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A survey on run-time supporting platforms for cyber physical systems

Key words: Cyber physical systems (CPSs); Run-time supporting platforms; Component; Service; Agent

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Motivation

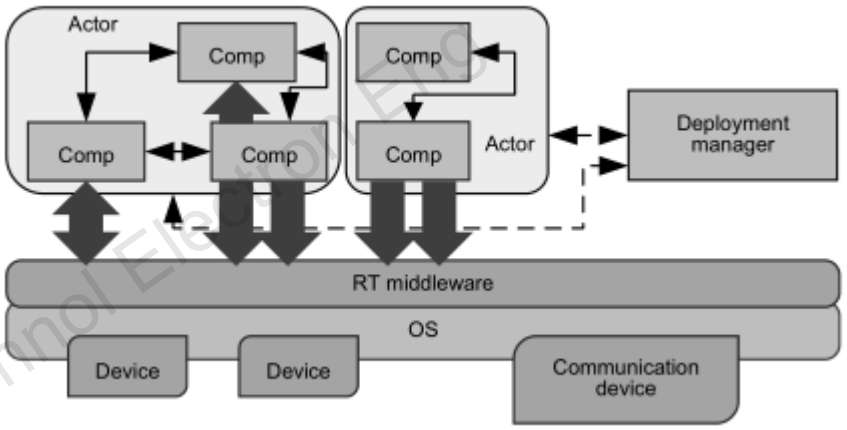
- The deep coupling and continuous interaction between computation, communication, and physical processes lead to a significant increase in complexity in the design and implementation of Cyber physical systems (CPSs) .
- Consequently, whereas developing CPSs from scratch is inefficient, developing them with the aid of CPS run-time supporting platforms can be efficient.
- In recent years, much research has been actively conducted on CPS run-time supporting platforms. However, few surveys have been conducted on these platforms.

Main idea

- We analyze and evaluate existing CPS run-time supporting platforms by first classifying them into three categories from the viewpoint of software architecture: component-based platforms, service-based platforms, and agent-based platforms.
- We compare existing platforms from two aspects: construction approaches for CPS tasks and non-functional properties support.
- We also outline several important future research issues.

1. Component-based CPS run-time supporting platforms

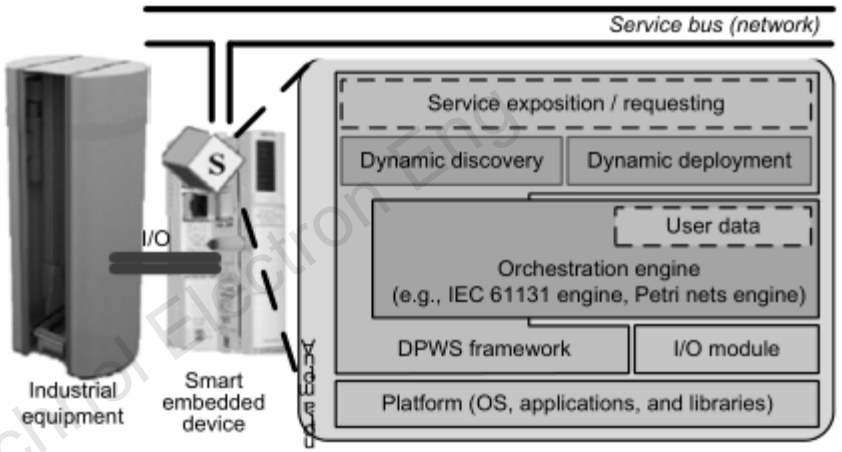
- **CPS components are employed to encapsulate low-level operations in both cyber and physical spaces, and CPS tasks comprise a set of CPS components.**
- **CPS component model**
  - **Real-time component**
  - **Independent component**
- **Construction and deployment of component-based CPS tasks**
  - **real-time, robustness and autonomy support**
- **Reconfiguration of component-based CPS tasks**
  - **to handle high dynamic nature of CPSs**



