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Cyber-Physical System (CPS) Application- A REVIEW

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ABSTRACT

Due to its vast number of suitable applications, Cyber-Physical Systems (CPS) has been one of the emerging and rapidly-developed technologies in modern life. Its applications can be integrated and deployed in numerous sectors, for instance the automobile, home appliances, medical and industrial sectors. This field has seen immense development and research taking place, including the architecture model, security, communications mode, control systems model and also signal processing. CPS plays an important role in Industrial Revolution 4.0, where it is an integration of urbane network with intelligent production or process system. CPS main objective is to control the global networks with high credibility of data secured. This paper is basically a review of the CPS architectures, characteristics and its applications in daily basis. This review paper discusses how CPS are implemented in various industries and how it improves the efficiency of a system or application. Additionally, security enhancements in certain aspects of CPS application will also be reviewed and addressed.

Keywords: *Cyber-Physical System, architecture, application, security, communication*

1. INTRODUCTION

Cyber is related to computers, information technology and virtual reality technologies. In the meantime, the physical system can be viewed as the component of the physical universe selected for the analysis and study. Vehicles, human, houses and chairs are examples of the physical component. Cyber-physical systems are those in which both sizes and levels of the cyber and physical elements are closely combined. Most researchers come from embedded systems CPS **(Park et al., 2012**) which are described as a computer system for performing specific functions with real-time computing constraints within some mechanical or electrical system. The close integration and synchronization between the physical and computational processes are used to distinguish the embedded systems. According to this concept, CPS networks different embedded devices for the sensing, monitoring and actuation of physical elements in the real world.

People are often confused about the distinction between the Internet of Things (IoT) and CPS. IoT has to do with connecting 'things', be it a machine or an object. Meanwhile, CPS are the integration of computational, networking and physical processes **(Ahmad et al., 2018 & Jamaludin et al., 2018).** In other words, IoT is a subset of CPS as illustrated in Figure 1 **(NITRD, 2012)**.

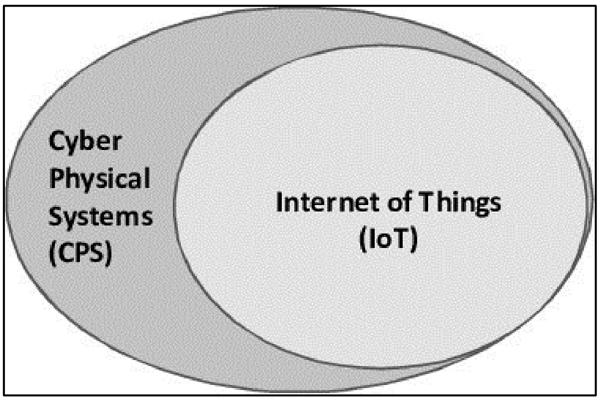

Figure 1. Relationship between CPS and IoT

CPS are very important for our industry. Majority of industries deal with mechanical system in early 18th to 19th centuries. The total number of productions are still controllable. Starting of the 20th century, many industries required an intelligent manufacturing system to control their massive demand of production. Industries required a system that can stored data and system that can automatically monitor the manufacturing processes **(Jamaludin et al., 2018)**. The integration of CPS and IOT are applied in this standard of living lifestyle nowadays to fulfil the necessity of Industrial Revolution 4.0.

2. CPS ARCHITECTURES AND CHARACTERISTIC

CPS is the integration of physical or mechanical system and network or computations system. According to Liu et.al **(Liu et al.,2011)**, there are four main characteristics of CPS; physical system, information system, the product of integration and heterogeneous systems and requirement of security, real-time capability and predictability.

The physical system is a mechanical part such as actuator or electromechanical system that is used in production line or processing system. Information system is more on network, data storage, and memory management. Meanwhile, heterogenous systems is the interaction controlling between physical and network. External communication network is a common system. This external communication system may disturb by a malicious cyber-attack. Requirement of security, real-time capability and predictability is one of the important characteristics in CPS. It is to avoid any issued occurred that caused the unpredictable system's behaviour **(Jamaludin et al., 2018).** Figure 2 shows CPS basic architecture.

