RoboCare: Pervasive Intelligence for the Domestic Care of the Elderly

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ABSTRACT

This article reports the state of advancement of the RoboCare project, which was launched in December 2002 to address the problem of providing assistance to elderly people using a combination of software, robots, intelligent sensors and humans. It addresses the creation of a multi-agent environment in which all these actors cooperate synergistically in order to provide user services. This paper details two aspects of the system in the making, namely the centralized, service-oriented supervision infrastructure, called *Active Supervision Framework* (ASF), and the robotic components in use in the present stage of system development.

1 Introduction

Many elderly people with physical or mental disabilities need constant care and support in several aspects of daily life, such as decision-making, reminding them of tasks or events and warning of dangers. Such intensive support is expensive to offer using human helpers.

The RoboCare project [1] was launched in Italy in December 2002 [2] to address this problem using a combination of software, robots, intelligent sensors and humans to provide powerful and wide-ranging assistance and guidance services such as health care for the elderly.

RoboCare shares some aspects with other high-tech projects for the assistance of elderly people, such as the Assisted Cognition Project [3] or the Pearl Mobile Assistant [4] but for the first time addresses the creation of a multi-agent environment.

The philosophy underlying this application of cognitive technology is to enhance the quality of care for the elderly by deploying a range of intelligent components which co-operate to provide services.

For instance, Alzheimer patients would benefit from a system which reminds them about certain sequences of actions to be performed such as switching off the gas after turning off the stove or wearing glasses before wandering out of the bedroom. In its simplest form, such a system could be made up of a team of agents like a gas monitor and a mobile robot capable of advising the assisted person. All the actors in the system would be capable of carrying out individual reasoning, but would also need to collectively reason about the situations which can occur.

Creating such tightly coupled intelligent systems presents an important challenge for the artificial intelligence and robotics communities, requiring the development of intelligent agents which are capable of complex symbolic reasoning tasks and high levels of interaction with humans.

It is true that researchers have already been successful in creating teams of robots [9] which are capable of co-operating in tasks such as foraging, the exploration of unknown environments and simplified forms of soccer-playing. And the artificial intelligence community has made significant advances in recent years in the study of planning and scheduling, and has developed mature technology for automated problem solving. However, the realization of a complete system to assist the elderly in a real-world environment such as a health-care institution or a home requires tight integration of these technologies. Not only: a central issue in developing support systems for the care of the impaired is *robustness*. From the software point of view, this means that the supervising entity must be capable of adapting to unexpected or unforeseeable perturbations in the nominal behavior of the system. On the other hand, the robotic components must be endowed with flexible behavioral characteristics, in order to successfully and safely react in any contingency.

The system must provide more than loose co-ordination between its components. It must provide a complete supervision framework which implements a solid infras-

[1] http://robocare.ip.rm.cnr.it

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[3] http://www.cs.washington.edu/assistcog/

[4] http://www-2.cs.cmu.edu/~nursebot/

tructure and maintains a global view of the system and provides control functions for human operators. And, as caring for elderly people is often all about routine, such as scheduling walks and daily social events, the system should be capable of planning and scheduling such needs, as well as interpreting them when they occur.
The RoboCare project also examines the issues surrounding user-acceptance of high-tech helper systems, looking for example at the psychological impact of robotic care helpers on elderly people. Since the level of social interaction which can be obtained between robotic agents and human beings is related to familiarity, we are also investigating the use of Sony's AIBO canine robots for monitoring tasks.
Overall, the issues which need to be addressed in the development of complex systems for the care of the elderly include communication, knowledge representation, human-machine interaction, learning, collective and individual symbolic reasoning — to name but a few. What follows is a brief overview of the work carried out by our Research Units in the context of RoboCare. The interested reader is strongly encouraged to read [1], an extended version of this article.

2 The Active Supervision Framework

In the context of the RoboCare project, we are concerned with the development of a control infrastructure, also referred to as *Active Supervision Framework* (ASF), which manages and supervises human agents, robotic systems, sensors and domotic components in an environment which supports a high level of human-machine interaction. All the actors of the system cooperate in order to provide services for human assistance.
Two possible environments have been identified as target applications for the ASF. On one hand, a domestic environment, in which the goal of the system is to assist elderly people in their daily life, predicting potential hazardous situations and delivering both cognitive and physical support to the assisted. On the other hand, we have focused also on a health-care institution scenario. The role of the ASF in this context would be predominantly that of enacting a predefined workflow of activities, i.e. compiling an efficient schedule of tasks to be carried out.
Even if the two environments pose different challenges and have different requirements, it should be clear that in many aspects the types of functionalities which the system must implement are overlapping. Basically, the role of the ASF can be rephrased more simply as that of "deciding and monitoring courses of actions for the whole environment".
The scope of this section is to introduce the reader to some issues and initial results that we are starting to encounter in the development of the ASF.

