Cyber Physical System: Paper Survey

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***Abstract*—Embedded systems form the basis of all devices that are currently growing. With increasingly sophisticated technology advancements the dimensions of the devices are getting smaller, and the computing capabilities are now almost on par with the PC in the past two to three years. Based on those abilities the device can be paired with other components such as wireless communication technology, sensors and other supporting components to determine the state of the environment, or actuators as well to give response. Because all of these things take place in the digital world, there arose a discourse what if the digital world were to be combined with the physical world. A system that combines the capabilities of computing, communications and data storage, in order to monitor or control the entities that exist in the physical are world called Cyber Physical Systems. This paper will discuss the things that happened in the early progression of CPS topics (2006 - 2013), as the process of declaring the term CPS, reviews by the research group guided by Edward A Lee in the CPS field, CPS development in terms of scientific publications in the International Conference on Cyber-Physical Systems (ICCPS), and further research opportunities based on the direction of the development of research topics in the CPS field.**

Keywords— CPS, embedded system, requirements system.

I. Introduction

The digital world has become part of the daily human life, one of the indications is the use of a calculator. The more sophisticated technology is the internet. By using these technologies, today's exchange of information through the digital world becomes easier, thereby eliminating the restrictions on time and place to exchange information.

In the process of information exchange (communication), computational processes are almost always involved. At first the process of computing is still simple, but as the development and the needs of the increasingly rapid process computing process then becomes increasingly complex. One of the things involved in the process of complex computing include processing a certain amount of data into information.

Computational speed is inseparable from technological advances that occur in it. Advances in technology also bring a change in dimensions of devices, sensors, and actuators. Today is commonplace a computing device dimensions only by a credit card, while the last few decades, the dimensions for the same tool can be as big as a lecture hall.

Internet becomes an inflection point in terms of the use of computing technology in everyday life. Initially, computing technology (Personal Computer) is simply used to facilitate human work in the office, in the lab, and so on. With the internet technology, the boundaries of the computer seemed to disappear. Apart from that, the internet technologies also raised a new style of communication, and moreover also a place to socialize (social media).

With increasingly smaller computing devices it is increasingly possible for these devices to be mounted on something, such as a jacket equipped with temperature information. If the device is equipped with a wireless component, it is possible that the device is connected to the Internet, thus enabling the occurrence of information exchange process in which the device is attached. A system that combines the capabilities of computing, communications and data storage, in order to monitor or control the entities that exist in the physical world is called Cyber Physical System (CPS) [1]. If the internet is changing how humans communicate, how and where to access information and make the process of buying and selling, then so does the CPS will change the way humans interact with and control the physical world around them.

This paper focuses on the research development that occurred since the term CPS declared until the end of 2013. Part II discusses the process of the declaration of CPS, resulting scientists to begin to make this topic as a research topic. The development of a group who studied CPS that one of its team adviser is Edward A Lee, is discussed in section III. While the development of the CPS, which in terms of an activity that embodies the publications in this field, namely the International Conference on Cyber-Physical Systems (ICCPS) which is incorporated in the annual event CPSWeek, is discussed in section IV. The limits of the discussion in this section focus on CPS research field trends that occurred in the period of 2010 until 2013.

II. Cyber Physical System Declaration

Cyber Physical Systems, a term coined at the moment of the workshop organized by Professor Raj Rajkumar of Carnegie Mellon University USA. In the presentation materials at the opening of the event, it is stated that the system that combines the capabilities of computing, communications and data storage, in order to monitor or control the entities that exist in the physical world called Cyber Physical Systems [1]. This event is sponsored by the National Science Foundation (NSF), which is a U.S. government research institute. Funding research is financed by the American Competitiveness Initiative (ACI). The proof of the funding of this research is the inclusion of the CPS theme in Computer System Research (CSR) in the program description for the research year 2007. Based on this document the researchers are as if triggered to do researches in the CPS field [2].

CPS is not the computer in general (PC), not the traditional embedded systems, and also not the sensor networks available at this time. The system is expected to have a greater ability than the existing system in terms of computation, communication, configuration and automation. The purpose of this system is more attached to the physical element, so that the process involving computational and physical elements can take place more natural [3].

Stringent restrictions are applied to the CPS, which is the control that should be done in a close loop state with a certain time limit. The running process is expected to represent events that occur in the physical world, which are parallel events. This is a challenge in CPS research because of the computational (cyber) process are sequential.

It is estimated, CPS topics will produce new science within 10-20 years, and one of the discussions is how to design the integration between physic and cyber more naturally. The new way of integration will change the design of a system, which originally referred to the design process of embedded systems. Furthermore, we will discuss the impact of the declaration research topic in the field of CPS.

