PhD Transfer Report

Emergent Self-regulation in Social Robotic Systems

Stage 1.3 report with a review of literature, current works and future research plans

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Chapter 1

Introduction

1.1 Rationale of Proposed Research

Robotic researchers generally agree that multiple robots can perform complex and distributed tasks more conveniently. Multi-robot systems (MRS) can provide improved performance, fault-tolerance and robustness through parallelism and redundancy (Arkin 1998, Parker & Tang 2006, Mataric 2007). However, in order to get potential benefits of MRS in any application domain, we need to solve a common research challenge i.e., *multi-robot task allocation* (MRTA) (Gerkey & Mataric 2004). MRTA can also be called as *division of labour* (DoL) analogous to DoL in insect and human societies. It is generally identified as the question of assigning tasks in an appropriate time to the appropriate robots considering the changes of the environment and/or the performance of other team members. This is a NP-hard optimal assignment problem where optimum solutions can not be found quickly for large complex problems (Gerkey & Mataric 2003, Parker 2008). The complexities of MRTA arise from the fact that there is no central planner or coordinator for task assignments and the robots are limited to sense, to communicate and to interact locally. None of them has the complete knowledge of the past, present or future actions of other robots. Moreover, they don't have the complete view of the world state. The computational and communication bandwidth requirements also restrict the solution quality of the problem (Lerman et al. 2006).

Existing researchers have approached the MRTA or DoL issue in many different ways. Traditionally task allocation in a multi-agent systems is divided into two major categories: 1) Predefined (off-line) and 2) Emergent (real-time) task-allocation (Shen et al. 2001). However predefined DoL approach fails to scale well as the number of tasks and robots becomes large, e,g,, more than 10 (Lerman et al. 2006). On the other hand emergent DoL approach relies on the emergent group behaviours e.g., (Kube & Zhang 1993), such as emergent cooperation (Lerman et al. 2006), adaptation rules (Liu et al. 2007) etc. They are more robust and scalable to large team size. However most of researchers have complained that emergent DoL approach is difficult to design, to analyse formally and to implement in real robots. The solutions from these systems are also sub-optimal. It is also difficult to predict exact behaviours of robots and overall system performance.

Within the context of the Engineering and Physical Sciences Research Council (EPSRC) project, “Defying the Rules: How Self-regulatory Systems Work”, we have proposed to solve the above mentioned MRTA problem in a new way (Arcaute et al. 2008). Our approach is inspired from the studies of emergence of DoL in both biological insect societies and human social systems. Biological studies show that a large number of animal as well as human social systems grow, evolve and generally continue functioning well by the virtue of their individual self-regulatory DoL systems. The amazing abilities of biological organisms to change, to respond to unpredictable environments, and to adapt over time lead them to sustain life through biological functions such as self-recognition, self-recovery, self-growth etc. It is interesting to note that in animal societies DoL has been accomplished years after years without a central authority or an explicit planning and coordinating element. Indirect communication such as stigmergy is rather used to exchange information among individuals (Camazine et al. 2001). The decentralized self-growth of Internet and its bottom-up interactions of millions of users around the globe present us similar evidences of DoL in human social systems (Andriani & Passiante 2004). These interactions of individuals happen in the absence of or in parallel with strict hierarchy. Moreover from the study of sociology e.g., (Sayer & Walker 1992), cybernetics e.g., (Beer 1981), strategic management e.g., (Kogut 2000) and related other disciplines we have found that decentralized self-regulated systems exist in nature and in man-made systems which can grow and achieve viability over time.

From the above mentioned multi-disciplinary studies of various complex systems, we believe that a set of generic rules can be derived for the emergence of DoL in MRS. Primarily these rules should deal with the issue of deriving local control laws for facilitating the emergence of global team behaviour.

We have intended to apply our research outcome in the area of automated manufacturing (AM). AM faces all the existing challenges of traditional centralized and sequential manufacturing processes such as, insufficiently flexible to respond production styles and high-mix low volume production environments (Shen et al. 2006). We believe that, by using our emergent DoL approach, AM industries can overcome many of these challenging issues, such as flexibility to change the manufacturing plant layouts on-the-fly, adaptability for high variation in product styles, quantities, and active manufacturing resources e.g., robots, AGVs etc.

1.2 Aims and Objectives

The aim of this study is to identify generic rules that promote emergent self-regulation leading to the emergence of division of labour in MRS. This manifests the following objectives of this study:

- To model self-regulatory dynamic task allocation behaviours of robots considering both biological and human social metaphors.
- To set-up an experimental framework of MRS and to find out the evidences of the emergence of division of labour through simulation and experiments.

1.3 Outline of this report

This report has been organized as follows.
Chapter 1 rationalizes the proposed study.
Chapter 2 and 3 reviews the general and robotic related literature in details.
Chapter 4 describes the completed research work of this year. It also critically reviewed the completed literature reviews.
Chapter 5 includes anticipated contribution to knowledge along with future research and publication plans.
Appendix reports my completed research skill trainings in this year.

Chapter 2

Literature Review : General Issues

In this chapter, at first we have reviewed the definition of necessary terms used across multiple disciplines.

