International Journal of Computer Science & Applications
Vol. 2, No. 1, pp. 33 - 37

Agent-based Coordination of Cameras

Jesús García, Javier Carbó and **Jose M. Molina**[1]

Abstract. This paper presents an application of software agents in a specific engineering problem: multitarget surveillance with several cameras sensing a closed environment. Each agent controls a camera, and from the coordination of them will emerge an improvement of the global surveillance task. Agents emulate human camera operators and, therefore human-like reasoning and human-like communication is pursued. Agents cooperate by exchanging speech-act based messages that allow them to interpret the situation faced locally.

1 INTRODUCTION

Usually surveillance systems are composed of several sensors (camera [7], radar [1]) to acquire data from each target in the environment that are fused in the fusion centre [14], place where a human operator is, usually, in charge of the supervision of the whole surveillance space. These systems face two kinds of problems [6]:

- Data fusion. It is related with the combination of data from different sources in an optimal way [14]
- Multi-sensor Management. It assumes that the previous problem is solved, and it is in charge of optimizing the global management of the joint system through the application of individual operations on each sensor [10].

This research is focused on solving the second problem (multi-sensor management) in a distributed way since we assume that sensors may have a high degree of autonomy, so that the last decision about tasks to be executed in the sensor is taken in their own management system [15]. In fact, sensors can be defined passive or active related with capacity of self-management, if sensor is able or not to manage its own resources. Active sensors allow a control on sensor operation, in this way sensor tasks depend (or sensor is adapted) to the real environment that surrounds the surveillance system. Functions that can be managed for a generic sensor are [14]: space management, management of operation type, temporal management and data (communication) management.

The coordination process must organize the flow of information in such a way that communication between the managers of an individual camera optimize the surveillance task. In our specific application, this optimization applies to what zones are covered at every moment as well as what objectives are followed by each camera/manager.

The management criteria used to optimize sensor operations are based on factors such as: the probability of detection, the quality of tracks, whether a target is identified or not [9], etc. In this way, we can distinguish two different subtasks:

- cueing: to redirect the attention of another sensor towards an specific target,
- hand-off: to transfer tasks from a sensor towards another one [1].

Distributed Artificial Intelligence techniques [2], in particular the theory of multiagent systems, may support a coordination process among sensors in a surveillance task. Rather than using a human operator to manage each sensor of a surveillance network, software agents may be applied. Automation of the coordination and local management of sensors may then improve the quality and performance of decisions, as previous works showed in [10], where multi-agent systems have been used to coordinate a net of sensors (in this case multifunction radar) in the air defense domain, using techniques of negotiation to determine the more appropriate distribution of tasks at every moment. This paper extends the application of multiagent systems to the distributed management of active cameras, including the management problem of space-temporary allocation.

The decision making of agents may be close to human-like reasoning by the use of fuzzy logic. This is the way followed by previous works related to surveillance systems, that the authors of this paper have developed: fuzzy systems to determine the priority of tasks in air defense systems [9] and to design techniques of segmentation of images (with a single camera) in complex situations [4] [8]. Specifically, in [9] a fuzzy system is developed to prioritize the set of tasks that the sensor has to execute according to the measured data and other collateral information, such as meteorological or terrain observations. The suitability of fuzzy systems to represent the uncertainty in the manager is justified by the robustness and the capacity of generalization of these systems. Besides, in this work, arising situations of conflict that require the collaboration between agents are defined with the knowledge extracted just from the own captured images. The analysis of the captured images at low level allows the agent to detect tracking problems that may need the use of several sensors to accomplish successfully the surveillance task[3] [8].

2 A SYSTEM OF AGENT-CAMERAS

2.1 Agents: roles, perceptions, actions and types of reasoning

Intelligence in artificial systems, such as our agent based surveillance system, emerges from the cooperation of elements with different goals. In our scenario we define a surveillance system where agents decide actions according to recent perceptions (images captured or messages from other agents) and current beliefs. Actions typically consists of operations over the camera, and communications with other agents. These communication acts have the final intention of satisfying, in a cooperative way, the global surveillance task although they reason and act locally. We also consider, as in [10] and [9], that agents in our system may play two types of roles:

- camera-role, where each agent controls a single camera. A limited zone of the surveillance space is assigned to each agent, with a

[1] Universidad Carlos III de Madrid, Leganés, Spain email: {jgherrer, jcarbo, molina}@inf.uc3m.es

medium/high level of overlapping with zones of the other camera-agents. Each camera-agent should monitor the movement of mobile targets while it observes the given zone of the surveillance space.
- fusion-role that is an assistant agent that solves a limited set of conflicting situations. It is in charge of acting as referee with information provided by conflicting agent-cameras with the intention of satisfy the global goal: every mobile target is monitored, and all the space of surveillance is covered. According with this intention, the fusion agent may force camera-agents to redefine their local goals (the set of mobile targets that is monitored).

