Expert Systems with Applications 40 (2013) 4737–4748

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

A cooperative multi-agent robotics system: Design and modelling ☆

Cecilia Garcia Cena [a,c,*], Pedro F. Cardenas [b,1], Roque Saltaren Pazmino [a], Lisandro Puglisi [a,2], Rafael Aracil Santonja [a]

[a] Centro de Automática y Robótica, Universidad Politécnica de Madrid, Jose Gutierrez de Abascal 2, 28006 Madrid, Spain
[b] Universidad Nacional de Colombia, Colombia
[c] Escuela Universitaria de Ingeniería Téncica Industrial. Ronda de Valencia, 3, 28012 Madrid, Spain

ARTICLE INFO

Keywords:
Robotic agent
Mechatronics
Mobile robot kinematics
Mobile robot motion-planning
Cooperative systems

ABSTRACT

This paper presents the development of the robotic multi-agent system SMART. In this system, the agent concept is applied to both hardware and software entities. Hardware agents are robots, with three and four legs, and an IP-camera that takes images of the scene where the cooperative task is carried out. Hardware agents strongly cooperate with software agents. These latter agents can be classified into image processing, communications, task management and decision making, planning and trajectory generation agents. To model, control and evaluate the performance of cooperative tasks among agents, a kind of Petri Net, called Work-Flow Petri Net, is used. Experimental results shows the good performance of the system.

1. Introduction

The field of multi-agent robotic systems (MARS) arose during the late 80s when several researchers started to work with mobile robots performing coordinated task (Arai et al., 1989; Asama et al., 1989; Beni, 1988). Since this early research, the scientific interest in multi-agent robotic systems (MARS) has increased considerably, (Alami et al., 1997; Balch and Arkin, 1998; Deloach et al., 2002; Fiorino and Tessier, 1998; Kok et al., 2003, 2005).

The increasing interest in MARS is due to a number of real world problems that are best modelled using a set of agents instead of a single agent. A multi-agent system is composed of a number of agents that are able to interact with each other in order to complete a set of goals. Therefore, MARS topics involves all the disciplines in robotics field like distributed control (Wang and Silva, 2010), perception (Franchi et al., 2009; LaValle, 2011; Liu et al., 2010), cognition (Bibel, 2010; Mehrjerdi et al., 2010), coordination (Kitts and Mas, 2009) and configuration (Wang and de Silva, 2010) among others.

However, multi-robot systems bring new problems that must be solved in order to increase the success of this "new" area in robotics: cooperation and coordination for being a social team. In Chen et al. (2010), a system of cooperative work where the robot responds to the targeted task and to temporary restrictions in a framework of individual automatic decision control and communications strategy through specifications of global task, is developed. The formulation of the problem is discrete. The Khepera robots are modelled as agents and the environment as a discrete graph. The execution of the task could be carried out individually or collectively.

Path planning in multi-robot Systems is another important field of research. In concept, considering a group of robots being able to carry out a task in an autonomous manner in changing environments, mainly depends on the sensorization and multi-planning of trajectories, which can be defined as trajectory planning in real time and in parallel with dynamic environment. In Du et al. (2011), a novel procedure is presented for the recompilation of future information and its quality in the planning process. The approach to the solution is associated to the problem in the stochastic dynamic programming. In Kolling and Carpin (2010), evasion-persecution technique in trees or graphs is used. The robotic agents perform a search and evasion on the graph, which models detecting intruders in the complex environments. In Minguez and Montano (2009), an evasion method is proposed (in the detection layer of collision), which considers the exact geometry, the kinematics and the dynamic effects of the mobile robot. The idea is to project distance measurements in a space where the robot can be regarded as a holonomic point. In Peasgood et al. (2008), an alternative method of multi-phase planning that solves the problems of coordinated planning, is discussed. In this method is necessary to make a graph of the environment, based on that, a tree branch is selected. Both are considered as the general free collision route. Besides the tree branch, heuristic approach for its selection is used. It maximizes the number of branches and their distances.

☆ The authors would like to thank the financial support of Spanish Government CICYT Project Ref. DPI2009-08778 and also to Comunidad de Madrid who support the project ROBOCITY2030-II Ref. P2009/DPI-1559.
* Corresponding author. Address: Escuela Universitaria de Ingeniería Téncica Industrial. Ronda de Valencia, 3, 28012 Madrid, Spain, Tel.: +34 605122476.
E-mail address: cecilia.garcia@upm.es (C.G. Cena).
[1] P. Cárdenas is granted by COLCIENCIAS.
[2] L. Puglisi is granted by MAEC-AECID.

0957-4174/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.eswa.2013.01.048

In this paper, the mechatronics development of SMART multi-agent system is presented.

In SMART multi-agent robotic systems, an agent is defined as a software or hardware entity with specific skills and capabilities in order to cooperate and complete a common task. Hardware agents considered in SMART system are:

- IP-Camera Agent. This sensor allows taking pictures of the robotic scene in which robotic agents perform the task in spite of the obstacles.
- A walker robot with four legs and 13 degree of freedom.
- A robot with three legs and eight degree of freedom.