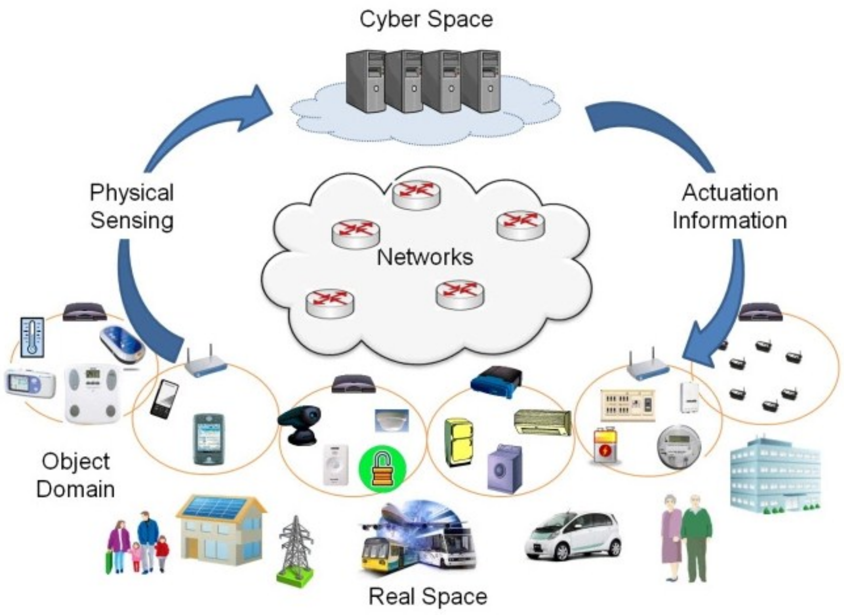

Figure 2. CPS basic architecture (Eroarke, 2014)

According to Figure 4, physical system consist of physical sensing will send an analogue signal to the cyber space. The analogue signal will be converted into digital data. This data needs to be protected from malicious attack. Data encryption and integration will be involved to protect the data credential, privacy and integrity. Cyber space will control, stored and process the data. Control centre will send a control command to the actuator network. This is a close-loop processes.

Another important characteristic in CPS is global reference time. Global reference time helps to make sure the CPS performance are conducted in a synchronous or asynchronous. This will help to ensure the data from physical system to actuator are send properly and accurately through cyber world.

3. APPLICATIONS OF CPS

CPS widely applied in smart building, social networking and gaming, industrial networking, electric power grid and energy systems, vehicular systems and transportation. The important role of CPS for these industries are to have a secure and safe operations systems. Below are discussing in detail on CPS applications.

2.1 Smart Homes and Buildings

In 2011, Li and his team modelled the smart community architecture which consists of three domains **(Li et al., 2011)**. This application is referred to as a framework of CPS which integrates objects in a networked smart home. The individual homes are designed as multifunctional sensors and are equipped with automated or human-controlled physical input wherever necessary to enhance community surveillance, quality of healthcare and security. The smart community platform offered two significant applications which are the Neighbourhood Watch and Pervasive Healthcare. The Neighbourhood Watch compromising a function of community association to prevent vandalism and any devoted crime.

The community centre defines the correlation of the event reports (data) obtained by statistical modelling. If they show a city-wide threat together, it sends notices to all houses in the city and contacts the call centre. The call centre sends received service calls to the relevant authority to take/provide appropriate action or input. The healthcare service provides instant data transfer if any urgent input or other relevant information such as the personal health information (PHI) via the equipped body sensors and home surveillance systems.

From the smart home community provided **(Li et al., 2011),** other value-added services correlated as well, such as utility management and social networking. Every home is equipped with smart metres in the smart community that send their measurements to the central controller, in impact, though in turn transmits the information to the community centre via the community network in a safe and form of protecting privacy.

The smart community environment also provides a platform for societal networks. The social network is accessible and cost-free for residents to use in order to communicate with other residents in the area. In certain cases, due to geographical vicinity, this sort of cultural network would have been more efficient than those based on the internet. Figure 3 illustrates the three domains that comprise smart community architecture, while Figure 4 presents a flowchart of smart community communication.

