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Control of Small Robot Squads in Complex Adversarial Environments: a Review

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Scope

The Robotic Force:

– Small military robots
– Moderately sized squads
– Ground combat environments

The Mission:

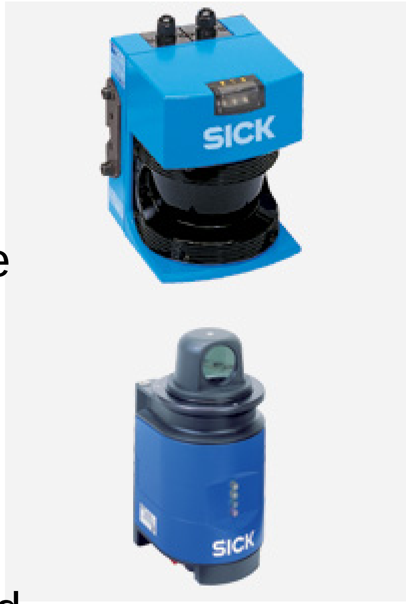
To clear and secure several three-story buildings

– Normally – leave behind a squad of soldiers
– Alternative – leave behind one or two UGS
– Better – leave 3-5 small robots and 5-10 small stationary sensors

A suitable challenge problem to the small-robot community

– Ready applications in real-world operations
– Combines numerous challenging technologies
– Enables easy experimentation

Perception

LADAR

- Scanning, Flash, MEMs
- COTS options:
  - **Sick LADAR**
  - **Swiss Ranger**
  - **Hokuyo URG-LX**
- LADAR-based collaborative mobility

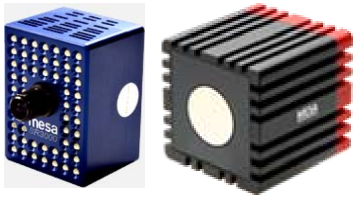
Vision

- Stereo-imaging approach

Hybrid

- Integration of LADAR-based and stereo-based perception





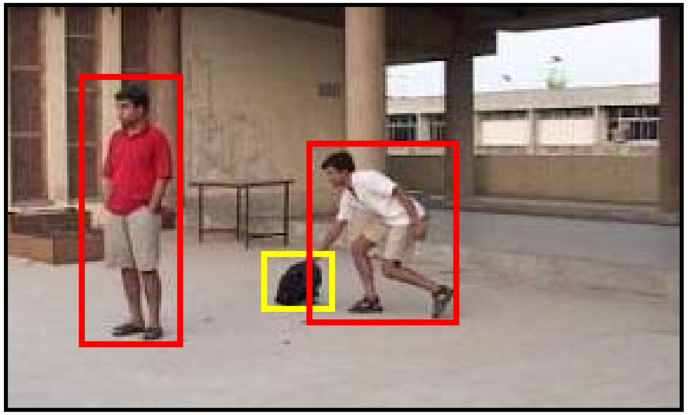
Situational Awareness

Friendly:

- Blue force tracking (with GPS availability)
- (SLAM) for self-localization in GPS-denied environments

Enemy / Non-combatant:

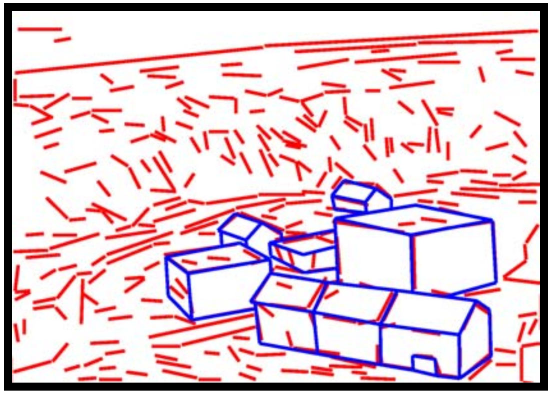
- Acoustic and video shooter detection
- Detection of humans and activities via computer vision



Integration of awareness

Individual platform architecture

- Robotic Intelligence Kernel (RIK)
- ACS (Autonomous Capabilities Suite)
- Mobility Open Architecture Simulation and Tools (MOAST) 4D/RCS



