Multisensor Data Fusion

Emil M. Petriu
Professor, University of Ottawa
http://www.site.uottawa.ca/~petriu

A **multi-sensor fusion framework** is needed to manage in a consistent way the usage of multiple sensor resources, while supporting user's trust, workload, attention and situation awareness.

The **multi-sensor fusion system** has to

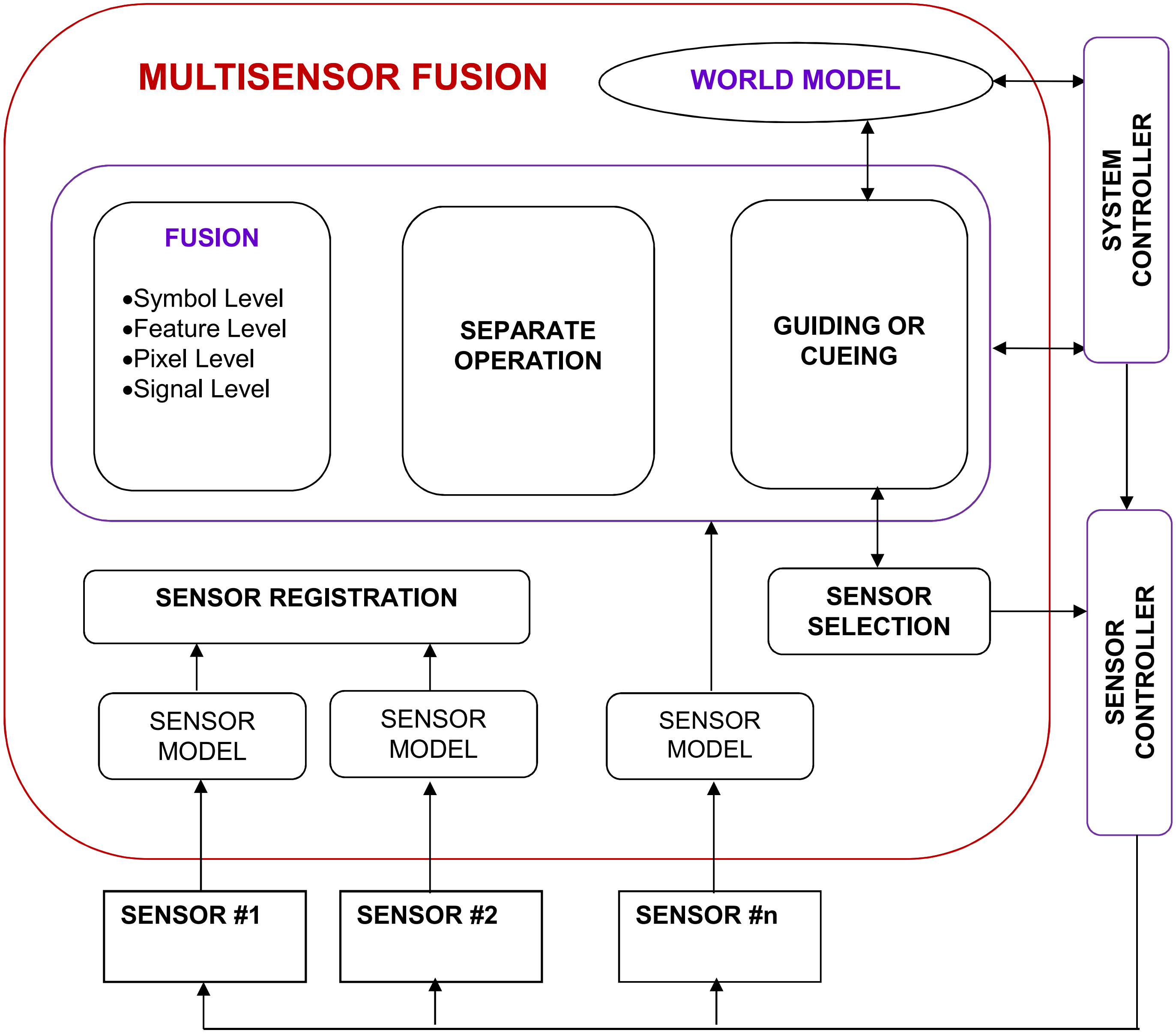
(i) organize data collection and signal processing from different types of sensor,

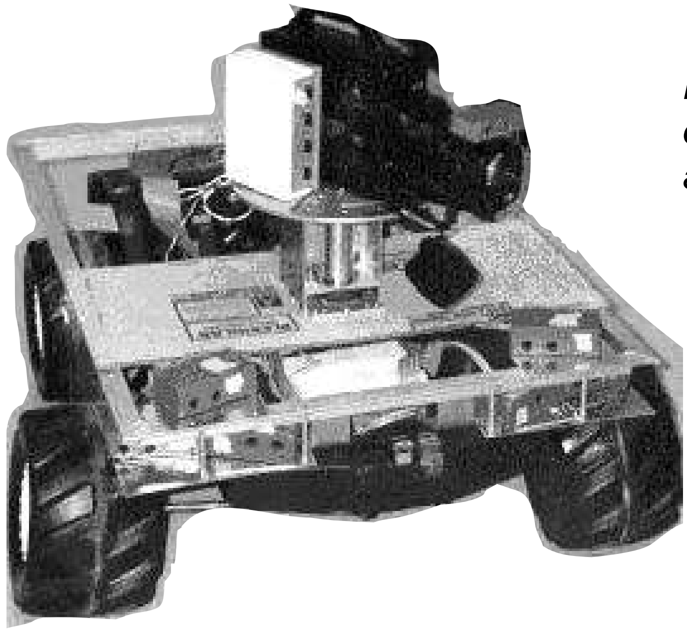
(ii) produce local and global representations using the multi-sensor information, and

(iii) integrate the information from the different sensors into a continuously updated model of the monitored system.

Multisensor Data Fusion

- ***Redundancy -*** Redundant information is provided from a group of sensors or by a single sensor over time when each sensor observes (possibly with different fidelity), the same features of interest
- ***Complementarity -*** Complementary information from multiple sensors allows for the perception of features that are impossible to be observed using just the information from individual sensors operating separately.
- ***Timeliness -*** More timely information may be provided by multiple sensors due to the actual speed of operation of each sensors, or to the processing parallelism that is possible to be achieved as part of the integration process.
- ***Cost*** - Integrating many sensors into one system can often use many in expensive devices to provide data that is of the same, or even superior quality to data from a much more expensive and less robust device.


