Robotic, Human, and Symbiotic Sensor Agents

Emil M. Petriu, Dr. Eng., FIEEE
School of Information Technology and Engineering
University of Ottawa
Ottawa, ON., K1N 6N5 Canada
http://www.site.uottawa.ca/~petriu

Abstract

This presentation will discuss a new generation of intelligent autonomous wireless Robotic Sensor Agents (RSA) working together with humans for monitoring complex unstructured environments. It will address three major topics:

- critical Infrastructure and environment monitoring for security and natural and man-made disaster mitigation applications;
- RSA technology development problems;
- human-computer interaction and symbiotic partnership in tele-monitoring applications;

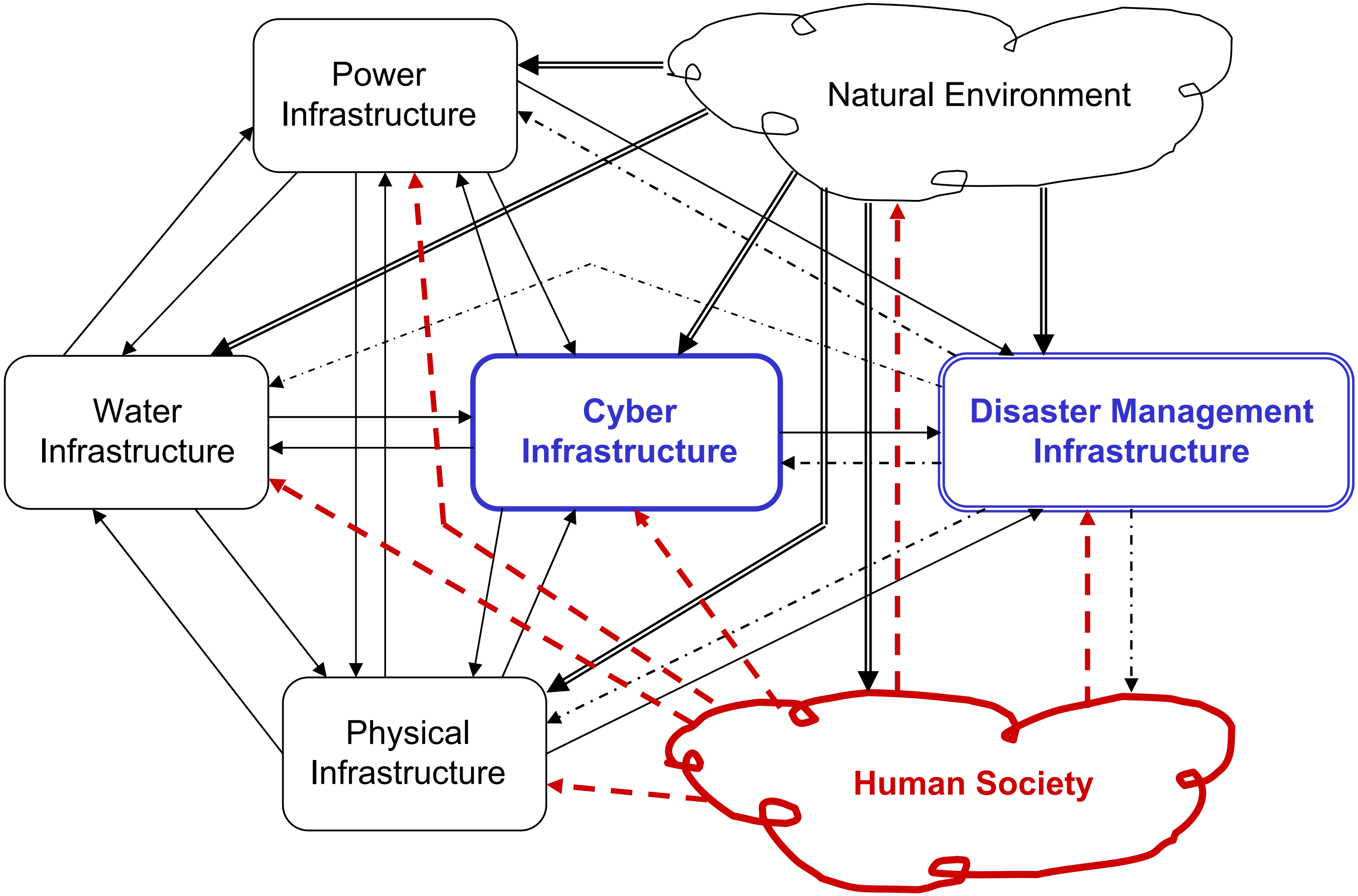
Critical Infrastructure and Environment Monitoring for Security, and Disaster Mitigation Applications;

☐ Evaluation of the impact of the natural disasters (earthquakes, extreme weather events such as hurricanes or tornados) and human-made disasters to the society must be evaluated based on their probability of occurrence and their interdependencies. The downstream consequences of such failure on the rest of society will depend on human responses to the failure and on site-specific relations between infrastructure components.

☐ Powerful modeling tools are needed to simulate disaster situations for the evaluation of critical failure interdependencies between infrastructure components. “What-if-scenarios” should allow studying all the aspects of risk mitigation, disaster preparedness and post disaster planning.

☐ Real-time smart sensor networks monitoring instances of infrastructure failure will allow running simulations which are conformal to the reality.

❑ Our approach to deal with the inherent complexity of the emergency response system is to develop a generic simulation tool that can consider any subset of relevant infrastructure components for which sufficient data and knowledge of infrastructure interdependencies are available. This simulation tool will allow the user to develop a model of interdependent infrastructure components for a particular location. The simulation software will have a modular open architecture allowing for the subsequent addition of new infrastructure elements, including social systems.



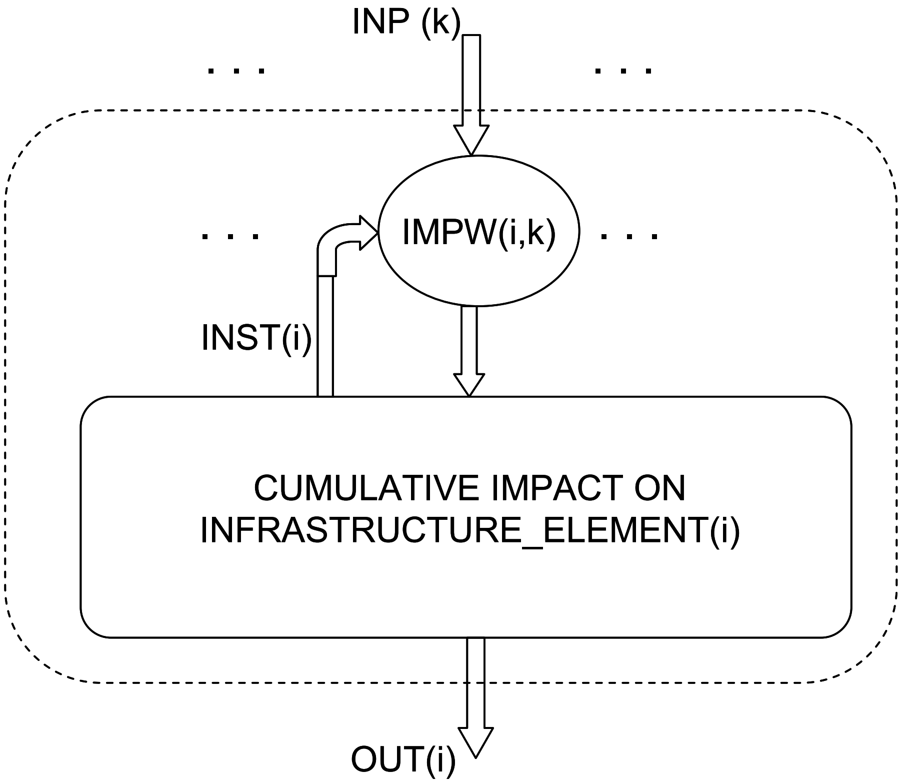
Interdependencies Between Infrastructure Elements.
Each infrastructure element is spatially and temporally indexed to facilitate modelling of infrastructure interdependencies.

Smart Sensor Network for Infrastructure and Environment Monitoring

- Networks of *Intelligent Sensor Agents* (*I*SA) are used for monitoring failure in various infrastructure components, including seismic or blast structural failure, dam failure, and water treatment failure. These sensor networks provide real-time data for detecting infrastructure failures and for updating simulations of critical infrastructure failure interdependencies during failure events.

- Monitoring critical parameters of the infrastructure elements and the environment will be infrastructure dependent. The complexity of this task is a function of the nature of the parameters and the nature of the environment to be monitored. Aspects to be considered in *ISA* design and sensor network architecture include: the type of sensors, their number and their bandwidth, the difficulties encountered while deploying the sensors in the field, the sensing region constant coverage under sensor- power constraints, and the reliability of the sensory data and of the data communication network. It is essential that redundancy is built into the system such that loss of a sensor or communication system will not impact the efficacy of the monitoring network.

Generic Infrastructure Element-Module



- Each **IMPW(i,k)** ***impact weight factor*** must be specified for each input vector/condition (k) for a given specific infrastructure element (i).

- Different formats will be pursued to implement IMPW(i,k), (DBs, analytic models, NNs and fuzzy cognitive maps.)

- The resulting impact of the ***input vector*** **INP(k)** can be affected by ***the internal state*** **INST(i)** of the infrastructure element at the moment when the input vector occurs.

Disaster management requires a clear understanding and monitoring of all critical environment and infrastructure components and their interdependencies.