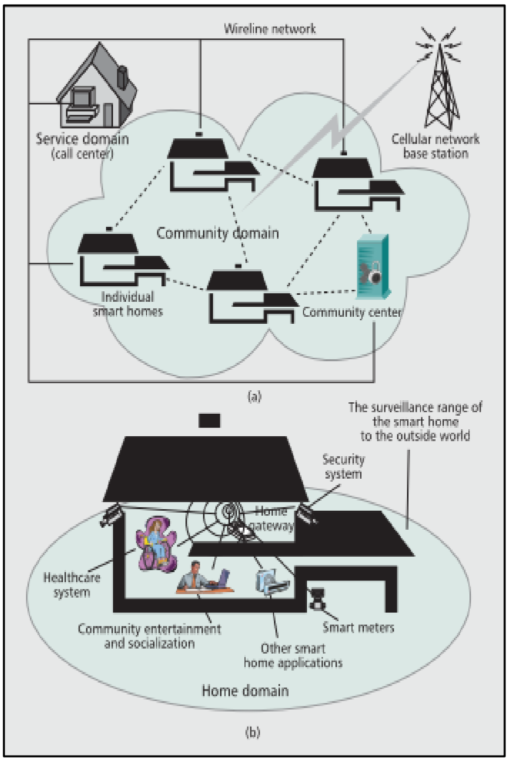

Figure 3. Smart community architecture, in which a) community and service domain b) home domain (Li et al., 2011)

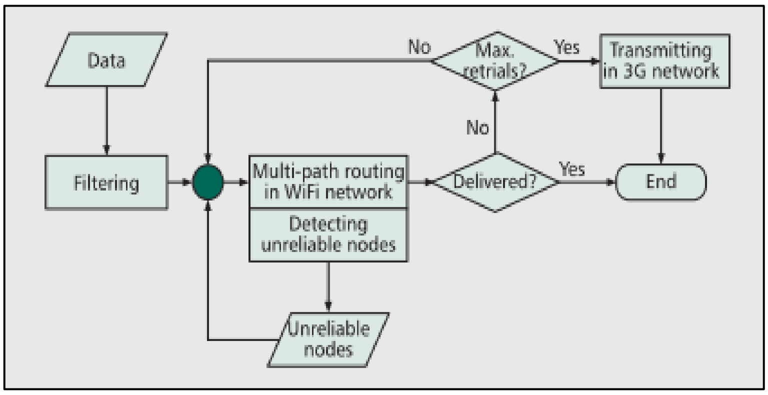

Figure 4. Flowchart of smart community communication (Li et al., 2011)

A group of researchers **(Xia & Ma, 2011)** proposed the vital drivers in building smart communities such as the Immense ageing of the population with expected consequences for disability and care problems. Apart from that, in order to assist living for the elderly, a smart community could provide a real-time emergency response, monitored the neighbourhood activity and remote medical service. Smart communities may, from a social point of view, allow self-awareness among participants through the use of several social sensors **(Quercia & Capra, 2009) (F. Wu & Tseng, 2011)**. However, in real-time, smart societies demand distributed multimodal collection of data. Therefore, the sensing task could be performed in a collaborative way to get complete and accurate data.

Since the smart group belongs to a wide range of wireless network communications and networking industries, it owns several main concerns, for instance, the control of transmission **(Holly, 1986)**, control of media access **(Xu & Saadawi, 2001) (Shan et al., 2009),** allocation of bandwidth **(Su et al., 2010)** and routing **(Stojmenovic et al., 2005)**. Therefore, intensive research has been done to overcome those issues. For example, a researcher provides an intelligent bandwidth allocation algorithm for multilayer traffic mapping. The solution could be done through the priority provision of burst selection criteria and scheduling mechanism **(Koster & Muñoz, 2010)**.

In addition, a survey and analysis that the energy consumption at the nighttime in buildings is substantial and involves a significant and rising fraction of the machine and networking equipment energy consumption were conducted in 2010 **(Kleissl & Agarwal, 2010)**. By modelling the cyber-physical energy system, one can implement sleep modes of the scheduling machine which according to real-time pricing transmissions that would minimize the greenhouse gas emission. Two main points of the application used to achieve zero net energy building (ZNBE) by integrating the CPS in buildings is by using more powerful LED bulbs and motion sensors to monitor the lighting. Besides, it is necessary to install solar photovoltaics to produce electricity generation by many buildings. Simulating a building as a cyber-physical energy system can play a crucial role in achieving and running zero net energy buildings (ZNEB).