2.1 Self-regulation

Self-regulation (SR) primarily refers to the exercise of control over oneself to bring the self into line with preferred standards (Baumeister & Vohs 2007). One of the most notable self-regulatory process is the human body's homoeostatic process where the human body's inner process seeks to return to its regular temperature when it gets overheated or chilled. In psychology, SR denotes the strenuous actions to resist temptation or to overcome anxiety. The concepts of SR is also commonly used in cybernetic theory. Here, SR in inanimate mechanisms shows that they can regulate themselves by making adjustments according to programmed goals or set standards. In physics, chemistry, biology and some other branches of natural sciences, the concept of SR is centered around the study of *self-organizing*(SO) individuals. The ingredients and properties of self-organization found in social insects are: positive feedback or amplification, negative feedback, reliance on amplification of fluctuations, and reliance on multiple interactions (Bonabeau et al. 1999). SR has also been studied in the context of social systems where it originates from the DoL that creates SO process that has self-regulating effects (Kppers et al. 1990). Two types of SR have been reported in many places of literature of sociology: 1) SR from SO and 2) SR from activities of components in a heterarchical organization. Thus SR in biological species provides the similar evidences of bottom-up approach of SR of heterarchical organization through interaction of individuals in the absence of, or in parallel of, strict hierarchy. In the area of organizational cybernetics, Stafford Beer's viable system model describes the bottom-up SR of an organization(Beer 1981).

2.2 Emergence

According to Encyclopedia Britannica, *emergence* is the rise of a system that cannot be predicted or explained from antecedent conditions. Emergence occurs when interactions among objects at one level gives rise to different types of objects at another level (Andriani & Passiante 2004, Kppers et al. 1990). Emergence is the central concept to the theory of complex systems. The typical characteristics of emergence in complex systems are: radical novelty or features not previously observed, coherence of integrated wholes that maintain themselves over some period of time, an observable global or macro level (Corning 2002).

2.3 Division of Labour

Originated from economics and sociology the term division of labour (DoL) is widely used in many branches of knowledge. As mentioned by Adam Smith (1776)- "The great increase of the quantity of work which, in consequence of the division of labour, the same number of people are capable of performing, is owing to three different circumstances; first, to increase the dexterity in every particular workman; secondly, to the saving of the time which is commonly lost in passing from one species of work to another; and lastly, to the invention of a great number of machines which facilitate and abridge labour, and enable one man to do the work of many." (Adam Smith (1776) in (Sendova-Franks & Franks 1999)). In the study of biological insects, a worker usually does not perform all tasks, but rather specializes in a set of tasks, according to its morphology, age, or chance (Bonabeau et al. 1999). In sociology, DoL usually describes three things: 1) description of tasks, services or products, 2) underlying social standards for divisions and 3) methods or processes of separating a whole task into small pieces of easy subtasks (Sayer & Walker 1992).

Chapter 3

Literature Review : Robotics Issues

3.1 Multi-robot Systems (MRS)

Historically the concept of multi-robot system comes almost after the introduction of behaviour-based robotics paradigm (Brooks 1986, Arkin 1990). In 1967, the first Artificially Intelligent (AI) robot, Shakey, was created at the Stanford Research Institute. The traditional sense-plan-act or hierarchical approach was used for designing Shakey's control architecture (Murphy 2000). In late 80s, Rodney A. Brooks revolutionized this entire field of mobile robotics who outlined a layered, behaviour based approach that acted significantly differently than the hierarchical approach (Brooks 1986). At the same time, Valentino Braitenberg described a set of experiments where increasingly complex vehicles are built from simple mechanical and electrical components (Braitenberg 1984). Similarly, Reynolds developed a distributed behavioural model for a bird in a flock that assumed that a flock is simply the result of the interactions among the individual birds (Reynolds 1987). Early research on multi-robot systems also include the concept of cellular robotic system (Beni 1988). From the beginning of the behaviour based paradigm, the biological inspirations influenced many cooperative robotics researchers to examine the social characteristics of insects and animals and to apply them to the design MRS (Arkin 1998). However, Parker categorized most of the recent research approaches into three paradigms: 1) Bio-inspired swarms, 2) Organizational/social and 3) Knowledge-based ontological and semantic paradigms (Parker 2008).

3.2 Task Allocation in MRS

Since 90s multi-robot task allocation (MRTA) is a common research challenge that tries to define the preferred mapping of robots to tasks in order to optimize some objective functions (Gerkey & Mataric 2004). Many MRS control architectures have been solely designed to address this task-allocation issue. In 2003 Gerkey et al. formally analysed the complexity and optimality of key architectures (e.g., ALLIANCE, BLE, M+, MURDOCH, First piece auctions and Dynamic role assignment) for this MRTA issue and it has been found that MRTA is an instance of the so-called optimal assignment problem (Gerkey & Mataric 2003) and generally known as NP-hard where optimal solutions can not be found quickly for large problems (Gerkey & Mataric 2004). If we look the MRTA problem from multi-agent system's perspective we can find it is broadly divided into two major categories (Shen et al. 2001):

1. Predefined (off-line) task-allocation and
2. Emergent (real-time) task-allocation.

Usually predefined task allocation method uses either centralized coordination or distributed task-allocation approach. Distributed predefined task-allocation approach is again subdivided into three subcategories:

1. Direct allocation,
2. Task allocation by delegation
3. Task allocation through bidding

In MRS domain, early research on predefined distributed task-allocation approach has been dominated mainly by intentional coordination (Gerkey & Mataric 2004, Parker 1998), the use of dynamic role assignment e.g., (Chaimowicz et al. 2002), and market-based bidding approach (Dias et al. 2006). In intentional coordination e.g., (Parker 1998), robots uses direct allocation method to communicate and to negotiate for assigning tasks. This is preferred approach among MRS research community since it is easily understood, easier to design, implement and analysis formally. Task allocation through bidding is mainly based on the Contract Net Protocol (Davis & Smith 1988). Predefined Task allocation through other approaches are also present in literature. For example, inspired by the vacancy chain phenomena in nature, (Dahl et al. 2003) proposed a vacancy chain scheduling (VCS) algorithm for a restricted class of MRTA problems in spatially classifiable domains.

