Basic Visual and Motor Agents for Increasingly Complex Behavior Generation on a Mobile Robot

MARIA C.GARCIA-ALEGRE, FELICIDAD RECIO

Instituto de Automática Industrial (IAI), Consejo Superior de Investigaciones Cientificas (CSIC)

28500 Arganda del Rey. Madrid. Spain.

maria@iai.csic.es

Abstract. Present work addresses the guidelines that have been followed to construct basic behavioral agents for visually guided navigation within the framework of a hierarchical architecture . Visual and motor interactions are described within this generic framework that allows for an incremental development of behavior from an initial basis set. Basic locomotion agents as, Stop&Backward, Avoid, and Forward are implemented by means of fuzzy knowledge bases to deal with the uncertainty and imprecision inherent to real systems and environments. Basic visual agents as, Saccadic, Find_Contour, and Center are raised under a space-variant representation pursuing an anthropomorphic approach. We illustrate how a complex behavior results from the combination of lower level agents always connected to the basic motor agents. The proposed methodology is validated on a caterpillar mobile robot in navigation tasks directed by an object description.

Key words. Mobile robots, agents, architectures, foveated vision, locomotion, fuzzy behaviors, behaviors composition

1. Introduction

For years Artificial Intelligence researchers have devoted most of their efforts to complex problem solving models disregarding real world applications. Emphasis has been placed on declarative knowledge, rational selection, and problem solving strategies (Simon, 1969; Nillson, 1971; Newell, 1990). In contrast to these traditional approaches , reactive and behavior-based systems propose a different methodology to design structures with low level of deliberative complexity created to function in dynamic, uncertain and noisy environments (Brooks, 1986;Maes, 1990;Brooks, 1991).

In recent decades, there has been increasing interest and attention focused on the design and construction of models that account for relevant interactions with real environments and their significance in proposed solution. Developed architectures are engaged in assembling knowledge, perception and action, within distributed systems able to cope with limited knowledge and resources in rarely structured worlds (Albus, 1992;Maes, 1991).

To account for major topics, hybrid architectures have emerged as a way to overcome the lack of prediction inherent to highly reflex behaviors, and the absence of real world constraints of algorithmic and heuristic models of Artificial Intelligence (Arkin, 1990; Garcia-Alegre et al., 1993;Crowley, 1994;Hayes-Roth, 1995;Van den Velde, 1995).

The more widespread models for synthesis of artificial behavior are those based upon the schema and agent concepts. Schema theory (Arbib, 1975), was initially drawn up to deal with complex systems in real domains, as a bridge among cognitive science, brain theory, and distributed artificial intelligence, providing a distributed model of computation.

On the other side, Agents theory evolves from Minsky (1986) proposition of the "Society of Mind" wherein members played a role quite similar to that of schemas. Initially translated to the robotics world by Brooks (1986) to build up robot controllers, it has been applied in behavior generation for situated robots.

Present work proposes a generic framework to incrementally build up a Multi-Agent hierarchy for ever complex behaviors generation. The model starts from an initial set of basic vision and locomotion agents, with the ultimate objective of deriving robots behaviors for fetch_deliver and guide_visits tasks. Basic agents are analyzed and compared to those designed in group behavior generation. Finally a case study is thoroughly analyzed for a situated robot that aims to follow a person in our laboratory.

2. Concepts and definitions

Hybrid architectures are used in a wide range of fields, from Artificial Intelligence, Robotics, Software Engineering to Neuroscience, Brain Theory, Ethology and Psychology. This gave rise to a lack of consensus in the meaning of the terms more frequently used as: agent, agency, schema and behavior.

Schema is defined (Arbib and Cobas, 1991; Corbacho and Arbib, 1995) as a modular entity involving data structure and control. It has been applied in robots' navigation as a model for multiple concurrent motion control processes (Arkin, 1989). Some of the relevant characteristics of the schemas theory, useful for our comparative purposes are :

- Network topology close to the structural elements. Disregard a top_level executor since schema instances can combine their effects by cooperative or competitive distributed processes.
- Construct of knowledge representations through assemblage of schemas, for relevant objects and actions involved. Permit different implementations, either biological or technological.