MULTISENSOR FUSION
WORLD MODEL
SYSTEM CONTROLLER
FUSION
•Symbol Level
•Feature Level
•Pixel Level
•Signal Level
SEPARATE OPERATION
GUIDING OR CUEING
SENSOR REGISTRATION
SENSOR SELECTION
SENSOR CONTROLLER
SENSOR MODEL
SENSOR MODEL
SENSOR MODEL
SENSOR #1
SENSOR #2
SENSOR #n



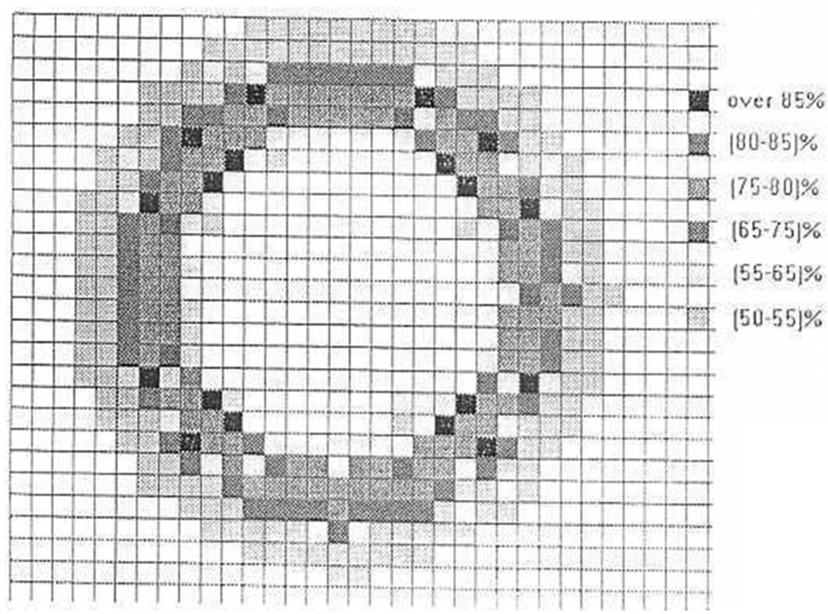
Intelligent Robot Sensor Agent equipped with camera, IR sensors and wheel encoders.

The ***multi-sensor fusion*** framework deals in a consistent way with a diversity of measurement data produced by ISA's. Such a multi-sensor fusion system has to:

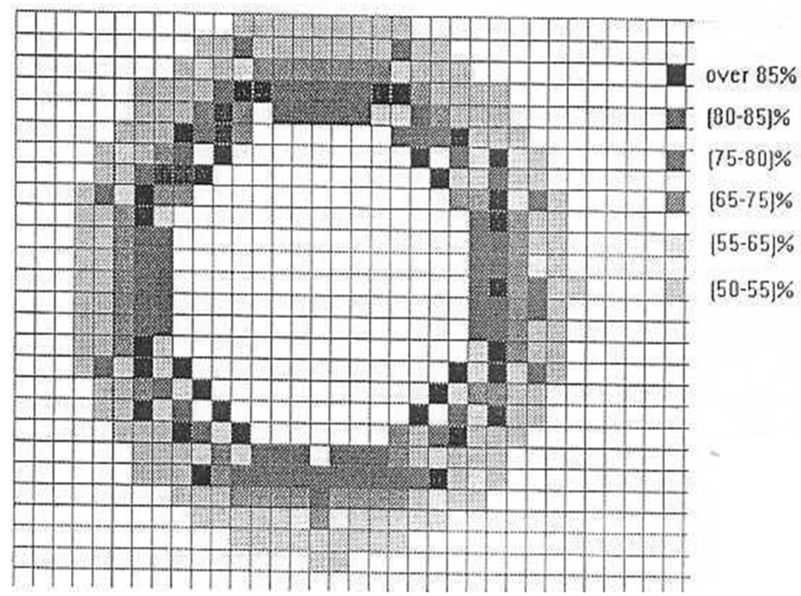
(i) organize data collection and signal processing from different types of sensors,

(ii) produce local and global world models,

(iii) integrate the information from the different sensors into a continuously updated model of the system.

