Introduction to Swarm Robotics

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What is Swarm Robotics?

- In a nutshell, swarm robotics (SR) is basically large number of robots mimicking insects or animals that gather and act together as a collective such as ants or bees.
- Historically, all robots in swarm robotics are identical, and preferably small. This is the homogeneous model.
- Today there is some call for extensions to heterogeneous model. We will discuss this in other tutorials.

Why?

- The cross section of large ant hill is a solid dome structure with passage ways and air vents (do not try checking this with tenants still intact, it will yield some very unhappy outcomes, particularly with fire ants).

- Dome shape is one of the most enforced structures. Another perk of the dome shape, is when it rains, the rain trickles down instead of flooding their habitat through the holes. Scientists have been intrigued for a long time on how such seemly simple creatures can construct something so intelligent.

Why? (con't)

- Moreover, how do they communicate to complete such task? Who decides it?
- The ant hill is just one of the amazing feat of ants, there are also weave ants that join their bodies together so that they can float on water, to escape a flood. This weave carries other ants that rotate with those in formation so that they do not drown. This social behavior is distributed with collective intelligence. The ants had demonstrated a society where the sum is far more than its parts.
- *If we can recreate such ability in a group of simplistic robots, the opportunities are endless.*

Don’t We have Multi-agent s Already?

- Yes, this is where the historical definition (homogenous) of swarm robotics comes in to clarify this.
- The original intent of introducing swarm robotics as a separate research is meant to address the need for *large numbers* of very *small, cheap* robots moving and working together as a swarm. This includes the ability to perform physical formation like the weave ants.
- Robots are expected to be simplistic because it is cheaper and can be mass produce; large in numbers so that it acts like nodes on internet - destruction of a single point/section will not annihilate the swarm.

It’s all in the Family…

- SR is and is not Multi-agents (MAS). MAS was the predecessor of swarm, in a way Distributed AI (DAI) is the predecessor of MAS.
- MAS is mainly about how to have multiple robots working together. It created the foundation for communication, coordination, task planning, and distributed agent frameworks.
- SR needs to scale to potentially thousands of robots. Many old MAS algorithms could not support such large numbers and did not address robot physical formation.
- However, another branch of robotics – modular robotics, are tackling this.

Architectures

- Swarm systems trace its heritage from Blackboard systems (DAI). Each robot designer may add their own architecture or framework. The following are some used in swarms:
  - ***Deliberative Reasoning Architecture*** (sense, think, then react) – layered, top-down approach
  - ***Reactive Architecture*** (sense, react) – horizontal decomposition. Modules work in parallel
  - ***Hybrid architecture*** – combines deliberative and reactive architecture. It comes in three kinds of style:
    1. *Managerial*
       - Much like deliberative task allocation through layer. Top level does higher planning, then pass it down to next layer, who refines and decomposes some more and then pass down and so forth. The lowest level is reactive. This information is passed upward, which then may readjust task or commands. Each layer tries to resolve its own issues and will request help from parent layer if it cannot resolve the issue.
    2. *State hierarchies*
       - Able to identify if activities are reactive or deliberative – reactive activity has no state.
    3. *Model-oriented*
       - More top down than managerial. They manipulate the global world model. The global world model acts as a virtual sensor and provide perception to the behaviors.

Types of Robots Used

1. ## Reconfigurable robots

Today, there is a trend in merging evolutionary algorithms with robot hardware, particularly seen in the "reconfigurable modular robots"[3][32][33][34][12][13], may also be called "evolutionary robots" or "self assembly robots". Basically, these robots consists of modules, which, in response to environment, stimuli, or simulated pheromones [9], may reconfigure itself for some reason - such as getting around an obstacle. Richard Beck[3] explained the typical physical requirements for these robots:

- **Shape** - they must be uniform. This makes it easier to reconfigure and perform self repair. It would also be helpful if the shapes are optimized so that other physical structures or wiring can be easily included
- **Mechanical** – keep it few, keep it simple. Also, they should be lightweight. The connections between modules must be tight yet easily connected or disconnected.
- **Electrical** – all electrical components required power. However, some components, such as actuators, are mandatory as it enables the robot for both linear and rotational movements. Furthermore, there are so many actuators in modular robots (bigger degree of freedom), the power consumption of each actuator must be efficient.

Types of Robots Used (con't)

2. Miniature (swarm) robots

Some of the miniature robots include the following: Sandia Laboratory has created dime size robots [25] to mimic swarm insects. Stoeter and Pananikolopoulos created the "jumping robot" [3]. Physical requirements:

- **Mechanical** – similar to full size robot but just in smaller version. Exact items depends on how the robot is designed
- **Electronic** – similar to full size robot but just in smaller version.
- **Sensors** – It can be surprisingly large for a small scout. It can include magnetometers, accelerometers, camera, video transmitter, microphone, vibration sensors and so forth.
- **Communications** – usually wireless, analog.
- **Computational System** - generally minimal. Due to size, it cannot carry much computation power .
- **Power** - low consumption.

Types of Robots Used (Con't)

- **Sensors** – this depends what the robot is used for.
- **Communications** – There are three types of communication – intra-module (within a module), inter-modules (between n modules) and global. The communication types can be wired or wireless.
- **Power** – The on board battery must be able to support the robot for at least a few hours through various configurations of the robot.
- **Computation system** – Aside from those required for handling the communication, sensors, and so forth, modular system also require distributed control software and enough memory for buffered communication. Furthermore, since these robots are modular, the system must allow designers to add new modules. Hence, interface support for the new modules should be included.

Issues

- Issues in sensor fusion

  Petriu et al [29] list the following issues in sensor fusion: communication delay and randomness from different sensor agents.

- Issues in miniature robots

  According to Stoeter[5],

  - miniature robots of 10cm or less are not able to have powerful computer on board.
  - miniature robot generally lacks reliable communication links. This is because these robots generally run on low power sources, which in turn can only support low power transmitters. These transmitters are not as powerful, thus they run into problems when transmitting data or receiving control instructions from central control.

Environment and Programming Languages

There are many Robotic Development Environments currently available. We list just a few here:

- ARTIS [14]: a real time agent architecture to develop agent.
- OROCOS [30]: a modular framework for robot and machine control
- IDEA [31]: a framework for planning and execution of agents
- ROCI [36]: a framework to support distributed sensors and actuators.
- CLARAty [15]: a framework for generic and reusable components for robots

Deployment Consideration

Some consideration and issues brought up by Chong et al [4] regarding the following issues in deployment and utilization of robots:

- Programming robots is a very tedious and overwhelming task for the average programmer.
- The complexity, dynamical, and unstructuredness of the environment also makes it difficult to pre-determine what to code.
- Large amount of knowledge is required for the reasoning
- Intelligence and knowledge is centralized in the robot controller.

Some of these issues is addressed in robotic *learning*.

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