A Survey Paper on Cyber Physical Systems

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Abstract— Cyber-physical systems (CPS) are engineered systems that are built from, and depend upon, the seamless integration of computational algorithms and physical components. CPS technology will transform the way people interact with engineered systems. CPS will bring advances in personalized health care, emergency response, traffic flow management, and electric power generation and delivery, as well as in many other areas now just being envisioned. This paper aims for providing an insight into this emerging multi-disciplinary methodology.

Key words: Cyber Physical Systems (CPS), Embedded Systems, Computation, Communication, Control

I. INTRODUCTION

The dynamics among computers, networking, and physical systems interact in ways that require fundamentally new design technologies [2]. In their program announcement, the National Science Foundation (NSF) outlined their goal for considering these various industries under a unified lens: by abstracting from the particulars of specific applications in these domains, the goal of the CPS program is to reveal cross-cutting fundamental scientific and engineering principles that underpin the integration of cyber and physical elements across all application sectors [3].

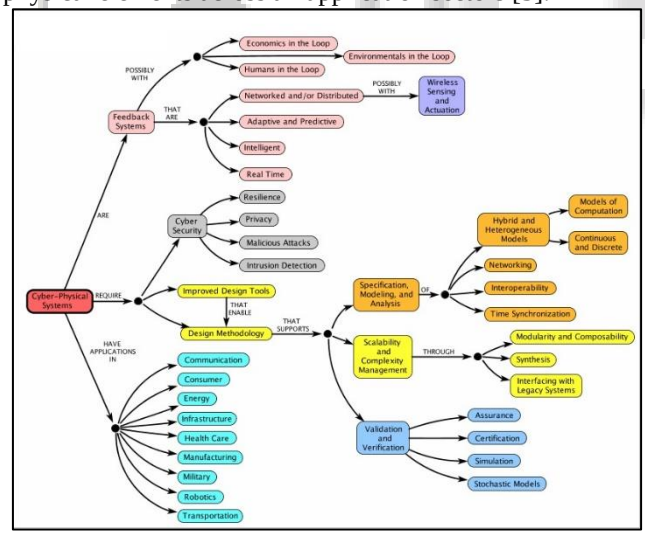

Fig. 1: CPS Concept Map [8]

Figure 1 shows a typical CPS Concept map. Other phrases that you might hear when discussing these and related CPS technologies include:

- Internet of Things (IoT)
- Industrial Internet
- Smart Cities
- Smart Grid
- "Smart" Anything (e.g., Cars, Buildings, Homes, Manufacturing, Hospitals, Appliances) [9]

Soon after the CPS term was coined, several research communities rallied to outline and understand how CPS security research is fundamentally different when compared to conventional Information Technology (IT) systems.

In the following years, CPS research evolved into a mature field spawning multiple surveys. One of the first surveys on CPS was written by Kim and Kumar [3], and it included several CPS research efforts real-time systems, wireless networks, and security. Recently, we have seen a large increase in the surveys of CPS focusing exclusively on security and/or privacy issues.

II. CPS FEATURES

Goal of CPSs research program is to deeply integrate physical and cyber design [2]. CPSs are different from desktop computing, traditional embedded/real-time systems, today's wireless sensor network (WSN), etc. and they have some defining characteristics as follows [2][4-7].

A. Closely integrated

CPSs are the integrations of computation and physical processes.

B. Cyber capability in every physical component and resource-constrained

The software is embedded in every embedded system or physical component, and the system resources such as computing, network bandwidth, etc. are usually limited.

C. Networked at multiple and extreme scales

CPSs, the networks of which include wired/wireless network, WLAN, Bluetooth, GSM, etc. are distributed systems. Moreover, the system scales and device categories appear to be highly varied.

D. Complex at multiple temporal and spatial scales

In CPSs, the different component has probably unequable granularity of time and spatiality, and CPSs are strictly constrained by spatiality and real time.

E. Dynamically reorganizing/reconfiguring

CPSs as very complicated systems must have adaptive capabilities.

F. High degrees of automation, control loops must close.

CPSs are in favor of convenient man-machine interaction, and the advanced feedback control technologies are widely applied to these systems.

G. Operation must be dependable, certified in some cases

As a large scale/complicated system, the reliability and security are necessary for CPSs.