7
5
6
5
6
1 available
www.ign.com


5
6
5
6
1 available
www.ign.com

Humans play an essential role in the operation of the Disaster Management Infrastructure because **:**

- humans are (still) far more intelligent than any computer;
- humans are able to adapt to a variety of computer interfaces;
- humans are able to “get the big picture” by extracting and fusing information even from incomplete and fuzzy data provided by a variety of sensors, some of them indirect sensors (e.g. vision) including from humans (“*humans as sensors*”);
- humans are able to act on incomplete or ambiguous instructions;
- humans are emotional, varying the characteristics of response function of explicit or even implicit context;
- humans are able to understand and interact directly with other humans;

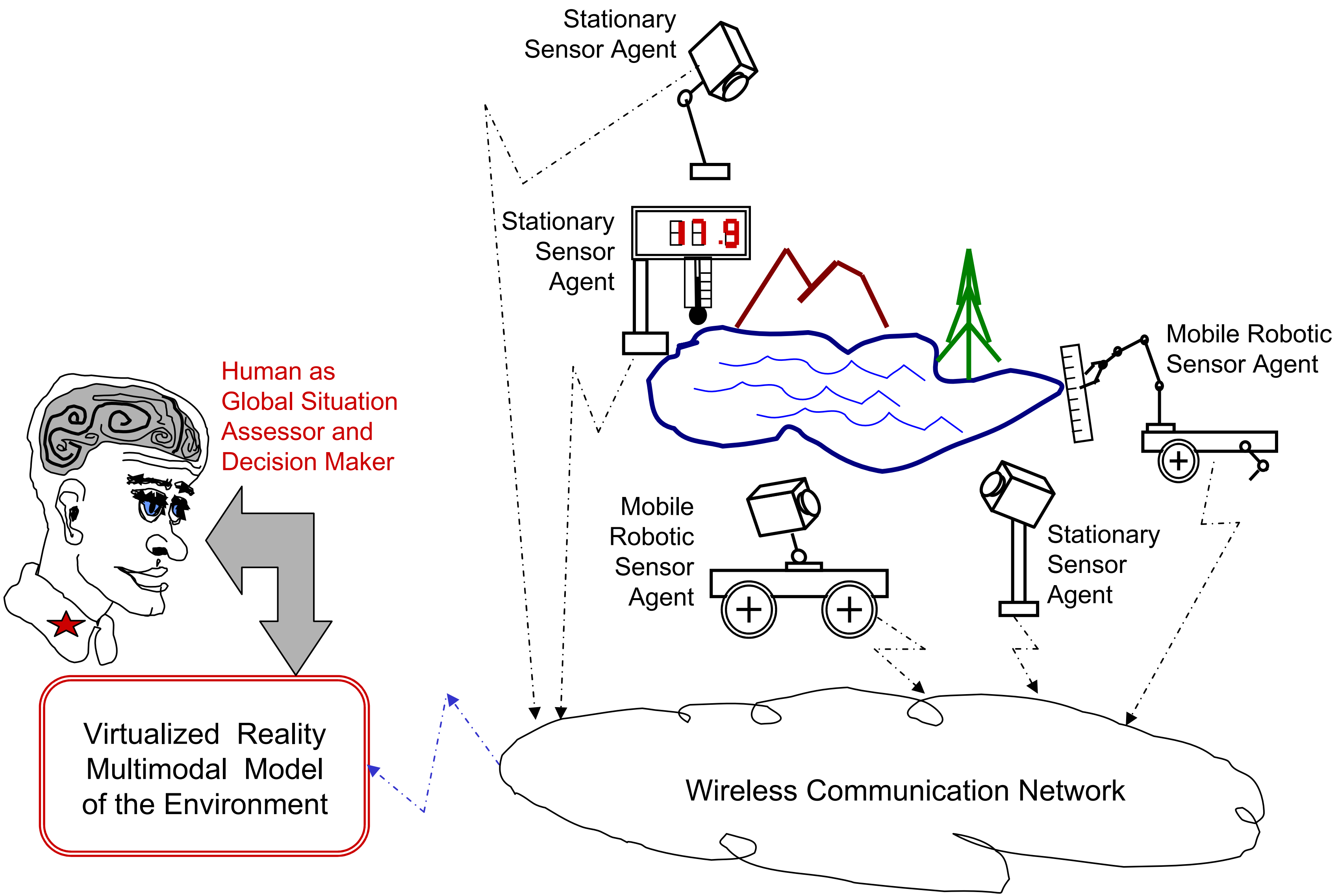
Distributed Wireless Network of Intelligent Robotic Sensor Agents for Environment Monitoring

- **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.


Stationary Sensor Agent
Stationary Sensor Agent
Mobile Robotic Sensor Agent
Human as Global Situation Assessor and Decision Maker
Mobile Robotic Sensor Agent
Stationary Sensor Agent
Virtualized Reality Multimodal Model of the Environment
Wireless Communication Network

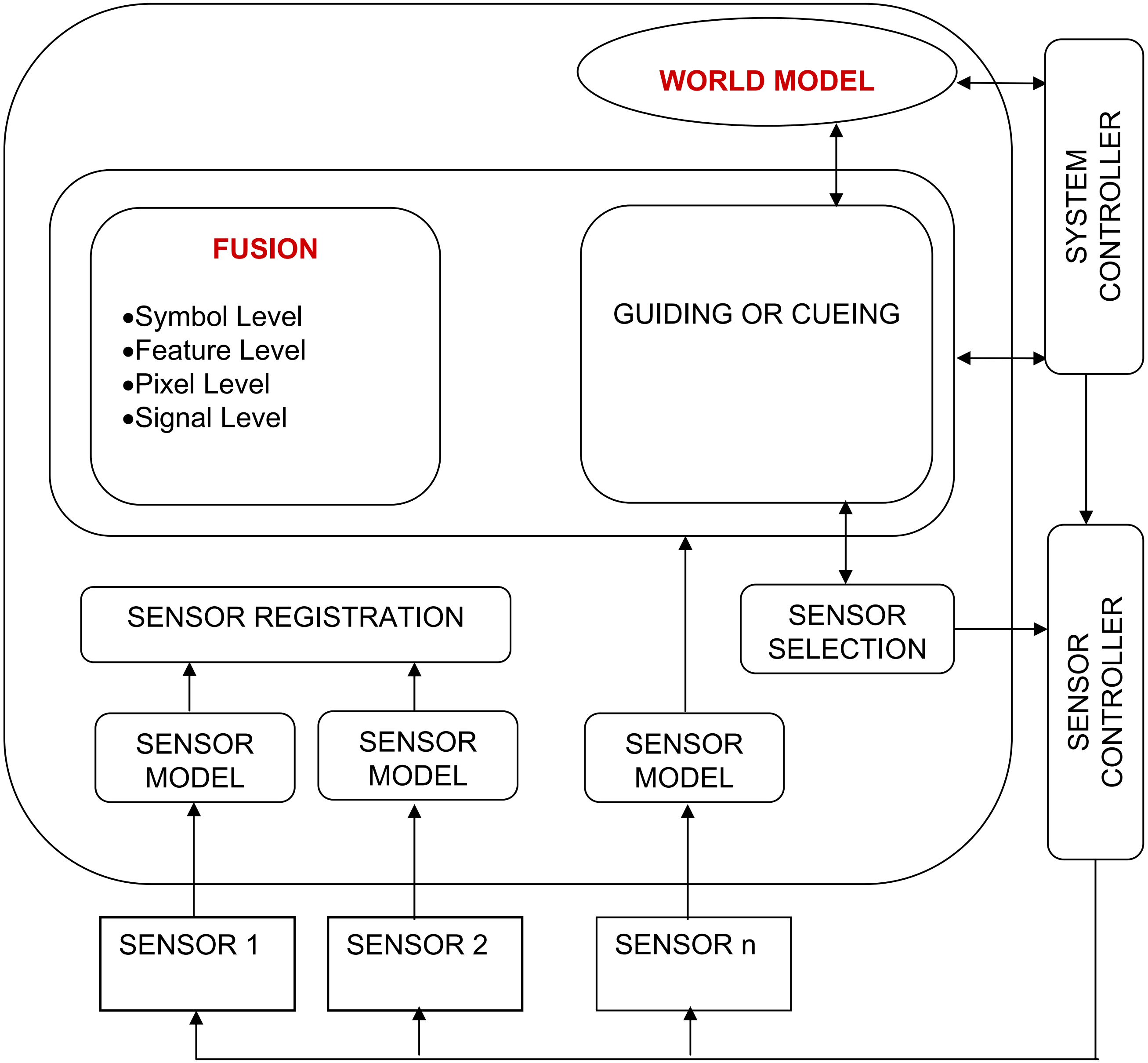
- *RSA*s should be capable of **selective environment perception** focusing on parameters that are important for the specific task and avoid wasting resources on processing irrelevant data.

  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.

Advantages of Multiple Sensors

- ***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 Data Fusion



- 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.