On the other hand emergent task-allocation approach relies on the emergent group behaviours e.g., (Kube & Zhang 1993), such as emergent cooperation (Lerman et al. 2006), adaptation rules (Liu et al. 2007) etc., that lead to task allocation with local sensing, local interactions. It typically uses little or no explicit communication or negotiations between robots. They are more scalable to large team size and more robust via parallelism and redundancy.

MRTA problem can be addressed in many different ways depending upon the paradigm selected to abstract the problem and its relevant constraints and requirements (Parker 2008). Firstly, in emergent task allocation in bioinspired swarms paradigm MRTA homogeneous robots are employed to perform mostly similar tasks only by local sensing and indirect stigmergic (or no) communication. Secondly, in organizational and social paradigm MRTA can follow one of the two major approaches: 1) task allocation by making use of roles and 2) task allocation through bidding. For example, in multi-robot soccer, each role encompasses several specific tasks and heterogeneous robots select their roles based on their position and capabilities. In market-based approach, robots can negotiate with other team-mates to collectively solve a set of tasks. Finally, in knowledge-based approach, also known as intentional coordination, MRTA is done through the modelling of team-mate capabilities, such as by observing the performance of other team-members performance with or without explicit communication.

3.3 Application of MRS in automated manufacturing

In order to examine the feasibility of our approach of emergent DoL, we have selected the distributed automated manufacturing application domain. Most of the research in this area is inspired by intelligent multi-agent technology (Shen et al. 2001). A few other researchers also tried to apply the concepts of biological self-organization (Ueda 2006, Lazinica & Katalinic 2007). In this section we have reviewed these concepts and technologies mainly focusing on physical embodiment of agents, i.e., the use of multiple mobile robots or automated guided vehicles (AGV).

3.3.1 Multi-agent based intelligent manufacturing

Since early 80s researchers have been applying agent technology to manufacturing enterprise integration, manufacturing process planning, scheduling and shop floor control, material handing and so on(Shen et al. 2006). An agent as a software system that communicates and cooperates with other software systems to solve a complex problem that is beyond the capability of each individual software system (Shen et al. 2001). Most notable capabilities of agents are autonomous, adaptive, cooperative and proactive. There exists many different extensions of agent-based technologies such as Holonic Manufacturing System (HMS) (Bussmann et al. 2004). A holon is an autonomous and cooperative unit of manufacturing system for transporting, transforming, sorting and/or validating information and physical objects.

Agent based technologies have addressed many of the problems encountered by the traditional centralized method. It can respond to the dynamic changes and disturbances through local decision making. The autonomy of individual resource agents and loosely coupled network architecture provide better fault-tolerance. The inter agent distributed communication and negotiation also eliminate the problem of having a single point of failure of a centralized system. These facilitate a manufacturing enterprise to reduce their response time to market demands in globally competitive market. Despite having so many advantages, agent-based systems are still not widely implemented in the manufacturing industry comparing to the other similar technologies, such as distributed objects and web-based technologies due to the lack of integration of this systems with other existing systems particularly real-time data collection system, e.g., RFID (radio frequency identification), SCADA (supervisory control and data acquisition) etc (Shen et al. 2006). Another barrier is the increased cost of investment in exchange of some additional flexibility and throughput (Schild & Bussmann 2007).

3.3.2 Biology-inspired manufacturing Systems

The insightful findings from biological studies on insects and organisms have directly inspired many researchers to solve problems of manufacturing industries in a biological way. These can be categorized into two groups: one that allocates task with explicit potential fields (PF) and another that allocate tasks without specifying any PF. Below we have discussed both types of BMS.

Explicit potential filed based BMS

The biological evidences of the existence of PF between a task and an individual worker such as, a flower and a bee, a food source and an ant, inspired some researchers to conceptualize the assigning of artificial PF between two manufacturing resources. For example, PF is assumed between a machine that produce a material part and a worker robot (or AGV) that manipulates the raw materials and finished products. (Ueda 2006) conceptualized this PF as the attractive and repulsive forces based on machine capabilities and product requirements. Task allocation is carried out based on the local matching between machine capabilities and product requirements. Each machine generates an attractive field based on its capabilities and each robot can sense and matches this attractive filed according to the requirements of a product. PF is a function of distance between entities. Here, self-organization of manufacturing resources occurred by the process of matching the machine capabilities and requirements of moving robots. Through computer simulations and a prototype implementation of a line-less car chassis welding (Ueda 2006) found that this system was providing higher productivity and cost-effectiveness of manufacturing process where frequent reconfiguration of factory layout was a major requirement. This approach, was also extended and implemented in a supply chain network and in a simulated ant system model where individual agents were rational agents who selected tasks based on their imposed limitations on sensing.

BMS without explicit potential fields

Several other researchers did not express the above PF for task allocation among manufacturing resources explicitly, rather they stressed on task selection of robots based on the task-capability broadcasts from the machines to the worker robots. In case of (Lazinica & Katalinic 2007), task capabilities are expressed as the required time to finish a task in a specific machine. They used assigned priority levels to accomplish the assembly of different kinds of products in the computer simulation of their bionic manufacturing system. In another earlier computer simulated implementation of swarm robotic material handing of a manufacturing work-cell, (Doty & Van Aken 1993) pointed out several pitfalls of such a BMS system, such as dead-lock in manufacturing in inter-dependant product parts, unpredictability of task completion, energy wastage of robots wandering for tasks etc.

Chapter 4

Completed research works

Within the context of our EPSRC project a multi-disciplinary model of emergent DoL has been proposed based on the evidences from the study of ants (from biological society), humans (from human society) and robots (from artificial society). The realization of this shared model, entitled as *attractive field model* (AFM) (Arcaute et al. 2008), in robotics domain is the main focus of our current research activities. Here, at first I have analysed the reviewed literature critically to distinguish our research from others. Following that some basic assumptions have been made in terms of expected research outcomes. Then, we have presented the completed research works since the beginning of this study in November 2007.