2.2 Social Networking and Gaming

The application of CPS technology in social networks and entertainment will bring about a revolutionary effect. For example, computer games that integrate CPS improve upon the virtual world that they create with added physical signals, such as those from sensing devices. This configuration will enhance the users' engagement and provide a more realistic experience.

CenceMe is a technology order to facilitate information collected from mobile sensors to be shared through social networks **(Miluzzo et al., 2008).** In order to do this, CenceMe detects a single user's behaviour in various environments, after which a social network such as Facebook or Myspace will share the information received by the user's sensors and actuators.

Various sensing element such as the GPS, camera, accelerometers, Bluetooth and microphone were used in expanding the capabilities of mobile phone. However, the usage of Bluetooth and GPS application serves a high number of energy usage. Therefore, power conservation is an important driver to be considered in the implementation of the CenceMe application.

By carrying multiple sensors on the human body, also known as body-sensor networks (BSN), the human motion could be captured. Data from the body sensors are captured and transmitted in real-time. An idea of a CPS network whereby users can practise traditional Chinese particular skill, Tai Chi, was discussed in a study in 2010 **(F.-J. Wu et al., 2010)**. By implementing the wireless sensor networks (WSNs), any group of people could make-up Tai Chi exercises and lessons anywhere and anytime lead by a Tai Chi master. This platform provides users to communicate by sharing conventional messages and images and even some sensory signal across several interesting ways. Figure 5 illustrates the architecture of this virtual-physical Tai chi social network.

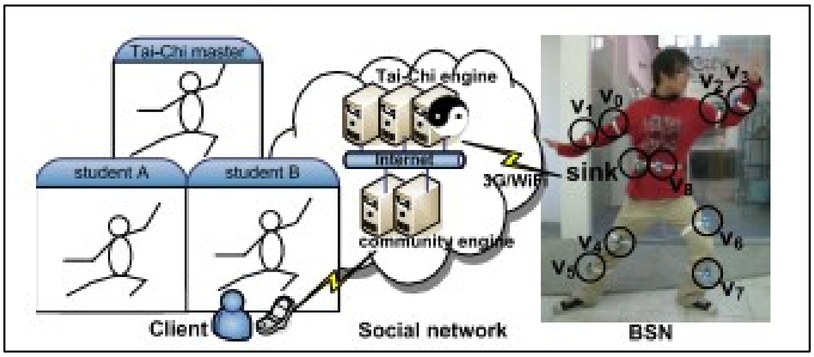

Figure 5. Architecture of the virtual-physical Tai chi network (F.-J. Wu et al., 2010)

Another case study on the exploring Quality of Experience (QoE) in the world of modern cyber-physical gaming in terms of 3D tele-immersive (3DTI) environments was presented in 2010 **(W. Wu et al., 2010)**. In the said study, the researchers analyzed non-technical influences such as age and social interaction effects, on user experience in 3DTI environments. This experiment includes mapping through the cameras' field of view of the virtual 3D coordinate world and the physical 3D coordinate.

Apart from the new game consoles, the various component in the physical configuration has been a new challenge in the CPS gaming environment. To promote fast coordination of kids in the cyber-physical platform, the snap-shooting and rendering devices should be exclusively associated. Impermissible physical space organization can lead to uncertainty, irritation, and lack of interest, thus degrading the gaming experience. The extension for Wu's Quality of Service (QoS) and the Quality of Experience (QoE) as in Figure 6 below.