III. KEY TRENDS

A. System Complexity

System Complexity has been one of the key trends due to various reasons. The important ones being increasing

functionality, increasing integration & networking interoperability, growing importance & reliance on software and increasing number of non-functional constraints.

B. *Nature of tomorrow's systems*

Due to the frequent changes in technology every day, tomorrow's systems need to be dynamic, ever-changing, and dependable with high-confidence. They should also be self-*(aware, adapting, repairing, and sustaining).

C. *Everywhere, used by everyone, for everything*

Expectations are that the systems will be 24/7 available, 100% reliable and 100% connected. They will be giving instantaneous response and will remember everything forever.

Also the systems will be accessible by different classes of people from young to old, able and disabled, rich and poor, literate and illiterate, etc. and also ranging in different numbers from individuals to special group of people to social networks.

IV. APPLICATIONS

Various areas have been identified where CPS can be highly useful in a part or as a whole. Figure 2 shows various fields where CPS is applicable.

1) Healthcare
2) Transportation
3) Process Control
4) Large-Scale Infrastructure
5) Defense Systems
6) Tele-physical Operations
7) Smart Grid
8) Robotics Systems

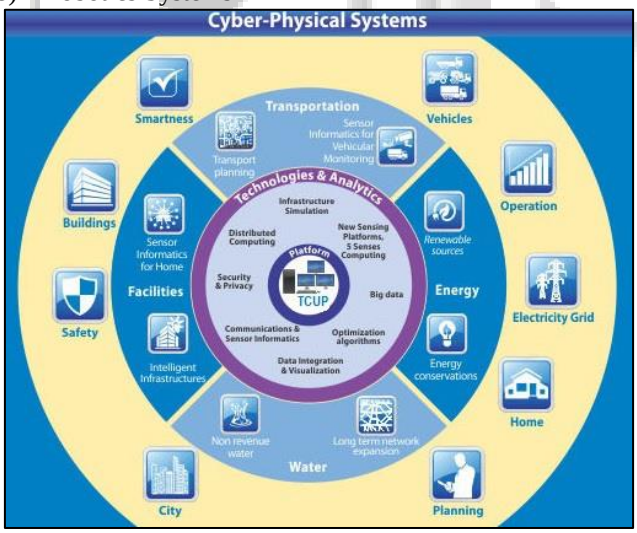

Fig. 2: CPS Applications

CPS has applications in Healthcare for medical devices and health management networks. CPS has also showed applications on a wide scale in Transportation for Automotive electronics, Vehicular networks, Aviation and Railroad systems.

Large scale infrastructure applications deal with physical infrastructure monitoring and control, Electricity generation and distribution, and Building and environmental controls. Tele-physical operations relate to telemedicine and tele-manipulation applications.

V. ARCHITECTURE AND DESIGN

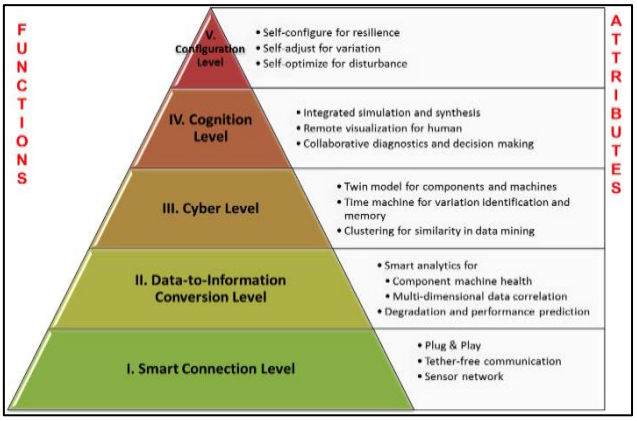

Fig. 3: CPS Architecture

A. *Architecture*

Designing and deploying a cyber-physical production system can be done based on the 5C architecture:

1) Connection
– Plug & Play
– Tehter-free Communication
– Sensor Network

2) Conversion
– Smart Analytics for component machine health
– Smart Analytics for multi-dimensional data correlation
– Degradation and performance prediction

3) Cyber
– Twin model for components and machines
– Time machine for variation identification and memory
– Clustering for similarity in data mining

4) Cognition
– Integrated simulation and synthesis
– Remote visualization for human
– Collaborative diagnostics and decision making