Collaboration across platforms

- Requires combining and de-conflicting maps
- In three-dimensions
- Unreliable localization

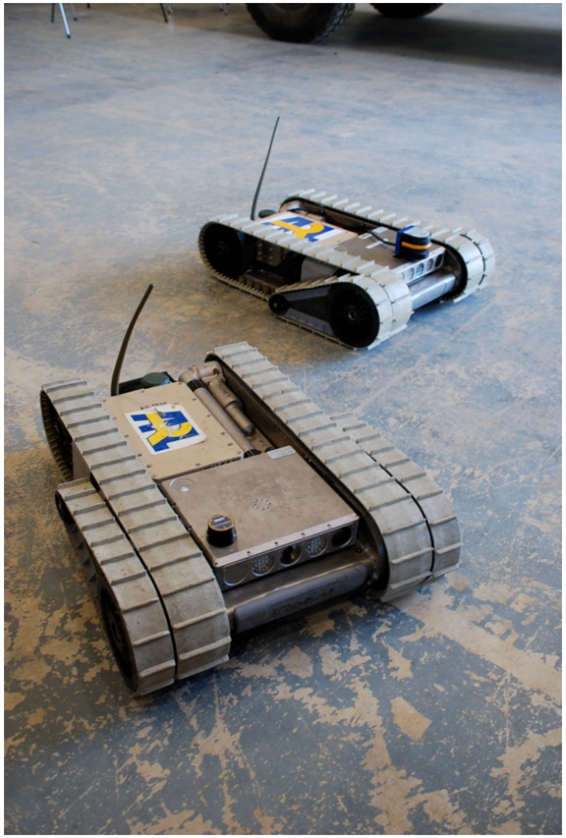
Integration with operator awareness

- At different levels of abstraction
- Before robots have built their awareness

Robot communication

Paradigms

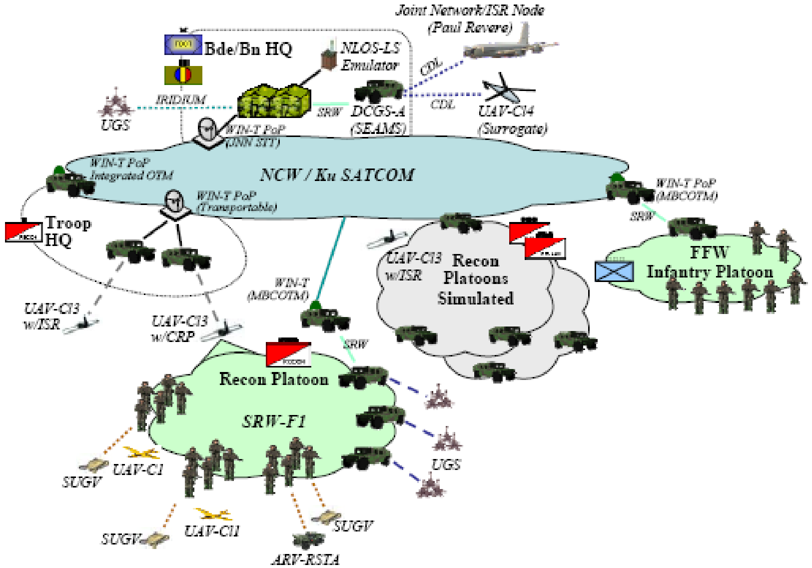
- Explicit comms; exchange of messages through RF
  - **Challenge: unreliable RF links**
- Stigmergic comms; observing the clues left by another robot
  - **Challenge: lack of visual contact**
- Combination of the two paradigms



Communication languages

- Should be frugally adapted for the mission
  - e.g. the important information may be who does what and when
- Should allow a description of the area to patrol
- Should communicate the planned sequence
- Should communicate windows of potential contact

