Ayman Abdel-Rahman

A Distributed Multiagent Architecture

for Remote Multirobot Interaction

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Chapter 1

Introduction

1.1 Motivation

Most of the new trends in robotics involve more interactions with the human user, whether for the purpose of entertainment or transmission of information for the benefit of performing given tasks (or services). Robots existing today have become intelligent to the ability to complete some tasks autonomously without human intervention. However, it is impossible for robots to carry out all the tasks autonomously, but the human must always play a role in the operation and guidance of the robots according to the requirements of the task. This new reality entails the opening of a new field of work to deal with issues concerned with human robot interaction. The human interaction and the robots autonomy are key functions that can spread the use of the robot in human daily life.

Remote interaction can be considered as a special type of human-robot interaction, where the human and the robotic system are separated by physical barriers but linked via telematic technologies. In recent years, human-robot remote interaction applications have grown in such a way that they currently allow users with different levels of familiarity with robotics to perform different tasks efficiently. These tasks may be visiting museums, giving medical care for elderly people, creating artwork, navigating undersea, performing an experiment, testing new algorithms, controlling a household appliance, etc. [1]. For the efficiency of any human-robot remote interaction applications, an efficient framework must lie underneath. In the past years, several architectures have been proposed with different levels of scalability ranging from single operator single robot to multioperator multirobot interaction support.

Cooperative behaviours in robotic systems have been an active field of research in recent years. It has been recognized that there are many advantages of using a multirobot system, where tasks can be performed more efficiently and robustly [2], [3]. Multiple collaborating robots can accomplish a task much faster than a single robot designed to accomplish the same task. Fault tolerance is a key advantage in multirobot systems. Just as human physical teamwork can perform labor impossible to do by one human, there are many tasks which are impossible to be done by a single robot, which are based on cooperation and collaboration. Multirobot systems take advantage of multiple resources, distributed amongst different bodies. Such a system lets separate robots play separate roles in order to accomplish a task together. Considering all these points, the main interest at present time in the field of robotics is concerned with multirobot systems.

According to *Internet World Stats*, the population of Internet users in 2005 is approximately 0.9 billion [4]. The Internet is accessible by approximately one sixth of the world today, and is yet increasing. It provides a cheap, readily accessible communication medium for any application. Especially with remote interaction systems, average users can easily control and monitor robots from any location. This global accessibility allows other users as well to access the system without having to be present at the locale of the system. Furthermore, robots may share resources with other hardware and software components residing at distant locations. This includes the skills of distant researchers as well.

Using the Internet as a communication medium at first glance seems superior over private networks. However, the constraints and limitations of the Internet make it unfeasible to have an efficient remote interaction system using the Internet as a medium. The problems of the Internet include restricted bandwidth, random time delay and data loss, which influence system performance. Internet performance as a communication medium has nondeterministic characteristics, which depend mainly on the network load. A method is needed to transpose these constraints.

Many research facilities and laboratories concerned with multirobot interaction systems hold many local cooperative behaviours that have been developed throughout many years. It is now the time to incorporate an Internet-based framework, in order to have these cooperative behaviours available openly to the public. Minimum amount of changes should be made to the behaviours in order to comply to a new architecture.

Very few research has been made on Internet-based multirobot architectures. So far in the proposed architectures, the behaviour of robots is not complex and the architectures are restricted only to a certain number of predefined behaviours. The scalability was not the focus, because the proposed architectures are targetted to custom applications.

A new architecture is needed that can apply to any application, while focusing on efficiently facilitating the activities of a cooperative population of robots. The architecture should be generic and scalable in a way to accept a large number of robots and access a large number of cooperative behaviours. Challenges include: resolving problems in operation methods and network communication techniques. The abilitiy to coordinate and manage different robots, while incorporating intelligent techniques is not an easy thing (while taking network traffic into consideration). A sophisticated interface system is also required in order to allow the user to perform complex actions through an Internet browser.

For this purpose, this thesis describes a generic scalable distributed architecture, which can be used as a platform for developing various remote interaction scenarios with multirobot systems. This framework solitarily accepts an unlimited number of robots and behaviors, while transposes the constraints and limitations of the Internet. The focus of this work is the scalability in managing and controlling complex multirobot behaviours residing in the local system through the user interface.

1.2 Objectives

The objective of this thesis is to propose an architecture suited for any robotic application that incorporates the Internet as a communication medium. The architecture must be generic in a manner to allow any application system to comply with its framework. This includes encompassing multiple operation modes within the system, considering any robot model, and handling input and output in multiple formats. The architecture must be capable of facilitating control from the system front-end to the remote multirobot system in order to manage and control complex operations. It must be structured in a way in order to aid maintenance or extensibility in future. Therefore, an architecture based on layers and multiagents is necessary.