4.1 Critical Review of Literature

For the purpose of implementing AFM in MRS, we have focused to develop a class of social robots, called hereafter as Social Robotic System (SRS). We distinguish SRS from other branches of MRS by the following attributes:
- SRS will share the same biological metaphors of swarm robotics (Sahin & Spears 2005), i.e. homogeneity, bottom-up control, local interactions etc., but additionally it will also include the human-social metaphors of forming viable society with decentralized strategies, such as the emergence of Internet or decentralized communication networks.
- SRS can also override the swarm robotic or even agent-based idea of being an individual robot incapable of completing a task on its own. Since present days robots are far more powerful than before we allow SRS to complete any local problem by an isolated individual within its reach.

- SRS will not include the continuous and direct interactions with humans in its activities as found in network robot system (Akimoto & Hagita 2006) or distributed robotics (Parker & Tang 2006). Rather SRS will remain operating as a society on its own.

Based on our observations and expert findings, we assumes some basic assumptions on emergence of DoL for archiving acceptable research outcomes. **Firstly**, we rely on emergent behaviours of robots (Mataric 2007) that provides structured or patterned observable behaviour that is apparent at the global level (from an external observer's viewpoint), but not at the local level (from robot controller's viewpoint). For example, in a scenario of constructing a brick-wall by MRS, it is not possible to predict which robot would carry which brick, but it may be possible to predict that all robots can finish building the wall over a time period.
Secondly, we rely on the bottom-up design methodology that can provide the above emergent behaviours (Crespi et al. 2008).
Thirdly, we assume that the obtained solutions of an emergent system that usually gives suboptimal solutions (Parker 2008) are acceptable in practice by the virtue of some averaging and approximation techniques, as used in phenomenological models (Lerman et al. 2006).
Finally, we have assumed that the lack of prediction of expected system performance can be compensated by the robustness of the system via redundancy and scalability without any significant communication cost.

Contrasting to the existing approaches of emergent task allocation, we emphasis on generic rules for collective robot behaviours that will cause-
1) the interactions among agents and between the agents and environment (*interaction dynamics*), and additionally
2) the formations of informal or loosely-coupled social networks among robots and/or tasks (*networking dynamics*) based on necessity of self-regulation.

4.2 Experimental infrastructure set-up

The core of our infrastructure consists of mainly three systems:
1. A team of homogeneous miniature robots,
2. A multi-robot id-pose detection and tracking system and
3. A wireless communication system among robots and host server.

In the beginning of my work, I configured and tested eight E-puck robots (from EPFL, Switzerland) for our experiments. These robots are controlled with micro-controller and bluetooth wireless system. So it was necessary to purchase micro-controller development tools and bluetooth hardware. Initially I tested the built-in capabilities of e-puck robots to sense through their Infra-red sensors and cameras e.g., the colour tracking by their built-in tiny camera. The blue-tooth communication system from server to robot was also tested. However, more work was required to carry out for these robots in order to find out suitable control paradigm and its suitable implementation on them. Moreover, the pose detection and tracking system was not shipped with robots.

4.2.1 Multi-robot localization and tracking system

The establishment of a multi-robot tracking infrastructure is the most critical task since its accuracy can influence the whole implementation. Below we have described our development process in the following three phases .

Phase 1: Review and Selection of Tracking Technology

we searched literature and existing state of the art for object tracking and detection technologies around the world. We conducted a series of technical evaluations of different technologies , such as: RFID radar from Trolly Scan Inc., Laser based object tracking from Metris Inc., and Vision-based multi-camera object tracking from Vicon Inc. Due to the lack of accuracy of positional measurements (in RFID radar), bulk size of equipment to carry (i.e. Laser emitter), and high cost of ownership prevented us to seek a commercial solutions. Open solutions were also found insufficent and incompatible. Therefore finally we decided to develop a vision based multi-robot tracking system from the scratch.

Phase 2: Software Design and Hardware Procurement

The idea of tracking small objects based on coloured marker placed suitably on their body surface is not new. But in mobile robotics domain, determining the position of the tracked object with a reference frame as well as finding their orientation in real-time is very challenging. . Hence the following issues were our primary concerns for setting up an effective tracking system.
Experimental environment set up: The requirements for the experiment area are mainly: enough space for moving at least 30-40 miniature robots,

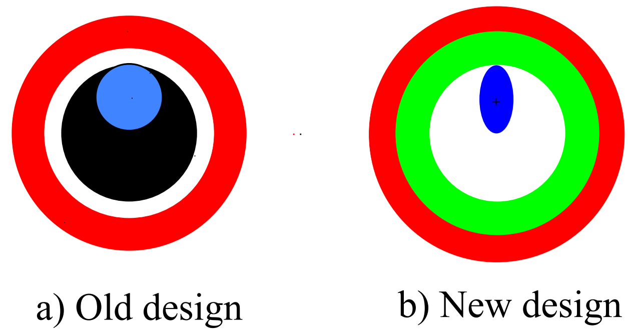

Figure 4.1: Robot Marker Schemes

controlled light and minimized illumination interferences. So, a 6 x 4 metre area with white reflective coating on the floor has been prepared for our robotic experiment with 30-40 E-puck robots (of 70 mm diameter each). To prevent unwanted sun lights from outside suitable blinds are ordered and under procurement.