Figure 1 outlines the roles and interactions of agents in our surveillance system.

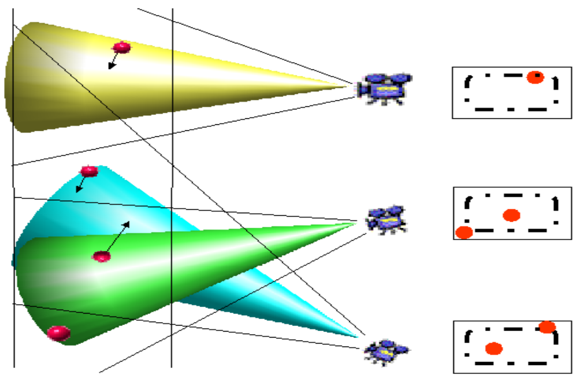

Figure 1. Cameras surveilling several targets

Software agents that manage cameras, have two different sources of perception: messages from other agents and captured images from the camera. This double nature of inputs forces the inclusion of complex abilities in the perception component in order to interpret the images captured by the camera before high level decision making would take place. The results of such analysis is considered by such reasoning process in order to take some action. Both components have to run in asynchronous mode, with different activating time intervals. Therefore image acquisition and analysis has to last longer than the reasoning process to decide the corresponding action to take and the execution of such action. Both process apply different artificial intelligence techniques: while image processing with data mining plays a central role in perception, decision making may rely on a reactive behaviour (i.e. neural networks) or on a deliberation (logic reasoning with symbols).

As precedents of our works, we can find examples of both alternatives. For instance, the authors of [7] propose a reactive approach with three interaction levels: the most basic level allows (reading/writing) access operations on a shared memory, the intermediate level implements the interactions among agents with the same target to be identified and located with enough temporal and spatial precision, finally the most complex level of interactions is the set of communications that intend the coordination among agents to re-assign the competence of targets to agents.

On the other hand, deliberation about plans and goals is considered by the authors of [12] in a similar problem. In this research, cameras act according to dynamically variable priorities of surveillance. Those priorities will depend upon the state of the environment. In our scenario priorities depend just upon the targets, not upon the environment that is close to them.

2.2 Setup of the surveillance scenario

We assume that cameras have the ability to identify the observed targets, through the image analysis process that is not the focus of our research. They will be continuously surveying several mobile targets (with different relevance) in the assigned zone. These cameras are placed in fixed locations, but they have the ability to turn laterally and up-down on both ways (pan-tilt controls). With these movements they can orient themselves to monitor the mobile targets followed. We can observe in figure 2 how the images captured by different cameras may be enough overlapped. We also consider that

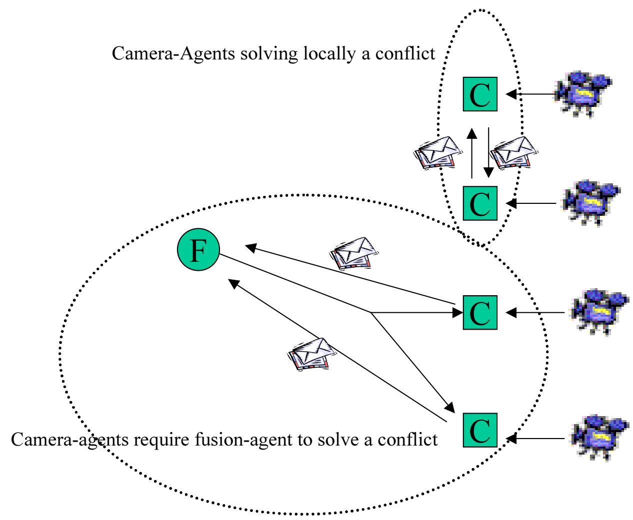

Figure 2. Multi-target surveillance with several cameras

the image captured by the camera has a central zone where the vision is optimal, but outside it the quality of the images is not enough and targets in these borders should be given up or the camera should turn to center them. Perception component will let execution component know about whether a mobile target is inside this central area or not. Figure 3 shows an example of this partition that is also outlined in the right side of figure 2. Then, camera agents are in charge to decide which mobile targets are going to keep monitoring, taking into account that any mobile target may be without surveillance, and furthermore considering an efficient surveillance coverage of the limited zone assigned to such agent.