An agent is understood as a process capable of perception, computation and action, that may or may not be physical; and behavior is defined as a control law addressed to effectively achieve and maintain a goal (Mataric, 1994).

Herein are defined the concepts that are been used from now on:

Agent: Formal unit of architecture which holds for both deliberative and reactive abilities without any constraint on its complexity (Garcia-Alegre et al., 1995). In this work agent and behavior will be indistinctly used in the sense of a computational and control process addressed to reach or to maintain a goal. The agent notion has been purposively established as general as possible, as what matters is the observable behavior not the nature of the mechanism by which it is achieved (McFarland, 1993).

Basic Agents: Elementary building blocks needed to solve a specific class of problems (i.e. collision-free motion). Agents have been created with a modular criteria in mind, in the sense of being able to generate other agents by combining basic ones. This main feature implies a scalable; flexible and incremental model; scalable to grow through heterogeneous processes and processors to avoid running out of resources, flexible to elude "a priori" constraints on the size and complexity of each software module; and incremental to allow the addition and deletion of agents.

Level: Corresponds to a set of agents that share a common language with their interlocutors at adjacent levels. The language is composed of a set of terms related to perception, knowledge representation, and actions. A level gravitates around a specific representation of the system and environment and may have a short or long term memory. This spatio-temporal window record may support future learning capabilities to improve the observable behavior competing each level (i.e. local piloting).

A notion similar to that of basic agents is being used for group behavior generation in a fleet of robots by Mataric, namely "basis behaviors" (Mataric, 1994;1995). In that work some fundamental group behaviors, dependent on both the domain and the goal, are selected as a minimal set with appropriate composition operators. Such behavior are decomposed in terms of individual structural or functional low level agents as: AVOID, FORWARD, TURN, MOVE_TO, namely HOMING for the group.

Basic agents, here selected do agree with both the definition and the composition rules for those "basis behaviors", being all basis and basic gross grain behaviors.

In respect to the level concept, present interpretation differs from Minsky suggestion on the term agency in that intra-level agents interaction do not occur in current organization (Minsky, 1986; 1994). Our level definition somehow resembles the layer of competence of the subsumption architecture (Brooks, 1986), but present notion proposes some additional characteristics as explicit knowledge representation and adaptation /learning (Guinea et al., 1993).

3. Selection of basic locomotion and vision agents

A great variety of motion and vision related tasks can be described and achieved in terms of dynamic sequencing of some basic agents. The set of lower level agents that have been selected are called basic in the sense that they form one of the minimal set for generating other agents of ever increasing complexity.

The proposed set of basic agents is not the unique nor the one with minimum components, but it is the one that allows for the completion of currently proposed tasks and of those expected in a near future (i.e. PICK _ UP _ BOOKS _ IN _ JAMES _ DESK, MOVE _ TO _ ENTRANCE _ DOOR).

3.1 Locomotion agents

Low level motion agents have been extensively studied during last years and they usually correspond to basic reflex behaviors of approaching, running away and non-colliding. These agents are survival instinct behaviors present in all mobile creatures. Present selection is based on the belief that complex behavior, would result from the combination, direct summation or temporal switching, of basic agents through simple arbitration rules.

Three Basic Agents are selected at the locomotive domain, namely: STOP & BACKWARD, AVOID and FORWARD. They are proposed in a decreasing degree of emergency. All three are embedded in a common skin: the piloting level, sharing a local world representation centered in the mobile robot. This representation is a mapping of ultrasonic, infrared, and tactile readings to distance and orientation of the obstacles in its vicinity.

STOP&BACKWARD: Driven by the tactile and infrared sensors, is needed to recover from unexpected events due to sensor failures or very acute obstacle shape. It appears as a branching in the actions, for identical perceptual conditions. As an example: 1) IF close-to-contact conditions THEN FORWARD, or 2) IF close-to-contact conditions THEN STOP & BACKWARD, where first rule produces a push behavior and second one a safe navigation. The appearance of more than one agents, introduces the concept of upper level to arbitrate the activation (action selection) of lower level agents.

