

A HUMAN SENSORY ARCHITECTURE FOR CYBER PHYSICAL SYSTEMS

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ABSTRACT

Cyber physical system (CPS) is a complex distributed system which contains computing, communications, and control. CPS is the combination of the cyber world and the physical world. The cyber world need huge amount of physical device sensing and commutating in order to collect and transform the information in the real environment. Then, system forecast the possible situation that can happen in the real environment by computing. Finally, provide the best proposal for system decision making. In the CPS, the decision is making by human. However, human always change their mind, there are many uncertainties that influence the decision making. This paper constructs a CPS architecture based on the human sensory system by analysis human body sensing that help CPS understanding the human requirement.

Keywords: *Cyber Physical Systems, Human Sensory, Architecture*

1. INTRODUCTION

Cyber physical system (CPS) is a multiple complex distributed system makes up of humans, computer and physical world. The system needs to sense the environment with physical device, humans bring the requirement forward, and the computing device changes the environment according to the people's requirements after computing. In this process, people is the source of the requirements, physical device is the bridge for exchange between cyber and physical world. CPS focuses on the effectiveness of controls; the decision of the control is made by people. With the raising intelligent of CPS, the decision maker gradually switched from people to computing units, and physical will not only sense the environment but also need to sense the human, achieve what is need actively instead of receiving human requirements and control decision passively.

People will have different requirements under different environments, and the environment will influence the decision making. CPS needs to sense humans and environment from the side of humans, make reasonable decision. This paper constructs a CPS architecture based on the human sensory system by analysis human body sensing.

The rest of the paper is organized as follows: In Section 2, recent CPS research and prototype architecture are reviewed. The relationship between human sensory and CPS are described in Section 3.

In Section 4, we propose a human sensory architecture for CPS. We conclude the paper and point out future work in Section 5.

2. RELATION WORK

Cyber physical system (CPS) is a popular field of cutting-edge research. In 2007, in the U.S. Presidential Science and Technology Advisory Committee report, CPS was listed as the highest priority funded status of the federal research funds, attracting wide attention. In addition, CPS attached great importance to the U.S. government, academia and industry, so has put a lot of manpower and material resources, engaging in the CPS fields of basic theory and applied research.

The concept of CPS is not unified as a clear definition. There are several theories which are more recognized: (1) Edward Lee thinks that CPS is an integrated system of computing power and physical processes [8]. This system utilizes embedded computer and network to monitor the physical process, set up a feedback loop, computation affects physical process and physical process impacts computation through the feedback loop; (2)CPS is an integrated system of computing, communication, storage capacity, monitoring, controlling capability of the physical and engineering system[2], which can be manipulated by safety, reliable, effective, and Real-time method; (3)Insup Lee believes that CPS is a system which integrated by computing, communications, and



physical processes, embedded computer real-time monitors and controls the physical process [9]. There are three common points of these theories: 1) interconnection by network between the calculating system and the physical system; 2) monitoring capabilities; 3) real-time performance.

Ying Tan, Steve Goddard and Lance C. Perez proposed a CPS prototype architecture [7], viewed from the embedded systems point. This architecture prototype CPS features: timeliness, reliability, fault tolerance, security, scalability and autonomy. Reference [6] proposed a CPS architecture which is similar to computer bus structure, very simple and not described the various functional modules. Albert Benveniste proposed a layered architecture based on postoperative rehabilitation in the medical fields [4]. Reference [1] proposed architecture with easing time arrival based on the real-time characteristics.

Computer science references human perception isn't a new things, such as video surveillance, draw lessons from eyes of the human, which makes the computer can "see" the world. Nowadays, the newest video monitoring system not only can see the world, but also be able to analysis the objects moving, action or behavior. Reference [5] proposed a real-time human tracker that detects human location and motion using cameras. Reference [3] proposed a hierarchical approach that recognizes activities, in which different image features and learning methods are used for different activities based on their characteristics. Draw lessons from ear of the human, in which makes the computer can "hear" the world. At the same time, people build language voice library that computer could understand what the meaning of people speak. Through using human neural network as example construct the computer neural network. Therefore, man - machine - objects in real surroundings are inseparable.

