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A CYBER PHYSICAL SYSTEMS APPROACH FOR ROBOTIC SYSTEMS DESIGN

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The analysis, design and development of complex, systems that can integrate physical with virtual components has been incorporated in emerging paradigms such as Cyber-Physical Systems or Internet for the Future. In the present paper, the authors propose a set of principles that have to be considered when developing and integrating Robot Systems. In order to demonstrate the principles a Robotic Development Platform architecture that integrates principles of Cyber-Physical Systems is proposed. The proposed architecture will allow robot systems to be tested in different environments, and facilitate the integration of real world simulation with virtual environment simulation.

Keywords: Robot Systems, Cyber Physical Systems.

1. INTRODUCTION

Cyber-Physical Systems as defined by the National Science Foundation represent: “engineered systems that are built from, and depend upon, the seamless integration of computational algorithms and physical components”

A generic CPS encompasses physical objects, sensors, actuators, computing devices, controllers and communication network. The Cyber-Physical System paradigm refers to the integration of “Cyber” (computation / communication / control) and “Physical” (natural / human-made systems operating in continuous time) components

CPS research areas are focused on:

- “capability, adaptability, scalability, resiliency, safety, security, and usability that will far exceed the simple embedded systems of today”
- extending control theory in order to handle:
    - networks of devices
    - networked control systems
- large-scale integration of the physical and cyber worlds
- systems of systems

With the development of “intelligent objects” concept, a new step towards integration and seamless communication has been made. Supported by these objects, a new capability, virtualization, was introduced. This capability means that such an object is able to interact with users and with other intelligent objects in the virtual world. An example of such an interaction may be between a refrigerator with “intelligent object” capabilities that will interact, through the internet, with an intelligent device, like mobile robot, and provide a list of items.

The concept of enabling interaction between intelligent objects is closely related and supported by the imminent change from the “Internet of Data” to the “Internet of Things”. We can define the “internet of things” as: “the Internet of the future will be suffused with software, information, data archives, and populated with devices, appliances, and people who are interacting with and through this rich fabric”. The 2D communication provided by the “internet of data”: any time, any place is completed to a 3D model by a new dimension: anything. In this context “changing business strategies becomes the name of the game”.

Challenges for Internet of the Future include:

- Integration with heterogeneous devices
- Scale to include geographic distributed systems
- Process huge amount of data – “big data”
- Implement communication infrastructure
- Adapt to changing environment - agility
- Model and analyses complex business environments
- Manage increasingly complex working environments

2. DESIGN PRINCIPLES FOR CPS-ROBOTICS SYSTEMS

The main challenge for future robotic systems is the development of federated, adaptive, scalable, open-architecture, interoperability-focused robotic systems.

The functions identified for Cyber-Physical Systems include:

- Real-time, adaptive, systems
- Dynamic reconfiguration
    - Robust network control including: network dynamics and cyber security
- Embedded systems power management
- CPS models and architectures
    - Relationships, integration and interoperability
- Human in the loop
    - human/robot interaction.
- Object abstraction
    - creating virtual representations for physical devices – sensors and actuators – and their capabilities.
    - enabled by formalized domain representation.
- Information processing.
    - information streams - virtual representations of enabled physical devices.
    - high-level applications and processes and human components
- Domain representation
    - Semantic Web technologies - set of ontologies
    - enabled by the information processing capabilities: relationships between concepts, concepts and rules

The following Design principles for CPS-Robotics Systems have been proposed:

Sub-systems	Components
Sensing and Actuating	Sensor and actuator networks technologies Semantic enabled sensors Service Oriented Architecture Data modeling, semantics, ontologies Real-time data management,
Human in the loop	Human to Machine - > human - robot interaction Machine to Human -> robot – human interaction Human-machine interface, augmented and virtual reality Context awareness multiple robot management, collaboration,
Robot control	Network control systems
Robot collaboration	Service oriented robotic systems Intelligent decision support systems integrated into robotic systems

	Machine to Machine collaboration - > Machine to Machine learning Semantic technologies

Principle 1: CPS modelling methods:

- System modeling: SystemML
- Networked Control System modeling
  - traceability within Intelligent Informational System
- Sensor modeling: SensorML
- Machine 2 Machine (M2M) communication
  - interoperability between P2P entities
- M2M learning

ROBOTIC SYSTEM as a Complex, Adaptive, Networked System, integrating various entities (objects): robots, smart devices, humans

Principle 2: The mobile robot acting as both service provider and service consumer.