Infrastructure for multi-robot communications

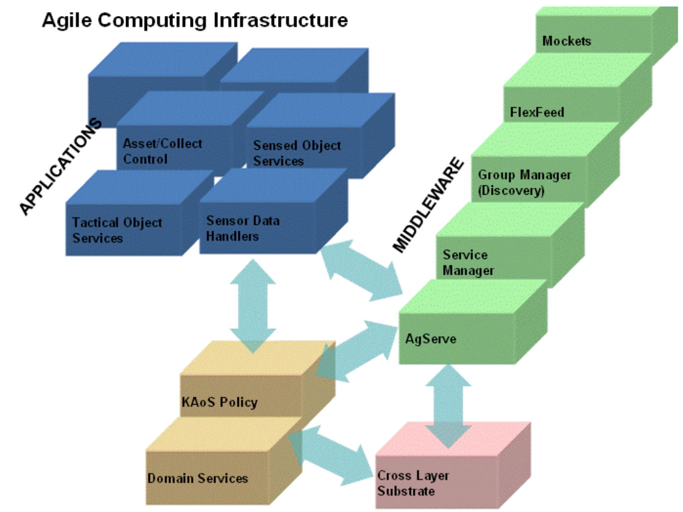


Middleware

- Application-agnostic, platform-agnostic
- Advertises the type of service they provide
- Provides automated service rediscovery

Networking layer

- Protects from changes in the underlying communications infrastructure
- Persists in inherently unstable battlefield network environment



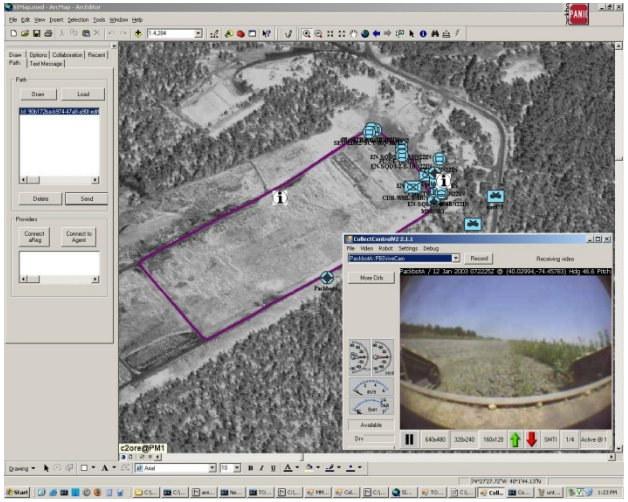
Interacting with human controllers

Paradigms for control

- Sequencing or switching paradigm
- Playbook paradigm
- Delegating approach
- Policy-based control

Human controller

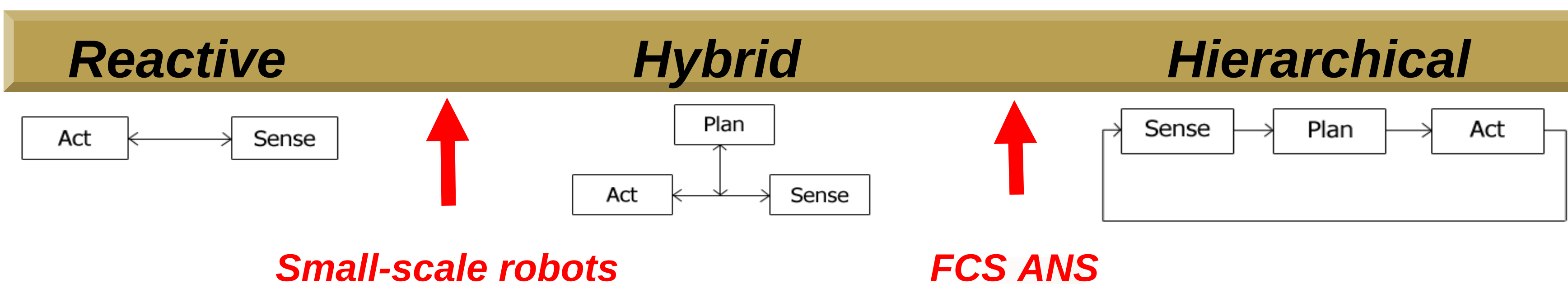
- Fundamental differences in human and robot reasoning and representation
- Operator has to continue to fight as a member of his platoon
- Physical interface must take this limitation into account.
- Increased autonomy reduces cognitive load