To sum up the research of CPS, the various fields of scholars research in different level of CPS. However, people have different understanding of the CPS. CPS is not a new product, it is a integration by the original traditional technology. That provides the theoretical foundation research of CPS. Nevertheless, the information inconsistency exists in different research fields. In the future information sharing between the various fields has brought the difficulty.

3. HUMAN SENSORY SYSTEMS

CPS is a product of the combination of the cyber and physical world, but also a communicating

bridge between the cyber and physical world. People play a leading role in the physical world, and therefore, the system not only perceives the environment, also need to perceive people. We can learn how to perceive the world according to the human sensory system, allowing the system to perceive the world in a way by which it makes decisions more close to the people's decision-making, to enhance the intelligent effect.

Human sensory system is mainly composed of the eyes, ears, nose, tongue, touch, sense organs and nervous system. Human sensory system is usually divided into two categories, sensation and perception. Sensation is an individual attributes reflection direct acting on sensory stimulation, including external feeling and internal feeling. The external feeling received external stimulation, reflecting the feeling of the characteristics of external things, such as vision, hearing, smell, taste, and skin feel. Its receptors are located on the surface. Contact skin feel and taste receptors are called contacting receptors. By directly contacting with only these two receptors external things can be felt; visual, auditory, and olfactory receptors, are called long-distance receptors. External things through the role of the media cause a feeling. The internal feelings, also known as body feel, compared to the reflection of the feeling of the external environment such as vision, hearing, but reflects the internal state of the body and internal changes, including the applying sensation, balance sensation and visceral sensation.

The perception is a process where the individual put the sensory information into meaningful content, which is based on sensation, including object perception and social perception. In the CPS system object perception is more concerned. Object perception is people's perception of the objects or things, and external relations. Any objects or things have spatial characteristics and time characteristics of its motion changes. Therefore, the object perception, include space perception, time perception and motion perception. Spatial perception reflects the perception of the spatial characteristics of the object's shape, size, depth, and orientation. The perception of time is continuous and sequential perception reflecting objective phenomenon. Motion perception reflects the perception of the speed of the displacement and the displacement of the object space. Spatial perception, perception of time and motion perception are all gradually formed and developed in the process of life practice.

Human sensation and perception can act on people before all external stimulation must be received, stored, analyzed and produce sensation and perception. The senses of people react on the stimulus. Sensory Perception Analyzer perceive, process the information and thus form a meaningful perception, screening and filtering those information based on subjective needs, intentionally or unintentionally, perceiving the information beneficial to us and neglecting others. Then, we can conclude that the human sensory system is able to accomplish the target of the data collection in the physical layer of the CPS system, and this perception architecture is very similar to the formation of the CPS system knowledge base, both processing and analyzing the data collected, and ultimately getting meaningful data.

4. HSA FOR CPS

4.1. General CPS Architecture

CPS (Cyber Physical System) is a complex distributed system with computing, communications, and control. CPS has unique characters, but they also have common attributes. Its unique characteristics caused by using in different fields and environment. The environmental factors for different fields are not the same. However, according to the properties of the CPS, CPS used to consider performance and energy consumption by expert suggestion, collecting and gathering the information of the different characteristics in different fields, finally take suitable operation. On the other hand, there are essentially common in the CPS, such as mass data processing, hard and soft real-time strategy and so on.

CPS is a complex distributed system, it is not a new product, but also a combination of distributed computation, real-time embedded system, wireless sensor network and etc. those tradition technology. Hens, the complexity of CPS makes the system is difficult to construct whole system architecture. Many researchers are from different angle to analysis the architecture of CPS. Such as Ying Tan, Steve Goddard and Lance C. Perez viewed from the general systems point that proposed a CPS prototype architecture in Figure 1. And Wang Yunbo, Mehmet C Vuran and Steve Goddard base on network structure which proposed a control network system architecture of CPS as Figure 2. However, the existing architecture of CPS is mostly machine as the center design concept. But, the purpose of CPS is to serve people and controlled by people. We need to consider the suitable architecture of CPS, and satisfy the people's demand as the ultimate objective. Therefore, we need to know about the relationship among people - machine and the objects, giving a reasonable solution based on the environment.