Furthermore, the architecture must consider the nondeterministic characteristics of the Internet and use methods to alleviate these constraints with the flow of the system. The end user must be able to use the system to control one or a group of robots located far from the user. The user should be able to rely on the interface in order to understand the situation at the remote site. Among many proposed methods, one of the most efficient ways to alleviate Internet limitations is to use high level commands that command the robots at the remote side to cooperate and behave autonomously in order to accomplish a task. This way a task can be completed quicker than directly controlling each robot, considering the Internet's time delay in sending each command then feeding acquisition data back to the user in order to make the next move. While a high level task is in progress, the user is periodically sent information about the progress of the robots in accomplishing the task. Therefore, a main objective of this work is to have an efficient system of integrating cooperative multirobot behaviours that are residing on a server machine.

A feature highly demanded in multirobot architectures is the scalability to incorporate a dynamically changing number of robots, with the least amount of effort and changes. Likewise, the scalability to incorporate an unlimited number of behaviours is desired. All these requirements are addressed in the proposed architecture.

1.3 Thesis Structure

This thesis is structured as follows. Chapter 2 addresses the fundamental concepts of human-robot interaction and remote interaction systems. This includes a definition of the essential components present in any remote interaction system, as well as the four different types of interaction that can occur between humans and robots. In order to demonstrate real life examples and signify the practical benefits behind robotic remote interaction systems, various applications using such systems are surveyed in this chapter. Chapter 3 discusses the concept of intelligent remote interaction agents and multiagent systems. Emphasis is made on the limitations of previously proposed multiagent multirobot systems in contrary with the proposed one. That is followed by a detailed description of the proposed architecture in chapter 4. Each layer of the architecture as well as each agent is explained thoroughly. In order to demonstrate how this architecture can be applied to any robotic application, the implementation of two application scenarios is described in detail in chapter 5. This includes an analysis of the results achieved in both scenarios. Finally, the conclusion and future work are summarized in chapter 6.

Chapter 2

Human-Robot Remote Interaction

2.1 Human Robot Interaction

The human interaction and the robot's autonomy are key functions that can spread the use of the robot in human daily life. Nowadays most of the available robots can interact only with their creators or with a small group of specially trained individuals. The long term goal of the most of robotic research is to develop a social robot that can interact with humans and participate in human society. Such a type of robot must have effective, adaptive and natural interfaces with high level of autonomy by which the robot will be able to survive in different situations.

In any robotic system, human robot interaction plays an important role since the goal of fully autonomous capability has not been accomplished yet. Even if this goal of true robot autonomy is accomplished, the human role and the level of interaction will vary but the human will remain being part of the system.

Human-robot interaction (HRI) can be defined as the study of humans, robots, and the ways they influence each other [5]. One of the challenges for HRI is to provide humans and robots with models of each other. In particular, Sheridan [6] claims that the ideal would be analogous to two people who know each other well and who can pick up subtle cues from one another (e.g. a musician playing a duet).

Any human-robot interaction system is one of four fundamental schemes: a single operator single robot (SOSR) system, a single operator multirobot (SOMR) system, a multioperator single robot (MOSR) system, or a multioperator multirobot (MOMR) system. Each is explained in the following subsections.

2.1.1 Single Operator Single Robot Systems

When only one user may control a single robot at any time through an interaction system, the system is called a single user single robot system, as shown in Figure 2.1. This is when the robot guarantees that all commands received are from a single operator, and when the operator can send commands to individual robots, but not send high level commands to a group of robots. If more than one robot exists in the system, then they are mutually exclusively related in terms of user's command operations and they cannot cooperate autonomously. A case where they are made to cooperate is when the user sends distinct commands to each robot, and then sends another set of distinct commands based on the feedback in order to facilitate this cooperation manually.

2.1.2 Single Operator Multirobot Systems

In most cases, sending distinct commands to each robot in order to facilitate a multirobot cooperation and accomplish a high-level task can be a tedious effort for the user. In this case, or when an individual robot cannot do a complex task alone, a multirobot system is used. In this system, the user can send a high level command to a group of robots, and the robots will autonomously facilitate and cooperate in order to accomplish this task, as shown in Figure 2.2.

2.1.3 Multioperator Single Robot Systems

Allowing immediate accessibility to a robot disregarding whether it is currently being used or not can be very beneficial in certain applications. For university students to access a simulation robot in a lab, it becomes very tedious for a student to wait for other students using the system before the student can use it. A multioperator system deals with matters of how numerous users may use a system at the same instance while being fair in distributing access and maintaining synchronization between them. The first type of multioperator