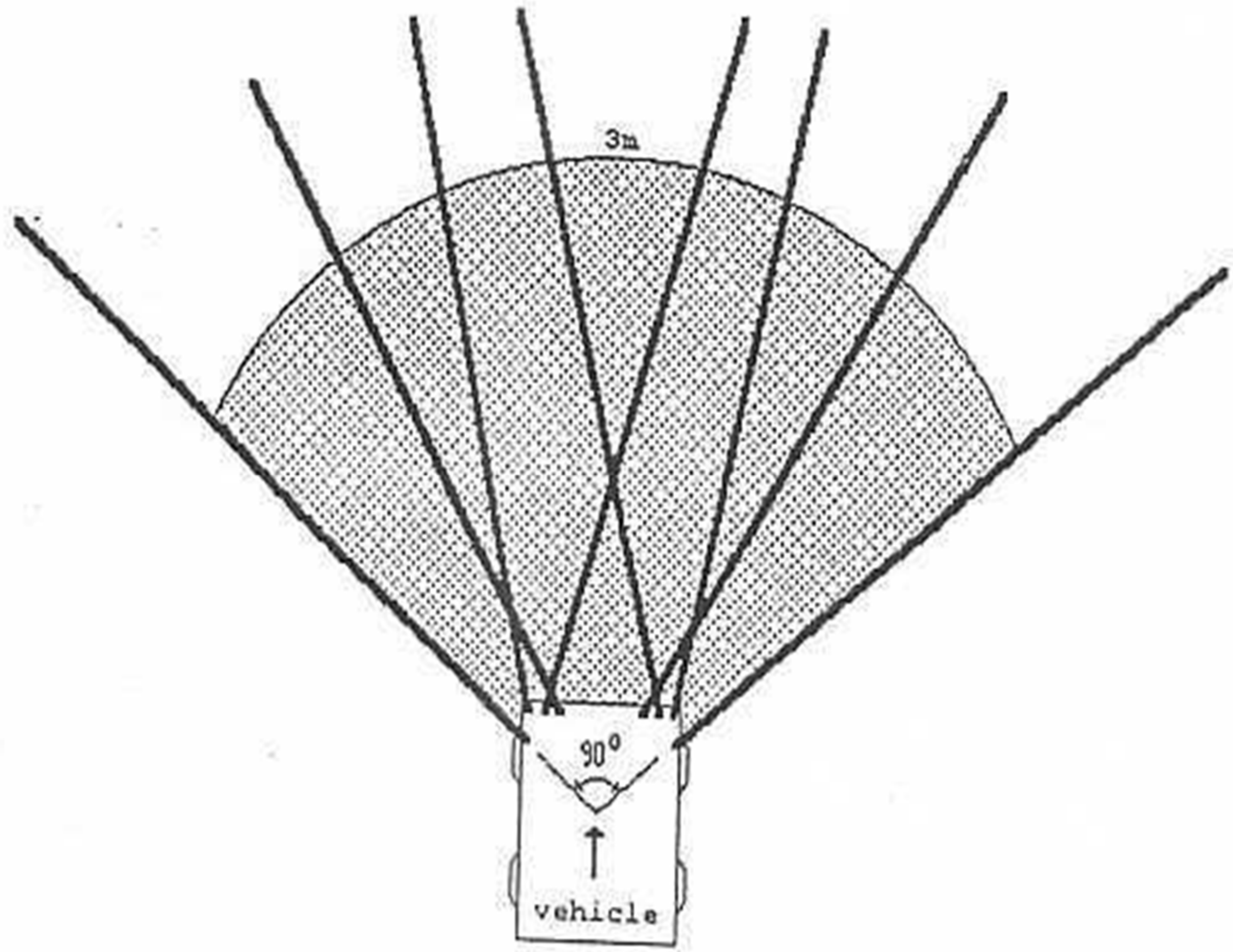


(a)

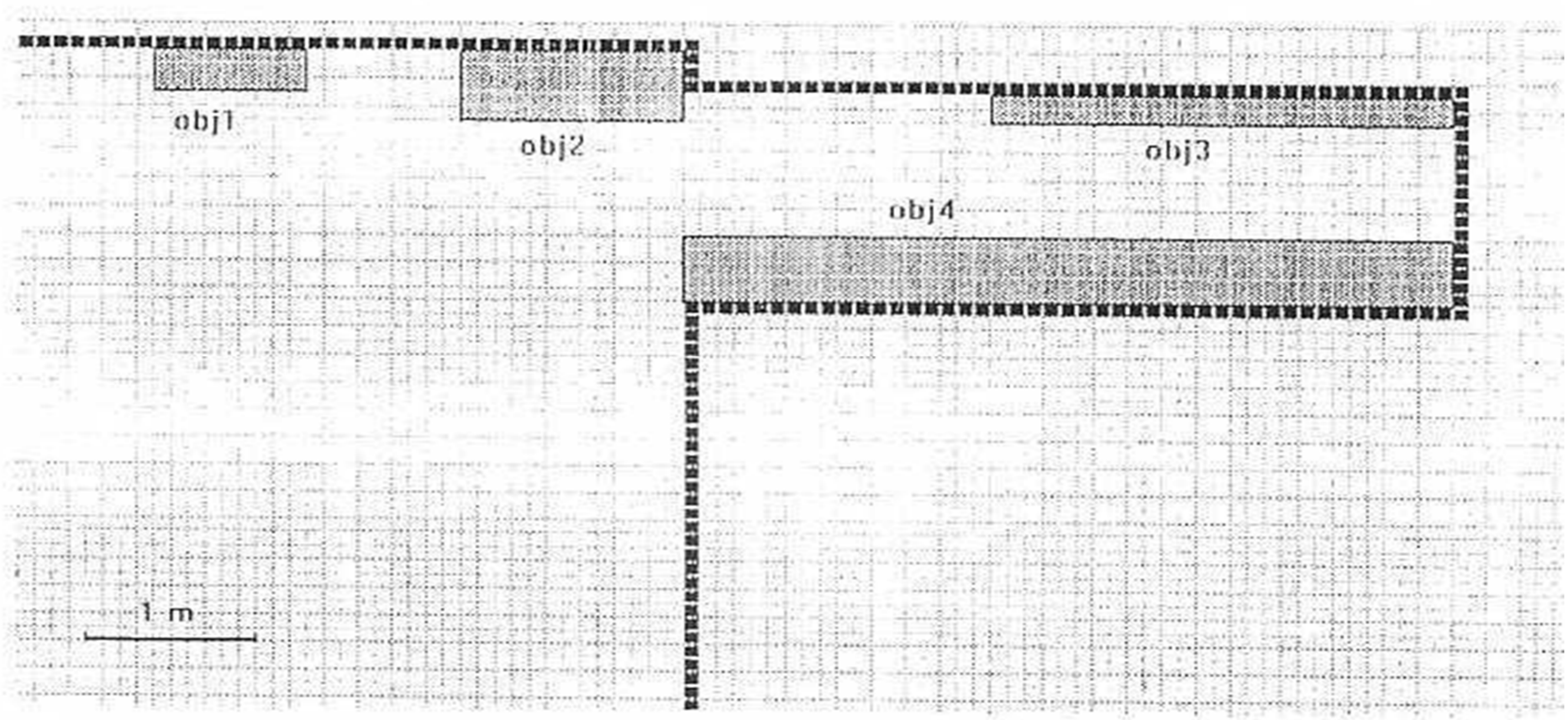


(b)