Collaborative planning and decision-making

Paradigms:

- Hierarchical
  - Multi-robot: often centralized
  - Social analogies
- Reactive
  - Avoids modeling and planning
  - Multi-robot: often decentralized
  - Biological analogies
- Hybrid
  - Combination of Hierarchical and Reactive Paradigms



Paradigm comparison

Deliberative

Advantages from C2 perspective:

- Controller understands this mode of operation
- Controller can supply partial or complete plan

Challenges:

- Centralized planning and allocation of tasks with unreliable and infrequent communications
- Reacting to unexpected events
- Heavy computing load on the ‘central’ robot
- Subject to computational and communications lag

Reactive

- Emergent behaviors (ant-like)

Advantages from C2 perspective:

- Does not require centralized intelligent node
- Requires less computational resources (important for small robots)
- Allows robots to act rapidly in a changing situation or in response to sudden threats
- Can operate robustly in communications-starved environments

Challenges:

- Can be naïve
- Deceived, exploited by an intelligent adversary.
- Difficult to understand and control

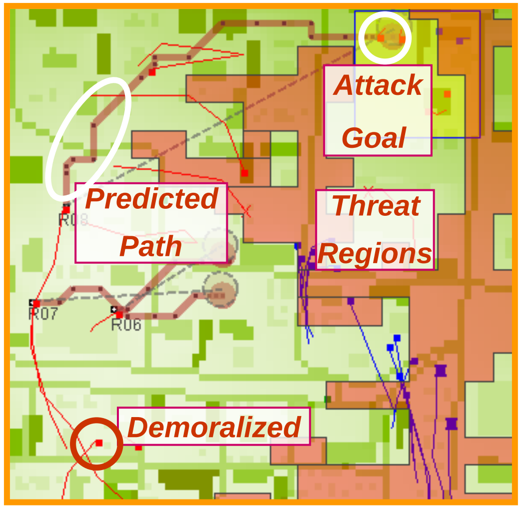
Paradigm comparison continued

Hybrid

- Adds a layer of supervisory or planning component to a reactive paradigm
- Less computationally expensive than deliberate
- Not as naïve as reactive system
- Often broken up in to basic modules (e.g. mission planner, mapping) which may be distinctly deliberative or reactive
- In a multi-agent system the concurrent but independent actions lead to an emergent social behavior
- Homogeneous robots: swarm approach may be applied
- Heterogeneous robots: marsupial approach may be appropriate

Reasoning in adversarial environment

- Explicitly consider enemy actions and counteractions
- Use terrain to avoid detection and hostile fire
- Maximize chances for success in spite of intelligent efforts by the enemy
- Several papers describing this such as DARPA RAID program which is focused on computational techniques of adversarial reasoning



Example:

- Define likely infiltration routes into and through the building.

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Delivering value to the warfighter

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- Identify potential hazards.
- Perform long-endurance surveillance
- Detect human intruders and peculiar activities
- Deploy small sensors in a marsupial fashion
- Modify human behaviors by mere presence
- Execute target designation
- Carry lethal or non-lethal weapons

Detractors say:

- Legal implications

Supporters say:

- Robots can be more ethical
- More compliant with Laws of War and Rules of Engagement
- Can reduce collateral damage, as compared to human warriors

Implications for C2

Challenging:

- Difficult to adjust to differences in perception and situational awareness
- Communicating the commander's understanding of the situation is hard
- Required precision and complexity can be burdensome to the human
- Execution decisions may be counterintuitive
- Non-human tactics to match robotic strengths and weaknesses
- Complex legal and ethical issues

Encouraging:

- ROEs can be rapidly changed and disseminated
- Re-tasking can be frequent and rapid
- Coordination between robots can be more precise and minute
- Can be more ethical
- Can cause less collateral damage than humans