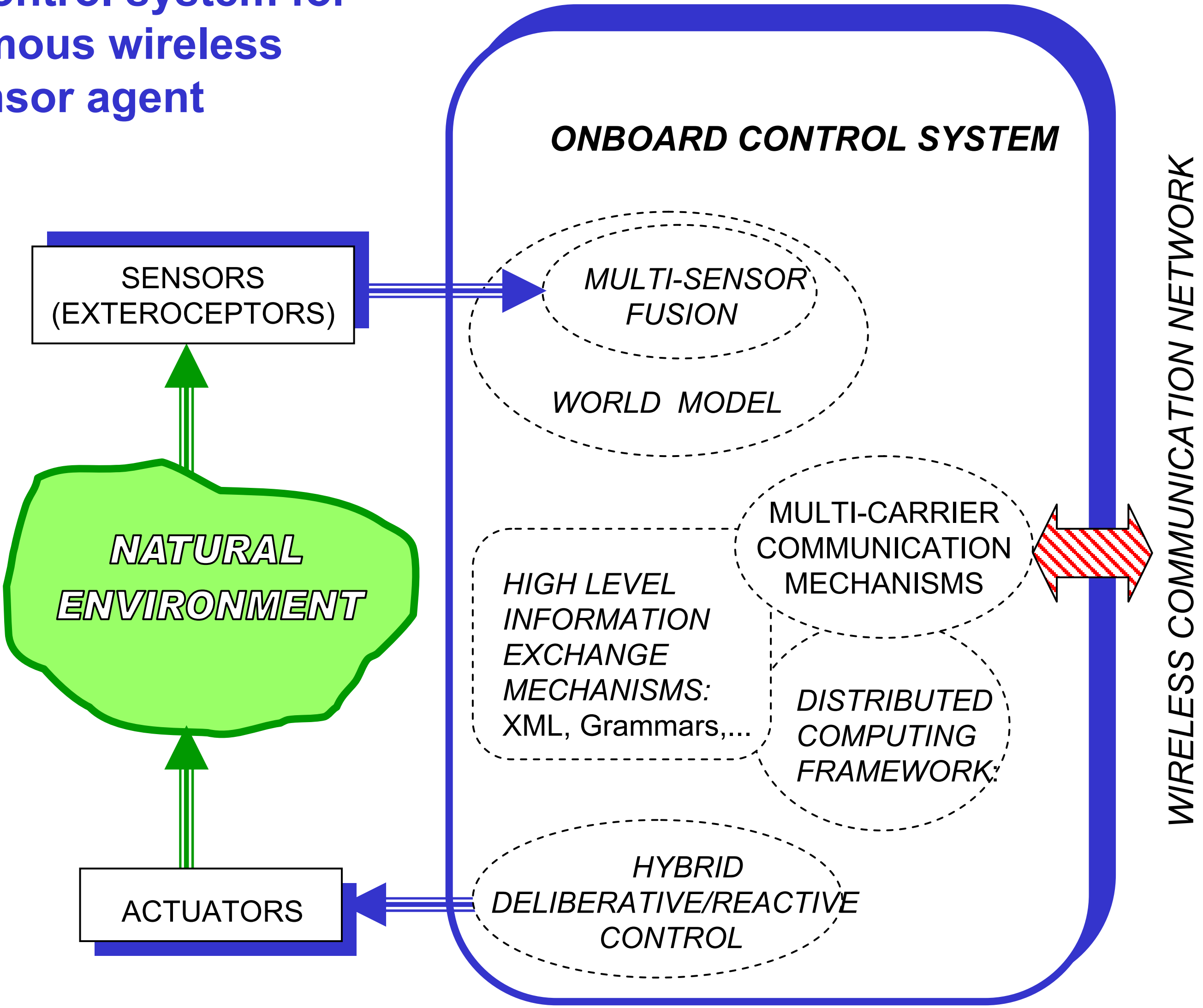
- ***RSA's are not functionally and operationally identical***. There are stationary and mobile agents that measure different environment parameters. Even if they measure the same type of parameters the sensors may have different characteristics. The robotic carriers may also have different operational 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.

- *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 communication management framework*** should be developed to allow ***for the management of heterogeneous functions and knowledge*** for a large diversity of RSAs.

- The ***RSA 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 speakers of different dialects.
  In order to provide a flexible extensible open communication *framework allowing the interoperability*, methods should be developed to allow different agents to exchange the grammars describing their own dialects and to learn to understand each other.

Onboard control system for an autonomous wireless robotic sensor agent



ONBOARD CONTROL SYSTEM

SENSORS
(EXTEROCEPTORS)

MULTI-SENSOR FUSION

WORLD MODEL

NATURAL ENVIRONMENT

MULTI-CARRIER
COMMUNICATION
MECHANISMS

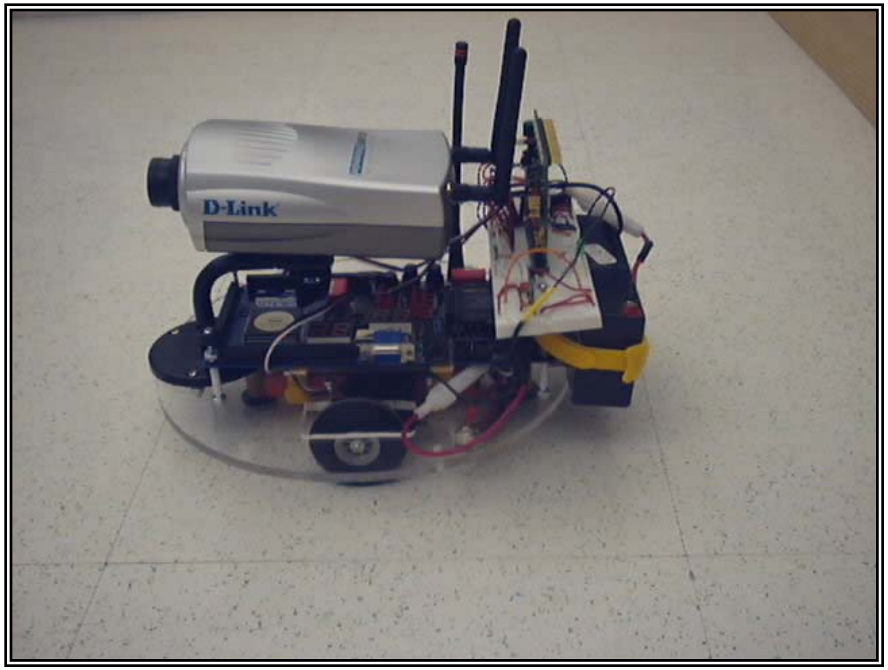
HIGH LEVEL
INFORMATION
EXCHANGE
MECHANISMS:
XML, Grammars,...

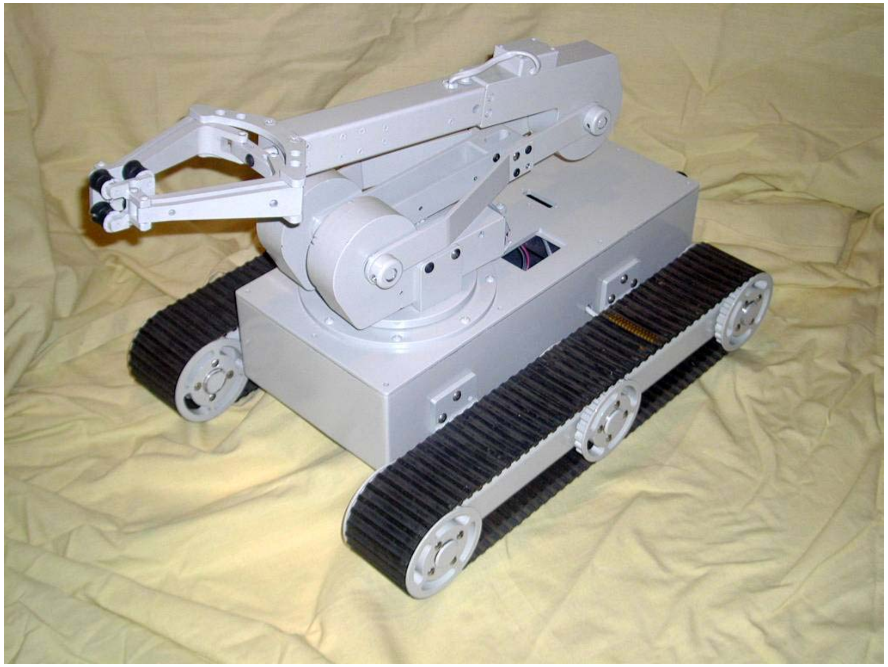
DISTRIBUTED
COMPUTING
FRAMEWORK:

ACTUATORS

HYBRID
DELIBERATIVE/REACTIVE
CONTROL

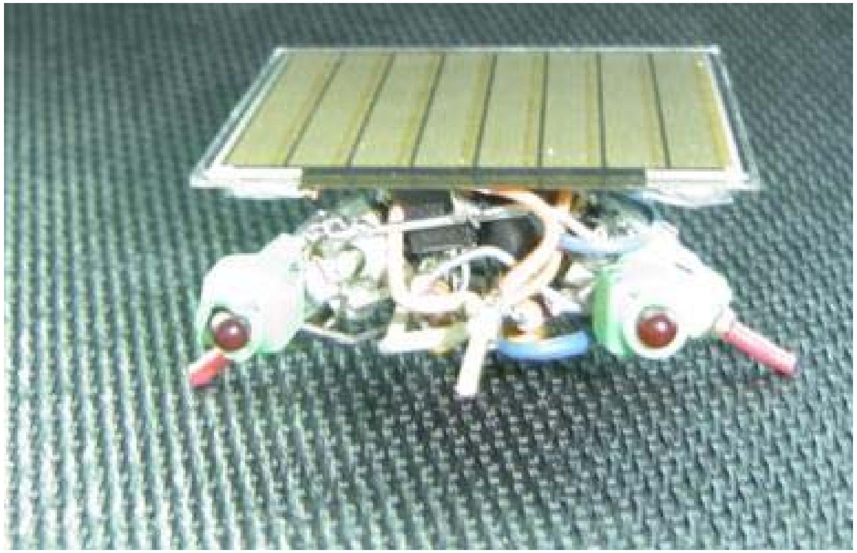
WIRELESS COMMUNICATION NETWORK





Two-wheel robotic platform for an experimental mobile autonomous RSA equipped with wireless camera and IR sensors, (*R. Abielmona, SITE, University of Ottawa*).

