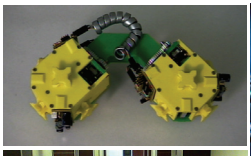
WTEC **World Technology Evaluation Center**
International Study of Robotics Research

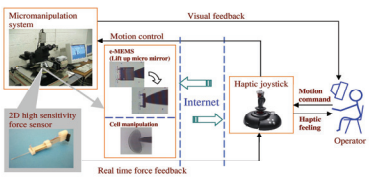
Networked Robots

Vijay Kumar, University of Pennsylvania [presenter]
George Bekey, University of Southern California
Arthur Sanderson, Rensselaer Polytechnic Institute

What are Networked Robots?

- Team(s) of robots and humans "connected" via electronic/physical link
  - Beyond capabilities of single robots
  - Improved efficiency
  - Harnessing physically-removed assets
  - Synergies with other networked devices

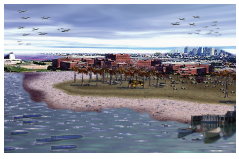




What are Networked Robots?

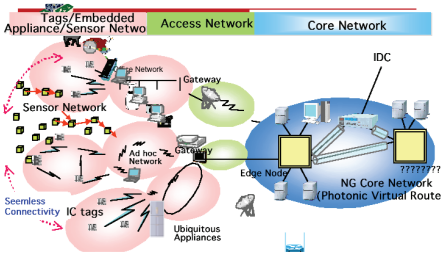
Whole greater than the sum
- Fault tolerance
- Robots servicing, repairing, manufacturing robots

Applications
- Manufacturing
- Defense
- Space
- Domestic robots



Market

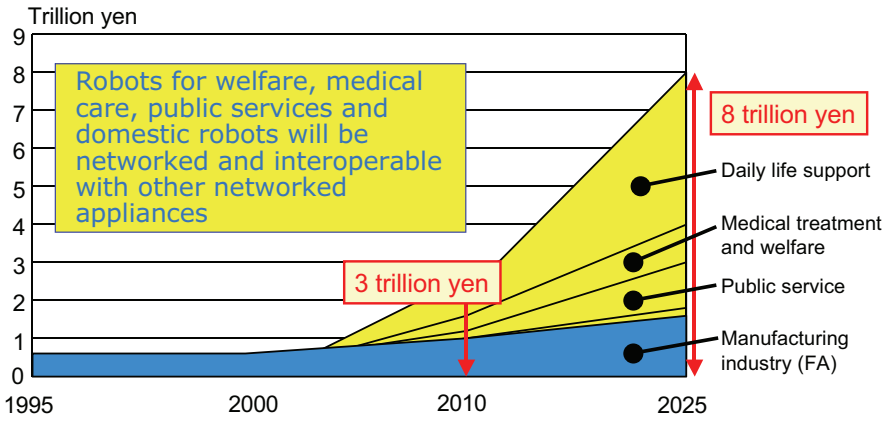
- Network Robot Forum established in Japan in 2003
- "Robot Network" industry expected to be $20B in 2013
  - Projected to 5 times the (manufacturing) industrial robot market
- Mobility for Sensor Networks
- Tele-medicine



Manufacturing workcell

[Market data from Dentsu Communications Institute]

Market for Service Robots

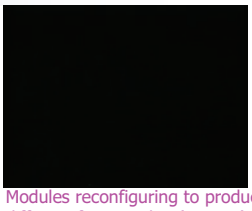


By 2013 network robots will create a market of $20 billion (5.7 times the market size of industrial robots), Dentsu Communications Institute, Japan

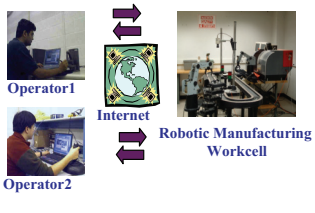
* Report investigating technical strategies for creating a robot society in the 21st century/Japan Robot Association (JARA)

How? What Technology is Needed?

- Network centric approaches
- Software infrastructure
- Information integration
- System of systems
- Embedded humans



Modules reconfiguring to produce different functionality (U Penn)



Human operators tasking a team of robots (UPenn)

Predator operated from a tactical control station on board USS Carl Vinson

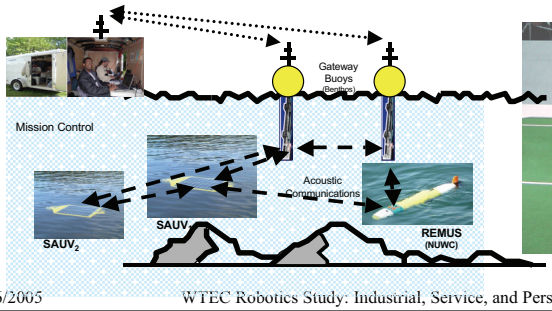
Why is it difficult?