AVOID: Triggered by ultrasonic sensors. Its objective is the detection of obstacles. It is in charge of the supervision of medium range distance all around the robot. When the safe-distance is reached a detour behavior is displayed; the selection of this value modulates the mobile behavior from a very precautious one to a high speed one

FORWARD: Driven also by the ultrasonic sensors. It aims the detection of free-space. Moves the robot to a location specified in polar coordinates and is provided with time-out mechanisms to avoid sticking to a behavior under sensors/actions failures or knowledge inconsistencies.

These agents are modeled as fuzzy knowledge bases for decision making on the robot heading and speed. They also take into account proprioceptive sensors readings at rate of one hundred and eighty milliseconds External and proprioceptive sensory variables are represented as fuzzy sets, and are defined through trapezoidal membership functions (Gasós et al., 1992).

The set of fuzzy rules that structure the knowledge base of the AVOID agent , is shown in Table1. These rules are designed keeping in mind simplicity:

R1: **IF** dist_obst is FAR. AND. speed is LOW
THEN DELTA v is POSITIVE

R2: **IF** dist_obst is NEAR. AND. speed is HIGH
THEN DELTAv is NEGATIVE

R3: **IF** dist_obst is FAR. AND. speed is HIGH
THEN DELTAv is ZERO

R4: **IF** dist_obst is NEAR. AND. speed is LOW
THEN DELTAv is ZERO

Table 1. Knowledge base of AVOID Agent

Key system-environment states are selected and defined as the relevant sensory patterns that trigger a basic agent; any other pattern not considered, generates a default action: STOP. In current implementation basic agents are triggered by mutually exclusive system-environment perceptual states, so as to circumvent explicit intra-level arbitration.

The finest grain level decomposition of motion behaviors, for individual mobile creatures, is performed in terms of the agents: FORWARD, BACKWARD, TURN _ RIGHT, TURN_LEFT, that obviously are connected with the control structures .

3.2 Visual agents

They are designed to selectively react to visual stimuli in a dynamic environment under the requirements of a specific task (Tistarelli and Sandini, 1992). Human vision forms multi-resolutional images at the visual cortex due to the non uniform photo-receptors distribution. Biologically inspired, the logarithmic-polar transformation has proved to be one of the most suitable approaches (Panerai et al., 1995) to implement this non-homogeneous sensing for space selective artificial vision.

To provide a space variant vision a foveated sensor has been implemented, mapping the image Cartesian plane to an image cortical plane. This transformation provides variable resolution in the visual field with a high resolution inner small area, namely fovea, that gradually decreases towards the periphery. This log-polar sensor highly reduces processing resources but requires more activity to accurately explore new image regions enlightening the classical paradigm of memory versus activity.

When looking for a specified target in a scene, visual agents must gather and coordinate all the information available about the target. This is the commitment of the SEARCH&TRACK agent, inspired in the ocular movements in human vision, that arbitrates sequential combinations of the basic agents. These processes according to our initial definitions are agents or behaviors in spite of being only perceptual or motor, very much like the perceptual and motor fine grain schemas of Arbib theory.

Three agents are selected as basic visual behaviors, taking into account that in the robot the eye and the head are rigidly coupled together (Bustos et al., 1995):

SACADDIC: Shifts the focus of attention toward different scene locations, by selecting targets from the periphery of the visual field. Targets are all kind of objects attributes according to the higher level descriptions. Outputs are short and rapid motions within the field of view. With such a design, attention is focused only in very small image regions.

FIND_CONTOUR: Extracts a closed contour from the edge filtered image. This contour is adjusted by considering the inner and outer gradient directions, and the relative position of the contour adjacent pixels. Once stabilized, inner region is classified in accordance with the target attributes: gray level and size.

CENTER: Maintains the recognized contour in the fovea region by tracking the contour centroid at the inner sensor area, at a rate of 25 fps. Periphery is dynamically defined as the outer region of the current segmented contour.

The real-time dynamic interaction of these Agents is arbitrated by higher level Agents as: SEARCH&TRACK or SEARCH&COUNT, and allows for the solution of a multiplicity of cases that concern visual stimuli guided navigation (Recio, 1995).

Eye movements and retinal segmentation, intentionally have been kept at the lowest vision level as three processes associated to short and rapid camera movements, while smooth long term camera displacements having a more purposive component are grouped at the next vision level. All three agents jointly generate an unique eye observable behavior in the sense of tightly coupling perception and action at a high activation ratio.