This compromise may be solved in a centralized way: a central entity with complete knowledge that makes decisions in behalf of all the cameras as it is suggested in [5]. However, a distributed solution may occasionally (scalability and fault-tolerance), become an interesting alternative. Distribution is obtained from a multi-agent system like ours, where each camera is represented and managed by an individual software agent.

Additionally to the computation restrictions, and the exchange of data, we may remark the distributed nature of target identification with image processing. It is compulsory a processor associated with each camera that will analyze the images captured in order to locally identify and locate the targets included in such image. In this way,

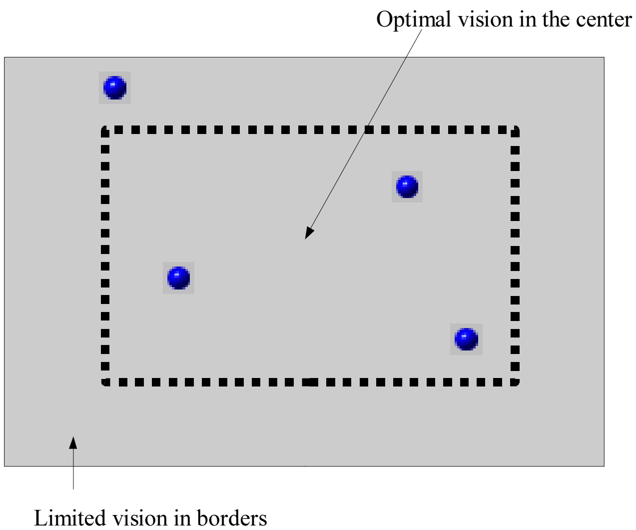

Figure 3. Partition of the image according to the quality of vision

coordination is a natural solution to this kind of problems, as the authors of [7] consider for a similar problem.

A particular agent does not know what is happening outside the area that it is observing, and it does not also know the orientation and monitoring intentions of the other cameras. Since agents count just on partial knowledge, it has to make decisions with this limitation. Consequently, the quality of the decision has to be not optimal. Optimal decisions can be taken if we consider optimal conditions: complete knowledge, no computational restrictions. This is the case of [13] where each agent works in a complete autonomous way. Even with partial knowledge, we try to show how with certain coordination among agents, the quality of decisions can be increased to be close to the optimal decision.

3 COORDINATION OF AGENTS

In this section we explain how camera-agents solve coordination problems by themselves (without the participation of the fusion agent), although we remark the conditions that would justify the mediation of the fusion agent. We also describe the messages that a camera agent may send, and the corresponding responses. These may take the form of execution requests or information sharing from other agents.

3.1 Knowledge Representation

The deliberative nature of the agents included in our proposal, represents knowledge in terms of the classical structure [11] of three levels of abstraction: beliefs, desires and intentions. Beliefs are facts assumed from messages and images that are related to the agent itself and hypothesis about the external world. The type of beliefs that our agents may manage are:

- *is at*: A description of where targets observed in the image captured by the camera are located
- *is centered*: An statement about if the target belongs to the central zone of optimal vision or not
- *monitors*: What targets is monitoring the given agent
- *exists* Which other camera-agents are running.
- *monitors*: pairs (camera-agent, target) that show what targets are monitoring the other agents
- *view*: pairs (camera-agent, target) that show targets that other cameras supposedly view.

The second element of knowledge that agents manage is intention. Intentions in the classic deliberative paradigm stands for actions that the agent expects to carry out in the very next future. In our system, intentions can take the form of:

- *turn*: operations over the camera: turning the camera in a given sense
- *send*: message exchanges that allow the coordination among camera-agents.

Finally, the most abstract knowledge level corresponds to the desires of the agent. They represent an abstraction of what is the agent pursuing, and they are are linked to a generic plan (sequence of potential intentions). When a given condition was fired, the abstract desire would be instantiated in a specific goal, linked to an instance of the corresponding plan. Taking all of that into account, we have included the next desires in our agents:

1. *Keep targets*: paying continous attention to the targets that the agents was previously monitoring.
2. *Acquire new*: trying to own a new target detected in the image.
3. *Give up*: losing the assignment of some target, since the agent can not keep monitoring it in the future.
4. *Cooperate* agree with other agents in the redefinition of assignment corresponding to a target, when another agent is not able any more to monitor the target that was carrying out.
5. *Explore* to survey the limited zone that is competence of our agent, in order to detect possible new targets.

3.2 Cooperation protocol

There are different forms of cooperation that take place in our agent system. Next, we describe how they are implemented. The type of coordination that occurs depends on the information shared, or execution requests received by other agents.

