interesting problems concerning autonomy, interaction with a dynamic environment on which the robot acts itself [8].

Visual behaviours involved in this task include

Figure 5: The *Tidying up chairs* task

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Wander around, Homing by landmarks,, Obstacle avoidance.,, Searching a landmark, Go towards. Because it is assumed that chairs carry landmarks, the last behaviours translate into *Searching a chair* , *Go towards a chair* . Beside visual behaviours, a number of odometric-based behaviours are also used.

The state automaton defined for this task repeatedly searches for a chair, detects it, goes towards it and pushes it to a specified parking zone. In addition, obstacle detection is activable and starts escape behaviours in case of activation.

IMPLEMENTATION OF MANO

The hybrid behavioural architecture is implemented around MANO [9]. It includes the robot Nomad 200, additional vision devices, dedicated vision systems and a network of Sun workstations which run the various software components, as shown in figure 6.

The dedicated vision systems are needed to perform real-time landmark tracking and for laser range imaging.

The various behaviours and tasks which constitute the heart of the behavioural architecture are implemented

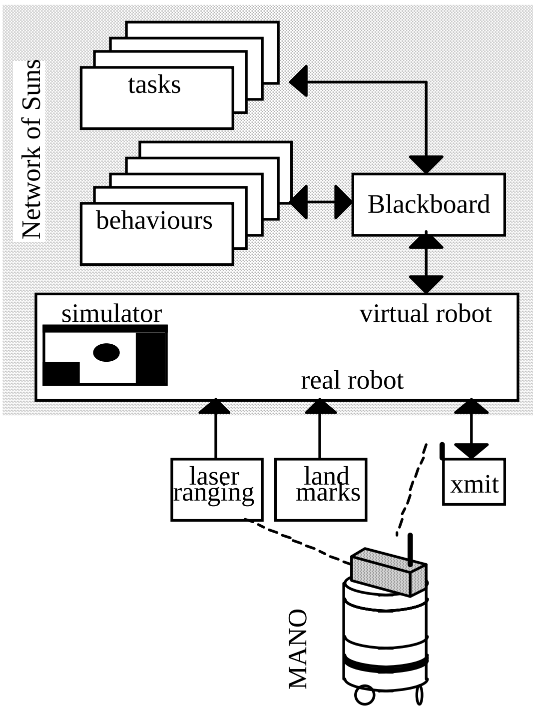

Figure 6: Experimental behavioural architecture

as UNIX processes and are therefore highly independent. The communication is through a blackboard which makes the independence of the behaviours really effective. An important feature of MANO is the virtual robot interface which provides equivalent interface to both the real robot and a simulated robot that navigates in an artificial world. The transition from real robot to simulated robot is possible at any time by a simple switch.

In addition to the simulator, the virtual robot interface provides full monitoring and tracing capabilities.

CONCLUSIONS

The behavioural architecture is an adequate and efficient means to integrate vision into an agent. The integration work requires to develop vision components at all three levels of the architecture.

At the physical level, by selecting and adding a number of vision devices or systems. At the behavioural level, by developing vision-based behavioural modules and including them in the set of modules. Finally, by taking advantage of the new behaviours in the description of the task at the cognitive level.

Integrating vision in an agent according to the presented scheme confers to the design, the advantage of the tight coupling of sensing and acting which characterises the behavioural approach: the system is physically grounded, provides a double abstraction and a response-time hierarchy and offers highly modular design.

We illustrated and demonstrated this general approach in autonomous mobile robotics with the experimental behavioural architecture of MANO, that encompasses various laser, landmark, passive, sonar and IR vision devices at level 1, and a large set of vision-based behaviours at level 2. At cognitive level 3, we selected tasks expressed as state automaton and demonstrated the tidying up task.

Shown to be successful in robot navigation tasks, we believe the behavioural architecture to be relevant also for other complex vision-based applications involving real-world and real-time interactions.

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