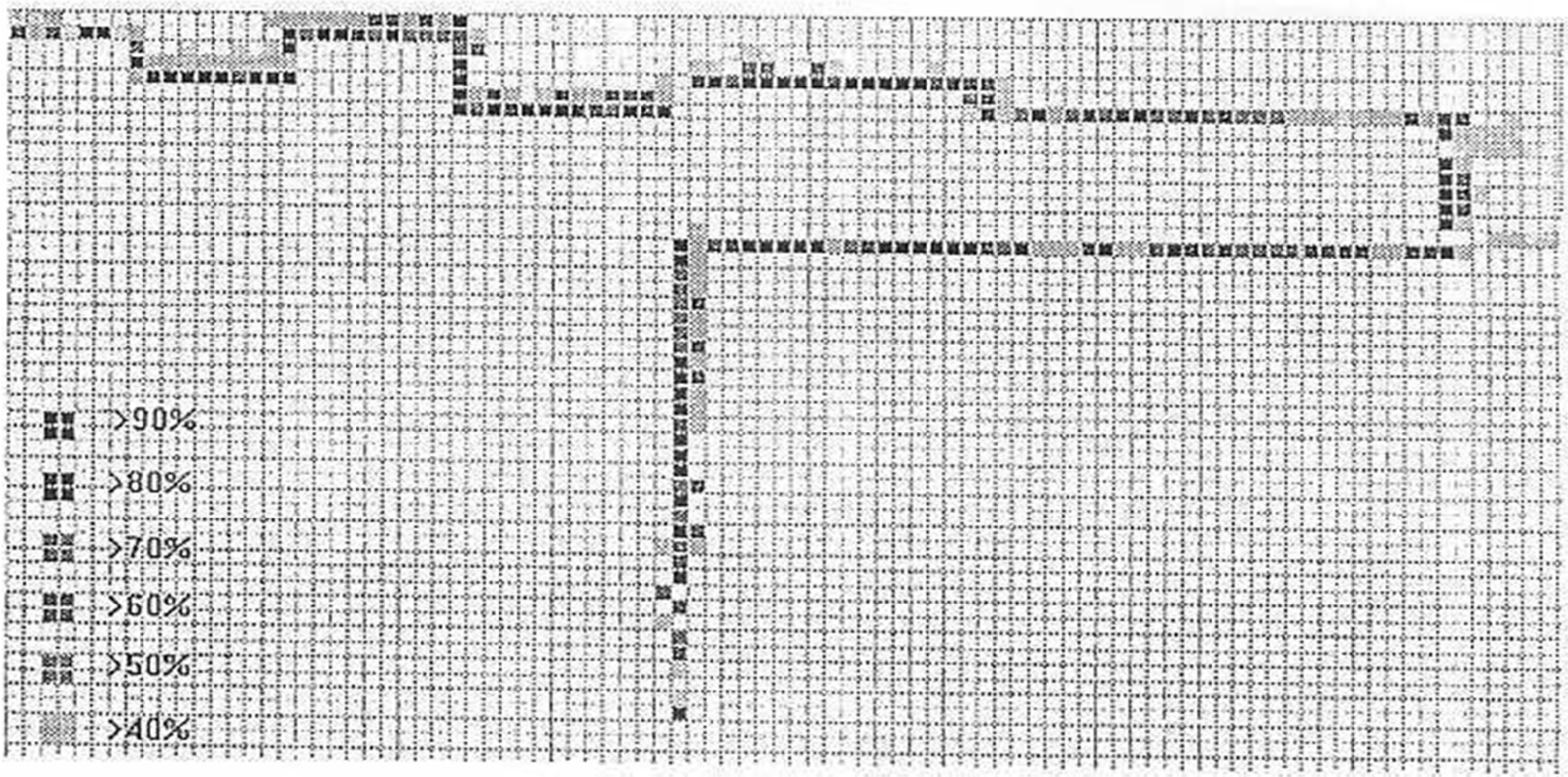
Occupancy grid map of a round wall around the rotating IR sensor after (a) one turn, and (b) ten turns



Multi IR sensor system on board the mobile robot

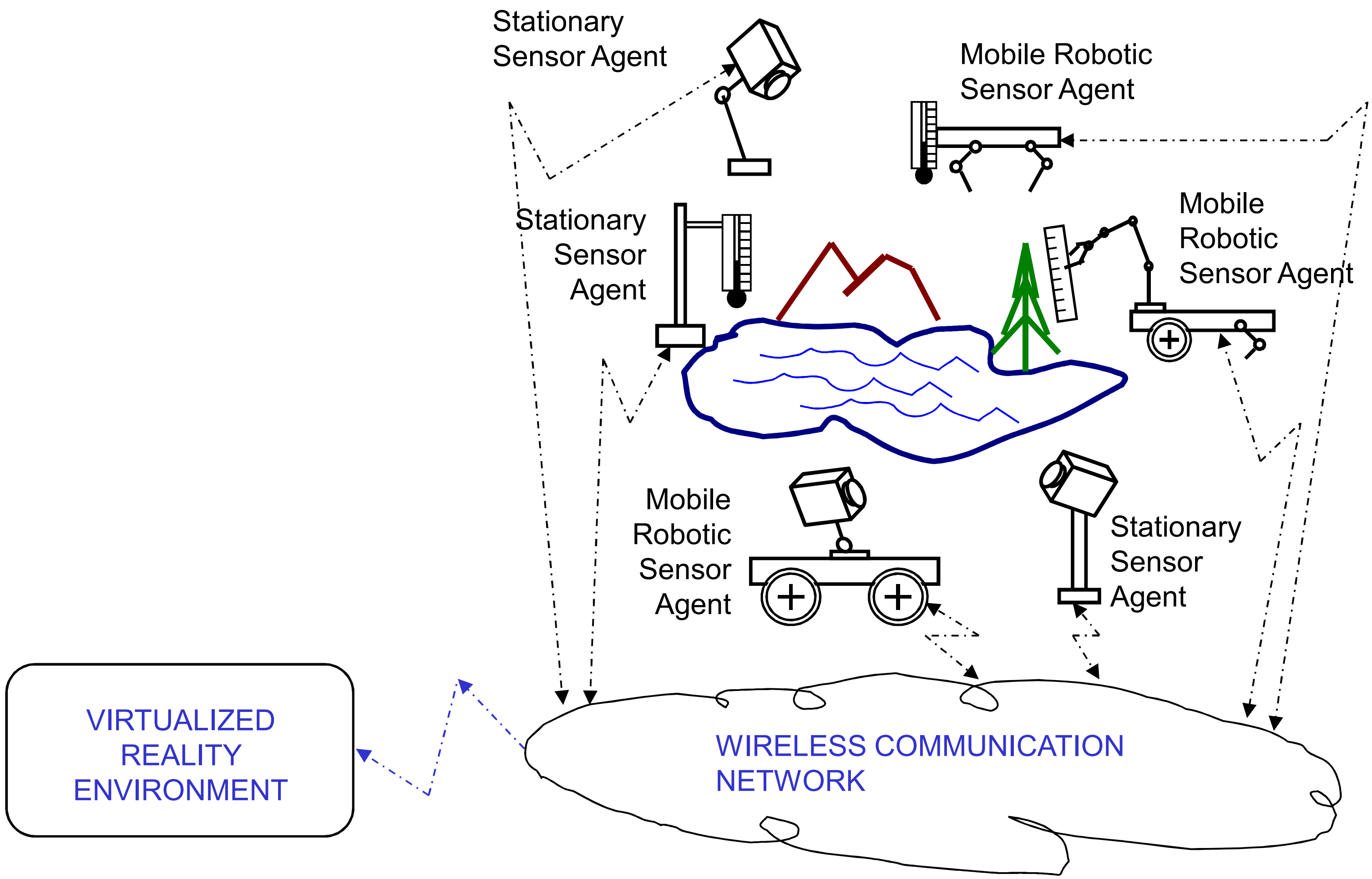


Layout of the room explored by the mobile robot
with eight on board IR sensors



The recovered shape of explored room by fusing the data from
the eight IR sensors using the probability occupancy grid method

Wireless Network of Intelligent Robotic Sensor Agents for Environment Monitoring



- **Monitoring environment parameters** is a task of great importance in many areas such as the natural environments, industrial or laboratory hazardous environments (biologically, radioactively, or chemically contaminated), polluted natural environments, water treatment plants, nuclear stations, war zones, or remote difficult to reach environments such as the deep space or underwater.

