Cyber-Physical Systems propelling Industry 4.0

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***Abstract*—Industry 4.0 is a new phase in the industrial revolution that is introducing intelligent networking of machines and workflows for industry with the help of information and communication technology. One of the propelling drivers of this revolution is Cyber-Physical Systems, the technical systems which promotes interaction between networked computers and robots (cyber space) and physical world. By 2050, these systems will be incorporated in many different domains including industry, home, healthcare and others. The understanding of impact and challenges of these systems are essential to exploit its potential to the fullest. This article dives into the features, applications and engineering challenges with respect to Cyber-Physical Systems and end up with its future scope.**

***Index Terms*—Cyber-Physical Systems, Industry 4.0, Smart Sensors, Engineering Challenges.**

I. Introduction

Industry 4.0 [1] is a very popular wave that is going on worldwide among different industries. Every business is trying to transform into Industry 4.0 compliance. To comply with Industry 4.0, there are different aspects that are important to be understood for industries. One of the most important aspect of Industry 4.0 is automation (full automation) where there is no human intervention ideally or atleast minimum human intervention.

This may be achieved using IOT devices and something called as Cyber-Physical Systems (CPS). In simpler words, this system involves interaction between components of cyber world and components of physical world. NIST (Engineering Laboratory) defines Cyber-Physical Systems or “smart” systems as co-operative interacting networks of computational and physical components. These systems make the basis of future smart services, provide the premise for our critical infrastructure and improve the quality of living in many areas.

A. Cyber-Physical Systems and Embedded Systems

CPS are Embedded Systems along with a physical system, constituting actuators and sensors that interact with the physical world. These systems possess computing, communicating, and controlling capabilities. Fig.1 shows the cyber space, the physical space and interaction between them, which together constitutes Cyber-Physical system.

II. Features of Cyber Physical Systems

To dive further, CPS constitute a physical space that passes some information to cyber space using sensors, then some decision is made in cyber space. Based on the decision, some action is performed in physical domain, which changes the physical state of a device. We see interaction happening between Device-to-Device or Device-to-human or human-to-human too. Fig.2 shows a loop that exists in CPS.

Table I: Differences between Embedded and Cyber-Physical Systems

Embedded Systems	Cyber-Physical Systems
Information processing systems are embedded into the devices	Complete system having physical and software components
Confined to a single device	Network of embedded systems
Constrained resources	No resource constraint
Issues include real-time response and reliability	Issues include timing and concurrency

The following points illustrates the key features of cyber physical systems.

1) “Reactive Computation” involving sequence of inputs and outputs, thus interacting with the environment in a continuous manner.
2) “Concurrency” involving multiple processes running concurrently and in synchronous or asynchronous mode of operation.
3) “Feedback Control” involving control systems with feedback loop. CPS are equipped with sensors that sense the environment and actuators that influence it.
4) “Real-time computation” involving time sensitive operations such as coordination and resource allocation.
5) “Safety critical Applications” involving precise modelling and validation prior to development.

III. Cyber-Physical Systems Applications

Over the past century, many computer-controlled and networked electromechanical systems have emerged from purely mechanical systems. As the Cyber-physical systems are going mainframe, computing has become an indispensable part of it. Fig.3 shows the transition from horseless carriages with a driver to a highly complex and adaptive driverless autonomous vehicles [2].

The applications of Cyber-Physical systems in major areas are enumerated below,

1) Healthcare
   - Highly accurate medical equipments and systems used in image-guided surgery and therapy, control of fluid flow for medicinal purposes and biological analysis and intelligent operation theaters and hospitals.
   - Engineering systems based on neuroscience and human cognition including brain-machine interface, prosthetics, therapeutic and entertainment robotics and many others.