III. CPS RESEARCH DEVELOPMENT: I

This section will discuss CPS research progress based on what has been done by the CPS research group led by Edward A. Lee [4]. Previously, he once wrote a paper which contains the basic factors that become the challenges in designing the CPS [5].

In the paper there are two characters from the system that continues to be emphasized, which is the system is predictable and reliable. These two factors are based on the physical world that cannot be guessed. While the cyber (computation) world must be reliable so that it can operate in any environment. To achieve these two factors then there are some requirements that must exist in the CPS design process. These requirements include the materials used, the process of computation, and programming languages used.

From the point of view of the materials used, in terms of durability of the device, the material used to make the components must pass the test 100%. Similar to the materials used to make electronic circuits. Although the components and digital circuits can be made of good material, but in practice, these devices will be activated continuously, so it is not impossible an error will occur.

From the point of view of computational processes, CPS should be predictable. The meaning is, CPS should have clear computational time. At the hardware abstraction level, it is generally recognized that this level has a high predictability factor. This issue arises when the processor architecture is abstracted with the instruction set architecture (ISA). This abstraction hides an important aspect required in embedded systems which is timing.

To keep the designed computation to have a high predictability factor, then the software designers use low-level languages, such as assembly or C. In fact, for a simple program, the used programming language already has a high predictability factor. However, these factors will continue to decline as the complexity of computing processes performed in the system increases, as shown in Gambar 1. Meanwhile, the level of abstraction of computing can be seen in Gambar 2.

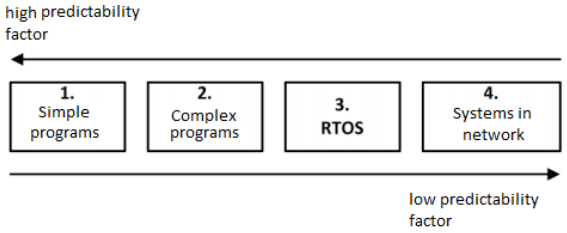

Fig. 1. System predictability level diagram.

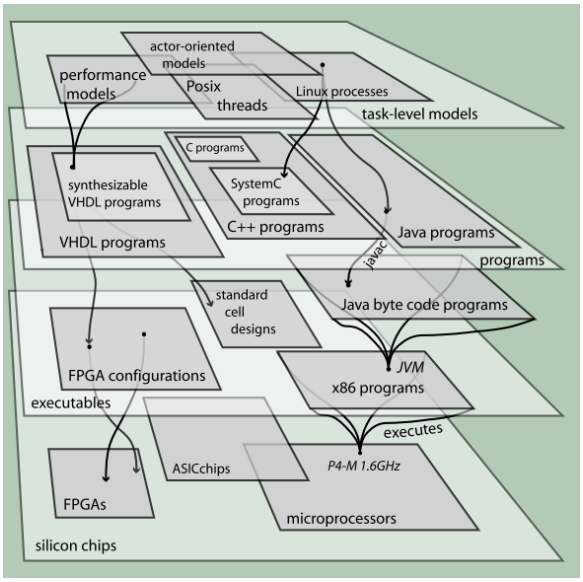

Fig. 2. Computation abstraction level [5].

The existing embedded system design process abstraction are already good, but when applied to the design of the CPS all of them become incompatible, because the abstraction does not yet accommodate the requirements of the CPS. Therefore, Edward Lee proposes to design CPS systems using Model-based methods. This method implements the Top-Down design solutions by considering the button-up design solution [5]. Based on some of the papers published by the group, his research interests direction can be seen. The following will discuss the research interest directions of this group.

A. Research development directions

Predictability becomes one of the main issues [5], which is a reference to future studies of this group. In the software domain, the predictability factor is closely associated with the execution time of a process (computation). To design a software development process that involves timing, tools can be used as described in this paper [6], [7], [8].

Still in relevance to time matter, if the previous discussion is more on the design of a system with a time component, then this discussion is more linked to the problem of time on the software. In this paper [9]; the approach time is more towards how a CPS device can perform a process with time sync with other CPS devices, so that the process that takes place can be

distinguished. This synchronization approach uses the theory of timestamps, and can help overcome the problem of latency and jitter.

One topic that has not been addressed in the previous studies is about security. This has not been a major topic, since research in the field of CPS is still relatively new (since 2006). However, because this topic is a primary issue in the domain of information, then this group is trying to raise security issues that may arise with the attack on a traditional IT approach [10].

CPS cannot be separated from the device, and devices at this time which can represent the CPS with various abilities are embedded systems. Research in the field of embedded systems has already been underway (since the early 19th century [11]) when compared with the CPS. However, according to Lee, to develop CPS, is the need to re-overhaul the design process that is carried out on embedded systems. The design process of embedded systems with the CPS approach is set out in this book [12].