- The objective is the development of a new generation of autonomous wireless *Robotic Sensor Agents* (**RSA**) for environment monitoring.

  Monitoring is done by continuously collecting sensor data from a distributed network of stationary and mobile RSA deployed in the field.

  Sensor data of different nature are fused in a ***world model***, which is remotely available to human supervisors as an interactive virtual environment model.

- *RSA*s should be capable of **selective environment perception** focusing on parameters that are important for the specific task and avoid wasting resources on processing irrelevant data.

  Different **sensor planning strategies** are used for the placement of fixed and mobile RSAs in such a way as to get optimum performance during specific sensing tasks and for the real-time selection of sensing operations.

- In order to avoid fatal errors due to communication delay and randomness between the information collected from the RSA’s , we are using a ***distributed virtual environment that allows maintaining a shared world model*** of the physical environment that is explored.

- In order to provide a flexible extensible open mechanism allowing for interoperability, an ***agent-based resource management framework*** should address the functional and communication needs of each RSA.

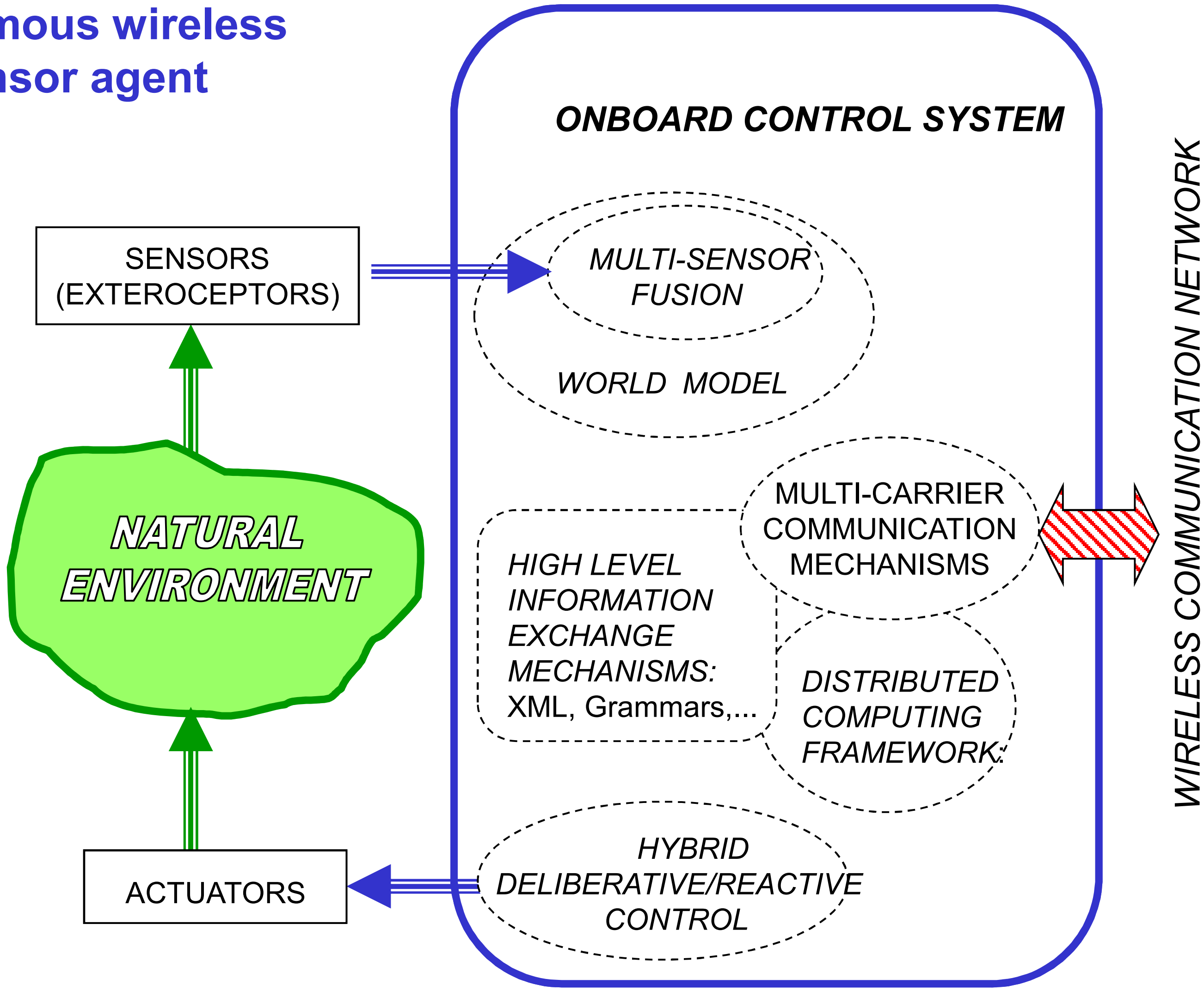
- The development of a distributed network of RSA’s should address ***wireless networking issues*** looking for the development of cost-effective solutions.

- Monitoring the environment, in practical terms, is a ***game with limited resources***. There is a limited number of RSA’s, which have limited operational parameters, communicating via a limited QoS wireless communication network.

- ***RSA’s are not functionally and operationally identical***. There are stationary and mobile agents that measure different environment parameters. Even if they measure the same type of parameters the sensors may have different characteristics. The robotic carriers may also have different operational characteristics. Like humans, the local controller of each *intelligent RSA* may have it’s own *personality.*

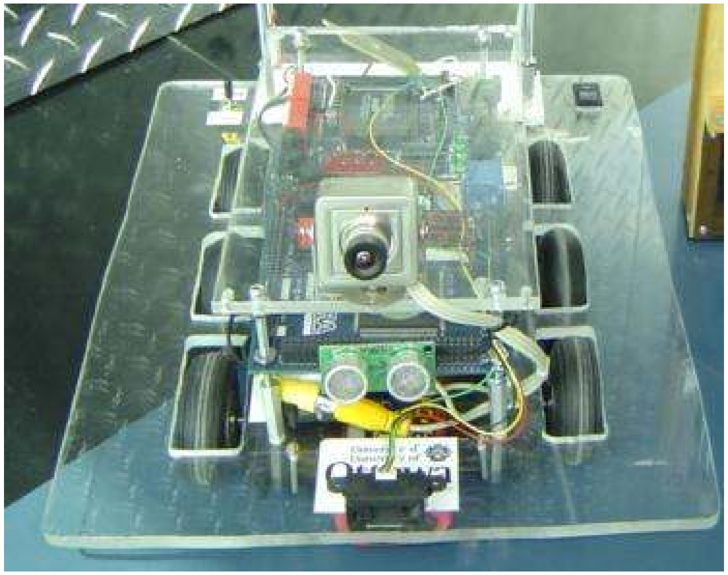
- *Human-to-human communication and cooperation* require a ***common language and an underlying system of shared knowledge and common values***. In order to achieve a similar degree of machine-to-machine *RSA* interaction and cooperation, an ***RSA social framework*** should be developed to allow ***for the management of heterogeneous functions and knowledge*** for a large diversity of RSAs.