4. A hierarchy of agents

A hierarchy of levels is proposed to handle complexity, wherein each level is associated with a degree of abstraction, time-response, and system-environment representation. This hierarchical approach is deeply grounded in the ethologic behavioral model of a hierarchy of functional and structural behaviors, namely centers , proposed by Tinbergen (1951).

The key questions underlying this loosely coupled architecture are:

- The design of a formalism that both deals with and do not drastically separate, motor control mechanisms from purely cognitive strategies (Mataric, 1997).
- To ease the incremental process of new agents construction, by reusing all the functionality of previously generated, starting from the set of basic agents
- To reduce development time, permitting several users to concurrently program different modules.

Levels in the hierarchy communicate through bi-directional channels, that have no associated protocol, consequently it must be defined between communicating agents based upon perception and acting possibilities.

From a global perception-action perspective, there are two informational flows: goal-driven which progress top-down, and event-driven which flows bottom-up. The first one depends on the arbitration mechanism to use lower level abilities of the system. The second one relies on the upwards information propagation of the robot-environment state.

Arbitration: Mechanism by which a basic agent allows the instantiation of its own behavior. Arbitration is a run-time process that depends on the system goal and situated robot. Agents of a level are arbitrated by agents of higher levels that requests some expression of their competence in order to reach their goal. In practice, there is no guarantee that the request will be achieved, hence time-out mechanisms and alternative strategies must be suggested to avoid system deadlocks.

Propagation: Perceptual information which flows from lower to higher levels. An agent propagates information when it is explicitly requested to do so or when an arbitrated demand can not be accomplished within the required constraints.

Figure 1.

This general framework has been kept as simple as possible under the assumption that complexity must grow in parallel for all three: robot, environment and tasks. The developed architecture is schematically shown in Figure 1.

The agents architecture displays a hierarchical topology, with a top-level executor human being and gross grain behavioral agents, that in current implementation do not hold intra-level interactions. In contrast, schema model underlies a network topology which could easily approach fine grain structures, and do not need top-level firing due to concurrent schema interactions.

The architecture for group behavior emergence exhibit a more open topology, highly dependent upon system, goals and domains. Group behavior is always gross grain, and up to now do not embed large cognitive tasks.

5. Visual and motor interactions: Approaching a visual stimulus

Interactions between basic locomotion and vision agents has been demonstrated with the caterpillar type robot: BOSS-IAI which has been built at the IAI/CSIC. The robot is endowed with a rotating ultrasonic sensor, one degree of freedom (dof) and a vision system. This system incorporates a conventional CCD camera (512x512 pixels) on a two dof Pan/Tilt unit. All sensors are located at the body, a six wheels platform with two degrees of freedom. The hardware architecture has evolved from a eight processors Transputer-based on a single Pentium/90 to the current Dual

Processor/PPro180 board, Linux O.S., that communicates with host Unix machines via Ethernet. Unix processes are connected by sockets, and communication protocols allow each level to behave as both a sockets server and a client, accepting and requesting connections at running time. The system assumes motion decoupling between the eye/head and the body (Guinea et al., 1995).

The missions for this robot are all addressed to solve a particular class of problems: those worried about a "safe navigation guided by visual stimuli" at indoor office domains. The success in reaching the goals repertoire, implies the accomplishment of tasks with ever increasing level of detail.

Activation sequencing will interactively depend on the dynamic of the system and environment information flow. Flow propagates bottom-up as perception/generalization mechanisms and top-down as planning alternatives / decision_making mechanisms.

We now present and analyze an instance of the class of problems already mentioned, for a situated system. The "FOLLOW-PERSON" agent, with some specified attributes, is activated by a human being. Next SEARCH&TRACK and MOVE_TO agents are triggered and these in one's turn arbitrate the activation sequence of the basic agents under the effect of real world interactions. A top-down cognitive model of what the robot has to see is used to control vision and drive the sequences of rapid eye movements and structure fixation required for an efficient human-like run over the image (Noton and Stark 1971).