RSA platform on tracks with an onboard robotic arm for hazardous material manipulation.



Frog-leaping RSA powered
by a solar panel equipped
with two light detector
sensors and a touch probe,
(*A. Stewart, SITE, University of Ottawa*).
.

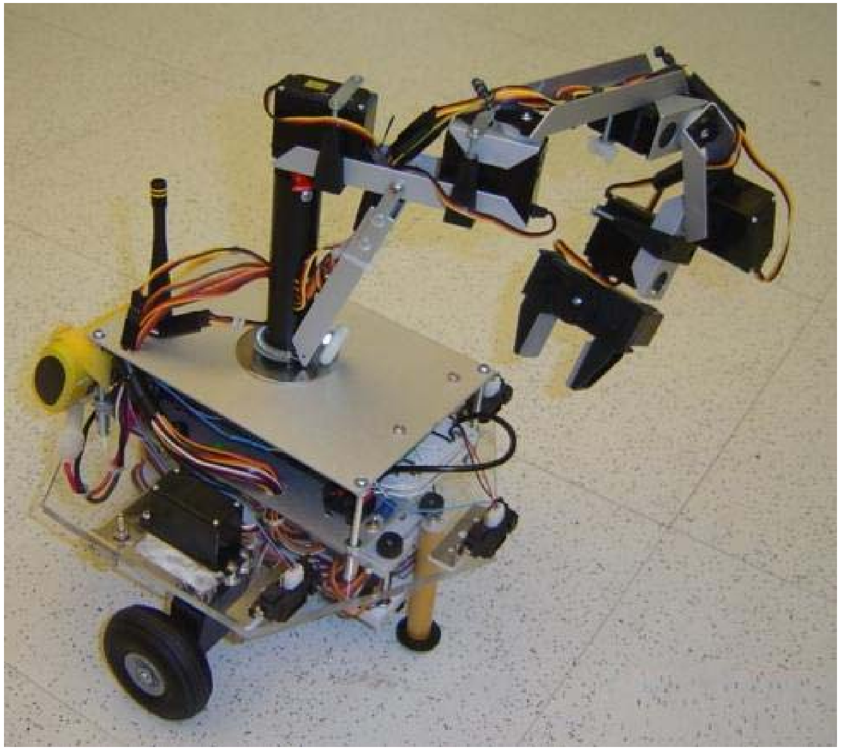
Four-leg RSA platform powered
by a solar panel, (*A. Stewart,
SITE, University of Ottawa*).

- ***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.

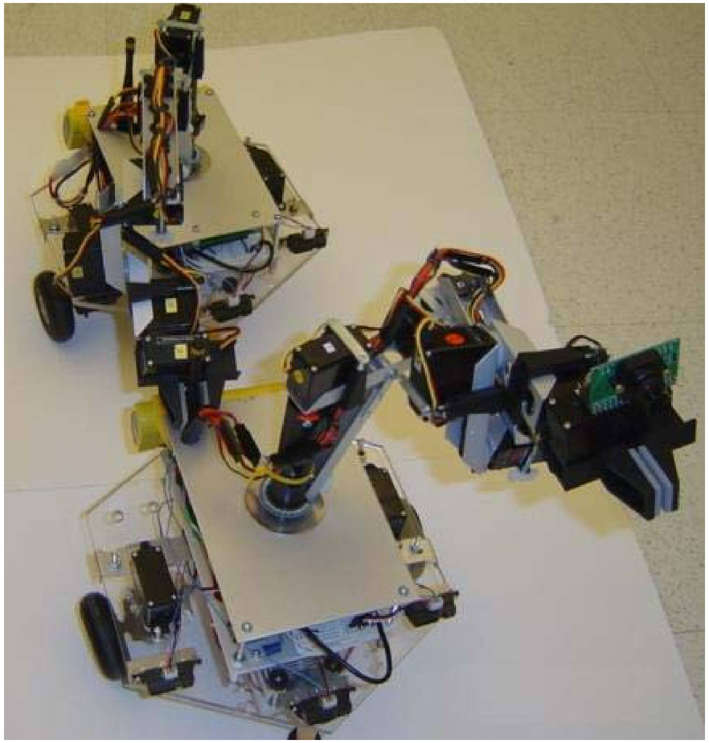
- ***Brooks' reactive-behavior paradigm*** => an alternative to the traditional function oriented *sensing-planning-acting* control strategies. The behavior paradigm is based on a task-wise decomposition of the control functions in special-purpose simple task-achieving modules. Neither strategic planning 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.



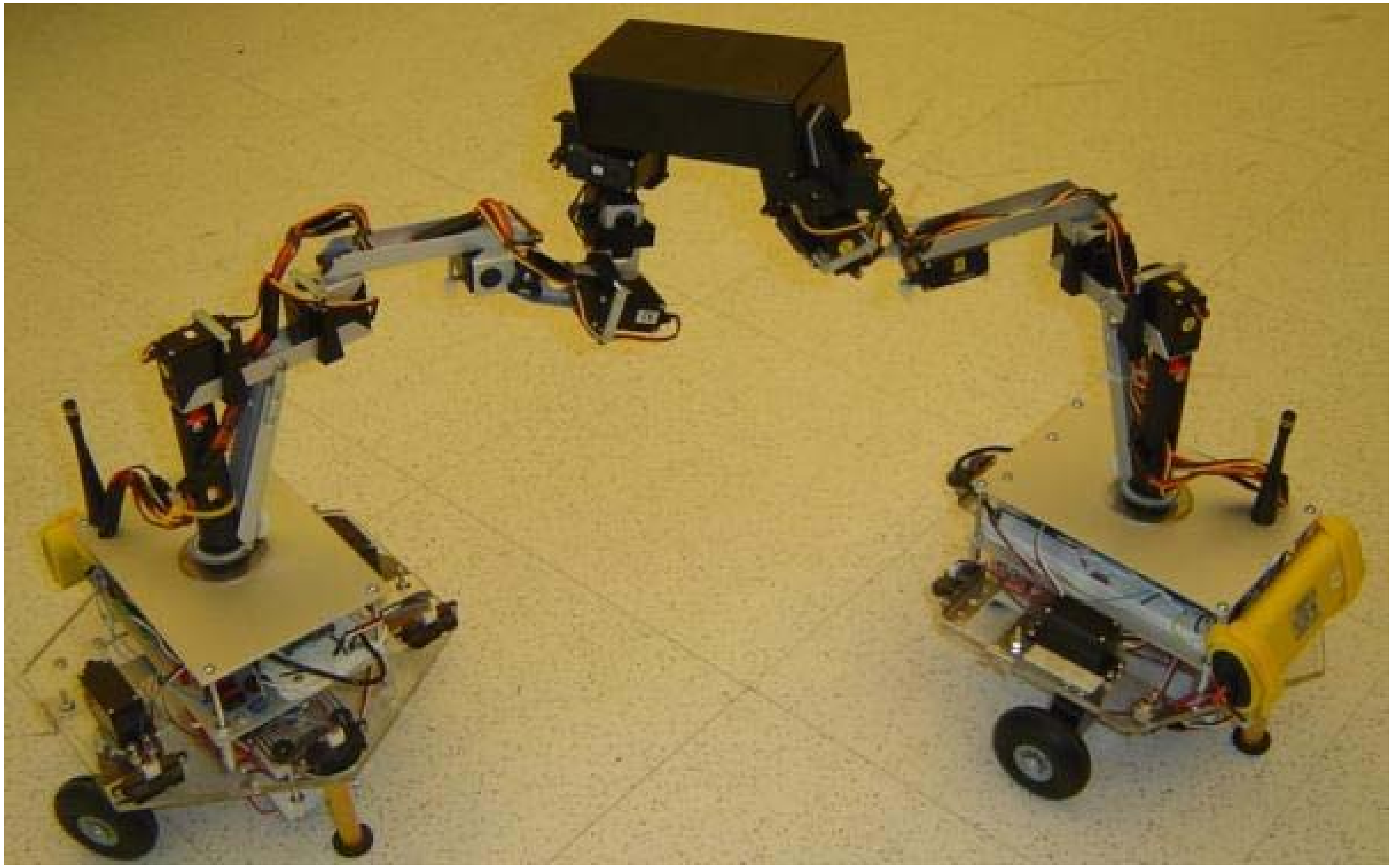
Two-wheel hexagonal-shaped modular RSA platform equipped with onboard manipulator arm, (*R. Abielmona, SITE, University of Ottawa*).



Two *RSA*s are temporarily joining to better perform their mission. The lead RSA has a video camera on the hand of its manipulator arm, (*R. Abielmona, SITE, University of Ottawa*).

- ***RSA’s should be able to cannibalize/recycle other agents*** that are operationally “*dead*”, which otherwise will be abandoned /left_to_rote in the field. This could also be extended to cannibalize /recycle RSAs that are operationally *“terminally/irrecoverably sick” ,* which **on the balance will be more useful for the overall_goal /mission** as spare parts for other RSAs than to be left to rote (dead or driving aimlessly) in the field.
  Operational resources of the incapacitated RSA’s will be cannibalized, taking over the energy reserves, sensors and other spare parts and using them either to repair or 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.