2.1 The Supervisor Agent

The ASF is conceived as a supervisory agent which is responsible for exporting deductive functionalities, or *cognitive services*, for the underlying multi-agent system. It is a centralized module, which is endowed with a *global view* of the system and its state (see Figure 1).

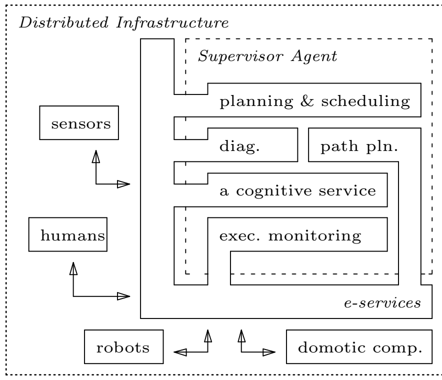

Figure 1: The Active Supervision Framework, a service providing infrastructure for the RoboCare project.

The (necessarily) distributed nature of the application is achieved through the use of a distributed infrastructure. Having such a transparently distributable system makes it possible to separate logically-grouped functionalities on different platforms, thus enabling us to allocate computational resources more efficiently.
The overall function of the ASF is twofold. On one hand, the centralized framework is responsible for implementing active cooperation among multiple agents. This is one of the hottest topics in multi-agent systems today, namely because we must identify where to draw the line between centralized decision making and distributed team deliberation. On the other hand, the ASF is conceived as a supervising entity, through which human operators can control the system at a high level, modifying the operational characteristics of the system and contributing to the execution of tasks in a mixed-initiative setting.
The functionalities of the ASF are made available to the actors of the system in the form of *e-services*. These services are invokable by all components of the system, although clearly most services are designed for either the robotic platforms or the human operators.
As a consequence of the above considerations, the functionalities the ASF offers range from path planning and integrated planning and scheduling, to diagnosis. In general, any functionality which satisfies one or more of the following requirements will be implemented as an e-service module of the ASF: (1) computational issues inhibit its execution on local components (e.g. onboard memory and/or computational constraints of the robotic components); (2) global observability is required (e.g. knowledge concerning the dislocation of people or objects in the environment); (3) functionalities

which are required by a variety of heterogeneous actors (e.g. consulting an agenda or remote-control tools).

2.2 Integrated Planning and Scheduling Service

At the current stage of development, the ASF is equipped with a preliminary implementation of an integrated planning and scheduling reasoner built according to the so-called *Naïve Component-Based Approach* (N-CBA), the details of which are presented in [12, 5]. This service is capable of efficiently obtaining instances of activity worflows based on a PDDL model of the healthcare institution environment. Thanks to the de-coupling of the causal and time/resource-related reasoning, we are able to solve large problems with tens of executing entities and complex goal specifications. This implementation of the N-CBA makes use of established off-the-shelf components for the planning and scheduling modules, the latter being O-OSCAR, a CSP-based scheduler [3] which employs the ISES algorithm [4].
The ASF has also been equipped with advanced execution monitoring capabilities, in order to assure the completion of the plan while constantly checking its consistency. In a real working environment which involves the presence of human beings, there are several events that may interfere with the correct execution of the plan, and each one of these events must be promptly counteracted [6].
In a nutshell, the integrated reasoner is capable of deriving high-level plans from a model which contemplates the causal and time/resource-related characteristics of the environment. Also, it is able to react to small contingencies by performing re-scheduling or adjusting the schedule which is being executed.

3 Robotic Components

A fundamental principle of the project is that the safety of the end users of the system must be of primary importance. Thus, we have decided to eliminate all the tasks that involve corporal care (i.e. cutting hair and nails, helping in body-wash and so on). According to this premise we focus on six achievable goals: (1) *reminder* ("it is time for your pill"), (2) *entertainment* ("let's have a chess match" or "read me the news"), (3) *transport* ("get me a coffee from the coffee-machine"), (4) *examination* ("check the stove"), (5) *search* ("look for Mr. Smith"), and (6) *escort* ("go for a walk with Mrs. Brown"). The previous tasks are ordered by difficulty: the first item in the list is also the simplest (an electronic talking diary); the Transport task is relatively more difficult to achieve (all the common problems of mobile robotics are present), while the last item is also the most complex (in the Escort task the robot is like a partner in a walk that entertains the human while it supervises that everything is all right, and is programmed to call for help in case of dangerous situations).