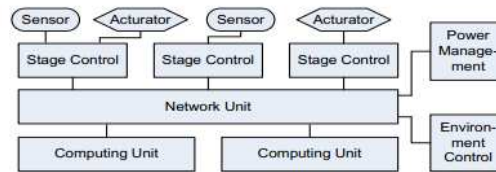


Figure 2: A Control Network System Architecture Of CPS [6]

Make overview to the CPS system in different fields of the environment, it is not hard to find the basic elements of CPS including human units, computation units, physical units and environment as Figure 3.

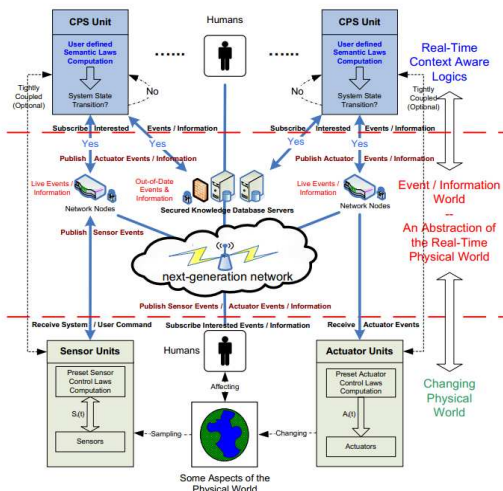


Figure 1: A Cyber-Physical System Prototype Architecture [7]

- Human units: the initiator of the demand in the entire system, but also is the one whole system service for.
- Computation units: all the equipment units with capacity to compute.
- Physical units: all the equipment units with the ability to receive and transmit information such as sensors, actuators, etc...
- The environment: means exactly where we use the whole system. Under the different Environments, the meaning of information and attributes are different.

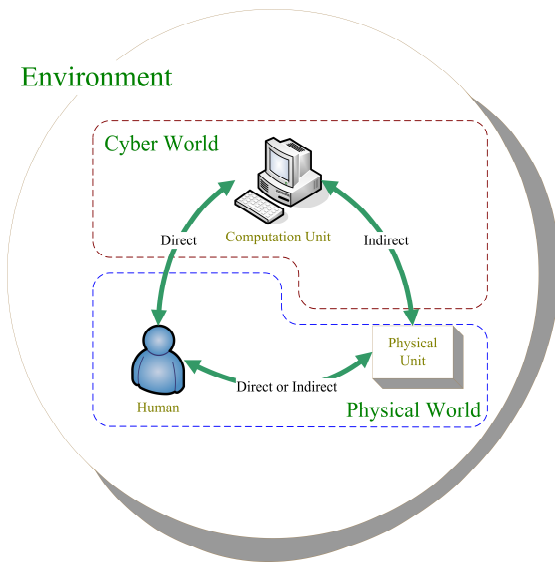


Figure 3: Relationship Between Each Basic Element In CPS

The series of activities among human - machine - objects are carried out in a real environment; the environment is being affected by the fields. People and the environment are affected by each other; Human have a direct communication and operation with computation unit, and also give the demand to the computation unit. There are diverse methods to operate the physical unit, such as can take direct operation, or control in the remote. Computation units need to communicate with the physical units, the physical units need to send a message computing and processing by computation units, and the result will be transferred back to physical units for controlling tasks performance. The computation units and the physical units use wireless networks to communicate. In this case, computation units include computing device and storage, while the physical units is means the equipment could perceive and change environment. In specific fields, according to demand by people, and then processing by computation unit. After that, the decision information will be passed to the physical unit and executed; finally the executed result will evaluate by people, and feed back to the computation unit.

4.2. Human Sensory Architecture

Early CPS systems, through the people or physical units (sensors) to sense environment and collect information, then people analysis of the collected data, made decisions, and finally send control instructions to perform the task through the remote execution units. However, as the CPS systems intelligence raised, information analysis

and decision makers gradually from people turning to computation units. People only need to sense the environment and put forward requirements, and then calculating and physical units deal with all subsequent works. In order to make computation units to make decisions which satisfy people's demands, they need to understand and sense the environment according to person's Angle.