- message routing
- REST service
- semantic enabled data acquisition
- context awareness
- Future internet as supporting environment
- Interoperability-focused (data/processes/knowledge)

When analyzing human – robot collaboration principles the following is to be considered: the robot should act as “on sight” service provider and both robot to robot and robot to smart device collaborative agent and human to robot collaborative control.

The goal becomes the development of robot to robot and robot to smartdevices interoperability and collaboration tools. Several approaches to achieve this goal have been proposed. One of the approaches enforces collaboration with the help of software robots acting as collaborative. Another approach consists of a network of heterogeneous robotic devices pervasively embedded in the environment.

The design approach should consider the human-machine system as a human-centered system. The human work situation is to be analyzed with regard of the three dimensions of human-cantered systems: The Workplace as individual worker and his/her work environment, The Group-work as the group of people co-operating to achieve the same task and The Networks as organizational networks of groups

To support the human robot collaboration the three communication channels available have to be

considered: the audio, the environmental and the video channel. Regarding the audio communication there are numerous systems readily available for automated speech recognition (ASR) and text to speech (TTS) synthesis.

Principle 3: Human in the loop

- Communication channels
  - a link between the data acquired from the sensors, the intelligent decision support systems and the control system.
- Environmental Channel
  - functions that allow the robot to identify the objects from the environment as well as user’s actions/commands.
- Social Awareness
  - ability of the robot to follow a behavior that respects socially acceptable conditions and gives readable social cues indicating how the robot tries to maintain engagement during the work scenario.

- Situation Awareness (SA)
    - “knowing what is going on around you. Three levels of SA have been explored: perception, comprehension and projection.

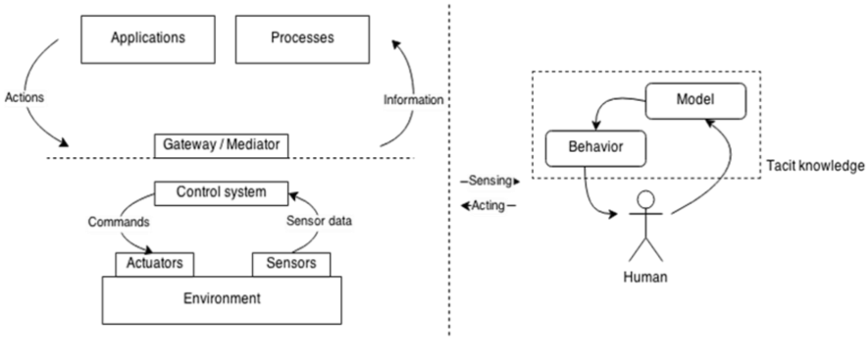

Figure 1. Human in the loop models

Principle 4: Process recognition
Methods organized in categories:

- data driven
- knowledge driven
- hybrid recognition methods: based on probabilistic logic, Advantages: handling uncertainty and incomplete information, based on log-linear description logic and Markov Logic Networks.

Process mining consists of: process discovery, conformance checking and process model enhancement. The process analysis technique proposed is based on a process discovery algorithm. Semantic process modeling systems use ontologies in order to describe the modeled components, the correspondence between instances of classes of an ontology and events is the basis for process representation.