5) Configuration
– Self-configure for resilience
– Self-adjust for variation
– Self-optimize for disturbance

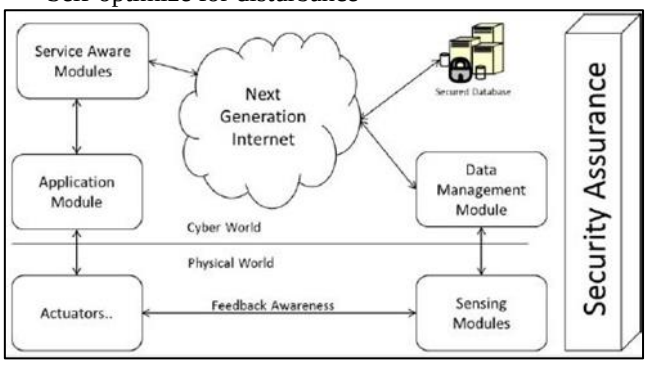

Fig. 4: CPS Design - Modules & Components

B. *Design*

Various modules and components in the design of a Cyber Physical System are as given below:

1) Sensing Module

Collection of data from the physical world through the sensors.

2) Data Management Module (DMM)
Consists of the computational devices and different storage media.
3) Service Aware Modules (SAM)
Sensed data is being recognized and sent to the services available.
4) Application Module (AM)
Services are deployed and interact with NGI and information is saved on database for QoS support.
5) Next Generation Internet
Enabling applications to select the path, or paths that their packets take between the source and destination.
6) Sensors and Actuators
Actuator receives the commands from the Application Module, and executes.

VI. CHALLENGES

Cyber Physical Systems will provide a lot of advantages to the world through its wide range of applications, but there are a lot of challenges in implementing it which are listed as follows:

A. Multidisciplinary Approach

All fields & subfields have different design & development conventions.

B. Design Abstractions

Most abstractions are with a stack-based approach that do not directly encapsulate characteristics like: Concurrency, Criticality and Timing.

C. Reliability & Safety

Hard to guarantee in interconnected and interdependent systems.

D. Integration

Putting the system together is much more challenging than implementing the individual subsystems.

E. Timing Predictability

Lowest abstraction layer (transistors) is pretty deterministic; however, higher levels lose all concept of timing.

F. Isolation & Composablity

One subsystem should not affect another unrelated subsystem. Also, verification of each subsystem in isolation and interaction among them.

G. Software Models

Current software programming models and languages are inadequate to support CPS design.

H. QoS-Aware Communication Protocols

Identification of application requirement of each type of traffic.

I. Resource Management

Auto Management Techniques are required to manage huge amount of dynamic data.

J. QoS-Aware Power Management

Dynamic Computing demands much CPU energy.

K. Simulation Tools

Simulation models dealing with dynamic communications.

VII. RESEARCH WORK

Currently research opportunities in CPS fields are still very wide open, because this is a relatively new research topic. CPS is a system that is multi-dimensional, both the application domain and the design domain [1].

Some researchers from various countries discussed the related concepts, technologies, applications and challenges during CPSweek and the international conference on CPS subject [2].

In the last few years there has been an increasing interest on strategies that preserve a certain level of privacy for control systems in addition to differential privacy, such as homo-morphic cryptography in feedback systems, and data minimization by changing sampling period[3].

CPS research trend in the future is in the energy, transportation and robotics fields. Not to close the possibilities the health or care field will be a trend once more, this is due to more and more people researching in this field, for example wearable electronic devices or sensors[1].

VIII. CONCLUSION

Cyber-physical system is an opportunity for human to get closer to nature, by means of the approach through the cyber world or computation. Why do humans need to be closer to nature? Because this is one of the ways to understand the changes occurring in nature, so that preventive measures can be done more quickly, for example, to know earlier an occurrence of flood or volcanic eruption.

Thus, the expected casualties can be reduced, and material loss can be suppressed. CPS development has been strongly supported by current technology advances, so there is an opportunity to do research on the other hand, for example the creation of a tool to speed up the system development process or also known as platform automation, frameworks, and design patterns.

In the last few years, this emerging domain for CPSs has been attracting the significant interest, and will continue for the years to come. In spite of rapid evolution, we are still facing new difficulties and severe challenges.

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