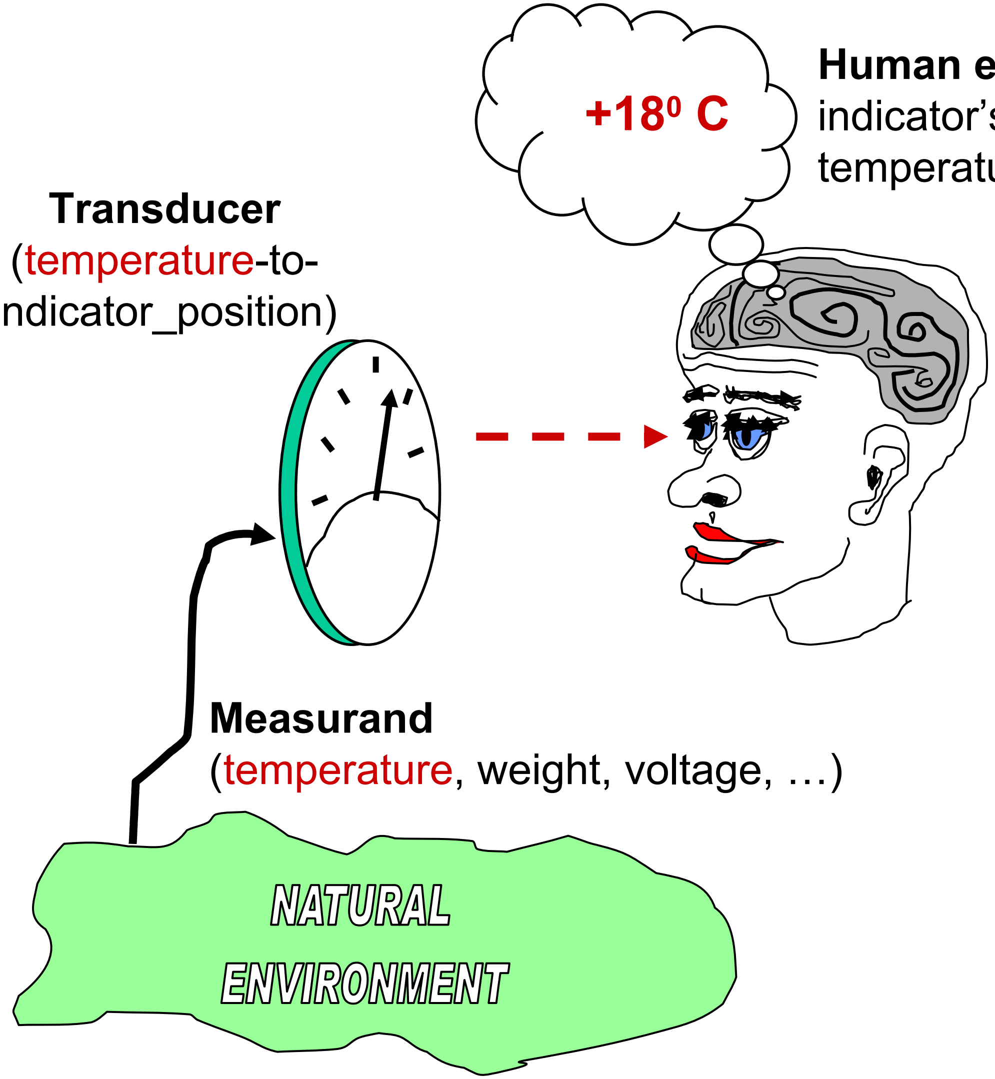


Two RSAs collaborating in order to carryout a given task,
(*R. Abielmona, SITE, University of Ottawa*).

- **In order to facilitate recycling**, RSA's should have:
  - *(i)* *modular reconfigurable structures,* with accessible and easy to assembly /disassembly components. including a convenient release mechanism that will expedite the disassembly of the components of any "dead" or "terminally/irrecoverably sick" RSA.
  - *(ii* *status advertising* mechanism telling other agents about their job functional qualification and health status/level.

- 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

Human-Machine Interaction and Symbiotic Partnership in Environment Sensing and Perception

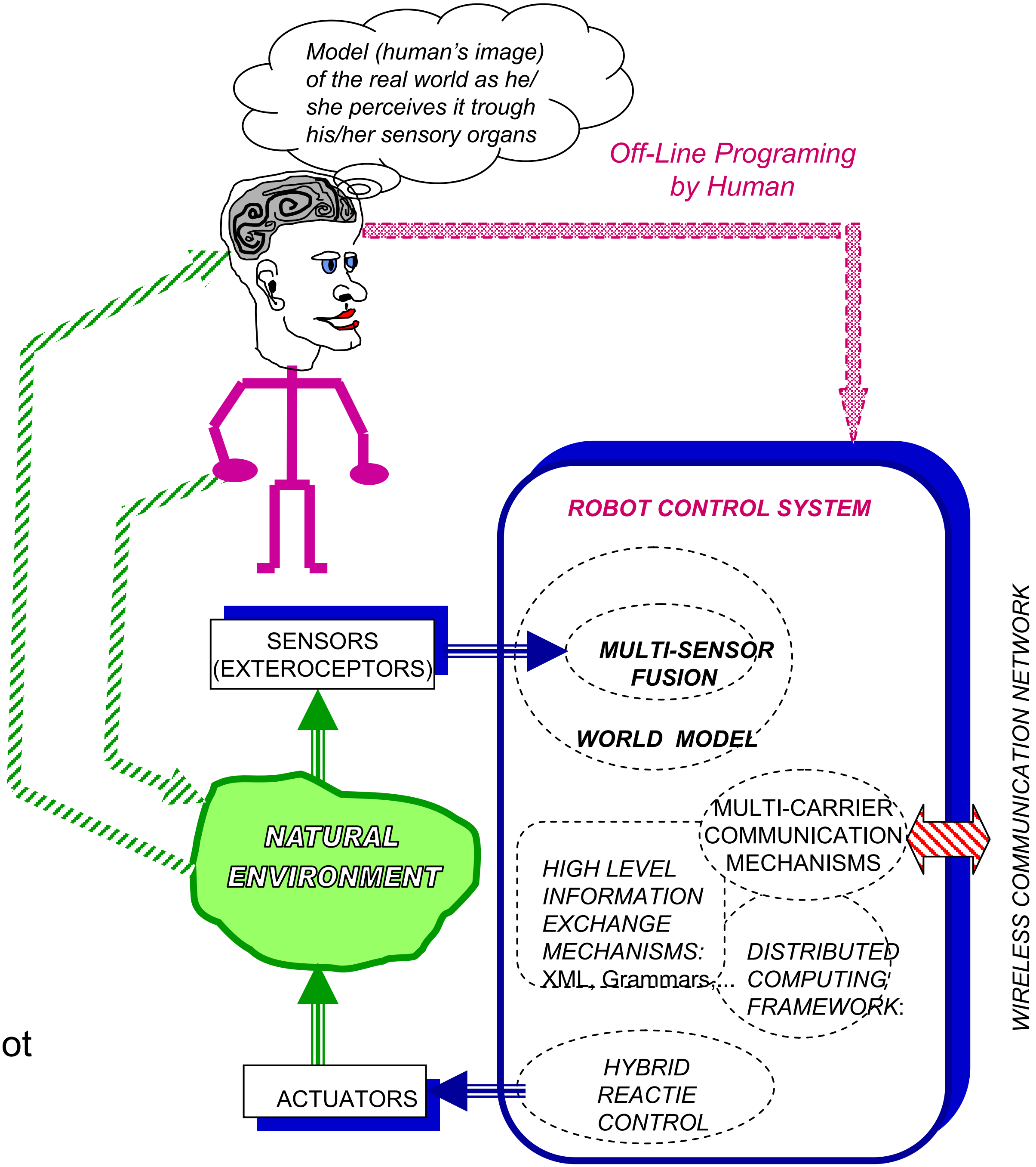


Human evaluation of the indicator's position on the temperature graded scale

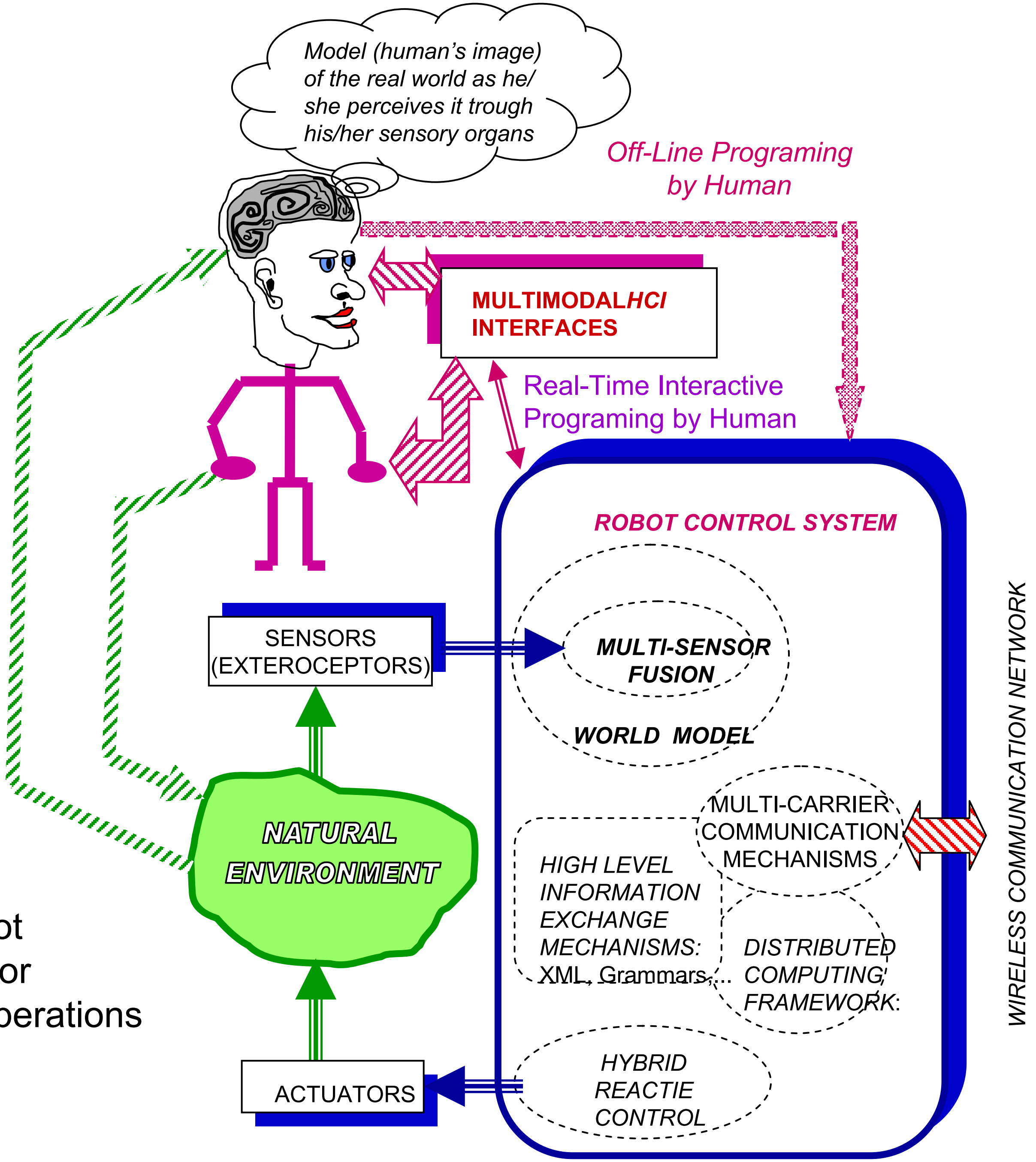
Transducer
(temperature-to-indicator_position)