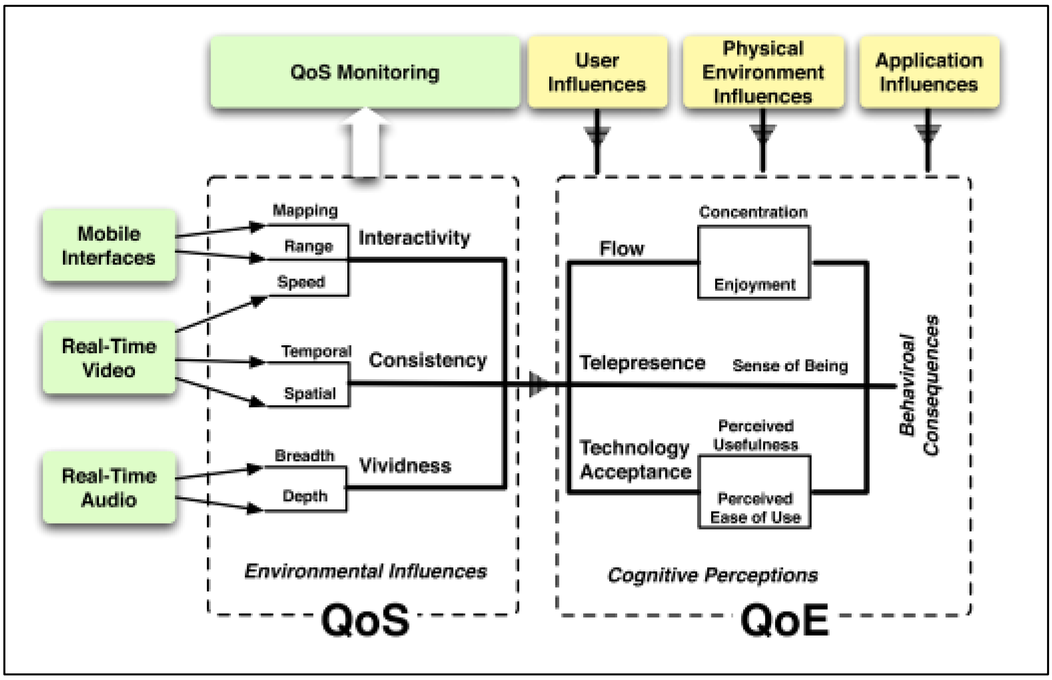

Figure 6. Extension to Wu's QoS-QoE model (F.-J. Wu et al., 2010)

Similar to the usage of BSN mentioned previously **(Wu et al., 2010),** an example of a video game with CPS that requires multiple game boards to expand the players' field of view in order to provide a more realistic in-game experience and interaction was addressed **(C. H. Wu et al., 2010)**. This game was developed with a network of body-area inertial sensors deployed on players as input sources which consequently increases the level of interactivity between the player and the game's virtual objects.

The difference with previous research was that the simulation is done by controlling several game drivers (G1, G2, G3 and G4) simultaneously via LAN framework for a multi-screen game engine. For the four-game drivers, four camera angles (east, west, north, and south) are set to provide a 360-panoramic view of the game scene. As a future recommendation, a few numbers of game engines and cameras with a different view of angles could be increased to widen the image cover-up and covey accurate data transmission.

2.3 Networking Systems

Video-based sensing application which equipped camera in mobile phones used for capture, send and receive real-time videos have been a popular platform for social communication **(Burke et al., 2006)**. In 2008, a group of researcher presented a network architecture known as AnySense that facilitates the internet hosts in CPS and 3G mobile phones*.* **(Xing et al., 2008)**. AnySense, integrates transcoding of video streams which is open to 3G mobile service providers through the interface of internet and the 3G cellular framework.

In 3G network video modelling, the Perceptual Evaluation of Video Quality (PEVQ) is an important factor to consider and the key challenge in this video modelling is to remove the impact of video encoders which affect the score for PEVQ. As a consequence, 3G networks from various providers are not accessible to an encoder-dependent video quality model. Optionally, without the dependency of encoding schemes, a video quality model can only convey the effect of network transmission variables. To this end, Xing and his team researcher propose a new reference-based modelling approach that can effectively minimize the effect of encoding on video quality quantification.

AnySense's approach is by associating the 3G networks of circuit-switched (CS) and the packet-switched (PS) Internet. Figure 7 is the architecture of AnySense.

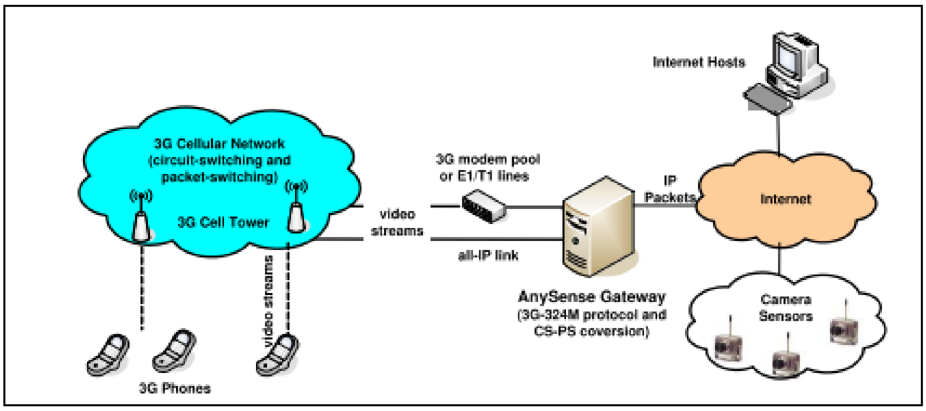

Figure 7. AnySense architecture (Xing et al., 2008)

