Cooperation between Omnidirectional Vision Agents and Perspective Vision Agents for Mobile Robots

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Abstract. Multiple robot systems in which every robot is equipped with a vision sensor are more and more frequent. Most of these systems simply distribute the sensors in the environment, but they do not create a real Cooperative Distributed Vision System. In this paper we propose an approach to realize a Cooperative Distributed Vision System within a team of heterogeneous mobile robots. We present two research streams which we are working on, along with theoretical and practical insights.

1 Introduction

In this paper, we present our researches on Distributed Vision for mobile robots. The most promising applications of Distributed Vision probably are surveillance and monitoring systems. Most of the previous works dealt only with static vision systems, we think that the introduction of mobile robots can improve the performances and robustness of the system. As an example, think of an industrial site controlled with a video monitoring system composed only of cameras with fixed locations (even pan-tilt-zoom cameras). If an alarm or a meaningful event happens outside the field of view of any of the cameras, the system cannot "*see*" this event. This is because the system has a *predetermined field of view*. If we mount some cameras on mobile robots, the system can send a robot to inspect the new location of interest. The system is more flexible and we realize what we call a *dynamic field of view*.

Nowadays, the relatively low cost of the vision sensors allows to equip every member of a multi-robot team with a vision sensor.

Introducing mobile robots fitted with cameras distributes the sensors in the environment, but this is not enough, a set of cameras scattered in the environment needs to communicate over a network in order to became a unique Distributed System. In the following we will prefer the term *Vision Agent* (VA) instead of "*vision system*". The term VA (Vision Agent) emphasizes that the vision system is not just one of the several sensors of a single robot, but that it interacts with the other vision systems to create an intelligent distributed system.

2 Previous Works

Our work has been inspired by the work of Ishiguro [2]. He proposed an infrastructure called *Perceptual Information Infrastructure* (PII). In his paper, he proposed an imple-

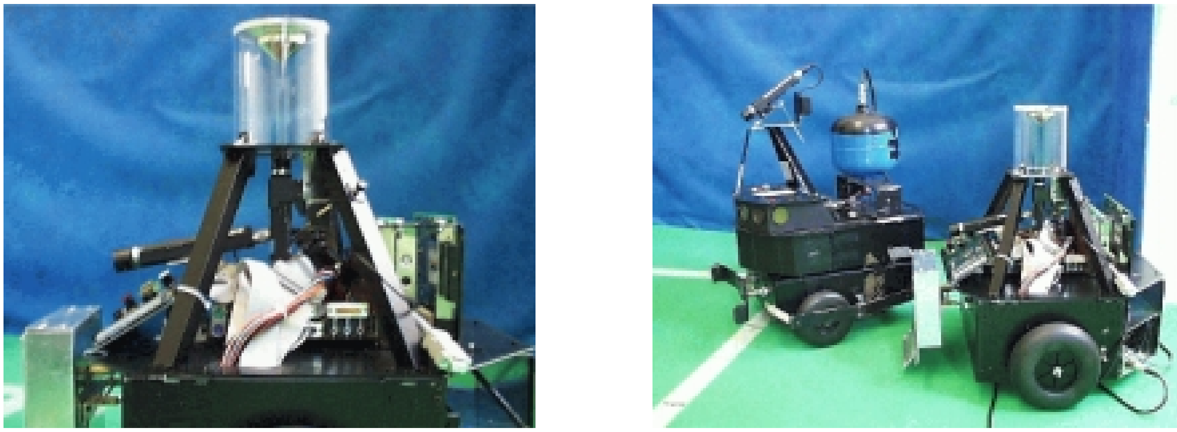

Figure 1: **(Left)** A close view of the vision system of Nelson. On the left, the perspective camera. In the middle, pointed up-ward the omnidirectional camera. **(Right)** A close view of two of our robots. Note the different vision systems.

mentation of the PII composed by static VAs, i.e. fixed cameras with a certain amount of computational power. This realisation of the *PII* was called Distributed Vision System. The assumption that every VA is static simplifies the problem and allows the use of very simple vision algorithms, but implies that the whole system is not scalable to include Mobile VAs.