A component-based CPS run-time supporting platform

2. Service-based CPS run-time supporting platforms

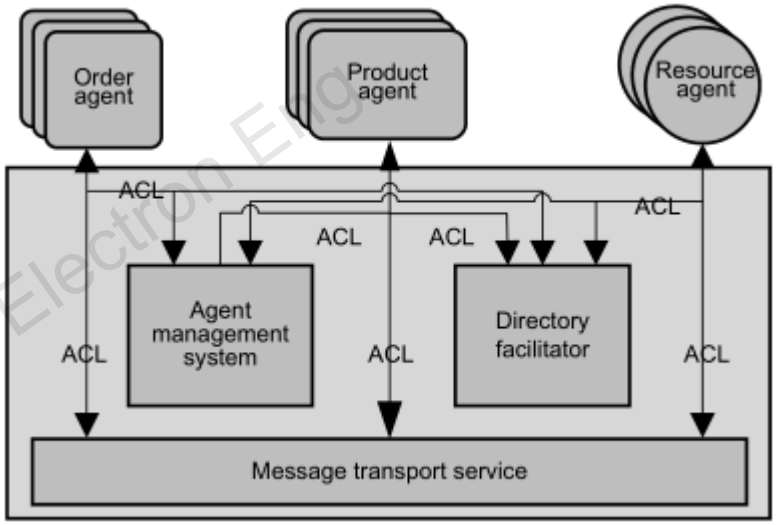
- **CPS services, which integrate the abilities of physical entities and related software, are treated as basic structural units of CPS tasks.**
- **Description of CPS services**
  - **Integration of operations in physical space**
  - **sensitive to physical environment**
- **Discovery of CPS services**
  - **the increasing scale of CPSs**
- **Composition of CPS services**
  - **static composition**
  - **dynamic composition**
  - **composition at design time**



A service-based CPS run-time supporting platform

3. Agent-based CPS run-time supporting platforms

- **CPS agents are used to manage autonomous entities in the system and CPS tasks need the collaboration of sets of CPS agents.**
- **CPS agents**
  - **Real-time constraints**
  - **Stronger Interoperability (Integration with existing heterogeneous engineered systems)**
  - **Semantic CPS agents (understanding knowledge)**
- **Evolution of CPS agents**
  - **CPSs are faced with an increasing number of uncertainties, such as disturbances and failures.**
  - **A set of CPS agents have to evolve through cooperation in order to handle uncertainties.**



An agent-based CPS run-time supporting platform

4. Comparison of construction approaches for CPS tasks

- **Three kinds of CPS structural units**
  - **autonomy is an essential attribute of CPS agents**
  - **CPS services have stronger interoperability than CPS agents**
  - **CPS agents have stronger interoperability than CPS components**
- **Composition of structural units**
  - **Fully static composition can be used for all kinds of structural units**
  - **fully dynamic composition and dynamic-static hybrid composition are usually used for CPS services and CPS agents.**
  - **fully dynamic composition and dynamic-static hybrid composition are able to employ dynamic properties**

Table 1 Comparison of three types of structural units

Structural unit	Autonomy	Interoperability	Adaptability
CPS component	●	●	●
CPS service	●●	●●●	●●
CPS agent	●●●	●●	●●

The number of black spots is used to indicate the degree of such aspects as autonomy, interoperability, and adaptability

5. Comparison of non-functional properties support

- **Most of existing platforms have varying levels of reconfigurability. In general, agent-based platforms have the strongest reconfigurability, whereas component-based platforms have the weakest.**
- **Several studies have been conducted on scalability, but the majority of them are not integrated into existing platforms. In general, knowledge-based approaches can obtain better scalability than decentralized control-based approaches.**
- **Almost all of the platforms are able to leverage context information and handle failures. In general, the platforms using centralized management (the majority of component-based platforms and service-based platforms) have lower resilience than the platforms using decentralized management (the majority of agent-based platforms).**
- **Real-time is only supported by several platforms.**
- **As far as we know, only a few of existing platforms are able to support security.**

6. The best platform architectures in different application scenarios

- **In general, in situations where the demand for real-time support is strong, such as vehicle electronic systems, using a component-based platform is the best choice.**
- **In dynamic environments, using either a service-based platform or an agent-based platform is feasible.**
- **However, if interoperability is also strongly needed, such as in IMSs, service-based platforms are best.**
- **If local autonomy is obvious, such as in smart grids, swarms of UAVs, ITSs, agent-based platforms are best.**

Table 3 The best platform architectures in different application scenarios

Application scenario	Real-time	Autonomy	Dynamics	Interoperability	The best platform architectures
Vehicle electronic systems	●●●	●	●	●	Component-based platforms
Intelligent manufacturing systems	●	●	●●	●●●	Service-based platforms
Smart grids	●	●●	●●	●●	Agent-based platforms
Swarm of UAVs	●●	●●	●●	●	Agent-based platforms
Intelligent transportation systems	●	●●	●●	●●	Agent-based platforms

The number of black spots indicates the degree of the key features

Conclusions

- Existing platforms have both advantages and disadvantages because they aim at different application fields.
- In order to choose an appropriate platform architecture, the particular characteristics of the application field have to be well known.
- Future research issues
  - Verification of CPS tasks
  - Support for human-in-the-loop applications
  - Runtime monitoring of CPS tasks