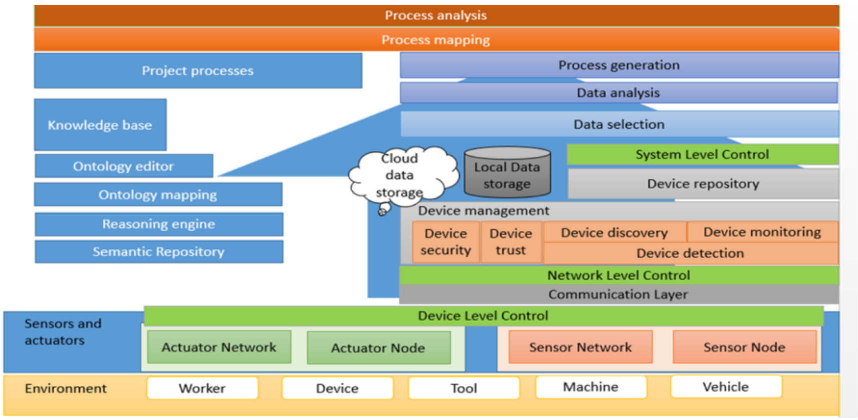

Figure 2. CPS Process Recognition Framework

3. CASE STUDY - VIPRO PLATFORM

VIPRO Platform Specific Environment is developed to enhance the facilities of a robot platform development environment. VIPRO platform consists of the following layers:
Communication layer that incorporates the network and communication technologies
Interface layer that allows the integration of intelligent interfaces with mobile robots
Management layer extended with a dedicated integration module for existing robot platforms
Control layer that implements intelligent control techniques and motion planning

User interaction layer

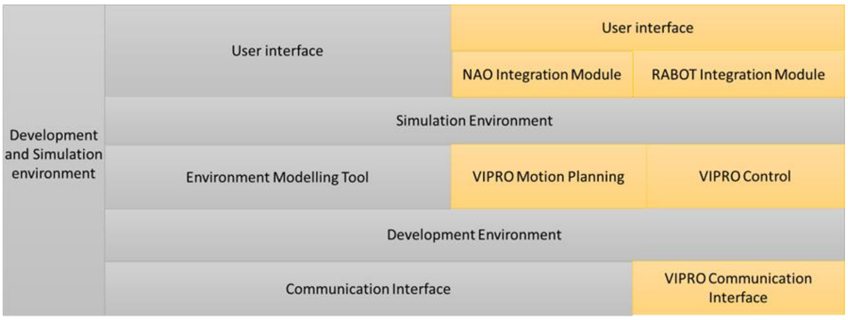

Figure 3. VIPRO Platform Specific Environment

VIPRO platform integrates several modules providing the possibility of direct control of the robot simulation or through a user interface:

- a way of communication with mobile robots independently or using intelligent interfaces
- a dedicated management module for different existing robotic platforms
- a module that implements intelligent control techniques and one for motion planning

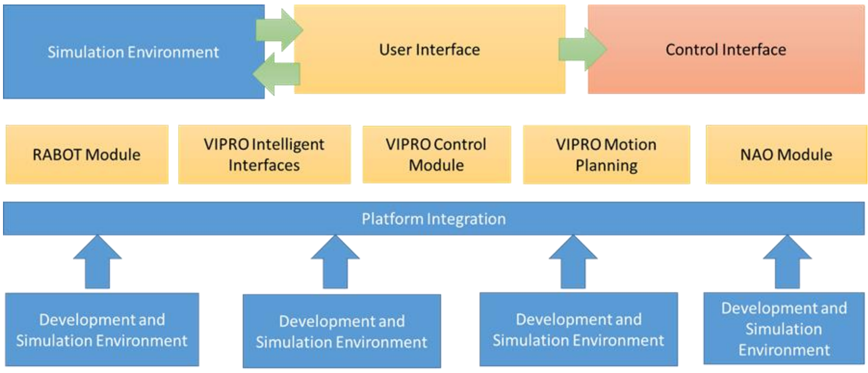

Figure 4. VIPRO Platform Components

4. CONCLUSIONS

The concepts, proposed within the Cyber – Physical Systems paradigm are becoming a reality due to the research efforts leading towards the development of new devices and integration within systems of systems.

A hybrid knowledge structure can be foreseen, where the interaction between human and non-human knowledge stakeholders will became transparent and will allow creation and use of meta-knowledge.

The proposed platform architecture facilitates the integration of development and simulation environments and enhances their capabilities by combining virtual environment simulation with real world testing.

Design principles for CPS oriented Robotic Systems must include capabilities such as: semantic concepts for the description of system components, support for both asynchronous and synchronous communication and distributed storage of the system's semantic concepts.

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