A parallel but independent work is the one of Matsuyama. He explicitly introduced mobile robots in the theoretical frame of its Cooperative Vision System. In the experiments presented in [3], he used active cameras mounted on a special tripod in order to have a fix view point. This allowed the use of a simple vision algorithm, not scalable to mobile robots.

As far as we know, no attempt has been tried to realize a DVS with truly mobile robots running robot vision algorithms.

3 The aim of our work

Our aim is to introduce a real Mobile Vision Agent in the DVS architecture, i.e. to apply the ideas and the concepts of Distributed Vision to a mobile robot equipped with a camera. We are on the way to create a Distributed Vision System within a team of heterogeneous robots fitted with heterogeneous vision sensors. The redundancy of observers (and observations) is a key issue for system robustness.

4 Implementation

4.1 Two VAs mounted on the same robot

The first step is to realise a Cooperative behavior between two heterogeneous vision agents embodied in the same robot: an omnidirectional and a perspective vision system. The omnidirectional vision sensor is a catadioptric system composed of an omnidirectional mirror and standard colour camera looking at it, Fig. 3 (Left). The omnidirectional mirror is a multi-part mirror with a custom profile we designed[1], Fig. 3 (Right).

The omnidirectional camera is mounted on the top of the robot and offers a complete view of the surroundings of the robot [6][5]. The perspective camera is mounted in the

[1]For details on the procedure we used to design the custom profile of the mirror, please refer to [4]

front of the robot and offers a more accurate view of objects in front of it. These two cameras mimic the relationship between the peripheral vision and the foveal vision in humans. The peripheral vision gives a general, and less accurate, information on what is going on around the observer. The foveal vision determines the focus of attention and provides more accurate information on a narrow field of view. So, the omnidirectional vision is used to monitors the surroundings of the robot for detecting the occurrence of particular events. Once one of these events occurs, the Omnidirectional VA (OVA) sends a message to the Perspective Vision Agent (PVA). If the PVA is not already focused on a task, it will move the robot in order to put the event in the field of view of the perspective camera. This approach was suggested by our previous researches presented in [1].

Experiments on such a system are running and they will provide more insights on the cooperation of two heterogeneous VAs.

Figure 2: The mirror with the custom profile we designed

4.2 Coordination of several VAs mounted on different robots

Another stream of research is the creation of a Cooperative Distributed Vision System for a team of robots depicted in Fig. 3. The first step is to implement the idea of the Cooperative Object Tracking Protocol proposed by Matsuyama [3]. In the work of Matsuyama the central notion is the concept of *agency*. An **agency**, in the definition of Matsuyama, is *the group of the VAs that sees the objects to be tracked and keeps an history of the tracking*. This group is neither fixed nor static. In fact, a VA exits the agency, when it is not able to see the tracked object anymore, and a new VA can joint the agency as soon as the tracked object comes in its field of view. The described algorithm has been realised by Matsuyama with his fixed view point cameras. As mentioned before, in such a system there is not a truly mobile agent and the system is not scalable to Mobile VA.

Our novel approach is to implement the Cooperative Object Tracking Protocol within a team of mobile robots. This requires a totally new vision approach, in fact, the point of view of the VA is continuously changing while the robot moves. So, the changes in the image are due not only to the changes in the world (as in the Matsuyama testbed), but also to change of position of the VA. Moreover, we have to introduce a measure of uncertainty in the estimation of the positions of the tracked objects, because the location of the Vision Agents is not exactly known anymore.