Robot marker design: The main requirement for robot markers is markers must be clearly distinguishable from one another even if they come very closer. They are also required to provide unique id and pose (both position and orientation). The number of colours painted on the marker should also be limited to detect them clearly in varying lighting conditions. The diameter of marker is limited to 70 mm. In order to satisfy these requirements and constraints, a number of marker schemes were designed and tested (as shown in Fig. 4.1). Initially, based on three colours: red, green, blue and green, several concentric circles were created on marker. If we denote each colour with a number such as (red = 1, green = 2, blue =3) and if we put 3 concentric circles on robot marker, they can give a robot id such as 123, 213 etc. The coordinate (x,y) of the robot is determined by the pixel location in the image. But the problem remains with the angular orientation. To overcome this issue, a novel approach was adopted by putting an eccentric ellipse inside the inner circle of the marker. In this case we know both the centre of concentric circles and the eccentric ellipse from the image. So a virtual line is drawn between these two points. The orientation of the robot is then determined by calculating the angle between this line and the bottom line of the image frame of reference. From this design scheme it is clearly understood that if we increase the number of concentric circles and/or colours we can accommodate more robots. But for getting more accurate detection we

limited the number of our concentric circle to two and number of colours to four which can accommodate more than 40 robots without reusing a single colour in the concentric layers of a specific marker.
Camera selection: The major features of the camera that directly controls the performance of the tracking system are: resolution, frame rate (frame per second), lens, processing time, calibration options etc. A mapping between the camera resolution and the experiment area was tested. Here we found that a camera with 768 x 576 resolution and 25 fps was able to track a area of (2.3m width x 1.2m height) from the 2.65m height from the ground. But in this case the marker circles are not clear enough to robustly identify them. After several trial experiments with Prosilica CCD cameras, GC2450C and GE4900C, we concluded to procure a very high resolution camera that can give at least 1 pixel per mm targeting to cover an area of 4m x 3m.
Vision library selection: In mobile robotics domain several open source and free vision libraries are available, such OpenCV (from Intel), CMU Vision (from Carnegie Melon University) etc. After some initial testing we found OpenCV library is suitable for our purpose.
Host server configuration: In order to run heavy image processing algorithms in real-time a high performance machine was essential. So a 4 x 2.5GHz quad-core Dell PC from Precision T5400 series was chosen and configured with 20GB RAM by 64bit Ubuntu Linux OS.

Phase 3: Implementation and Testing

Based on the above mentioned hardware and software platforms we implemented our multi-robot localization and tracking code on top of OpenCV video surveillance and blob tracking library. A detail description of this modules can be found in (Chen et al. 2005). Although this blob tracking library provides a generic object tracking facility it has neither support for identifying each object based on their coloured marker nor it has any technique to capture the heading (angular orientation) of each object. Therefore we designed a robot id-pose detection algorithm and implemented as C++ classes which then integrated with the existing tracking code. A brief description of this algorithm and C++ class implementations are presented below.
Robot id-pose detection algorithm: In order to ensure robustness of detection at first we converted the captured image from default RGB (Red-

