A Prototype of CPS Systems

Semantical approach
– Extended abstract –

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Abstract

In the present paper I briefly summarize the descriptions of cyber-physical systems considered for overviewing general terms, discovering typical approaches, surveying case study types encountered in the literature, making connections with distributed systems, and using semantical approaches for modeling and design.

First, the most common notions and terms are presented for a structural and systematic description of the CPS systems. Second, the survey of some case studies have the goal of looking into methodologies and research evaluations types about CPS systems. Especially the description of fault tolerant systems are important studies regarding the safe behaviour of CPS systems.

The description is presented from the perspective of the applicability in designing and coordinating CPS systems. The sections covering the descriptions are pointing to important features considered relevant for defining a prototype of CPS systems.

The paper includes the initial research steps taken for describing the semantical modeling and designing of CPS systems, with conclusions regarding further deep analysis and considerations on systems' definitions.

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1. Introduction

The goal of the paper is to present a brief summary of the survey of CPS systems in terms of semantics, case studies about modeling, connections with distributed systems, interoperability with other complex systems, and to define a prototype of CPS systems according to the established main features.

The analysis covers general terminology used in CPS systems for describing the collaborating computational units controlling physical entities, probability ontology questions, relationships with other type of complex systems (embedded systems and distributed systems), and design issues for executable semantics approach for modeling and designing.

General structural description is considered when modeling and designing steps are taken for describing CPS systems by probabilistic semantical approach. The CPS systems' analysis of the paper covers aspects, features, and approaches from various point of views in order to establish the prototype model of the CPS systems. Several important notions, definitions of CPS systems' world are clarified, while a survey of case studies of CPS systems is given.

Studying relationships between CPS and distributed systems, or CPS and embedded systems are important for taking the write design and modeling steps. The paper makes important comparisons with distributed systems due to the earlier expertise in multi-layered distributed system description with semantics given in executable way.

In the CPS system design important questions of semantics of complex systems are addressed from probabilistic ontologies' viewpoints as well. Executable semantics application possibilities for CPS systems are considered.

The interoperating units, the CPS actors are identified in order to design and model a prototype of CPS systems using system descriptions and features a priori established. The semantical descriptions of complex CPS systems contributes to the establishment of a CPS prototype model.

2. General description of CPS systems

The term cyber-physical systems (CPS) was pointed by Helen Gill (at the National Science Foundation in the U.S.) to underline the integration of computation with physical processes. In CPS systems, as opposed to the general purpose software systems, the matter of time is a key element in order to execute a task in a well-defined critical period, where the correct functioning of the collaborating system units are essential. However, the most important feature of CPS systems is the intrinsic concurrent physical environment they appear in.

2.1 Designing phases

Designing phases can be observed in concrete CPS system types. Embedded systems (see the introductory book [3]) play important role in the cyber-physical world with well-defined technologies.

The embedded computers or units are monitored and controlled by the physical processes inside a complex network. In CPS systems the key steps are in designing, modelling, analyzing and implementing in an iterative way, by refinement steps taken to adjust, coordinate and control the envisaged co-acting units. Modeling includes the dynamic behaviours, the continuous dynamics building and the establishments of actors. A number of properties to be studied involve causality, memorylessness, linearity, time invariance, and stability with a constant feedback control. Two aspects can be set in CPS systems: a discrete and a continuous one.

The actors are modeled by functions, the properties are encapsulated in states, while the changes are mapped to state transitions. Different type of state machines enable to model all the operations considered for classes of hybrid systems' transitions.

The compositionality of the models offers a vide range of topology constructions using the basic units established. It can be distinguished side-by-side synchronous or asynchronous concurrent composition of actors, shared values concurrent composition, cascade and hierarchical compositions, or reactive models of actors. The structured and dynamic dataflow make the models controllable in various process models.