Onboard control system for an autonomous wireless robotic sensor agent

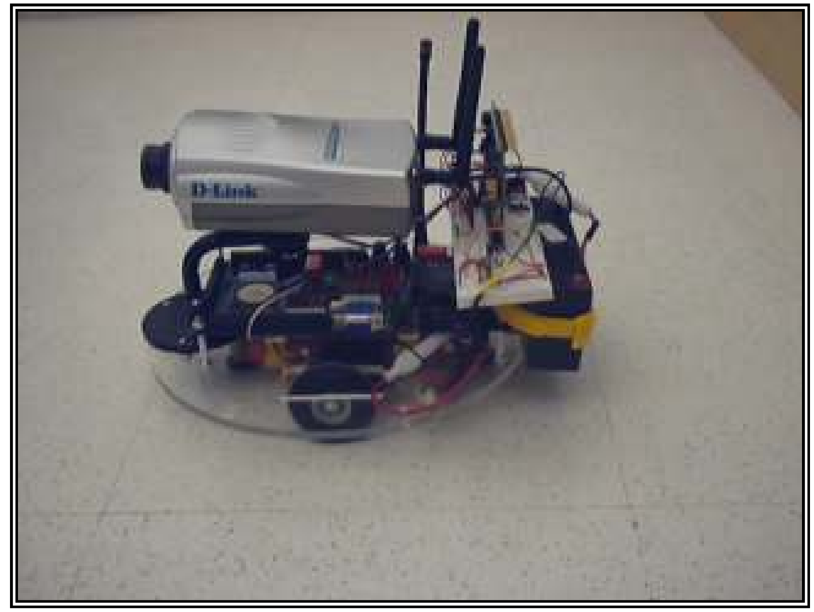


- Heterogeneous RSA's cannot realistically be expected to talk exactly the same language. However, they will share domain-specific knowledge, which may be expressed by each of them in a different dialect.
  Accordingly, the communication management framework should define a domain specific semantic for common knowledge and functions. This framework is expected to act as a universal translator between different dialects.

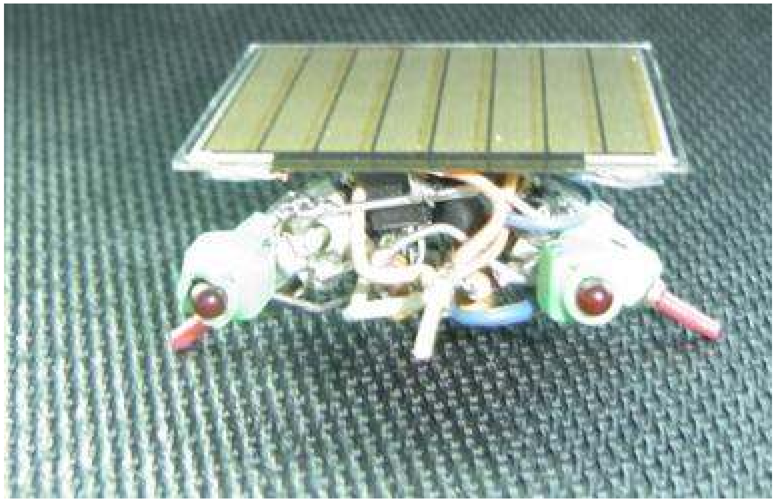
  In order to provide a flexible extensible open framework allowing for interoperability, methods should be developed to allow different agents to exchange the grammars describing their own dialects and to learn to understand each other. This way, the agents would be able to advertise their own functions, search and discover providers of required services, and express their needs in a collaborative environment. XML (Extensible Markup Language) could provide high-level protocols for exchanging information between RSA's.



Six-wheel robotic platform for an experimental mobile RSA equipped with video camera, sonar, and infrared range sensors.



Two-wheel robotic platform for an experimental mobile autonomous robotic sensor agent equipped with a wireless camera, IR sensors and on computational power



Frog-leaping RSA powered by a solar panel equipped with two light detector sensors and a touch probe.

Four-leg RSA platform powered by a solar panel.

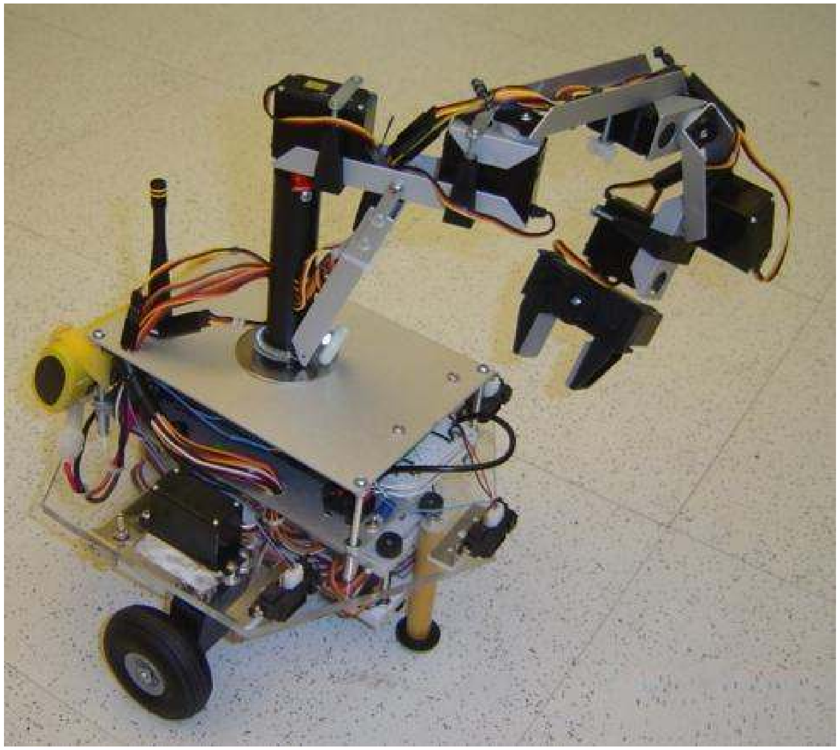
- ***Learning*** allows RSA's to acquire knowledge by interaction with the environment and subsequently adapt their behavior. Behavior learning methods could be used to solve complex problems that a real RSA encounters while exploring an unknown real-world environment.