Human sensation and perception based on CPS system architecture, mainly according to the human sensation and perception to build people-centered CPS system architecture. The human sensation is mainly to feel with the environmental situation, in the view of CPS, they are sensors of CPS system, and their main function is to collect environmental data. And perception is according to the sensory information form meaningful data, similar with data preprocessing and knowledge base constructing of CPS system.

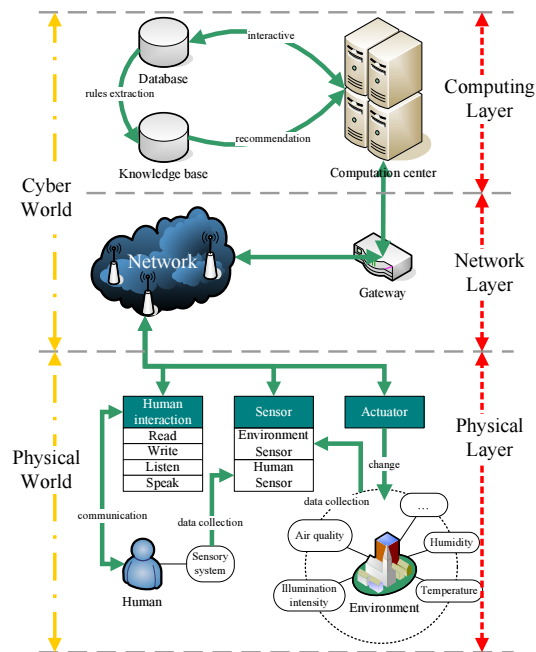


Figure 4: A Human Sensory Architecture For CPS

Human sensation and perception based CPS system architecture, mainly divided into three levels: computing layer, network layer and physical layer as Figure 4. The computing layer is the core of the CPS system, data storage, decision-making, knowledge base constructing are all done in this layer, in other words ,it is the brain of CPS. The purpose of the knowledge base is that lead machine to understand people's thought more by data. The knowledge base function is similar to perception of human which assists CPS decision-making. The formation of knowledge base, not only makes the



data into system, but also greatly improves the decision-making efficiency. The network layer is a communication layer of CPS system, mainly as a channel of communication, routing, data transmission, data forwarding, etc. are finished in this layer. The physical layer is an interaction terminal of CPS system and physical world, CPS system through sensors to collect data information from the physical world, through actuators to change physical world environment. In CPS system, people has ultimate control right, the final control decisions are made by people. Therefore, while sensing the physical world, the CPS system also need to sense people, through "sense what people feeling" to understand decisions of the people.

The physical layer of HSP architecture is added the communication interactive function. Communication interaction is divided into five kinds of behaviors which according to the human communication: reading, listening, speaking, writing and observe. The traditional man-machine interactive orders are initiated in the way of writing, which need a keyboard etc. outside equipment to input commands. Systems execute the command by reading the input information. With the join of speaking and listening these kind of behaviors, although increased the complexity of the system, yet simplified people's operation, makes the man-machine interactive more convenient. Observation is a deeper interaction, every detail action of behavior is for satisfy people's demand, if the system can observe people's behaviors and analyze, find out the requirement, that will provide the good helping role for judgment and forecasting of decision-making. And observation is also a process of improving system self-learning, when people have not established in language, mostly through the observation for learning. The system can through the observation to received feedback information after completing the task of in time. Such as task finished well, people will be happy, or have praise expression, and if the task finished unreasonable, maybe people will have angry expressions. In general, communication interaction, on one hand, can provide processing and optimization for different information, on the other hand, improve the convenience of human-machine interaction, diversified way of communication makes people more easily to express their demands to the system, make the strategy formulation more close to people's needs.

General CPS system architecture is basically centered on machine, through the environment information collection, execute the task that

according to the specific rules. Machine information demand is basically through the established rules to collect, and then execute tasks by the established rules, which achieve the goal of industrial automatic control. Machine based strategy in the industrial control can avoid wrong operations in the process of tasks, and also have very good constraint in task execution time, namely, increasing the control of real-time. But in machine based strategy, only applies to certain environment and specific demand, does not suitable for Complex changing environment. However human sensation and perception based CPS system architecture through own knowledge to understand the environment, state, task and other multiple information, and then dynamic form adjustable rules. So, it can be more suitable for the variable real environment.