Measurand
(temperature, weight, voltage, …)

The classic measurement process: an early example of human-transducer cooperation for environment sensing.



Traditional
human-robot
interaction



Model (human's image) of the real world as he/ she perceives it trough his/her sensory organs

Off-Line Programing by Human

MULTIMODAL*HCI* INTERFACES

Real-Time Interactive Programing by Human

ROBOT CONTROL SYSTEM

SENSORS (EXTEROCEPTORS)

MULTI-SENSOR FUSION

WORLD MODEL

MULTI-CARRIER COMMUNICATION MECHANISMS

HIGH LEVEL INFORMATION EXCHANGE MECHANISMS: XML, Grammars,...

DISTRIBUTED COMPUTING FRAMEWORK:

NATURAL ENVIRONMENT

HYBRID REACTIE CONTROL

ACTUATORS

WIRELESS COMMUNICATION NETWORK

Human-robot interaction for symbiotic operations

- ❑ ***Symbionts*** combine intrinsic machine-sensing reactive behavior with higher-order human-oriented world-model representations of the immersive virtual reality.

Humans are very high-bandwidth creatures:

- their visual system is capable of perceiving more than a hundred megabits of information per second, and
- their largest sense organ, the skin is capable of perceiving nearly that much as well.
- human speech conveys information in the form of intonation and inflection as well as the actual words uttered.

People communicate through "body language“ which includes facial expressions and eye movements.

Interfaces Enhancing Human Natural Capabilities

HEALTHY OR CRIPPLED HUMNAN BEING

- Brain – PDA
- Eye – eye glasses, binoculars, IR night vision device, HMD for augmented VR, ..
- *Eye +* Artificial Cornea
- *Ear +* Hearing Aid (Implant)
- ♥ Pacemaker
- Hand – gloves (baseball glove), hand tools (pliers)
- Artificial Hand
- *Knee Joint +* Artificial Knee Joint – footwear, skates, bike, exoskeleton,..

ARTIFICIALLY ENHNCED HUMAN = **SYNBIONT**

Human beings are valuable in a symbiotic partnership to the degree that their capabilities complement those of the computers/machines:

(i) humans are still far more intelligent than any computer, are able to act on incomplete or ambiguous instructions, able to adapt to a variety of computer interfaces, and able to interact directly with other humans,

(ii) humans are mobile being able to leave the vicinity of the computer, perform complex tasks in a variety of different environments, and then return to report on the outcome,

(iii) humans can recognize visual, auditory, olfactory, gustatory, and haptic stimuli,

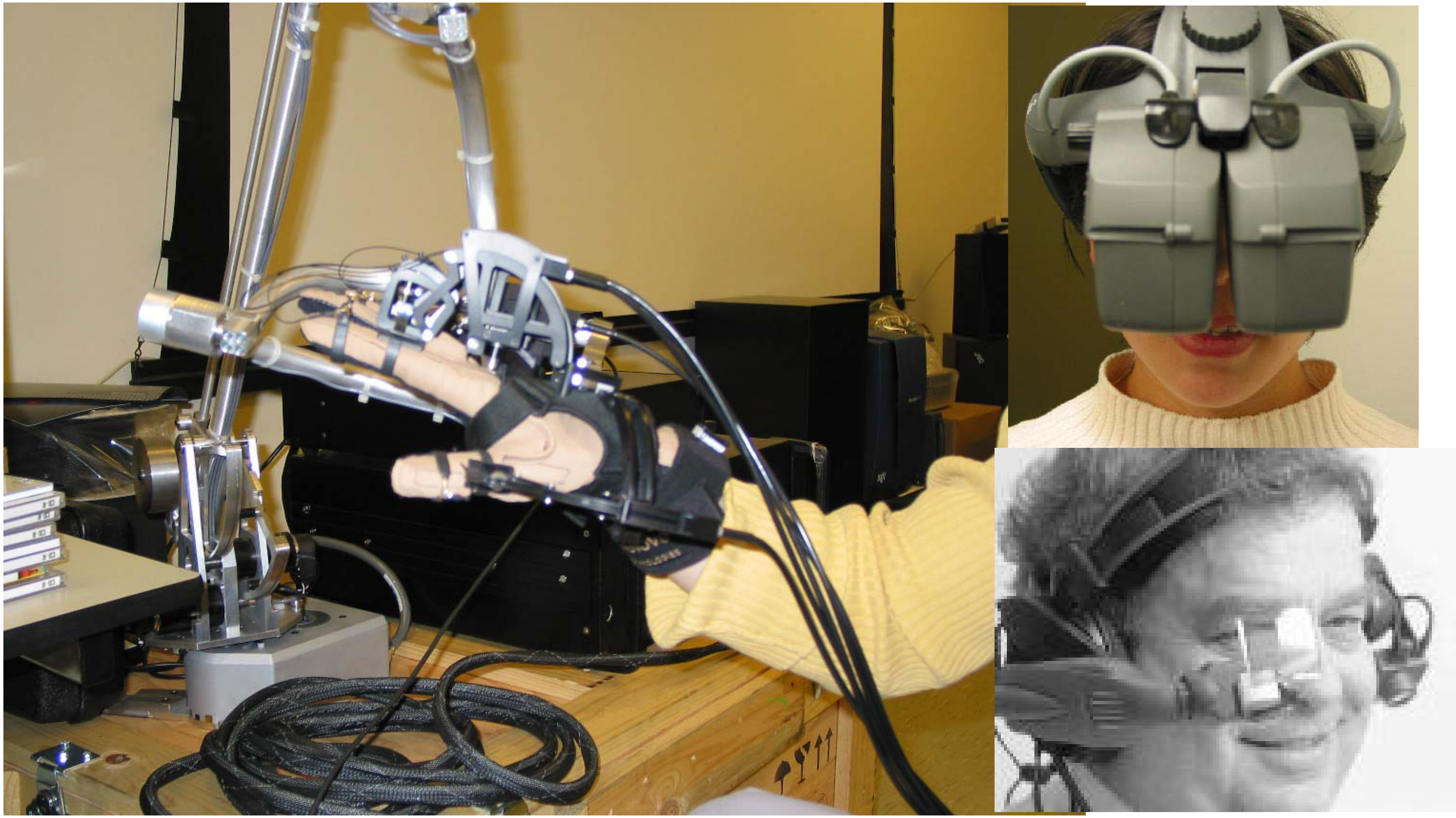
(iv) humans are dexterous, which allows them to precisely manipulate a wide variety of objects,

(v) humans are emotional, varying the characteristics of response, depending on the global state of each individual.

The ***symbiotic teleoperation system*** has a bilateral architecture allowing to connect the *human operator* and the *robotic partner* as transparently as possible.

Conformal (1:1) mapping of human & robot sensory and perception frameworks

Using a head mounted display for augmented visual virtual reality, haptic feedback, and other human oriented sensory displays the human operator controls the operation of a remote mobile robot equipped with video camera, tactile sensors , and other sensors.