- ***Brooks' reactive-behavior paradigm*** => an alternative to the traditional function oriented *sensing-planning-acting* control strategies. The behavior paradigm is based on a task-wise decomposition of the control functions in special-purpose simple task-achieving modules. Neither strategic planning nor carefully calibrated sensors are necessary to produce robust intelligent reactive-behavior in RSA. An **autonomous RSA** uses a combination of intrinsic reactive-behaviors with higher-order world model representations of the environment.

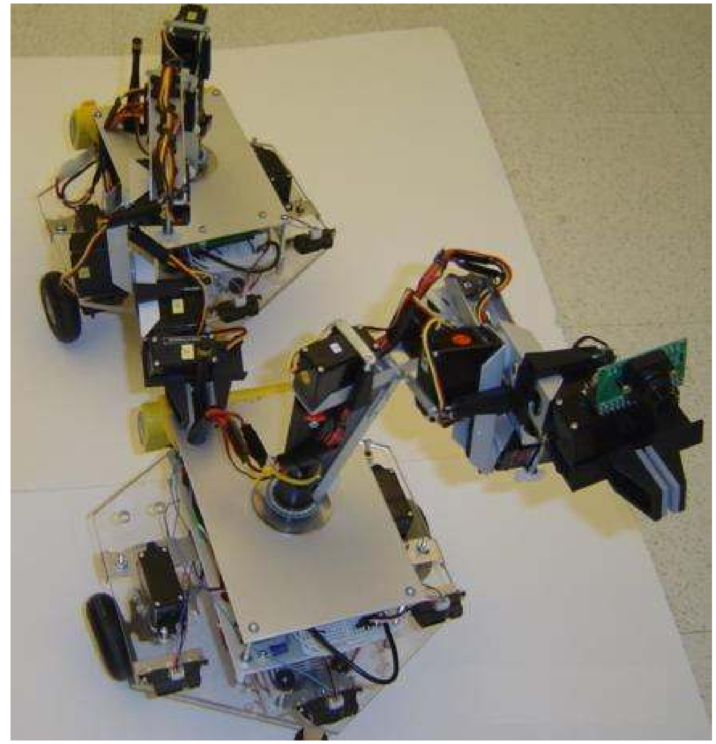
- All RSA are by definition ***instinctive information seeking agents*.** When the costs of deploying sensors agents is prohibitive, RSA's would benefit from having *survival instinct*, *cooperation skills*, *adaptation* and *learning abilities,* as well as *evolutionary* capacity.

- ***Cooperating agents*** should be able to work together with other mobile or stationary RSA's toward the *overall goal, which is to maximize the information acquired from the environment*. For instance, two cooperating RSA's could assume the best relative positions in order for them to get a stereo image of a region of the environment. Or, a RSA could illuminate the subject for another RSA to take images. This cooperation should also allow modular RSA's to permanently or temporarily couple forming new structures better adapted to solving specific problems. As an example, two or more RSA's can couple to make a bridge over a trench, or one could be helped by another to get over an obstacle.

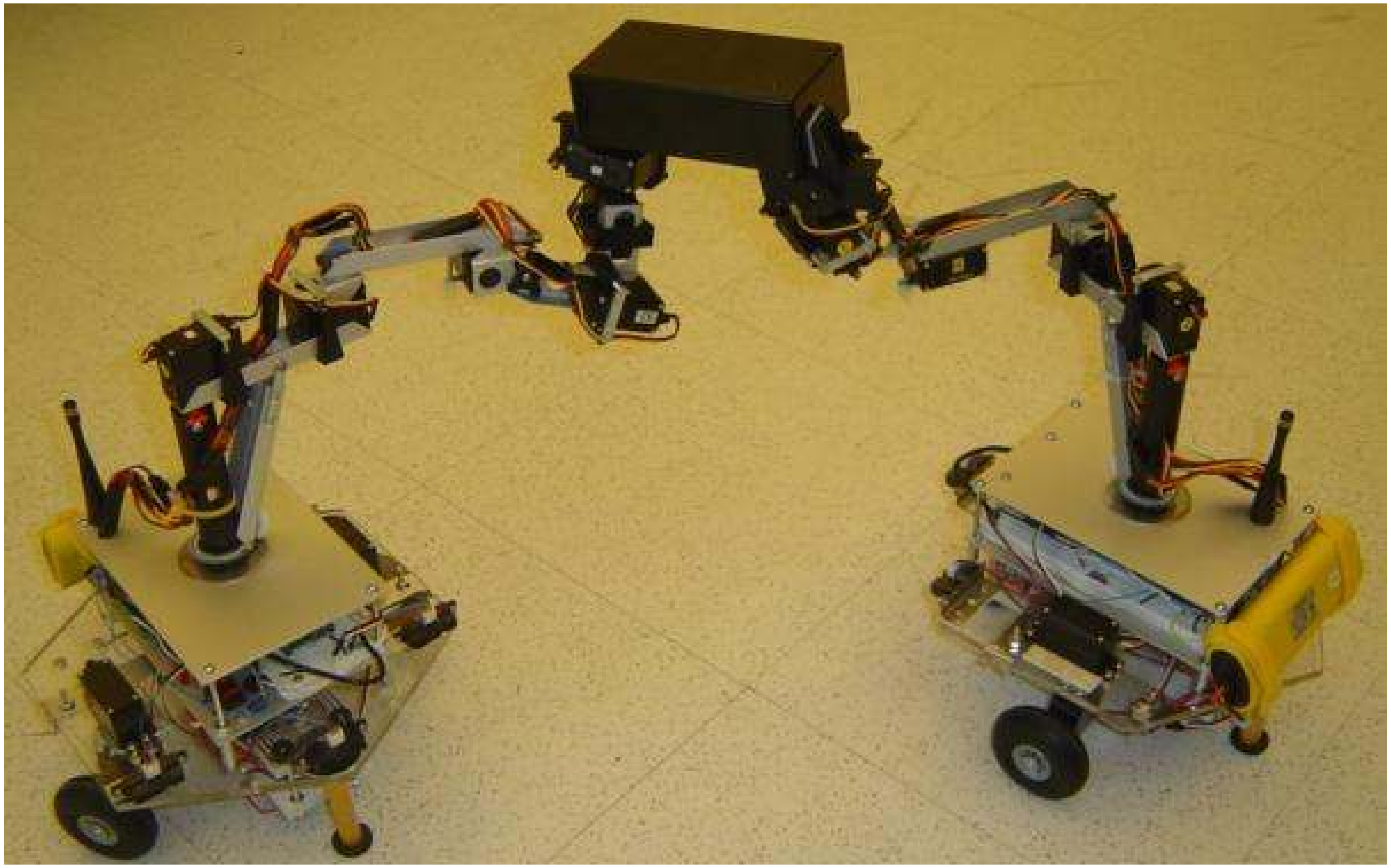
- An ***evolutionary mechanism*** would allow a RSA to pass over to other RSA's the *learning experience* and *behavioral genes* they acquired while operating in the field