CPU and radio are the significant sources of power operating expenses on cyber-physical wireless networks. To deal with this, intensively research to implement this practice have been done **(Rhee et al., 2008)** but unfortunately bring to another challenge in embedded applications. Therefore, Darmawan **(Darmawan, 2019)** described a method to utilize the energy consumption in wireless CPS for real-time applications.

His work proves by implementing the radio sleep configuration for wireless sensor nodes and computer execution modes could optimize the power consumption on a CPS device system. Different schemes were proposed based on various wireless network topologies to reduce the expenditure of energy through maintaining the timing limit and limit of precedent. In practice, this technique is effective, though it's pseudo-polynomial algorithm.

2.4 Electric Power Grid and Energy Systems

In 2010, a technique proposed to utilize the reduced emissions from gridable vehicles (GV) by integrating the cyber-physical energy system (CPES) with renewable energy sources (RES) and conventional thermal power plants **(Saber & Venayagamoorthy, 2010).** According to the author's analysis, RES and GV could be maximized in order to decrease cost and greenhouse gas emissions. The intelligent scheduling provides great significant in controlling the energy system integrating the electricity and transportation framework. Figure 8 is the flowchart that claimed as maximum utilization of renewable energy in CPES with GVs.

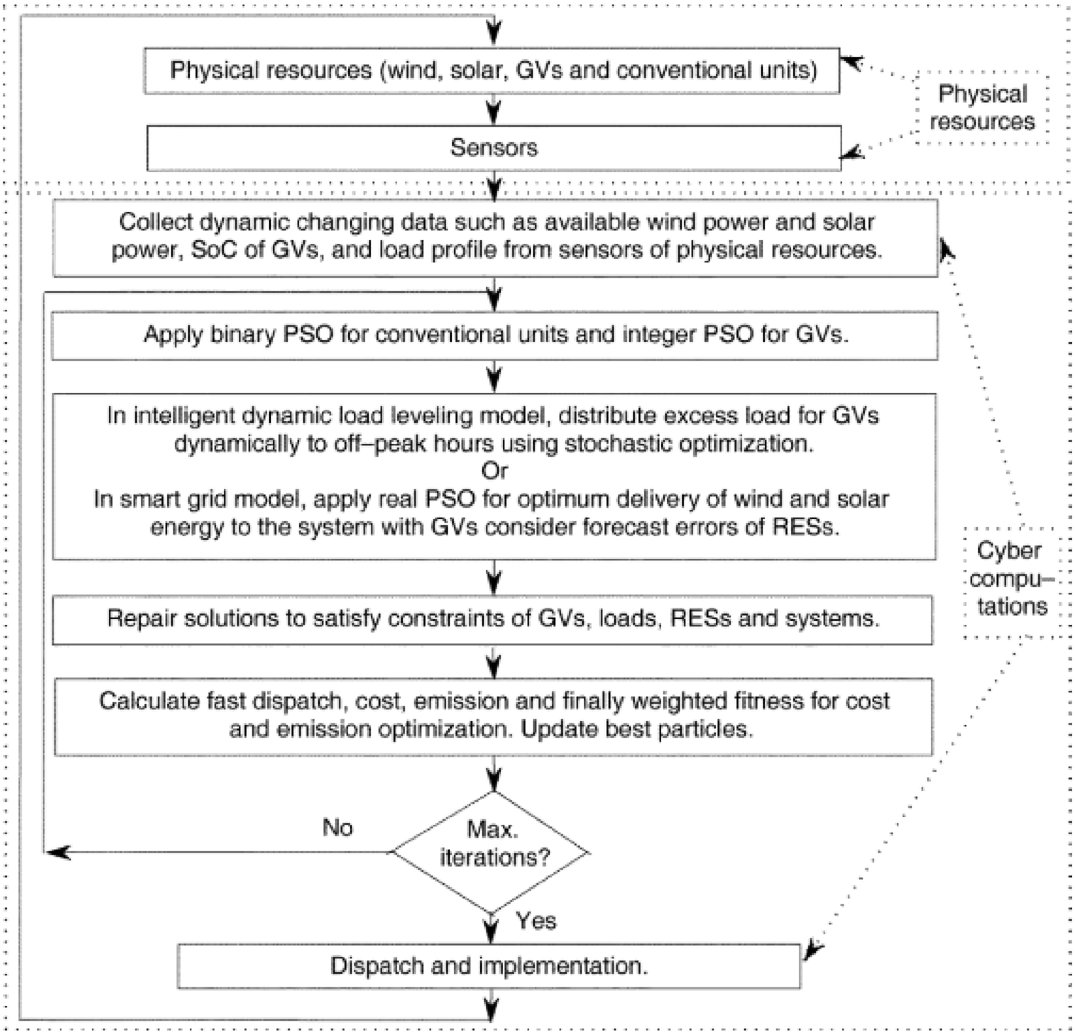

Figure 8. Flowchart for the maximum utilization of renewable energy sources in CPES (Saber & Venayagamoorthy, 2010)