The physical world has a concurrent aspect, or a world where everything can be run simultaneously (parallel) based on units of time. Thus, to pour it into the cyber system, obstacles will arise, because the system is running (a process being done) sequentially. In order for the system made in accordance with the physical world in which the system is placed, it is necessary to do design, modeling, and testing. An example of modeling process with heterogeneous and concurrent aspects approach in the physical world is the case in aircraft fuel management, which is discussed in this paper [13].

Still on the modeling, this paper emphasizes on the things what needs to be known by the decision makers if willing to develop applications in the field of CPS. The discussion is specified to a systematic framework as a guide for the development of the system. The framework used by Broman, focus on the determination of standpoints, formalism, and language and tools selection [14].

To date, the modeling of such systems range in what will be built, and how the from a different point of view. CPS design process involving more than one discipline, can lead to problems when the interface takes place. The design contract at the beginning of the CPS design process can be a means to connect different disciplines. A case example in this paper is intended to the control system and the embedded software engineer in terms of system timing and functionality.

In addition to modeling and simulating mathematical equations, this group also models about data communication network between CPSs. The simulated communication network is Ethernet. Factors that are reviewed are real-time performance of time-critical systems [15].

This research group has also published a paper on the view of the world future of the CPS world, until the year 2020 [16]. In the paper three trends are raised, namely: 1) Smart, Domain-Specific development process, the development of which is particular to a specific purpose, so as to enhance the creativity of system designers. 2) New Input Devices, this is based on the number of interface devices using touch screen. 3) Transition to Cloud, since the more widespread use of cloud technology which allows any system to be synergized through the internet.

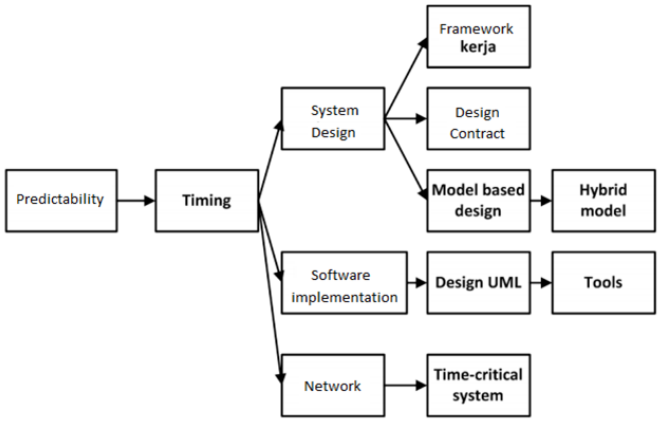

Fig. 3. Lee Group research map.

Gambar 3 maps research topics conducted by Lee. Most of the research is done in the field of system design. This is aimed to obtain the CPS in accordance with the original vision, which is in order to develop new design methods for CPS inspired from the design process of embedded systems.

CPS design is done with model-based design approach because the physical world can be modeled in a mathematical model. This model can be simulated, so that designers can get the imagination if the system is implemented. However, the simulation also has shortcomings, which cannot perform concurrent execution.

In order to test the model with concurrent processes, an additional device is required. An examples of a device that can support parallel processing is Field-programmable gate array (FPGA). Program code adjustments are necessary, so that the system design model can be tested using an FPGA. Software design has its own difficulties.

Software engineering is one of the different scientific fields with embedded software engineering. In the software design for embedded systems, designers are faced with limitations, such as a little memory, processor speed, and time-base. This is very different from typical software development. To simplify the software design and can be understood by others then this design using a specific language, for example the Unified Modeling Language (UML).

Timing issue becomes a topic which is of considerable concern, because it involves the ability to perform computational processes, data processing, and transmission. This issue becomes a major concentration in any part of the existing research, which is on the system design, software implementation, and network. The further discussion is about CPS developments by the ICCPS CPS conference.

IV. CPS RESEARCH DEVELOPMENT: II

This section will review the application domain of the publication target at the CPSWeek workshop [17]. This workshop is a series of activities in which there are multiple events (conferences), one of which is the International Conference on Cyber-Physical Systems (ICCPS). Application domain discussed will be drawn from a study published in the ICCPS

Fig. 4. CPS research field trends at CPSWeek.

conference, from 2010 until 2013. This workshop has been going on since 2010, and this year it took place in Berlin, Germany.

Gambar 4 shows the research field trends published at ICCPS. In general, the papers published are not limited to that described. The fields indicated are only a few research fields that are always had every year in the conference, while the ICCPS conference for 2014 is depicted with dashed lines, because at the time this paper was written, the conference has not been held.

