Colonial Robotics: Sustained Operations

Anthony Engwirda

Abstract - Large-scale populations of autonomous mobile robots inserted into remote and hostile environments will require autonomous maintenance. Issues include fault detection, identification and rectification as well as routine servicing. The cooperative autonomous robot colony architecture (CARC) demonstrates a coherent resolution strategy that enables near optimal physical graceful degradation on a sub-robotic scale. Proof of concept is demonstrated with experiments that verify sustained multi-robot operations within an error prone environment. CARC is a synergy of mobile agents that utilise a modular architecture and static agents that provide a base of operations. Maintenance issues include assembly, disassembly, routine service, fault detection and correction, and polymorphism. Faulty modules were identified and replaced, robots were disassembled or polymorphed. Hygienic simulation is the powerful tool that has enabled a walk-through of concept feasibility.

I. INTRODUCTION

Robot Colonies consisting of multiple dynamic teams of cooperative autonomous mobile robots rival the complexity of social insect colonies. Desired applications exist in remote and hostile environments. Fault detection and recovery should minimise downtime. Issues of complexity, access and downtime give rise to automated systems for sustained operations.

CARC addresses the issue of sustained operations with modular mobile robots and static support agents. The static support agents enable increased independence by achieving or enhancing interaction, management and sustainability.

II. CARC ARCHITECTURE

When contemplating large-scale robot operations it might be appropriate to believe that the world can not be known, the world is its own best model, and that we exert influence and not control. Pirjanian said that plans should guide and not control reactive components. Solutions should aim for satisficing rather than optimisation [1].

Fukuda says that robot costs can be reduced and production increased by adherence to standards and a modular approach that enables mass production. Greater reliance on automation generates a synergy that empowers mobile robotics and greater diversity in human resources generates new ideas [2]. Fukuda speaks of a robotics problem that is not rooted in technology but paradigm.

The notion of a colony of robots was introduced by Bekey and Agah [3]. A colony is comprised of mobile robots with a modular architecture and static agents that provide operational support to the mobile population. Colonies are capable of improved performance in Interaction, Management and Sustainability.

A robot population should implement graceful degradation [1]. Sustainability is defined as the ability of robots to continue to operate beyond disabling events [4]. Real-world and real-time environments are dynamic requiring adaptability and ability to satisfy multiple goals. Prolonged agent functionality and polymorphism are enabled by a synergy of mobile and static agents [5].

The traditional approach to damage or failure with mechanical systems has been to engineer improved reliability. There has been some work towards mobile robots that recharge themselves such as that of Warwick [6]. Research by NASA JPL is hopeful of a field repair system utilising Adaptive Directional Force Graphs (ADFG's). It is recognised that the combination of hostile environments coupled with finite component life reduces mission potential [7].

Elimination of mundane events reduces human workload, complexity and cost. Therefore, efficiency and productivity are increased due to real-time diagnostics and maintenance [8]. Sustenance Functions, listed below, are tasks that may be automated to sustain the population.

Sustenance Functions
- Assembly
- Retirement
- Replace or Repair Modules
- Recharge or Refuel Robots
- Clean Robots
- Calibration of Sensors
- Programming Robots
- Mission Briefing and Debriefing
- Polymorphism [4]

III. EXPERIMENTS

The proof of concept simulation was written in the C++ programming language and compiled on a Pentium III 550 personal computer. The colony was required to achieve and maintain build orders with limited resources in an error prone environment. Progress was monitored over time. Significant events are logged and a summary produced.

Modules were supplied for 50 mobile robots. Build orders required achievement and maintenance of a population of 25 robots from the pool of 650 modules. Faults within the colony were generated at 0.01% to 0.04%. Time was measured over 100 to 300 intervals, where one interval is...
the time required to assemble one robot. This resulted in 12 variable combinations. Each variable combination was run 20 times to ensure data variation. The average result was then plotted as a graph.

IV. OBSERVATIONS
Increasing the failure rate decreased the size of the sustainable population. Increasing the desired population enabled more agents to be assembled up to the limits imposed by failure rate and throughput. Increasing the module quantity resulted in increased operational time. Increasing the operational time resulted in decreased operational modules and eventually leads to critical failure. CARC demonstrated significant potential capability to deal with all listed errors. System complexity increased with error testing requirements.

V. APPLICATIONS
CARC was designed to enable large-scale applications in diverse environments. Such applications include site preparation and construction, resource gathering, defence, sensory stations and flexible manufacturing. Remote environments are isolated either by distance or communication. Hostile environments impede and perhaps preclude economical human effort. Typical applications vary from urban construction to large-scale mining operations in the desert, ocean or off-world. The most promising application domains for multi-robot systems are rationalised with economics.

VI. RELATED WORK
Asteroid mining research by Sonter indicates trends for increasing demand for resources lifted into low Earth orbit (LEO) and increasing project size [9]. The Mars Direct plan outlined by Zubrin embraces the historically successful concept of travelling light and living off of the land [10]. Typical human colonists encumbered by protective environmental adaptation suits would find it difficult to work in an economically sustainable manner.

NASA JPL is conducting research known as Robot Outposts [11]. Robot Outposts are also comprised of several distinct sites identified by navigation beacons enabling simplified control algorithms [14]. Primary command responsibilities were assumed by an autonomous agent in the pioneering Remote Agent Experiments, RAX. These experiments demonstrated increased mission capability while decreasing human control, communication and costs [8].

VII. CONCLUSIONS
Sustained operations enabled by the Cooperative Autonomous Robot Colony (CARC) architecture has been presented. Hygienic simulation experiments of the Colony Operations Site have verified the potential of this concept. Verification includes agent flow, module flow and sustenance functions; assembly, retirement, module replacement, refuelling, polymorphism, cleaning, calibration and code downloads. Observations include the maximum population function determined by failure rate and operations throughput.

Operations site support is finite and multiple sites are desirable for some large-scale operations. Increasing the error rate decreased agents deployed and increased occupancy of static agents. Observing error rate and time enabled prediction of critical failure with incremental accuracy.

Robotic independence through Self-Reliance is perceived as achievable with current technology. Self-Reliance is achieved with modular mobile agents and static support agents. CARC exhibits flexibility and reliability with reduced resources. Operational life of robots can be increased with reduced downtime.

This approach is ideally suited for large-scale applications in remote or hostile environments such as undersea mining and off-world resource gathering and construction. Previous work includes task force distribution, communication, navigation and collision avoidance.

REFERENCES