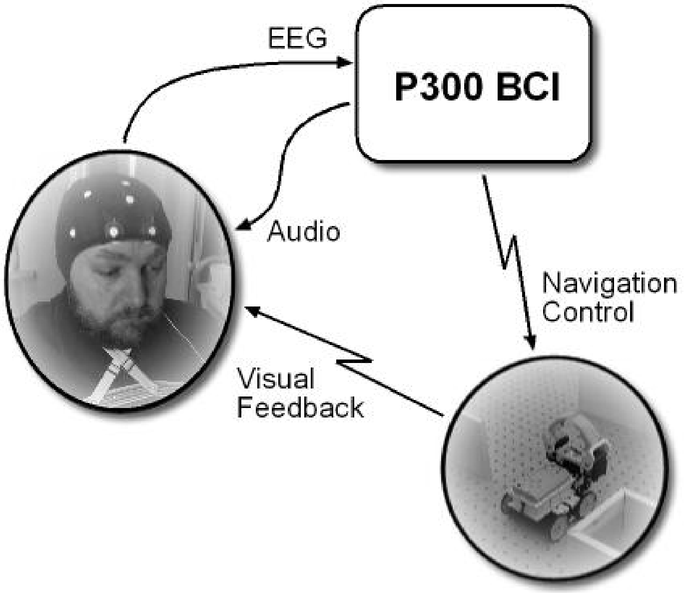


Commercial Virtual Hand Toolkit for CyberGlove/Grasp ,
Head Mounted Display, and see through visual display

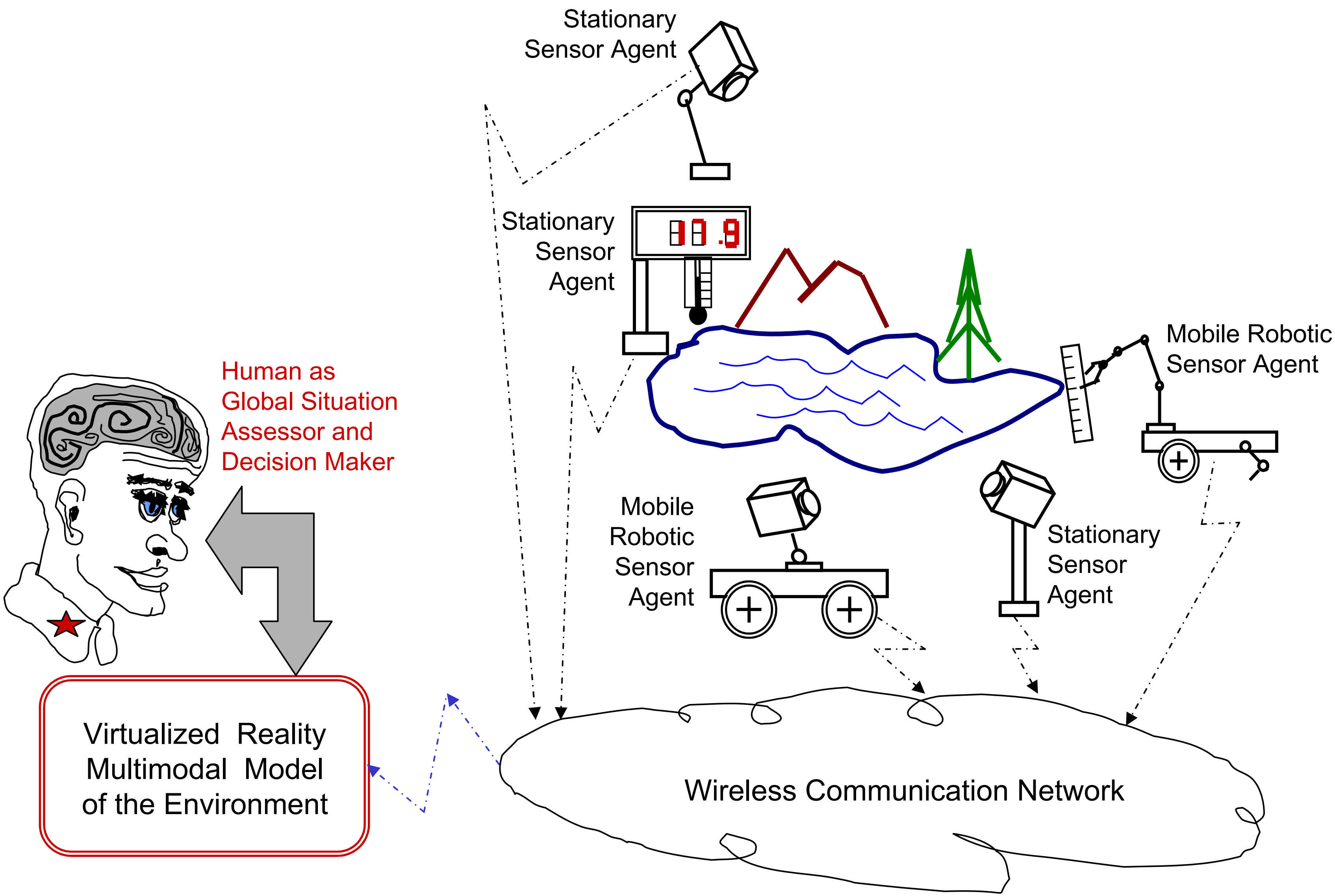
A critical requirement is the need to maintain the ***synchronism between the diverse but time correlated sensor (visual, tactile, etc) feedback modalities***. For instance, while being two distinct sensing modalities, both haptic perception and vision convey information about identical or highly correlated (in space and time) geometric parameters of the 3D objects that are manipulated.

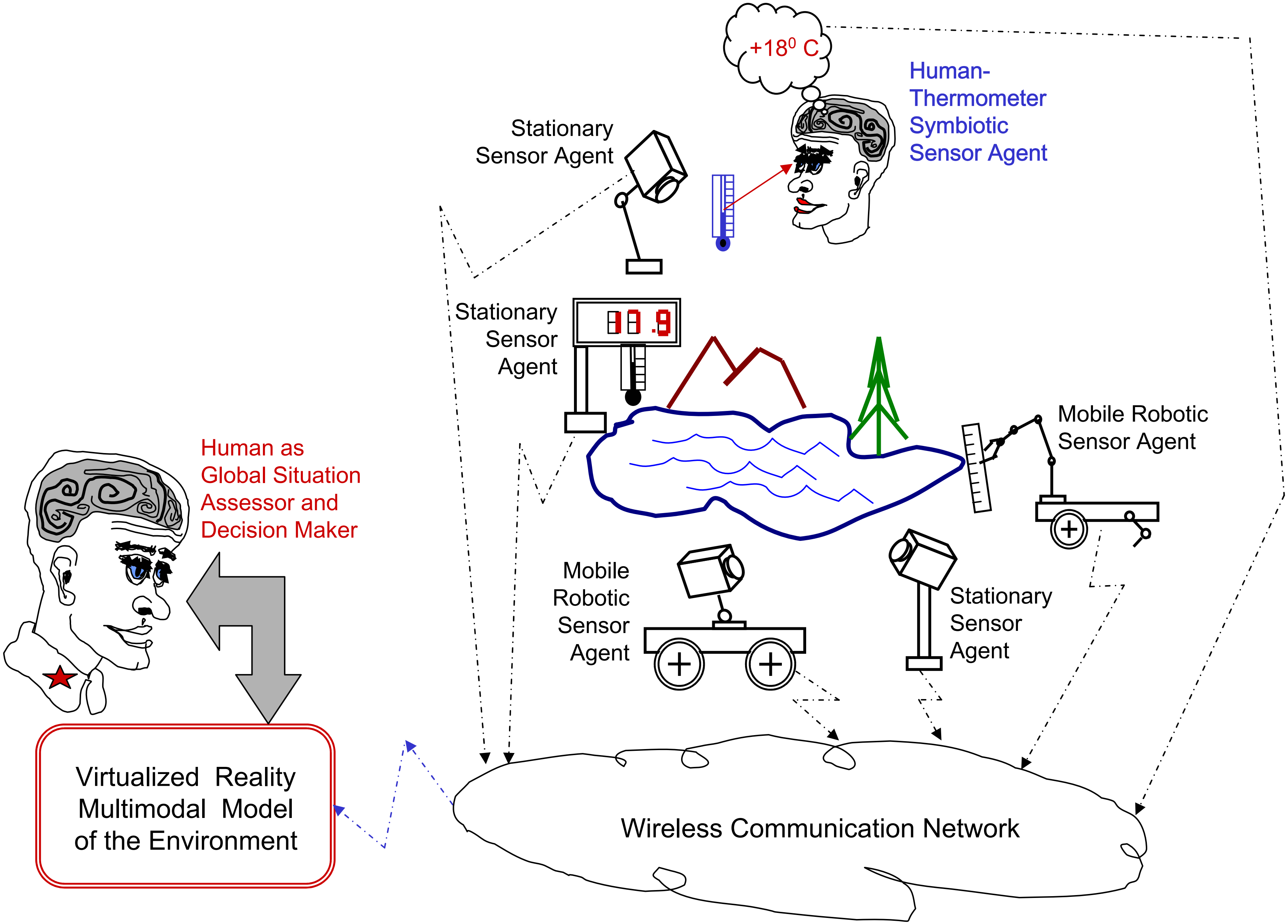
The **time clutch** concept is used to disengage **synchrony between operator specification time and remote robot operation time** during path specifications. In order to avoid fatal errors and reduce the effect of the communication delay, we are using a **distributed virtual environment allowing to maintain a shared world model** of the physical environment where the telemonitoring occurs.