Furthermore, we will discuss the development of each research field. Publicized papers are selected from some papers that are relevant by the author or still have continuity each year. Some of the research fields of which are: sensor networks, healthcare (medical devices), energy, and transportation.

A. Network sensors in CPS

Sensor networks aims to collect data from several sensor points attached. Means of sensor data delivery must use a rule (protocol) to avoid confusion between points, and between points and the center. At first, to distinguish priorities, sensor networks use static priority values and deadlines. At CPS, the priority is the dynamic situation that exists in the physical world [18].

Data from one sensor in a system does not cause problems in the readings, what becomes a problem is if the system uses several sensors so it needs a special rule in the context of reading the data. The Paper that discuss the rules of reading data or algorithms for reading a lot of data are published by Aida in this paper [19]. The algorithm is applied to airplanes and cars.

B. Health (medical devices)

Medical devices have high standard and is not haphazard, it is required because if something goes wrong the worst risk is human lives. The sophistication of medical devices is returned to the human skills that use them. To reduce the error caused by humans, then clinical scenarios are applied with close loop control. These studies in the long run will lead to the patient-in-the-loop system validation, for the safe and correct operation [20].

Basically a medical device is developed as a stand-alone unit. In providing health information systems (HIS), then the data from the medical devices must be sent to a central, to be processed. The process of a system is also applicable in a larger system, so it is known as system of system. The Paper that discusses the architecture rules and principles of the medical application platform is discussed by Hatcliff in [21].

There are devices that are connected in a network and cooperate to obtain a specific data, if it is associated with the medical world. This device is called the Body Sensor Network (BSN). One issue on the BSN is energy efficiency; this aspect can lead to a mounted sensor that lasts longer. Energy issues are discussed more detail by Bidmeshki in [22].

C. Energy

The availability of energy sources becomes a major concentration in recent years, due to the availability of fossil fuels that are running low. One way to save energy is implementing the control strategy for data centers (energy management). This process will handle computation resources and cooler resources [23].

Energy use in an area has a certain pattern; it requires the energy providing company to be able to provide energy in accordance with the pattern. This user pattern is directly related to the time, called the time-varying demand. This should be expected early for the company to provide energy on demand. In a paper written by Taneja [24], the pattern of electricity usage based on data from the California energy provider company California Independent System Operator (CAISO) is discussed.

D. Transportation

One application of CPS in the transportation field is in the Cooperative vehicle safety (CVS) system. In this system, the vehicle disseminate the physical state information through the wireless network, which is convey to other vehicles to be aware of its whereabouts to predict the possibility of a collision. Further discussion of the CVS system can be seen in the papers [25].

The term auto pilot is often used in flights that aim to explain that the aircraft is controlled automatically or without the intervention of humans. In the automotive field this term is also known as Autonomous driving. The main thing discussed by Azimi in the paper [26] is how to make a vehicle (car) to able to run to its destination automatically, especially using the vehicle-to-vehicle (V2V) communication methods and Vehicle-to-Infrastructure (V2I) to know the environment around the vehicle.

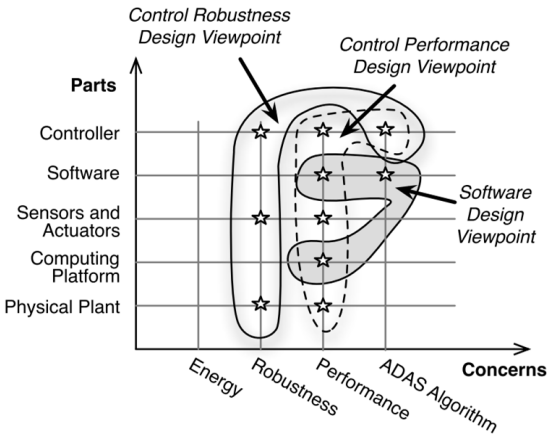

Fig. 5. a Viewpoint Matrix Example [14].

V. RESEARCH OPORTUNITIES

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. Application domain is where the system is implemented, while design domain is more to the abstraction level system development process. To see the research opportunities that exist in the CPS Gambar 5 can inspire. This image shows the viewpoint matrix in determining the parts that will be used and focus on the system to be built, because it is so simple, this image can help designers or decision-makers to begin the process of research in the field of CPS.

In addition to a clear design contract caused by the system complexity, challenges are also present in the process of the device development. The existence of a design flow framework as a CPS device development reference is highly needed. Challenges are also present in ways of mathematical equation implementations. Complex equations must be handled without burdening the system, because it is highly related to the CPS device response to environmental changes.

Research in the CPS field is still growing, some general requirements of this system is predictable and reliable. The vision of the CPS is a system that can be interconnected to form a large-scale system [27]. 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.

VI. CLOSING

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.

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