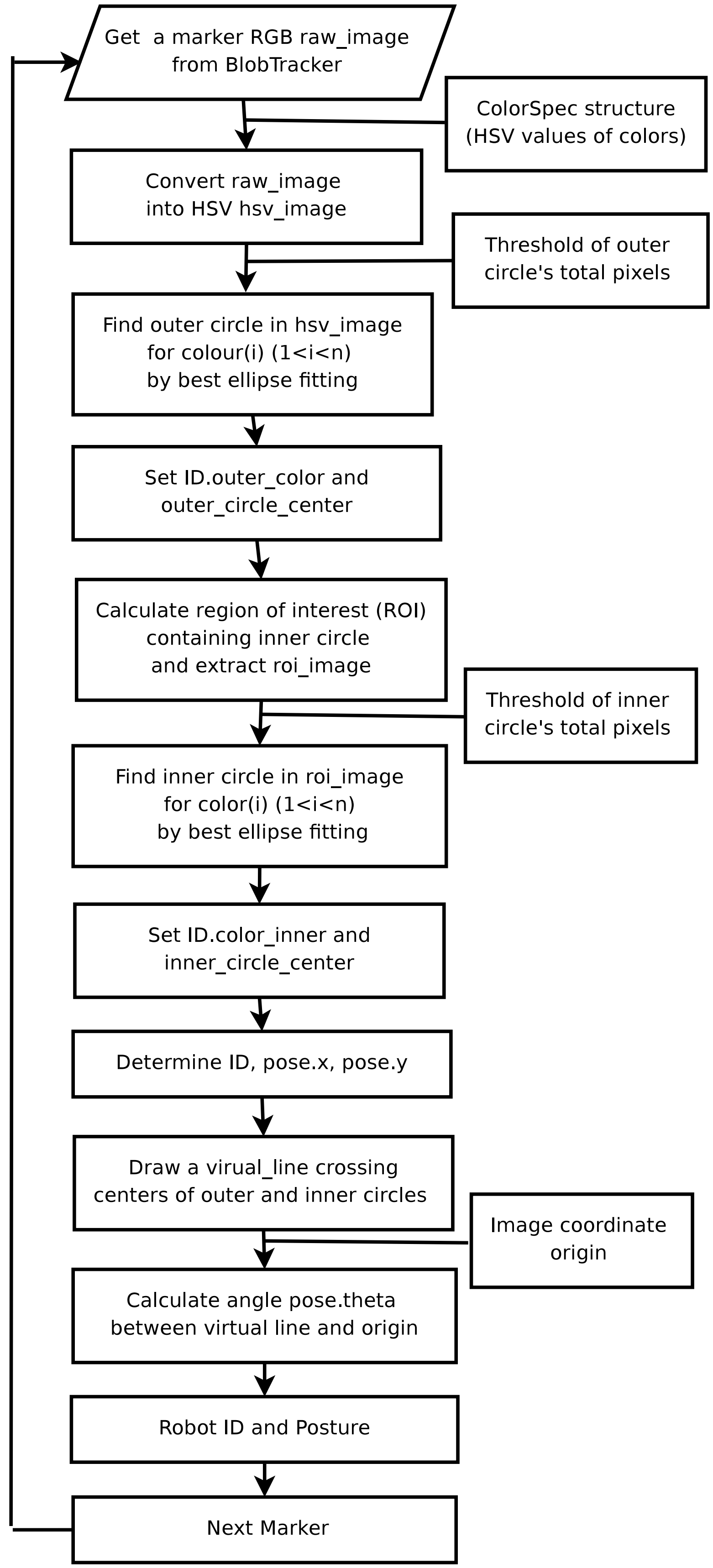

Figure 4.2: Robot ID-Pose Detection Algorithm 1

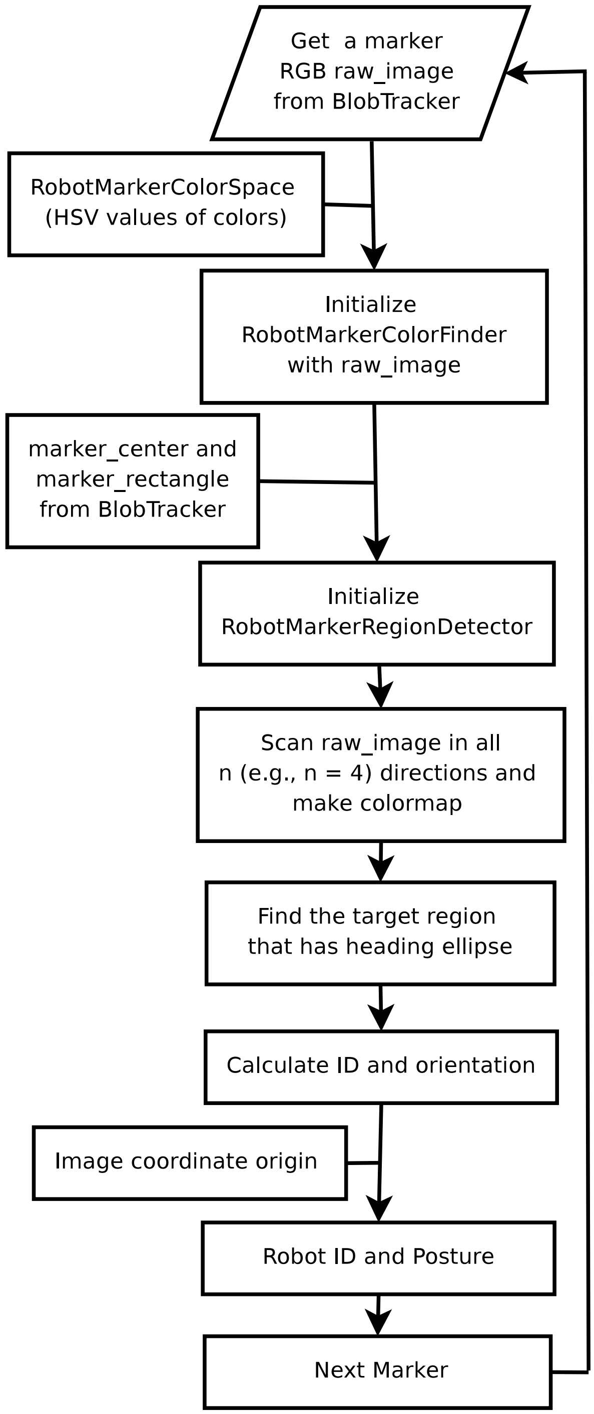

Figure 4.3: Robot ID-Pose Detection Algorithm 2

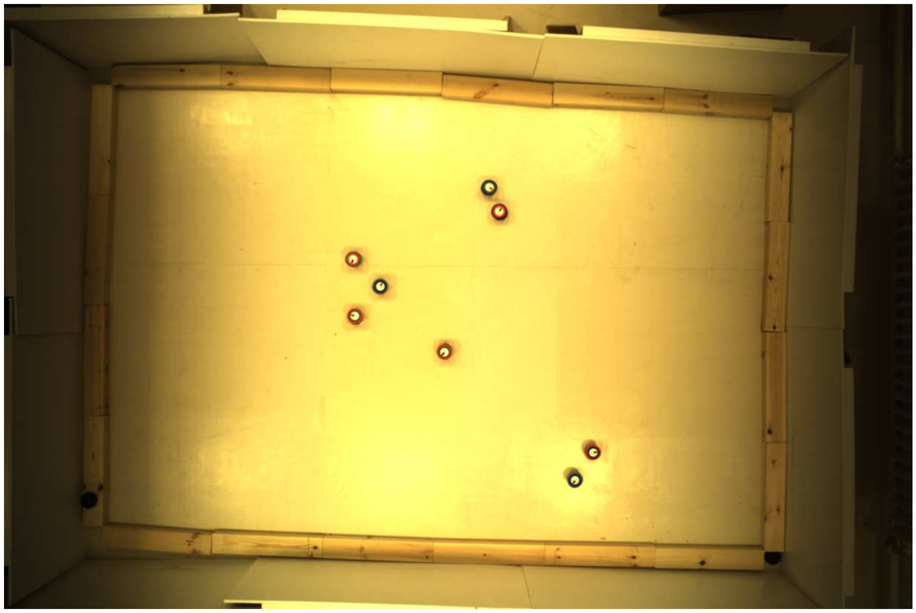

Figure 4.4: Experimental set-up

Green-Blue) colour space into HSV (Hue-Satuartion-Value of Lightness) colour space. Then an initial idea was to identify the outer coloured circle of each marker and then with a gradual reduction of region of interest (ROI) in that marker image we can have all other concentric circles detected. A flow chart of this algorithm is presented in Fig. 4.2. This algorithm works reasonably well when there is only one outer circle and one eccentric circle in the marker (Fig. 4.1a)). However if we increase the number of concentric circles such as in Fig. 4.1b) this method failed to find the inner circle and hence it becomes ineffective in id-pose detection. So we have developed another algorithm that scans the marker from its detected centre through four directions: top, bottom, left and write to make a list of colours it encountered to reach the edge of the marker. This algorithm is described in 4.3. It can robustly detect all colour layers and can provide an orientation accuracy of 90 degrees as it is now scanning only in four perpendicular directions.

