Self-Organization in Autonomous Sensor/Actuator Networks

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Overview

- **Self-Organization**
  Introduction; system management and control; principles and characteristics; natural self-organization; methods and techniques

- **Networking Aspects: Ad Hoc and Sensor Networks**
  Ad hoc and sensor networks; self-organization in sensor networks; evaluation criteria; medium access control; ad hoc routing; data-centric networking; clustering

- **Coordination and Control: Sensor and Actor Networks**
  Sensor and actor networks; coordination and synchronization; in-network operation and control; task and resource allocation

- **Bio-inspired Networking and Nano-Communiation**
  Swarm intelligence; synchronization, artificial immune system; nano-networking and nano-machines
Sensor and Actor Networks

- Sensor network assisted robots
- Robot assisted sensor networks
- Principles and objectives
- Application examples
Sensor/Actuator Networks (SANET)

Mobile robots

Wireless sensor network

[SelfOrg], SS 2010
Sensor/Actuator Networks (SANET)
Composition of SANETs

- Components of sensor and actor networks (according to the depicted example)

  - **Sensor nodes** – Sensor nodes are employed to measure the temperature at dedicated places and to establish an ad hoc network infrastructure able to carry exchanged sensor messages. Sensor nodes need to be deployed with a high degree of redundancy in order to prevent system outages due to single node failures.

  - **Mobile robots** – The mobile robot systems are used for floor monitoring as well. They are responsible for observations in the building, e.g. by taking pictures at predefined places. If only a few robots will be used, either they have to operate fully autonomously (resulting in less accurate coordination) or a separate network infrastructure, e.g. a WLAN network, must be installed for inter-robot communication.
Sensor network assisted teams of mobile robots

- **Localization** based on well-known geographic positions of sensor nodes and distance estimations, e.g. based on the measured radio signal strength.

- **Intelligent landmarks** providing storage and computational facilities to build an intelligent environment in which robots can coordinate among each other.

- **Cooperative tracking** relies on the intensive collaboration of robots with stationary sensor nodes that are used to observe well-defined regions.

- **Communication infrastructure** based on established ad hoc routing principles to enable communication and coordination between distant robots.
Robot assisted sensor networks

- **WSN deployment** optimized by laying out new sensor nodes in uncovered regions or in geographical proximity of nodes that are estimated to fail early due to battery outages.

- **Energy harvesting** supported by mobile robot systems, e.g. inductive energy transmission between resource-rich robots and distributed sensor nodes.

- **Software management** based on on-demand composition of software modules according to a global objective with subsequent node reprogramming accomplished by mobile robots.

- **Communication relay** provided by mobile robots to bridge communication holes in WSN and to connect different network types.
Properties and definition

- **Properties**
  - Broad heterogeneity – Reflected in multiple dimensions: different hardware components, varying installed software modules, different parameter settings of deployed nodes
  - Two concurrent objectives – coordination and communication need to be considered simultaneously because coordination essentially relies on communication and, at the same time, energy efficient operation and the ability to work in delay and loss tolerant networks is demanded
  - Self-organization and emergence – Inherent need for self-organization techniques for management and control, non-linear behavioral properties lead to an emergent behavior

- **Definition SANET**
  - A SANET typically consists of heterogeneous and mobile nodes able to sense their environment (sensor) and to act on it (actor). The most prominent challenges of SANETs are communication and cooperation issues. Similar to WSNs, SANETs are assumed to be strongly resource restricted in terms of communication, processing and storage capabilities, and in terms of available energy.
Composition of SANET Nodes

- **Main processing and storage system** – usually low-power processing units but also more powerful embedded PC systems

- **Sensors** – similar to sensor nodes + mobile robots are able to carry and to operate more resource intensive devices, e.g. video cameras

- **Actuators** – ranges from simple electronic switches over motors and wheels to various forms of manipulators; active RFID tags can be used as intelligent landmarks

- **Wireless communication** - besides low power radio chips, other heterogeneous communication techniques and devices can be used
Composition of SANET Nodes

- Microcontroller
- Memory
- Storage
- Radio transceiver
- Actuator 1
- Actuator 2
- Actuator n
- Sensor 1
- Sensor n
- Actuator 1
- Actuator 2
- Actuator n
- Battery
An example – the Robertino robot

- Actuators
- Video camera
- Sensors
- Drive line and chassis
- Gateway to sensor networks
- Wireless LAN
- Embedded processing unit and storage (PC)
- Batteries
Application examples

- **Temperature control** – two sub-systems are needed in this example: sensors measuring the temperature in a given environment and actors that are able to control the temperature.

- **Fire detection** – besides sensors measuring the temperature and smoke detectors, water sprinklers are typical actuators in this scenario; the higher complexity arises through the need to enable the SANET not only to detect fire and to turn on the sprinklers but to connect to other networks for automated emergency calls.

- **Intruder detection** – one of the most complex application examples, includes the use of mobile system and heterogeneous sensors and actors in a collaborative scenario.
Application Examples

- **Robot and Sensor Networks for First Responders**

1. During an operation tens of agents will enter a building
2. If floor plans are available a priori, agents will use them to expedite the search process, acquiring information and providing an integrated view for situational awareness
3. The agents’ small size will let them penetrate nooks and niches, possibly being teleoperated by a human operator
4. The agents will autonomously organize themselves to communicate effectively, integrate information efficiently, and obtain relative position information quickly
5. They will record temperature gradients, measure concentrations of toxins and relevant gases, track sources of danger, and look for human victims. They will then cordon off areas of threat (for example, areas where the temperature is greater than 300°F) and convey to remote human operators information about the environment and about emergency response personnel inside the building
6. Information broadcast from each group will be integrated into an immersive environment that rescue workers and firefighters can visualize on remote workstations or helmet-mounted display
Application Examples

- Robot and Sensor Networks for First Responders

(a) 

(b) 

Radio tags  Mote temperature sensors  Human firefighter  Furniture  Robots

Mote sensors placed by humans or robots

Trapped (no mobility)

Failed sensor

Flow of Information

[SelfOrg], SS 2010
Application Examples

- Robot and Sensor Networks for First Responders
Application Examples

- Robot and Sensor Networks for First Responders
Autonomous Sensor/Actuator Networks

- Research areas
  - Localization
  - Navigation assisted by sensor networks
  - Exploration, mapping, and monitoring
  - Communication in sensor networks with dynamic topologies
  - Image processing and video communication
  - Quality of service and redundancy
  - Optimized positioning of stationary and mobile sensor motes
  - …
Summary (what do I need to know)

- **Sensor and Actor Networks (SANET)**
  - Principles
  - Robot-sensor interaction

- **Properties and Definition**
  - SANET properties and capabilities
  - Node composition
References