Chapter 1: Introduction

Until recently, robots have been seen as a novelty. Today, the variety of robotic applications is growing at a tremendous rate and the trend will carry on in future as the progress in technology opens new possibilities in applications. A single-robot system is not an optimal solution for all applications. The growing range of existing and envisaged tasks that benefit from applications of multi-robot teams are, for example, search and rescue tasks, mapping of hazardous/hostile environments and space exploration/colonisation. However, the issue of coordination of multi-robot teams is not adequately resolved. To compound the problem, many robot architectures do not easily facilitate the implementation of coordination mechanisms. This thesis is aimed at contributing towards more efficient multi-robot teams, through development of a multi-robot architecture that facilitates coordination, as well as by proposing a new coordination mechanism.

1.1 Motivation

In the ‘80s and early ‘90s, robotic research focused on finding optimal robot architectures, often resulting in non-cognitive, insect-like entities. In recent years, processing power has improved and that, together with improvements in technology, has allowed for more complex robot architectures. Focus has thus shifted from single-robot to multi-robot teams. The key to the full utilisation of multi-robot teams lies in coordination. Unfortunately, many agent architectures are not designed with coordination in mind.

Although there are coordination mechanisms applicable to multi-robot teams, not one of them views a multi-robot team as a society. If a multi-robot team can be seen as a society, then some of the traditional society-based concepts (such as social networks) can be utilised for coordination.

Social networks are particularly attractive for application in multi-robot teams due to their emergent and self-organising nature. The new, social networks based approach to coordination is envisaged for application to multi-robot teams; it is not robot-specific, and can be applied to any Multi-Agent System (MAS) without major modification.

1.2 The Objectives

There are two primary objectives of this thesis, both aimed at facilitation of coordination in multi-robot (and more general, MAS) systems:

- The development of a new agent architecture framework that facilitates implementation of coordination mechanisms. The emphasis is on robotic application and the architecture must utilise the best features of various robot architectures.

- The development of a new coordination mechanism that is applicable to multi-robot teams and MASs that operate in environments with a high degree of uncertainty.

Besides these two primary objectives, additional objectives of this thesis can be summarised as:

- The development of a simulated robotic environment, where experiments with various coordination mechanisms can be conducted.

- The full implementation of the proposed agent architecture framework in a physical environment, using a cheap, commercially available robotic platform.

1.3 The Main Contributions

The research effort that resulted in this thesis has achieved all objectives as stated in the previous section. The summary of the main contributions of this thesis can be stated as:

- A new flexible architecture framework for embedded agents was developed. The new framework, INDABA, can be seen as an extension of the currently predominant three-layer hybrid robot architectures with an additional layer that facilitates coordination. INDABA was successfully implemented in simulated and in real-world physical environments.

- A new coordination mechanism, through task allocation, was developed based on social networks. The agents in a MAS are treated as members of a society and social networks were used to determine agents' affinity to a particular type of task.

- A novel new way of implementing a complex agent architecture, such as INDABA, using a readily available, reasonably cheap, robotic platform. The novelty is that the architecture was easily split (due to its layered approach) into a component that resides in a PC and a component that resides in a physical robot. By doing this, the new architecture combined the processing power of a PC with a physical, real-world embedded robot.

1.4 Thesis Outline

This thesis is organised as follows. Chapter 2 provides a general background to agents, MASs and the origins of the agent paradigm. In addition, related issues such as interaction, coordination and cooperation between the agents in a MAS are also overviewed in chapter 2.

Chapter 3 focuses on robotics and three main agent architecture models, namely symbolic reasoning, reactive and hybrid agent architectures are overviewed. Each agent architecture model is firstly considered in a generalised manner, followed by a more detailed discussion of a particular, representative, agent architecture. The representative agent architectures are implemented in real-world robots.

The overview of agent architectures, given in chapter 3, is extended to multi-robot systems in chapter 4. The overview of multi-robot systems follows the format used in chapter 3. Two multi-robot architecture models are considered in generalised terms, followed by a more detailed discussion of a particular implementation in a multi-robot team.

Chapter 5 introduces a new architecture, INDABA, that is designed for applications in multi-robot systems. Although designed with robotic applications in mind, INDABA is still general enough to be easily applied to any MAS. INDABA extends the currently predominant three-layer robot architectures by adding an additional layer that facilitates coordination.

Chapter 6 shifts focus from agent architectures towards coordination mechanisms that are used in MASs and multi-robot teams. The chapter starts with a brief overview of existing coordination mechanisms, followed by an introduction to the concept of social networks. Social networks are then applied as a coordination mechanism in a new coordination approach, which forms the main contribution of this thesis. The new social networks based approach is then applied to multi-robot teams.

The applicability of the new social networks approach is investigated in an abstract simulated environment in chapter 7. The agents in the abstract simulated environment were built around the INDABA framework. The results have confirmed the soundness of the social networks approach to coordination of abstract multi-robot teams.

The next step in confirming the social networks approach was to implement a more realistic multi-robot simulator environment. The results of experiments, together with the description of implementation of such multi-robot simulator environment are presented in chapter 8. Again, all simulated robots are built around the INDABA framework.

The final proof of soundness of any robotic architecture (or any of its components) is in its application in a real physical environment. This is achieved using the INDABA framework. The results of implementation of INDABA to a real robotic platform are presented in chapter 9. Furthermore, a social networks approach was applied to a scout selection process, and the results are described in the same chapter. Based on the results from application of the social networks approach to simulated environments (chapters 7 and 8), the assumption was made that the social networks approach will perform well in a real, physical environment. The social networks approach is applied to a scout selection process in chapter 9. The results show that the social networks approach performs well in a real, physical environment.

Chapter 10 summarises this thesis and presents some directions for future research.