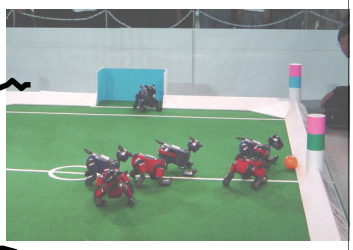
- Many of the challenges associated with "single" robots

and…

- Fundamental challenges associated with network of robots

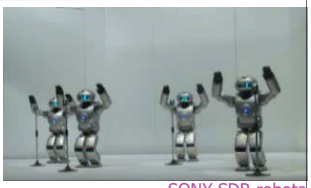
Tohuku Univ, Japan



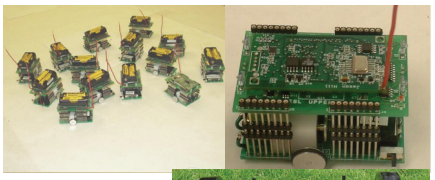


Examples

Space, mining, military, entertainment, service, environmental, homeland security



SONY SDR robots



USC

U. Minnesota

Caterpillar

Fundamental Challenges

- Integrated approach to
  - Action (locomotion, manipulation)
  - Perception (feedback, modeling/reasoning)
  - Communication (for coordination, getting information)
- Complexity increases because
  - Decentralization
    - Computation
    - Action
    - Perception
    - Communication
  - Spatially and temporally distributed

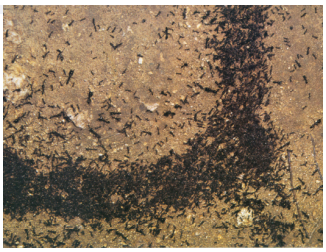
Fundamental Challenges

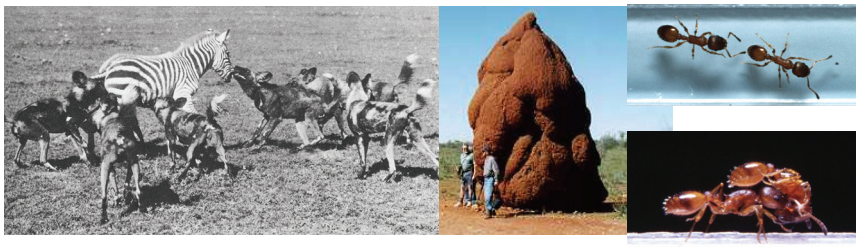
- System of systems
  - From 10's to 100's and 1000's
- Spatial coverage
  - From static to dynamic
- Embedded computing
  - Increase Gbits/coverage area/sec
- Self organization
  - Position/context aware
- Adaptation (control, learning)
  - Inverse problem (e.g. swarming)
- Seamless integration of control, communication and perception
  - Centralized to decentralized
- Composing subsystems to build systems

Scientific Challenges

Bio-inspired behaviors

- Synthesis of behaviors for emergent properties
- Cooperation
- Anonymity (big groups)





Groups perform tasks that individuals cannot perform

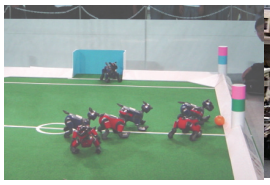
International Survey

U.S.

Collaborative Manipulation/Transport

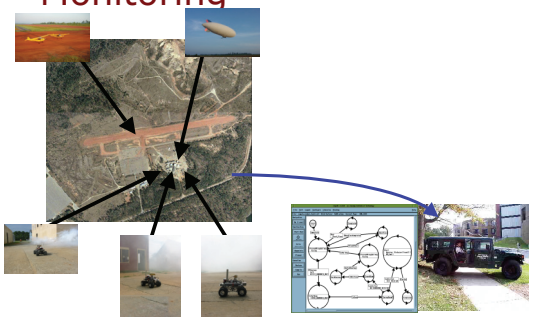




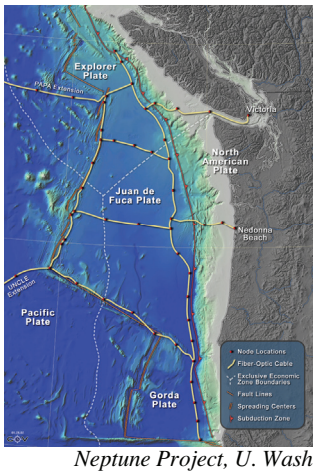



U.S.