Software agents are developed under C++ language and are listed bellow and :

- Image processing agent: functions developed in order to process the pictures taken by the IP-Camera and obtain information about the position of robots and obstacles in the scene.
- Path planner agent: specific functions that generate and plan the robots's trajectories.
- Communication agent: software that provides communication (TCP/IP and bluetooth) among agents and manages the information packets generated by each agent.
- Decision maker: this agent, called *engine*, has the knowledged of the system and the goals. Therefore it takes decisions about the next step in the system.

A key aspect in the SMART systems is the problem of coordination: the process that ensures that the individual decision of the agents turns out to be a "good" decision for the entire group. In order to ensure the coordination and cooperation between agents, a Petri Net (WF-PN) Work-Flow is used. Fig. 1 summarizes the philosophy of SMART systems. Robotic agents are deployed in a bounded but not structured workspace. Agent camera takes a picture at 15 FPS in bmp format and it is then sent to the central PC via TCP/IP communication. The picture is processed and the information about global position of the robot and obstacles is taken by engine software to plan the task, decide about the next step, which is to re-plan the trajectory (in the agent path-planner) or send a command to the robot by bluetooth communication.

This work is organized as follows, Section 2 describes the electromechanical design of robotic agents. The kinematic model, under screw theory, and the walking s pattern of robots are presented in Section 3. The path planner used for robotics agents is described in Section 4 and experimental results are showed in Section 5. Conclusion and futures works are explained at the end of the article.

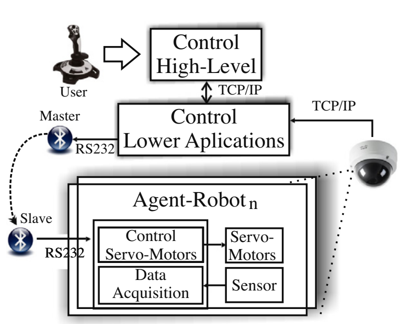

Fig. 1. Multi-agent systems architecture mechatronic.

2. Mechatronics design of the smart system

In this section all the agents developed in this project are described. Firstly, the hardware agent are presented and then the software agent. The mechanical design of robotics agents tries to weigh out complexity of design and performance. Therefore the main goal is to develop a robot with the sufficient degrees of freedom so as to carry out a wide variety of movements. The topics considered in order to achieve the best mechanical design are:

1. The kinematic control must be as simple as possible.
2. The robotic agent must be autonomous.
3. The robotic agent must be able to perform many different task

Two kinds of robotics agents were developed, with three and four legs. Each agent has different locomotion capabilities. The agent with three legs is faster than the agent with four legs, however this latter is able to climb stairs or jump obstacles.

2.1. Agent Robot3L

Fig. 2(a) The module consists of 3 legs and a platform base. The front legs have three degrees of freedom: two rotational and one translational while the hind leg has two rotational degrees of freedom. Likewise, the agent has the ability to go straight and to make turns. Because of the linear actuators, it is possible to move the gravity center up or down. For reasons of balance, it is absolutely necessary that the three legs are resting on the surface. Therefore, the robot moves sliding. Fig. 3(a) shows a picture of the agent built.

2.2. Agent Robot4L

This robot has four legs (see Fig. 2(b)) with three degree of freedom each one (two rotational and one prismatic). This agent can walk using different synchronized patterns like straight line, turns, move the gravity center. There is an extra degree of freedom in the middle of the robot that allows it to stand on two legs. Because it can stand on three legs, the fourth leg can move freely. It is possible to change speed or movement pattern easily. The geometry of the robots is based on the servo-actuators. It thereby reduces the total weight of the structure. Fig. 3(b) shows a picture of the agent built. The robotics agents are controlled by a simple Pololu control board which support Bluetooth protocol. Table 1 summarized the main components used in both prototypes.

2.3. Communication agent

In this project, two different protocols have been used: TCP/IP and Bluetooth. Communications among IP-camera, PCs and software agents have been done using TCP/IP protocol. The communication between robotics agents and control PC has been done on Bluetooth protocol. The central PC is equipped with a Belkin Bluetooth USB adapter. Belkin F8T009 Bluetooth adapter supports Bluetooth version 1.2. SMART robots are equipped with OEMSPA 312iadapter by ConnectBlue. Once connected to its host system and configured, the Serial Port Adapter can communicate, using Bluetooth, with a wide range of other Bluetooth enabled devices such as other Serial Port Adapters, mobile phones, handheld computers and laptops.

For the communication with the serial port adapter, baud rate has been changed to 9600, while Pololu mini servocontroller used to control the SMART robot servos, only works at 2400 or 9600 baud. This can be done, using the OEMSPA312i Serial Port Adapter in AT mode. Communications between IP-Camera and control PC and between software agents and control PC is done on TCP/IP