Two-wheel hexagonal-shaped modular RSA platform with onboard manipulation capabilit.



Two *RSA*s are temporarily joining in order to better perform their mission. The lead RSA has a video camera mounted on the hand of its manipulator arm.

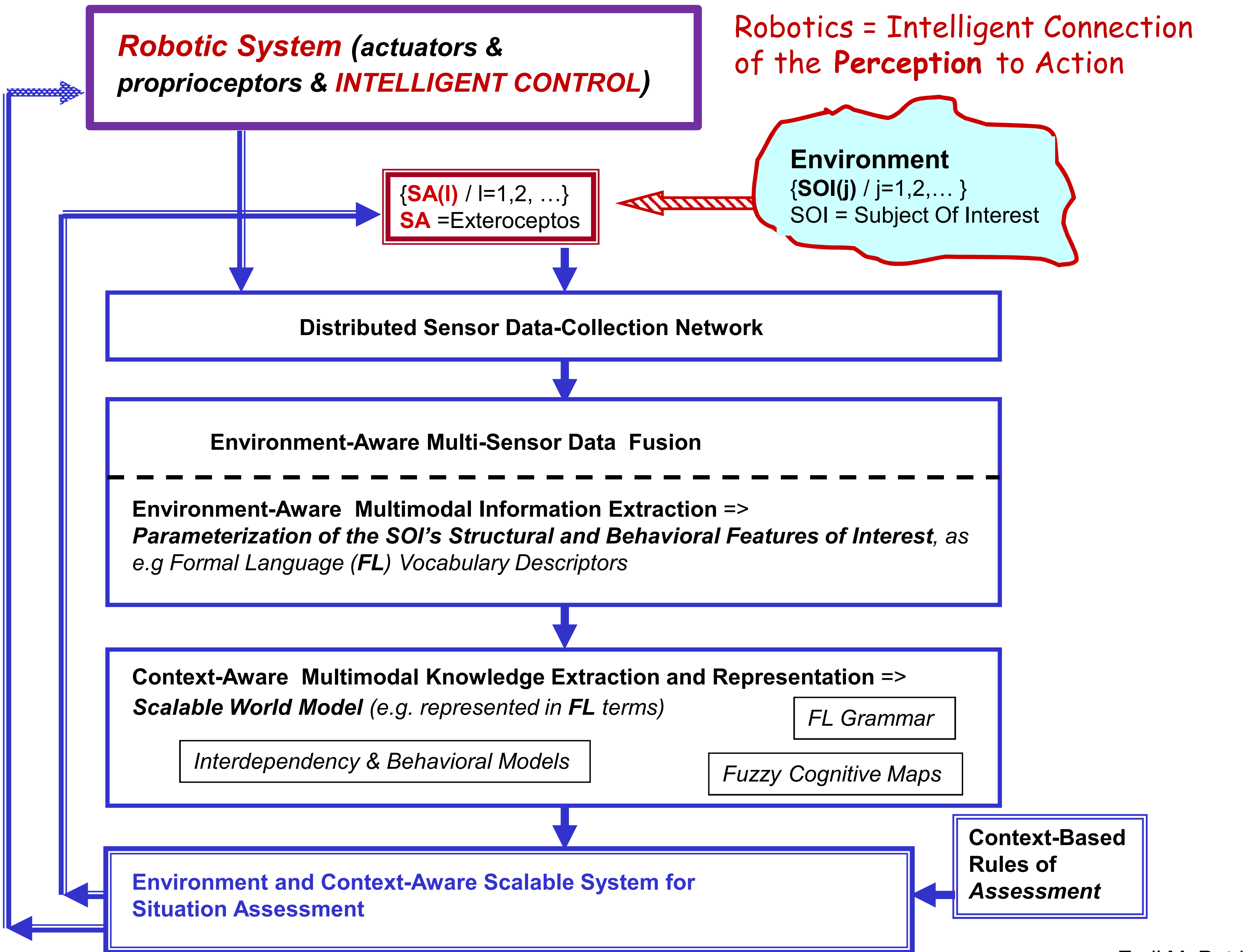


Two *RSA*s collaborating in order to carryout a given task.

- ***RSA's should be able to cannibalize / recycle other agents*** that are operationally dead, which otherwise will be abandoned in the field. Such a behavior would contribute to the ***RSA species survival.*** Operational resources of the incapacitated RSA's will be cannibalized, (e.g. taking over the energy reserves, sensors and other spare parts) and used either to upgrade the operational capability of other surviving RSA or they can be combined making a new operational RSA's from the incapacitated agents.

  ⇒ **???** Value of extending *recycle_the_dead (..i.e. the useless)* RSA cannibalism to a more aggressive *big_fish_eats_smaller_fish* survival of the fittest cannibal behavior.

- **In order to facilitate recycling**, RSA's should have:
  (i) *modular reconfigurable structures*, with accessible and easy to assembly /disassembly components.
  (ii) *status advertising* mechanism telling other agents about their job meaningful *functional qualification* and *health level*.



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The **multi-sensor fusion architecture** may be based on the mission-critical *JDL Data Fusion Model* developed by the Joint Directors of Laboratories Data Fusion Group .

This architecture has five functional levels.

* *level 0* "Signal/Feature Assessment" and *level 1* "Entity Assessment" essentially asses the measurement data;
* *level 2* "Situation Assessment";
* *level 3* "Impact Assessment" essentially asses the information recovered from data;
* *level 4* "Performance Assessment" provides sensor management functions for process refinement.
* a supplementary knowledge-management *level 5* "User Refinement" is used delineate the human from the computer in the process refinement and allow for the adaptive decision of who can query and respectively access the information and the collected data in order to support cognitive decision support and actions.