Implementation of robot id-pose detection algorithm: Algorithm 1 was implemented as a C program module with OpenCV library. Initially all detectable colours are specified by their maximum and minimum vales of HSV through a ColorSpec structure. Surely, these maximum and minimum values of HSV are subjects to change depending on the lighting conditions and appearance of marker colours. Then the input RGB image is converted into HSV image to find the largest outer circle (by approximating it as an ellipse) of a marker using a threshold of pixel count. This threshold discards the smaller circles and only larger circles remain for further analysis. Algorithm 2 is implemented by three C++ classes: 1) RobotMarkerColourSpace that replaces the ColorSpec structure, 2) RobotMarkerColourFinder performs the HSV colour finding job and, 3) RobotMarkerRegionDetector scans the perpendicular regions and makes the colour maps which gives the id and orientation information. An example experimental setup has been shown in Fig. 4.4.

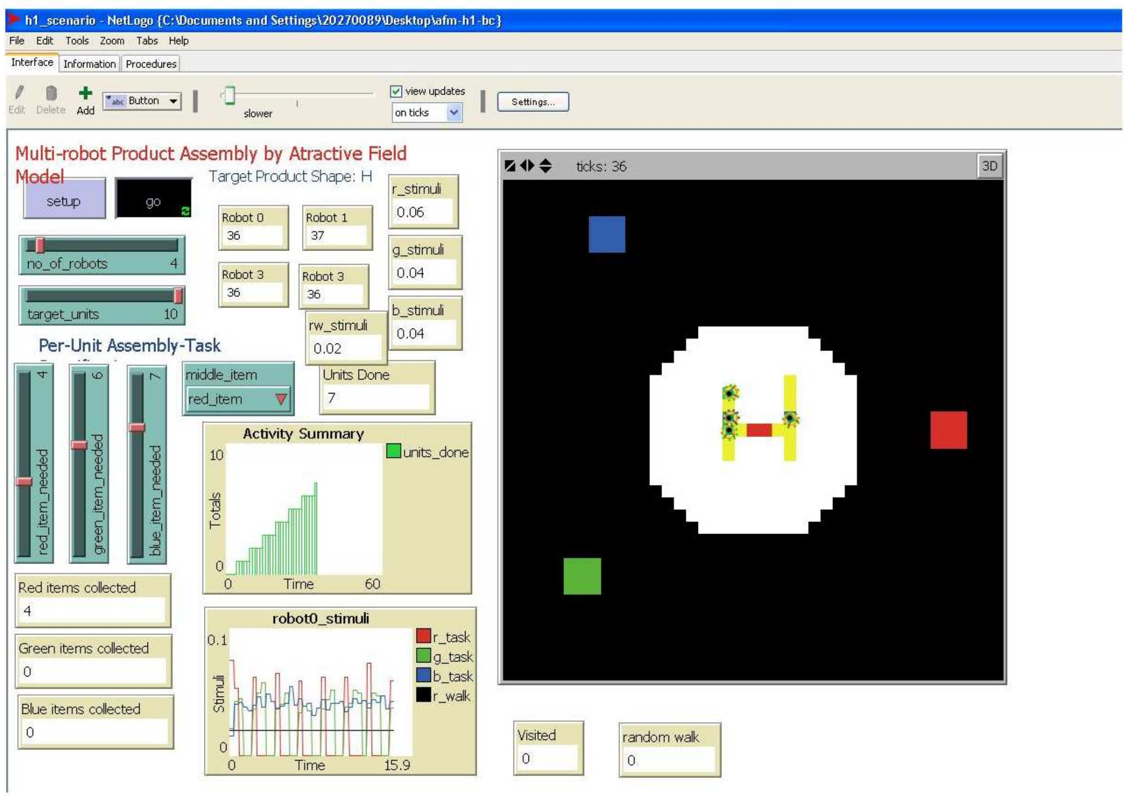

Figure 4.5: AFM simulation in NetLogo

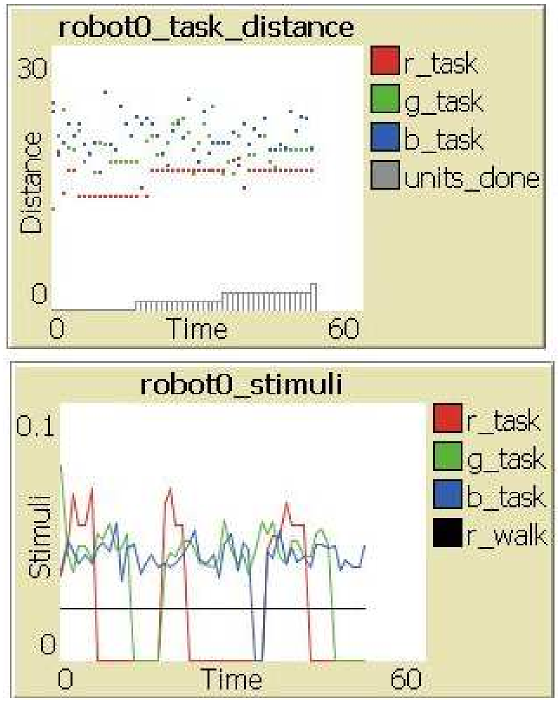

Figure 4.6: AFM simulation results from NetLogo

4.2.2 Multi-robot control system

The behaviour based distributed control paradigm has been selected to control the e-puck robots by compiled C code. These code is compiled into the dsPic micro-controller and run locally in e-puck robots. The limited amount of memory and processing power of dsPic micro-controller also restrict us to limit our code size and real-time algorithms. After this initial testing, at this moment e-puck robots are ready to put real experimental codes.