In general, firstly, human sensation and perception based CPS system architecture constructs the knowledge base in the computation layer, knowledge base can analysis and understand discrete data, make the machine to set up its own knowledge system. The construction of knowledge base is the foundation of the machine self-learning, semantic understanding etc. Secondly, the communication interaction is added in human sensation perception architecture for CPS, communication interaction is the channel of human and machine. In the base of knowledge base construction, communication interaction through the convenient interactive way to study people's behaviors; Through the semantic to understand the requirement of humans. Human sensation perception architecture for CPS highlight important position of people in CPS system, CPS system need to sense, understand and service for people.

5. CONCLUSIONS

CPS is a complex distributed system, it is not a new product, but also a combination of some tradition technology. Nevertheless, CPS has its own characteristics, such as field uniqueness, mass data, and real-time control. The related domain involved in many areas, such as distributed computing, data mining, network transport, embedded, parallel computing and so on. The researcher in different area have different understanding in CPS. This paper propose a CPS architecture based on human sensory, make the CPS may sense what people sense, and provide an information source work for CPS decision making. CPS is a whole system which can combine the computing, communication, and control together and involve in many different fields. However, the meaning of the data in



different domain of CPS is not the same. In the future, we could build a part of language library base on Ontology which can make the information exchanging and resource sharing between different domains more and more conveniently.

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REFERENCES:

- [1] X. Ma, X. Tu, J. Huang, and J. He, "A cyber-physical system based framework for motor rehabilitation after stroke," presented at the Proceedings of the 1st International Conference on Wireless Technologies for Humanitarian Relief, Amritapuri, Kollam, Kerala, India, 2011.
- [2] CPSWEEK2011. (2011). Available: <http://cpsweek2011.cs.illinois.edu/>
- [3] C. Wu, A. H. Khalili, and H. Aghajan, "Multiview activity recognition in smart homes with spatio-temporal features," presented at the Proceedings of the Fourth ACM/IEEE International Conference on Distributed Smart Cameras, Atlanta, Georgia, 2010.
- [4] A. Benveniste, "Loosely time-triggered architectures for cyber-physical systems," presented at the Proceedings of the Conference on Design, Automation and Test in Europe, Dresden, Germany, 2010.
- [5] N. Quoc Cuong, S. Dongil, S. Dongkyoo, and K. Juhan, "Real-Time Human Tracker Based on Location and Motion Recognition of User for Smart Home," in *Multimedia and Ubiquitous Engineering, 2009. MUE '09. Third International Conference on*, 2009, pp. 243-250.
- [6] Y. Wang, M. C. Vuran, and S. Goddard, "Cyber-physical systems in industrial process control," *SIGBED Rev.*, vol. 5, 2008, pp. 1-2.
- [7] Y. Tan, S. Goddard, and L. C. Pérez, "A prototype architecture for cyber-physical systems," *SIGBED Rev.*, vol. 5, 2008, pp. 1-2.
- [8] E. A. Lee, "Cyber physical systems: Design challenges," in *11th IEEE Symposium on Object/Component/Service-Oriented Real-Time Distributed Computing, ISORC 2008, May 5, 2008 - May 7, 2008*, Orlando, FL, United states, 2008, pp. 363-369.
- [9] L. Insup. *Embedded and Cyber Physical Systems*. Available: <http://www.seas.upenn.edu/~lee/09ci480/reading.html>
- [10] W. Zhong, C. Ming-Rui, F. Yi-Fu, and F. Xing, "Lighten 3D data and its application in manufacturing industry," *Journal of Theoretical and Applied Information Technology*, vol. 43, 2012, pp. 181-186.
- [11] X. Xu, J. Zhao, and Y. Deng, "Integrated optimization and deployment mechanism of information resources in complex manufacturing collaborative logistics network," *Journal of Theoretical and Applied Information Technology*, vol. 44, 2012, pp. 153-160.
- [12] V. Violet Juli and J. Raja, "A comparative study on algorithms for mobility in wireless sensor network," *Journal of Theoretical and Applied Information Technology*, vol. 41, 2012, pp. 51-59.