<->**FOLLOW-PERSON** [Target Attributes]
[WHAT?(gray level, size, free-space, safety-distance),
WHERE?(pan and tilt area, proximity-distance)
HOW?(slow, fast, accurate, fuzzy for camera/head and body)]

-->**FOLLOW-PERSON** [Actions]<=>

<->**SEARCH&TRACK** [Target Attributes]
[WHAT?(gray level, size),
WHERE?(pan and tilt area),
HOW? (slow, fast, accurate, fuzzy)]

||

<->**MOVE** [Target Attributes]
[WHAT? (free-space),
WHERE? (J=camera / head - bodyº, r = proximity -distance),
HOW? (slow, fast, accurate, fuzzy)]

AND

-->**SEARCH&TRACK** [Actions] <=>
While active goal & not time-out
if **FIND_CONTOUR** not recognized then **SACCADIC** to next target direction
else **CENTER** target

||

-->**MOVE** [Actions]<=>
While free-space distance>proximity distance **FORWARD**
if free-space distance=proximity distance **STOP&BACKWARD**
else **AVOID** or **STOP&BACKWARD**

-->REPORTS (to **HUMAN**)

The SEARCH&TRACK agent will take into account target attributes before determining the actions sequence to be tentatively triggered at a first glance, notifying the FOLLOW-PERSON agent on success or failure. This agent arbitrates three agents at the adjacent lower level, see Figure 1. When a target is lost, a search in periphery is activated in the target emergence direction. Here again the interaction of the three agents along with their eventual arbitration, generates an emergent behavior able to cope with a new and ever more complex class of problems.

FOLLOW-PERSON agent relies on the SEARCH&TRACK agent ability to recover from tracking failures by continuously alternating between searching in the scene area and smoothly pursuing the centroid of the recognized targets

In very extreme situations both agents will report from failures to FOLLOW-PERSON, that will either proceed to look for a new strategy or send some message to the human being. MOVE agent ensures mobile robot safe motion avoiding obstacles within the direction and distance constraints, solving most unexpected events. MOVE agent modulates the ultrasonic sensors readings to obtain a local representation of the surrounding free-space.

The PUSH agent has been generated as an alternative to the MOVE agent to derive a different action regardless of having identical system-environment perception. It is defined as:

PUSH [Target Attributes]
[WHAT? (obstacle)
WHERE?(J=obstacle-direction, r= target_d, push_d),
HOW? (slow, fast, accurate, fuzzy)]

PUSH [Actions] <=>
if free-space distance<= safet_d .AND. curren_d < (target_d - safety_d)
THEN **AVOID** or **STOP&BACKWARD**
else **FORWARD**

Herein the first premise is concerned with the control under specific target and safety distances. A tracking sequence of a human being wearing black trousers, is shown in Figure 2 as an example of the FOLLOW-PERSON behavior.

Figure 2.

Unexpected observable behaviors sometimes emerge as an effect of the interaction among the physical system-environment, the proposed goal, and the explicit arbitration algorithm embedded at each behavioral agent. Experimental results over a wide range of initial conditions and scenarios, point to coordination as the main cue for well-suited observable behavior. This explicit coordination of both experimental and expert knowledge can be greatly improved by using some learning techniques as proved by Mataric in the optimization of group behavior (Mataric, 1996).

6. Discussion

A set of basic behaviors for visually guided tasks in an office-like domain, is selected, implemented and demonstrated with a physical robot in a dynamic environment. It aims at an interactive tasks repertoire accomplishment focused on the development of ever more friendly and ease interactions with humans.

Such basic behaviors are embedded in a general framework that reuse their abilities to derive ever more complex and abstract agents to incrementally reach the set of tasks required for a specific application.

The design characteristics of the proposed architecture allowed four scientist to develop in parallel vision and locomotion related agents according only to the pre-defined communication protocols.

The set of basic agents for locomotion tasks are formulated by means of fuzzy rules bases approaching human expert strategies for mobile piloting. They generate smooth trajectories to attain a location within some tolerances. Environmental and structural knowledge is injected to the systems as arbitration strategies and target attributes values, to help pruning the perceptual space and get real time performance.

The proposed architecture is an appropriate framework for agent-environment interactions descriptions, that allows for an easy incremental increase of the class of problems that can be tackled with the available perception and action system.