Cooperative Search, Reconnaissance, Mapping, Monitoring



MARS 2020 Project, U. Penn, Geogia Tech, USC



Neptune Project, U. Wash

U.S.

- Software for Distributed Robotics (SDR, DARPA)
  - Intrusion detection and tracking by multiple robots

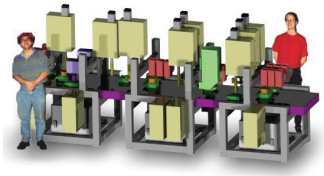
- Networked Infomechanical Systems (NSF)
  - Mobile sensor networks for studies on organism abudance and diversity



U.S.

Coordination between networked devices


Electronic assembly, Adept

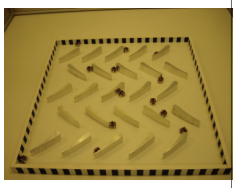


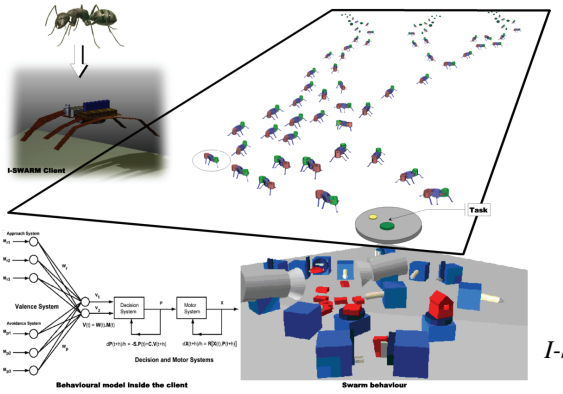

Architecture for Agile Assembly, CMU

Europe

Swarm Intelligence

EPFL





I-Swarm project, Karlsruhe

Europe

Laboratoire d'Analyse et d'Architecture des Systemémes

- Multi-robot cooperation and coordination
- Planning
- Task allocation
- LAAS Architecture

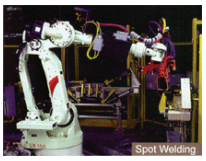
http://www.laas.fr/

Japan

Coordinated operation in shared environment

- Fanuc, multiple robots
- Yaskawa, two-arm workcells

Fanuc Workcells



Coordinated Arms for Spot Welding (Kawasaki)

Coordination/cooperation with humans

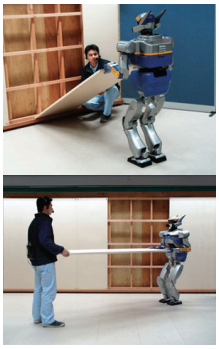
AIST, Tokyo

Motoman Bartender (Yaskawa)

Japan (continued)

Collaborative Manipulation

Tohuku Univ, Japan



AIST, Tokyo

International Comparisons: Areas of Emphasis

- US
  - Cooperating vehicles
  - Mobile sensor networks
- Japan, Korea
  - Networks of sensors, robots, appliances
  - Human-friendly robots
- Europe
  - Swarm intelligence
  - Bio-inspired robotics

Qualitative Observations

- U.S. leads in basic and applied research
  - Convergence of sensor networks and mobile robotics
  - U.S. emphasis on network-centric control of unpiloted networks
  - Control of embedded devices and robots via the internet
- European program on swarm robotics and intelligence has no comparable counterpart in the U.S.
- Network robot forum has over 50 private companies in Japan
  - Convergence of ubiquitous computing, sensing and personal service robots

Qualitative Comparisons: Emphasis

Basic	U.S.	Europe	Japan/Korea
Control	****	**	***
Perception	****	***	***
Networking	****	***	***
Technology			
Sensors	**	**	**
Robots	*	***	***
Robot Networks	***	**	**

- U.S. leads in basic research
- Multi-robot, sensor networks, robot networks work in the U.S. has had higher impact
- Momentum gaining in Asia and Europe

Future Challenges

- Technical challenges to scalability
- Performing physical tasks in the real world
- Human interaction for network-centric control and monitoring