To explain these issues, let us see a simple example. In the cooperative tracking of an object, if a VA sees the tracked object, it sends a message to the agency's master. This

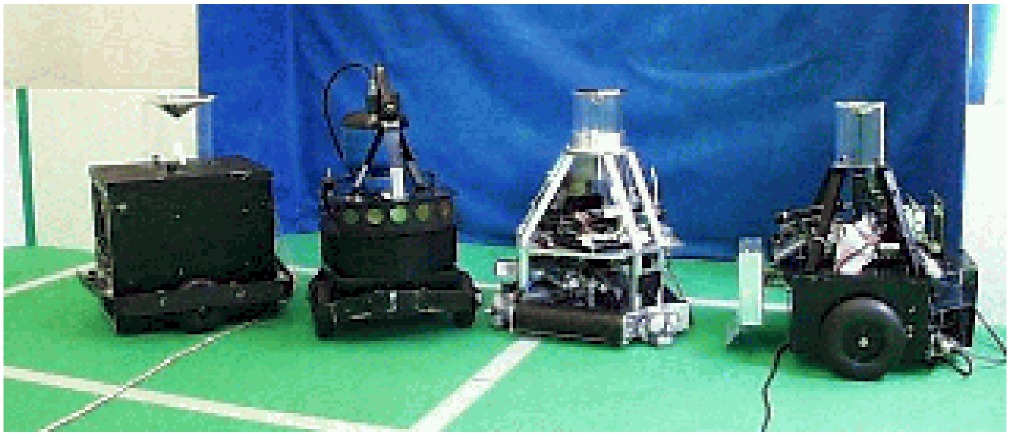

Figure 3: Our team of heterogeneous robots

checks if the latter has seen the correct object. Errors can result either because the robot sees another object resembling the tracked one or because it is not properly localized and so it reports a fallacious position for the object. To cope with the uncertainty in the objects position, every VA transmits to the master the calculated object position with the confidence of this estimation. The master dispatches to the other robot a position calculated as an *average* of the different position estimations, weighted by the confidences reported by every VA.

The master role is crucial for the correct functioning of the agency. The master role cannot be statically assigned. If the object is continuously moving, the first robot that sees it will not have the best observational position for long. So, the master role must pass from robot to robot. The processes of swapping the master role is critical, if the master role is passed to a robot that sees an *incorrect object* the whole agency will fail in the *tracking* task. The simplest solution could be to pass the master role to the robot with the highest confidence on the object's position. This means to shift the problem to identify a reliable confidence function. This makes sense. In fact, if a robot is correctly localized and correctly calculates the relative distance of the object, it will have strong weight in the calculation of the object position; given this, it can reliably take the role of master.

4.2.1 The confidence function

The confidence function ψ_{abs} associated to the reliability of the estimation of the absolute object position is a combination of several factors. In fact, the position of the object is calculated by a vectorial sum of the relative distance of the object from the robot and the absolute position of the robot. So, the confidence of the estimation of the absolute position of the object is the sum of the confidences function associated to the self-localisation, ψ_{sl}, and of the confidence function associated to the estimation of the relative position of the object with respect to the robot, ψ_{rel}. In our experiments, the self-localisation process uses the vision of landmarks. The process is run only by time to time and if the landmarks are visible. Between two of these processes the position is calculated with the odometers. This means that the localisation information degrades with time. The confidence function associated with the self-localisation is the result of the following contribution: type of vision system (perspective, omnidirectional, etc.), absolute error made from the vision system in the calculation of the landmarks position (estimated a priori) and time passed after the last self-localisation process. The relative position of the object with respect to the robot is calculated as in [4] and the confidence function depends on: type of vision system and distance from the robot.

At the moment the exact definition of the confidence function is under testing. The experiments will tell us how much every contribution should weight in the final function.

5 Conclusions and Acknowledgments

In this paper we presented two of the research streams we are following to implement a Cooperative Distributed Vision System. We proposed to realise the DVS with heterogeneous mobile Vision Agents. We suggested a way to fuse the information coming from two heterogeneous VAs mounted on the same robot. Regarding the problems introduced by the mobile Vision Agents, we suggested a way to cope with the uncertainty introduced in the localisation of the objects of interest.

At the time of writing experiments are running on such a systems providing theoretical and practical insight.

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