Acknowledgments

Present work is funded in completion by Spanish CICYT Grants: TAP94-0171 and TIC96- 1392-C02- 01. Authors want to thank D. Guinea and P. Bustos for fruitful discussions; G. Sánchez for valuable help in sensors integration; and Sara Steele for final proof-reading. Thanks also to Prof. G.A. Bekey and anonymous referee for valuable comments and suggestions that have led to a much improved paper.

References

Albus, J.S. 1992. RSC: A Reference Model Architecture for Intelligent Control, *IEEE Computer, Special Issue on Computer Architectures for Intelligent Machines*, May 1992.

Arbib, M.A. 1981. Perceptual Structures and Distributed Motor Control. In: *Handbook of physiology-The Nervous System II. Motor Control*. Amer Physiol.Soc:

Arbib, M.A., Cobas, A. 1991. Schemas for Prey-Catching in Frog and Toad. In: *From Animals to Animats: Proceedings of the First Intern. Conf. on Simulation of Adaptive Behavior*. pp. 142-151.

Arkin, R.C. 1989. Motor Schema-Based Mobile Robot Navigation. *Int. J. Robotics Res.*, 8 (4): 92-112.

Arkin, R.C. 1990. Integrating Behavioral, Perceptual, and World Knowledge in Reactive Navigation. *Robotics and Autonomous Systems*. 6: 105-122.

Brooks, R.A. 1986. A Robust Layered Control System for a Mobile Robot. *IEEE Journal of Robotics and Automation*, RA-2: 14-23.

Brooks, R.A. 1991. Intelligence Without Representation. *Artificial Intelligence*, 47:139-160.

Bustos, P., Recio, F., Guinea, D., Garcia-Alegre, M.C. 1995. Cortical Representations in Active Vision on a Network of Transputers, In: *Proceedings of First ECPD Intern. Conference on Advanced Robotics and Intelligent Automation*, Athens, pp. 259-264.

Connell, J.H. 1991. SSS: A Hybrid Architecture Applied to Robot Navigation. In: *IEEE Intern. Conf. on Robotics and Automation*, Nice, pp. 2719-2724.

Corbacho, F., Arbib, M.A. Learning to Detour. *Adaptive Behavior*, 3 (4): 419-468.

Garcia-Alegre, M.C., Ribeiro, A., Gasós, J., Salido J. 1993. Optimization of Fuzzy Behavior-based Robot Navigation in Partially Known Industrial Environments. In: *The Third Intern. Conf. on Industrial Fuzzy Control and Intelligent Systems*, Houston, TX, pp. 50-54.

Garcia-Alegre, M.C., Bustos, P., Guinea, D. 1995. Complex Behavior Generation on Autonomous Robots: A Case Study. In: *Proceedings of IEEE on System, Man, and Cybernetics*, Vancouver, B.C, pp. 1729-1734.

Gasós, J., Garcia-Alegre, M.C., Garcia, R. 1992. Fuzzy strategies for the navigation of autonomous mobile robots. In: *Fuzzy Engineering towards Human Friendly Systems*. IOS Press: Amsterdam, Holland.

Guinea, D., García-Alegre, M.C., Kalata, P., Lacaza, A., Meystel, A. 1993. Robot Learning to Walk: An Architectural Problem for Intelligent Controllers, *Eighth IEEE Int. Symp.on Intelligent Control*, Chicago, ILL, pp.493-498.

Guinea, D., Sánchez, G., Bustos, P., García-Alegre, M.C. 1995. A Distributed Architecture for Active Perception in Autonomous Robots. *IEEE Int. Conf. Syst. Man and Cyber*., Vancouver, Canada, pp.1740-1745.

Hayes-Roth, B. 1995. An Architecture for Adaptive Intelligent Systems. *Artificial Intelligence, Special Issue on Agents and Interactivity*, 72 (1-2), 329-365.

Luck, M., d'Inverno M. 1995. A Formal Framework for Agency and Autonomy. In *Proceedings First International Conference on Multi-Agent Systems*, San Francisco, CA, pp. 254-260.

Maes, P. 1990. Situated Agents Can Have Goals. In: *Designing Autonomous Agents: Theory and Practice from Biology to Engineering and Back*, MIT Press/Bradford Books: Cambridge, CA.