3.1 Robotic platforms

The hardware involved in the project is made up of mobile robots and several fixed devices. The robot team is composed of heterogeneous members which differ in cost and appearance.
We employ robotic platforms based on the Pioneer series, equipped with various types of sensors which are plugged in to a powerful on-board notebook. The mobile bases have a payload of about 20 kilos and rather high power autonomy.
A different kind of robot is the Sony-AIBO, whose locomotion is based on four legs instead of wheels. It will be involved mostly in the entertainment task as a entertainment dog.
We are investigating the possibility of designing a self-made platform.

3.2 Basic Robot Capabilities

All the applications of mobile robotics have to deal with some common problems in order to make the robot able to move from one place to another and to recognize the components of the world:
Localization. Localization is the task of evaluating the robot's position in the environment, given a sensor history and the knowledge of a map. A wide range of localization methods have been studied, mostly based on an explicit representation of the robot position belief in which the position estimate is iteratively refined as the robot moves and detects environmental landmarks. In the ROBOCARE environment several efficient and reliable solutions can be studied and implemented, like the ones proposed in [8]. Moreover, the ability to give structure to the environment allows for devising some external systems for automatically measuring the precision of a localizing robot, granting the possibility of performing accurate experiments and evaluations of the developed localization algorithms.
Safe Navigation. When robots have to move around in a real-world environment, they are required to navigate without colliding with things and human beings. We use tested techniques of computer vision (color segmentation, edge detection and heuristic algorithms) to identify obstacles in the environment and therefore to compute a free path that leads the robot to the desired position avoiding collisions. Several approaches in the literature address the problem of safe navigation and particularly interesting for our application is safe navigation in dynamic unpredictable environments [7].
Human Body Detection and Tracking. Human body detection is one of the most sophisticated and challenging aspects of object detection. There are two types of issues in human body detection which have to be considered: on one hand, distinguishing the human body from other objects in an image frame or video stream, and on the other hand, presence detection and motion tracking. One way to do this is to divide the job in to

three phases (Clustering, Classification, Modeling) As for human presence detection and localization, one of the known methods consists of using the dynamic contours and assigning them to each moving object in the scenario [2]. In order to ensure the safety of the people we fuse the information coming from some additional sensors (thermal, active position transmitter) with the images from the cameras.

Coordination. Coordination among robots is achieved by a coordination module that selects which sub-task must be accomplished by every robot. In our cognitive systems, each task is related to a goal to be achieved by a robot and thus to a plan to be executed. Tasks are assigned during robot operation by means of a distributed protocol that allows information about the current state of each robot in the team to be shared, and provides the necessary autonomy in case of network failures [10].

Reasoning. As for the robots' planning and reasoning framework, it relies on an epistemic representation of the world, which explicitly takes into account the robot's knowledge, rather than the true status of the world. The domain description includes the specification of the basic actions the robot can perform, which are defined in term of preconditions (conditions that must be verified for an action to be executed) and effects (conditions that are verified after the execution of the action) [11].

4 Current Stage of Development

The effort at integrating symbolic-level cognitive services and multi-robot systems we are pursuing is being tested in an experimental domestic environment which reproduces a small flat composed of two rooms, a bedroom and a dining room with a kitchen. The environment attempts to simulate situations in which the agents contribute to the assistance of an elderly person in his or her own home. Also, we will use the corridors of the institute to test the ability of the robots to work in large spaces (in accordance with the nursing home scenario). A fundamental characteristic of our application is that the robots are not the only components of the system: there are also a number of fixed devices that are useful to obtain precise information about the environment (fixed stereo-cameras for people and robot localization and tracking and other such components).

Overall, our work is strongly based on our experience in the fields of planning and scheduling on one hand, and of multi-robot systems on the other. Nonetheless, we are strongly projected towards the unexplored area of integrating these two disciplines. The aim of RoboCare is to design and implement an intelligent infrastructure which makes use of autonomous robots and an array of state-of-the-art domotic components to be deployed in a real environment for the care of the elderly. The success of our ambitious project depends strongly on the synthesis of many disciplines. Hopefully, by the end of RoboCare we will have matured enough scientific and technological know-how to create a single, coherent outcome that can benefit some of the most vulnerable in our society.

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