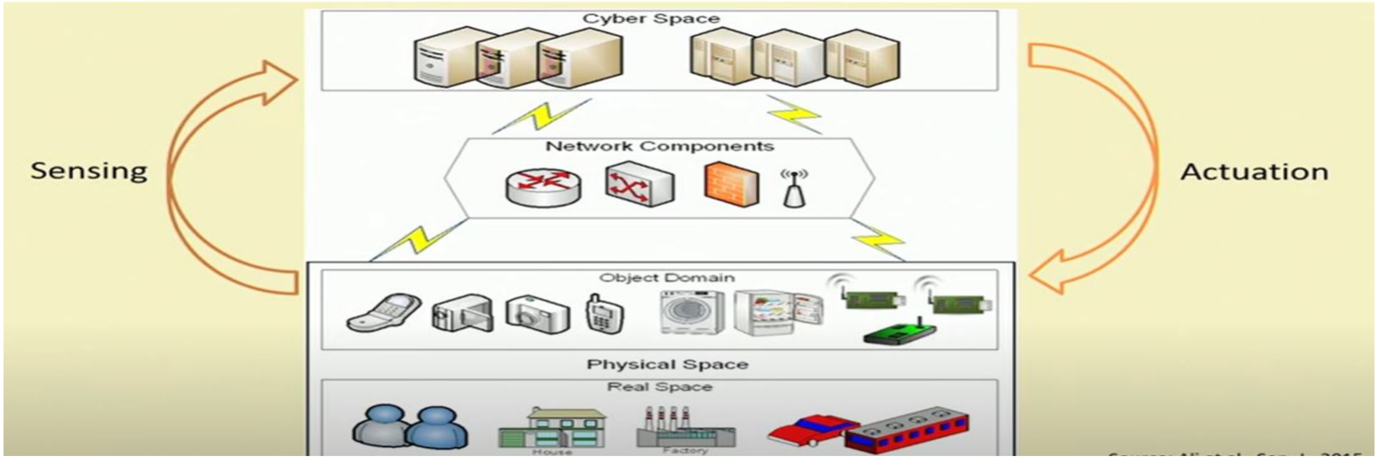

Fig. 1: Cyber-Physical System (Source: Ali et al., Sen. J., 2015)

2) Transportation
   - Real-time monitoring of traffic infrastructure and traffic control
   - Vehicle-infrastructure coordinated transportation CPS like queue warning for ambulance.
   - Vehicle-based transportation CPS including vehicle health monitoring system.
3) Smart Grid
   - Smart meters involving demand management with distributed generation and intelligent substations with automated distribution.
   - Wide area control of smart grids.
4) Industry
   - Manufacturing systems and logistics integrated with communication abilities, sensors, and actuators.
   - End-product customized as per user need.
   - Flexibility of development of systems.

IV. Engineering Challenges

A fundamentally new engineering paradigm is required for advancement from physical product to cyber-physical system, provided the huge difference between software engineering and mechanical approaches but this comes with its own set of challenges.

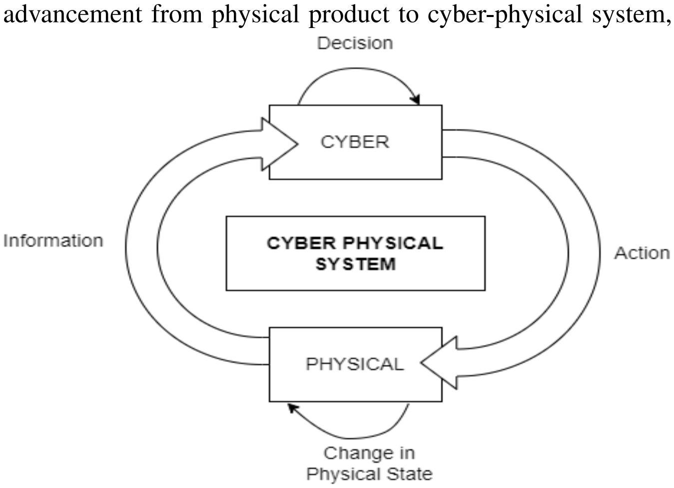

Fig. 2: A cycle existing in Cyber Physical Systems

Challenges in development and deployment of cyber-physical systems, are with respect to,

- Safety, robustness, and security
- Sensing and mobility
- Computational challenges
- Architecture and modelling
- Verification, validation and certification
- Education and training of systems

The required engineering process is neither a traditional engineering extension nor a straightforward application of software engineering. Instead, it must take into account insights from electrical, computer Science and mechanical engineering [2,6].

Along with a new hybrid engineering approach, need of next generation sensors is rising to implementation CPS on a physical level. Industries and academic labs are working on making sensors intelligent so that these sensors, not only sense and send the signal but also run some light-weight algorithms and send out signals intelligently. Some expected features in Next-Generation Sensors are,

- Interoperability of networks, transducers, and control systems of different manufacturers
- Compatibility with other sensors actuator bus standards
- More usage of existing networks instead of proposing new standards

"Smart Sensors" is the integration of sensors and actuators with a processor and a communication module. Defined by IEEE 1451 Standard as:

"Sensors with small memory and standardized physical connection to enable the communication with processor and data network."

These sensors have their own limitations which is to be overcome by "Intelligent Sensors".

V. Conclusion and Future Scope

CPS are revolutionizing social processes and economies. Their effective development and deployment needs break-

Fig. 3: Cars have evolved from horseless carriages to complex and highly adaptive computer-enabled vehicles in today's time.

throughs in several areas including polity, law, technology, social science as well as business.

National and industrial initiatives have emerged to develop workflows that will address the emerging challenges in converting mechanical process to cyber-physical processes. The goal is efficient and low cost production processes. Some notable initiatives among them are the Industry 4.0 in Germany, the Industrial Internet in the US, and the Super Smart Society (Society 5.0) in Japan. the concept of using hierarchy of CPS for full automation in various fields leads to flexibility, resilience, safety, autonomy and low cost, enabling all actors-manufacturers, operators and customers-to modify the system parameters as per their interest.

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