Maes, P. 1991. A Bottom-Up Mechanism for Behavior-Selection in an Artificial Creature. In: *From Animals to Animats, Proc. of the First Int. Conf.on the Simulation of Adaptive Behavior*, MIT Press/Bradford Books: Cambridge, MA:

Mataric, M. 1994. Interaction and Intelligent Behavior. M.I.T. Artif. Intell. Lab., Massachusetts Inst. Technol., Cambridge, MA, A.I. Memo. 1495.

Mataric, M. 1995. Issues and Approaches in the Design of Collective Autonomous Agents. *Robotics and Autonomous Systems*, 16 (2-4): 321-331.

Mataric, M. 1996. Learning in Multi-Robot Systems. *Lectures Notes in Artificial Intelligence (LNAI)*, Vol.1042: 152-163.

Mataric, M. 1997. Studying the Role of Embodiment in Cognition. *Cyber. & Systems*, 28 (6): 457-570.

McFarland, and Bösser T. 1993. *Intelligent Behavior in Animal and Robots*. MIT Press: Cambridge, MA.

Minsky, M.L. 1986. *The Society of Mind*. Simon & Schuster Ed. : New York.

Minsky, M.L. 1994. A Conversation about Agents. *Communication of the ACM*, July 1994: 22-29.

Newell, A. 1990. *Unified Theories of Cognition*. Harvard University Press: Cambridge, MA.

Nillson, N.J. 1971. *Problem Solving Methods in Artificial Intelligence*. McGraw Hill.

Noton, D., Stark, L. 1971. Eye movements and visual perception. *Scientific American*, 224 (6): 34-43.

Panerai, F., Capurro, C., Sandini, G. 1995. Space variant vision for an active camera mount. LIRA-TR 1/95. LIRA-DIST, University of Genoa.

Simon, H. 1969, *The Sciences of the Artificial*, MIT Press: Cambridge, MA.

Steels, L. 1994. Building Agents with Autonomous Behavior Systems. In: *The Artificial life route to Artificial Intelligence: Building Situated Embodied Agents*. Lawrence Erlbaum Assoc. : New Haven, MA.

Tinbergen, N. 1951. *The Study of Instinct*. Oxford University Press.

Tistarelli, M., Sandini G. 1992. Dynamic Aspects in Active Vision. *CVGPI: Image understanding*, (56), 1, 108-129.

Recio, F. 1995. Tracking Monocular. Informe Técnico. 09/95, Dept. of Systems, IAI/Consejo Superior de Investigaciones Científicas.

Van den Velde, W. 1995. Cognitive Architectures-From Knowledge Level to Structural Coupling. In: *The Biology and Technology of Intelligent Autonomous Agents*. Springer Verlag.

Table 1. Fuzzy knowledge basis of AVOID agent for DELTAv control

Fig. 1. Multi-Agents hierarchical architecture

Fig. 2. Visual tracking sequence of FOLLOW_PERSON agent

MARIA C. GARCIA-ALEGRE is a staff scientist in the Systems Department at the Instituto de Automática Industrial (IAI), Consejo Superior de Investigaciones Científicas (CSIC) in Madrid since 1990. She received a Ph.D. degree in Physics at the University of La Laguna, Tenerife in 1983, where she held a permanent position as an Assistant Professor. She was a visiting Professor at the Applied Machine Intelligence & Robotics Laboratory, at Drexel University, Philadelphia in 1992 doing research on hierarchical architectures in control systems. Participant and leader of several European and National Research Projects on Mobile Autonomous Robots, Fuzzy Logic, Distributed Architectures and Artificial Vision Systems. She is a member of several professional societies, IEEE, FLAT, AEIA. Her work has been published in professional journals, books and conference proceedings in Computer Science, Fuzzy Logic and Robotics.

FELICIDAD RECIO is a Ph.D. candidate in the Systems Department at the Instituto de Automática Industrial (IAI), Consejo Superior de Investigaciones Científicas (CSIC) in Madrid. She received the B.Sc. in the University Complutense, Madrid. She is interested in artificial vision systems for robotics and in active vision mechanisms.