4.2.3 Multi-robot communication system

In order to exchange localization info, camera image and experimental data, e-puck robots are required to communicate with nearby tracking server and with other robots in the team. We have tested the bluetooth RS232 serial line open source communication library CTB with e-puck robots and found the smooth communication among server and multiple e-puck robots.

4.3 Simulation of attractive field model (AFM)

We have simulated AFM in a manufacturing scenario using NetLogo simulator (Tisue & Wilensky 2004). AFM contains two different types of nodes. One set of nodes describes the sources of attractive fields and other set describes the agents that are being attracted. The strength of the attraction filed of a robot to a task depends mainly on the distance, priority, learning ability, concurrency and life-time of a task (Arcaute et al. 2008). In our simulation, there were manufacturing assembly tasks (attractive field sources) and robots (agents). There were three different kinds of machine parts coloured in red, green and blue. As shown in Fig. 4.5 robots were required to collect them required number of machine parts of each category to a designated workshop area (H shaped). At the beginning of the simulation robots were randomly distributed. At runtime they decided to switch among tasks or to walk randomly based on the strength of attractive fields to the tasks (i.e. distance from machine parts). Here, we found that DoL could be observed among these robots over time. As shown in Fig. 4.6 the plot of stimulus to various tasks of a robot told us robots could select appropriate task based on their stimulus. We have planned to compare these findings with future real-robot experimental results.

Chapter 5

Future Plans

5.1 Anticipated Original Contribution

This research has been aimed at finding the generic rules that can provide the emergence of DoL in different societies, particularly in artificial societies like SRS. Existing literature of related disciplines reports that the so called top-down principles are unsuitable for emergence of DoL in a large group of individuals. Moreover the various bottom-up approaches has shown very little success in this issue. Our proposition is, the emergence of DoL observed in ants and humans, can also be emulated in robots through a set of generic rules derived from the study of ants and humans. Hence we are expecting to report our experimental observations whether DoL in robots emerges as a consequence of various local interactions and communications governed by a set of generic rules. This can potentially create an opportunity to open up a new window of huge knowledge on emergence of DoL, not only in the area of artificial systems but also in other complex social systems. This can also significantly change the whole way of thinking about decentralized control of a large number of individuals provided that we are able to find the subtle link between the generic rules and the sufficiency of emergence of DoL in artificial systems.

5.2 Plans of Research Works

In forthcoming years of my study I intend to experiment our current AFM in SRS context and also to extend the current version of our model with further study and experimentations. As the next year's work I have planned to focus on three major areas: 1) Complete infrastructural set-up including emulated-pheromone based communication system, 2) Verify AFM by real robotic experiments in different communication modes and 3) Extend existing AFM with the concepts of viable DoL from human social domain. The summarized yearly plan is outlined below:

First quarter of 2009 (January March): Start the first tier AFM experiments (with global and local communication modes enabled) and record as much data as possible. Set-up a light projection system for emulating pheromone based communication.

Second quarter of 2009 (April June): Develop a suitable software module of pheromone-based communication system.

Third quarter of 2009 (July September): Perform AFM experiments with all available communication modes and analyse previous and latest data to find necessary results.

Fourth quarter of 2009 (October December): Extend the existing AFM by introducing the concepts of viable DoL from social sciences domain.

5.3 Plans of Publications

In 2009, we have planned to publish our research results in two conferences and in two journals. After the initial experiments in the first quarter of 2009 we are expecting to submit a paper in IROS (IEEE/RSJ International Conference on Intelligent Robots and Systems) 2009 conference which is due in March 2009. Similarly after completing the detailed experiments in second and third quarters of 2009 we are planning to submit our results in ICRA (IEEE International Conference on Robotics and Automation) 2010 which is due in September 2009. Based on those accumulated results we are also expecting to publish a paper in a reputed journal of robotics. Another second journal paper is planned to be co-authored with our EPSRC research project collaborators which will include results from all participating areas. As a consequence of our infrastructural set-up work we are also examining the possibility of publishing two further papers on multi-robot tracking system and pheromone-based indirect communication system. Both of these planned systems will have high potential values considering our large experimental set-up and the value our experiences to the larger multi-robot research community.

Research Skill Development

Research students professional development programme

This was held on 17-18 March 2008 at the University Allt-yr-yn campus. Majors sessions were:
Elements of a research degree This was a conducted by a panel of renowned professors of our University who presented the role of originality, creativity, innovation etc to get a research degree.
Essential research skills and techniques: Several renowned professors of our University clarified us about the skills and techniques of a research degree such as developing theoretical concepts, data analysis etc.
IT skills: Several experts from the IT department of the University provided hands-on training on finding information from various sources including internet search engines etc.
Managing the pressure of being a research student: Emma Falkner discussed a very hot topic on work-load management of an effective research student including time management, communication, confidence etc.
Research student progress and Viva board: These two parallel sessions conducted by a panel of experienced professors provided various tips and practical advice on facing these examination processes. I attended the presentations on Viva process.
Career Management: Eluned Bush discussed various tips and tricks on effective career planning and management which helped us to plan for my future career options.

IET Life skills training session

In this three-hour training session held on 13 November 2008, Isobel Brown, an expert IET Professional Skills Officer, conducted an interactive training session entitled Making Your Career Happen. She discussed major elements of presenting an individual's professional career to the prospective employer. Starting from the personal objectives and assessment, she continued her discussion into major personal presentation (particularly CV making), communication, networking and interpersonal skills.

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