1. *Monitor a recently detected target*. The execution of that goal is fired is desire is when a new target results detected in the last image captured by the camera. The corresponding agent cooperates with the other agents that cover the close area to its limited preassigned zone. This agent let the others know about the ownership of the monitoring corresponding to its recent discovered target. After that communication, and during a given lapse of time, the discovering agent may receive a response from other agent that states the previous discovery and ownership of such target. In the case of no answers in that lapse time, the competence of the agent over the given target becomes confirmed.
2. *Reassignment of targets*. The condition that fires this desire is the next one: several monitored targets are located in opposite borders of the image. Therefore, the agent is forced to decide what target among them is going to stop monitoring. Different factors may influence on this decision: priority of targets, how much centered are each of them, number of targets in opposite borders and finally, the availability of other cameras to monitor the targets left. The next desire details the sequence of interactions that take place when such decision is made. item *Cooperation with other agents in the reassignment of targets*. The execution of the corresponding plan

of this desire is caused by changes in beliefs, nor from the analysis of the image captured. The changes in beliefs take place when a message from other agent giving up some target is received. If the received message informs about a recently detected target, and such target was previously monitored by our agent, it will answer advising of that circumstance to the sender agent. In other case, our agent does not see the target and therefore will not answer. But if the received message informs about the intention of giving up the monitorization of a given target, and that target is in the central zone of vision (the optimal one), our agent will communicate every close agent its decision of accepting the competence on such target. Finally, the last case occurs when the received message informs about the intention of giving up the monitorization of a given target, and that target is not in the central zone of vision (the optimal one), then it will wait for another message from other agent accepting the competence of such target. But in the case whether this second message does not appear until a given latency time, it will evaluate the possibility of accepting the monitorization of that target. In the case of two similar answers, the agent who caused the reassignment desire from the decision of giving up such target will decide in behalf of the other two conflicting agents. In all the cases, the fusion agent verifies that at the end of the negotiation every target has associated a camera agent; otherwise it is able to re-open the negotiation protocol.

3. *Explore the assigned area of surveillance*. This last desire of the agent intends to avoid the possibility of targets undetected in the limited zone pre-assigned to that agent. It is instantiated periodically to cover the hidden parts of such zone. This desire has less priority than the others, so if intentions from the plan corresponding of this goal coexist with intentions of other plans, the exploration intention is suspended until the other cooperative desire becomes definitively solved. Coordination of these tasks with the other agents will follow a negotiation process similar to the previous one.

Although these briefs descriptions have not been already tested with real data, we expect from them a behaviour that will make surveillance problem solved in a nearly-optimal way, such as complete knowledge centralized solution would do it. Figures 4 and 5 show graphically the firing conditions of the two first desires.