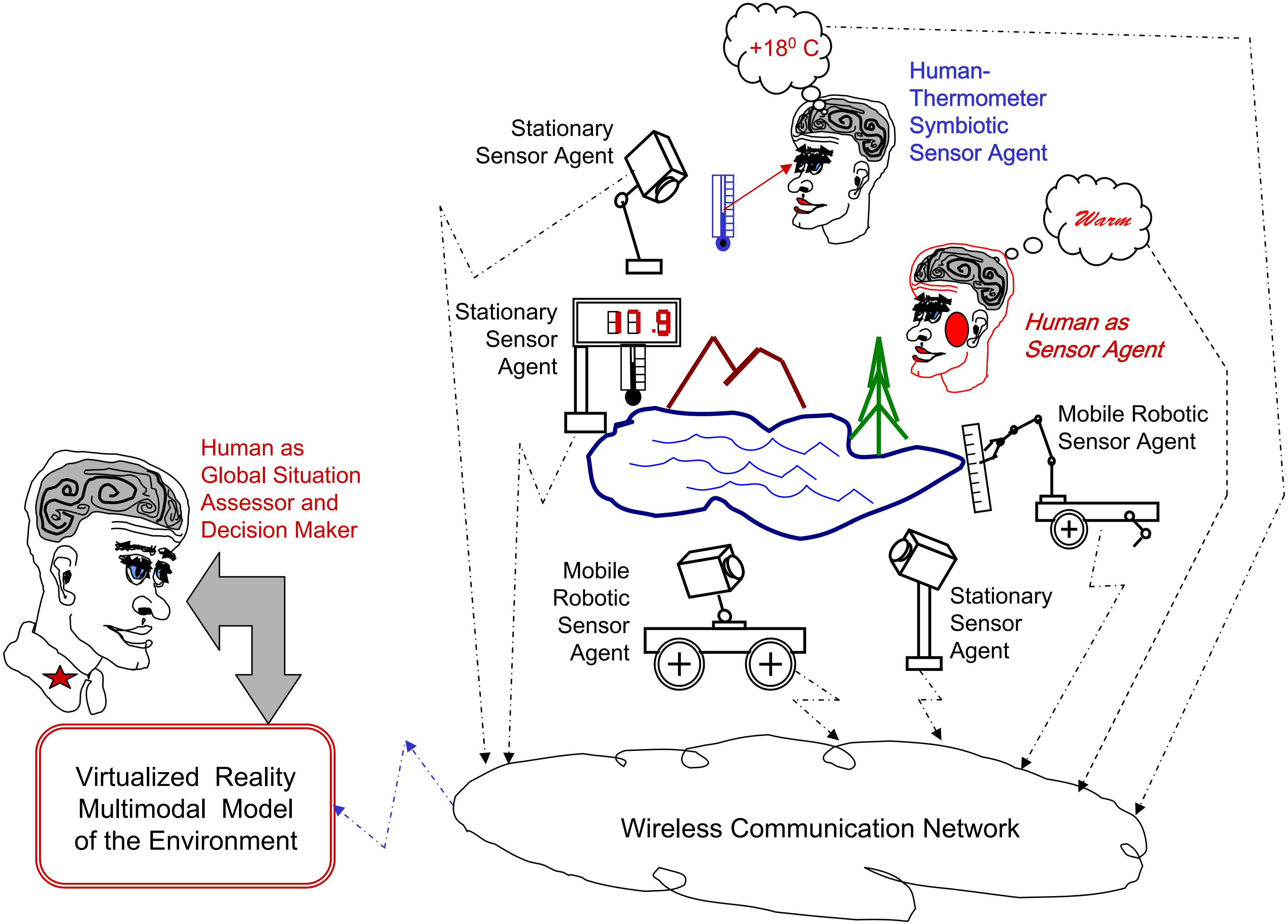
Neural Network Classification of Brain-Computer Interface Data for the Telecontrol of Symbiotic Sensor Agents

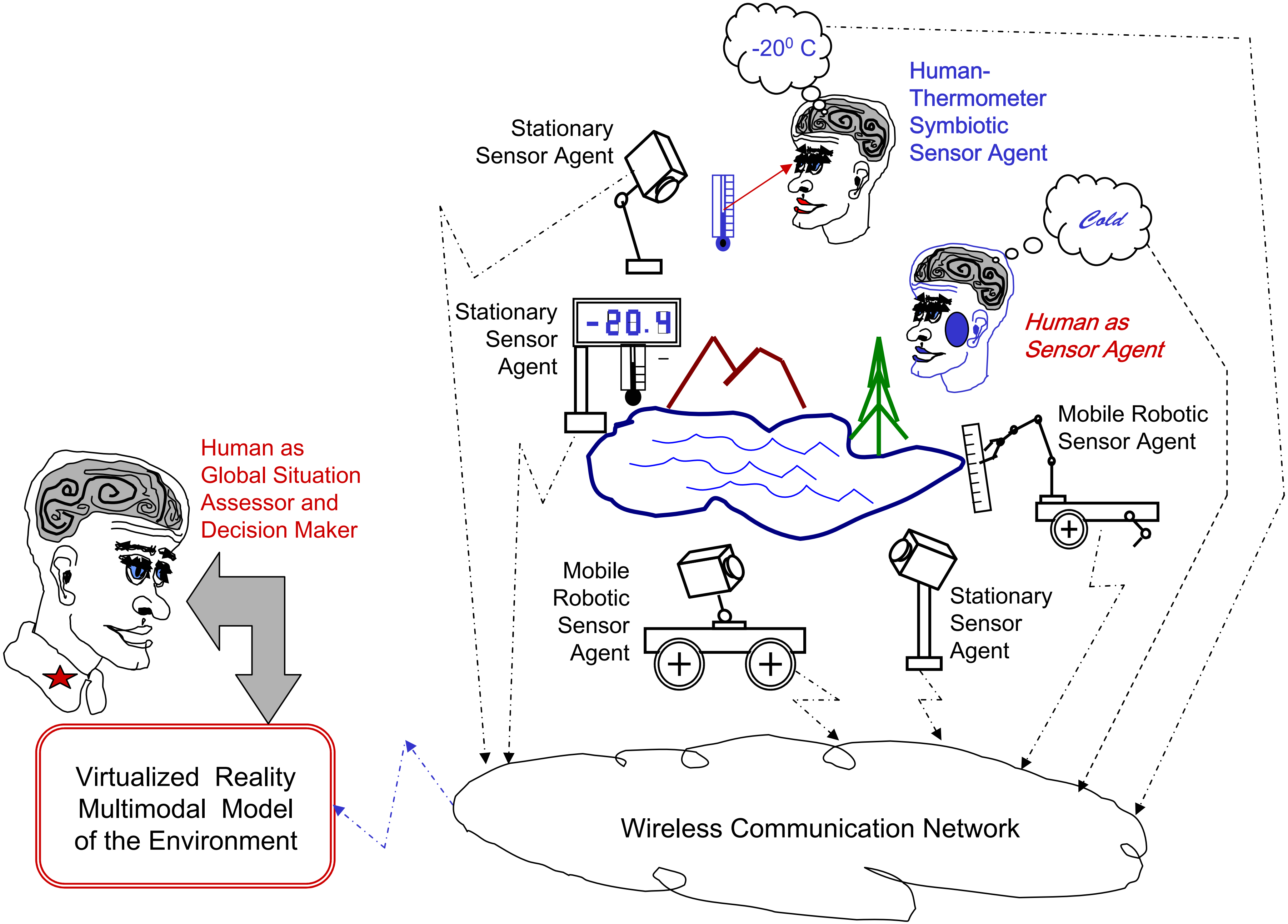


Our Brain-Computer Interfaces (BCI) system is based on the well-known oddball paradigm that uses a positive deflection in EEG signal of about 300ms (P300) after rare expected stimuli is evoked. The advantage is that subjects do not have to be trained to generate the P300 effect as it occurs naturally in human subjects. We are using auditory stimuli to generate the P300 responses and a less computationally intensive MLP feed-forward NN for the classification of the EEG responses. In our experimental setup a human teleoperator equipped with visual and audio HCI, and a BCI controls at the strategic level the movements of an intelligent semi-autonomous RSA equipped with an on board camera and three IR sensors that semi- autonomously navigates through a maze using a tactical-level obstacle-avoidance algorithm


Stationary Sensor Agent
Stationary Sensor Agent
Human as Global Situation Assessor and Decision Maker
Mobile Robotic Sensor Agent
Mobile Robotic Sensor Agent
Stationary Sensor Agent
Virtualized Reality Multimodal Model of the Environment
Wireless Communication Network


+18^0 C
Human-Thermometer Symbiotic Sensor Agent
Stationary Sensor Agent
Stationary Sensor Agent
Mobile Robotic Sensor Agent
Human as Global Situation Assessor and Decision Maker
Mobile Robotic Sensor Agent
Stationary Sensor Agent
Virtualized Reality Multimodal Model of the Environment
Wireless Communication Network


+18⁰ C
Human-Thermometer Symbiotic Sensor Agent
Stationary Sensor Agent
Warm
Stationary Sensor Agent
11.9
Human as Sensor Agent
Mobile Robotic Sensor Agent
Human as Global Situation Assessor and Decision Maker
Mobile Robotic Sensor Agent
Stationary Sensor Agent
Virtualized Reality Multimodal Model of the Environment
Wireless Communication Network


-20⁰ C
Human-
Thermometer
Symbiotic
Sensor Agent
Stationary
Sensor Agent
Cold
Stationary
Sensor
Agent
-20.4
Human as
Sensor Agent
Mobile Robotic
Sensor Agent
Human as
Global Situation
Assessor and
Decision Maker
Mobile
Robotic
Sensor
Agent
Stationary
Sensor
Agent
Virtualized Reality
Multimodal Model
of the Environment
Wireless Communication Network

- Human sensor information is “fuzzy quantizied” while the machine sensor information, both the symbiotic analog_ transducer & human, and the fully automated digital one, is “sharp & concatenated quantized” [E.M. Petriu, G. Eatherley, “Fuzzy Systems in Instrumentation: Fuzzy Control,” Proc. IMTC/95, IEEE Instrum. Meas. Technol. Conf., pp.1-5, Waltham, MA, 1995.]

- It is possible to reduce the uncertainty of the measurements involving humans as sensors part of multisensor systems, by using Fuzzy Cognitive Maps, NNs, and Associative Memories.

Thank You !