In case of embedded systems in CPS processors are playing the role of micro-controllers with a vide range of possible architectures, where I/O operations are used for signal processing using multitasking and scheduling algorithms. The analysis and verification of CPS systems at all level require invariants and temporal logic properties' study. Establishing equivalences and model refinement is part of the design phase. The simulation of real application provides reachability and model checking steps in modeling. Quantitative analysis and control flow simulation are also necessary for the verifications offered by feasibility simulations with bounds and limitations analysis when considering the fault tolerance of CPS systems.

2.2 Survey of some case studies

This subsection overviews some of the already made major case studies, in order to observe the conclusions and applicability of them in the own design.

Two cases studies of distributed cyber-physical systems (DCPS) are carried in [4]. DCSP computing systems are a collection of individual computers communicating with each other and interacting with their physical environment through sensors and actuators. Examples of such systems include: mobile robots or aerial vehicles used for rescue tasks, automated highway network systems, the electric grids or SmartGrids, management of computers for dynamic voltage and frequency scaling, wireless sensor networks and actors.

DCSP systems are tested for cyber, physical and communication failures. The fault-tolerance is achieved by synchronous update of all sensors and actors, and by self-stabilization algorithms. The failure detectors are reporting permanent failures (rupture of services(, distributed consensus failures (synchronization problems), intermittent failures (agent behaviour anomalies). Stabilizers regain the control of erroneous components and are transferring the workload to non-faulty components.

The distributed cellular traffic control case study analyzes the safety and progress properties, stabilizes the routing algorithm of the cells, and reconsiders the routing algorithm towards the targets. The simulation of the self-stabilizing distributed traffic control protocol for the partitioned planes has each partition controlling the motion of all entities within that partition.

The algorithm guarantees the entities, that did not face crash failures of the software controlling a partition, are progressing to the target.

The second study is about safe flocking problem, where the agents maintain a minimum safe separation by avoiding collisions, form an equally spaced flock, and reach safely together a destination. It is applied especially in robotics.

The modeled DCPS combined with failure detector satisfy self-stabilization property. A reduced form of safety, when a single failure occurs, is simulated where a strong flock reaches a destination by failure-free execution without causing their neighbors to follow or diverge. The fault-tolerant DCPS is coordinated in a way that the collapse of the system is avoided.

3. Semantical approach of system descriptions

Several semantical approaches in describing the CPS systems' connected units are enumerated from probabilistic aspects. The probabilistic semantics descriptions are present in some very different topics. However, the experiences can be useful to be applied when modeling CPS systems as well.

First an overview of some literature paper will be given, considering papers describing the probabilistic approach for the semantics of various entities.

An interesting probabilistic semantic representation is given in [1], which introduces the notion of semantic network for representing semantic information. Such models can be used in topologies that are organized in bipartite graphs. The probability of information distribution is used over such graphs for semantic representation. The model can be used in case of CPS where probabilistic relationships between the information transferred on dataflows are varying on different contexts.

The semantic web services and semantic interoperabilities among web resources are considered in [2]. Shared repositories representation of knowledge in domains characterized by uncertainty enable service composition opportunities, and provide a semantic mapping under different probabilities. The probability has two roles: in the security and uncertainty of the availability of the information and in the probabilistic assessment and request of the information on web services. Semantic web considerations opens analogies between the web services and the services of CPS system components.

The probabilistic approach is mostly present in fault tolerance analysis of system components. The semantics issues of CPS systems, evaluated according to the applicability of probabilistic semantics of some other fields, offers new ways of CPS systems' model and design, earlier being not covered in literature.

4. Modeling and describing systems

Modeling CPS systems are considered according to the application area envisaged, where the notions connected to CPS units are specified in terms of the domain where it is used. A complex prototype study and important properties are identified in [5].

The important design phases are identified as:

- system definition
- distributed parameters for coordinating, controlling, identifying, observing and following units
- heterogeneous dynamics sensing with parameter estimations
- remote sensing policies and protocols
- establishing control framework
- parameter estimations and optimizations
- optimizing dynamic sensors
- scaling and building fault-tolerances
- communication topology building.

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