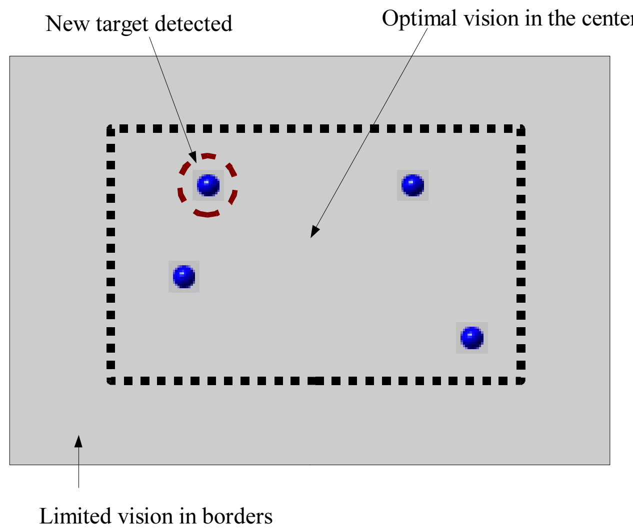

Figure 4. Conditions to fire desire *Monitor a recently detected target*

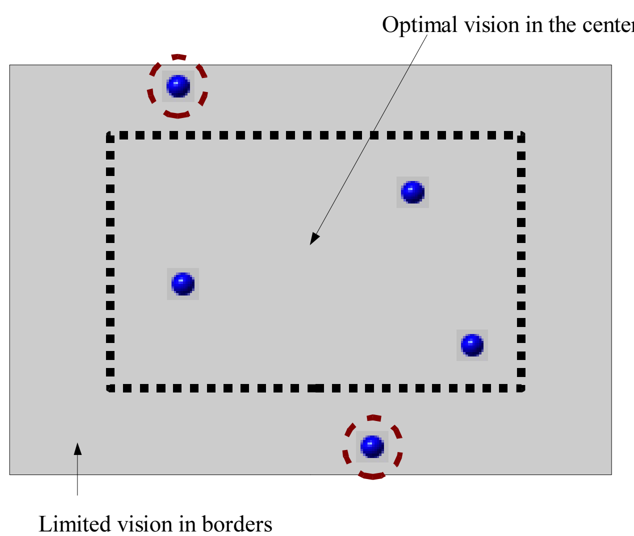

Figure 5. Conditions to fire desire *Reassignment of targets*

4 CONCLUSION

In this work the systems based on software agents have been applied to the management of a surveillance system using cameras as sensors. The use of software agents allows the design of a more robust and decentralized system, so that the management is distributed between the different camera agents. The architecture of each agent and his level of reasoning has been presented, as well as the rules of coordination. As close future work, we are applying data mining techniques to learn from real situations how to extract knowledge from the environment in order to detect conflicting situation and therefore, to help in the cooperation among camera-agents. Next we also intend to test our approach with real pre-processed data in order to compare our distributed view with the classic centralized one.

ACKNOWLEDGEMENTS

The research reported in this paper is partly supported by CICYT (TIC2002-04491-C02-02) and CAM (07T/0034/2003 1) projects.

REFERENCES

[1] Y. Bar-Shalom, *Multitarget Multisensor Tracking. Vols. I-II*, Artech House Inc, Norwood, Massachussets, U.S., 1992.

[2] Decker and Keirh S., *Distributed Problem-Solving Techniques: A Survey*, IEEE Transactions on Systems, Man, and Cybernetics, IEEE Computer Society Press, New York, U.S., 1987.

[3] J. García, A. Berlanga, and J.M. Molina, *A machine-learning approach to multiple-detection data association for ASDE radar*, Proceedings of the Seventh International Conference on Information Fusion, Stockholm, Sweden, 2004.

[4] J. García, J.M. Molina, J.A. Besada, and J.I. Portillo, 'Fuzzy approach for data association in image tracking', *Mathware and Soft Computing*, **10**(2-3), (2004).

[5] H. Landau, C. Rago, and P. Arambel, *Video-based tracking of multiple vehicles from disjoint scenes*, Proceedings of the Seventh International Conference on Information Fusion, Stockholm, Sweden, 2004.

[6] J. Manyika and H. Durrant-Whyte, *Data Fusion and Sensor Management a decentralized information-theoretic approach*, Ellis Horwood, 1994.

[7] T. Matsuyama and N. Ukita, 'Real-time multitarget tracking by a cooperative distributed vision system', *Proceedings of the IEEE*, **90**(7), 1136–1150, (2002).

[8] J.M. Molina, J. García, J. de Diego, and J.I. Portillo, 'Neuro-fuzzy techniques for image tracking', *Lecture Notes in Computer Science*, **2686**, (2003).

[9] J.M. Molina, J. García, F.J. Jiménez, and J.R. Casar, 'Surveillance multisensor management with fuzzy evaluation of sensor task priorities', *Engineering Applications of Artificial Intelligence*, **15**(6), 511–527, (2002).

[10] J.M. Molina, J. García, F.J. Jiménez, and J.R. Casar, 'Cooperative management of a net of intelligent surveillance agent sensors', *International Journal of Intelligent Systems*, **18**(3), 279–307, (2003).

[11] A.S. Rao and M.P. Georgeff, *Modeling rational agents within a BDI architecture*, 473–484, Procs. 2nd Int. Conf. on Principles of Knowledge Representation and Reasoning, Morgan Kaufmann, San Francisco, U.S., 1991.

[12] A.C. Reinaldo, A.H. Bianchi, and R.C. Rillo, *A purposive computer vision system: a multi-agent approach*, 225–230, Proceedings of the 2nd Workshop on cybernetic vision, IEEE Computer Society Press, Los alamitos, California, U.S., 1997.

[13] M. Saptharishi, K.S. Bhat, C.P. Diehl, J.M. Dolan, and P.K. Khosla, 'Distributed agents for autonomous reconnaissance and surveillance', *IEEE Transactions on Robotics and Automation*, **18**(5), 162–182, (2002).

[14] E. Waltz and J. Llinas, *Multisensor Data Fusion*, Artech House Inc, Norwood, Massachussets, U.S., 1990.

[15] R. Wesson, *Network Structures for Distributed Situation Assessment*, Readings in Distributed Artificial Intelligence, Morgan Kaufmann, San Francisco, U.S., 1988.