Since security is crucial in CPS, a group of researcher introduced an approach to enhance the security of the smart grid's application and infrastructure **(Sridhar et al., 2012)**. Cyber vulnerabilities can occur in an electrical grid due to, among others, inappropriate privileges and access controls, poor firewall rules, cryptographic problems, and a lack of validation data. A structured approach to risk assessment was adopted and consequently implemented based on the need to protect both the physical power applications and the supporting cyber infra framework. The power grid cyber-physical infrastructure is shown in Figure 9.

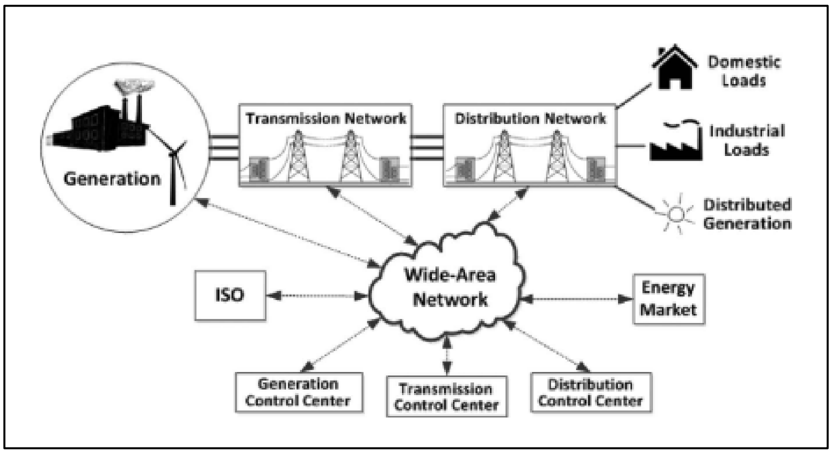

Figure 9. Power grid cyber-physical infrastructure (Sridhar et al., 2012)

Meanwhile, a dynamic battery model that supports control systems in CPS to enable the prediction of battery life was discussed in 2009 **(Zhang et al., 2009)**. This is jointly done by an online scheduling algorithm and battery management framework to optimize the performance of the batteries, computing device and the plant as a whole. This study improved the Rakhmatov- Vrudhula-Wallach (RVW) model through the experiment conducted. For a square wave present, the optimal discharge profile is calculated and simulation results are given to compare the battery life of different discharge profiles.

2.5 Vehicular Systems and Transportation

Smaldone and his researchers' team described a method to enhance cycling safety by deploying computational capabilities and video processing **(Smaldone et al., 2011)**. This cyber-physical bicycle system continuously monitors the area behind the cyclist, detects back wheel-approaching vehicles automatically and warns the cyclist after their arrival. In the said study, the aforementioned authors identified the safety of cyclist as an issue that could be addressed using video streaming sensing and encoding.

To address the issue, the authors presented the modelled of a cyber-physical bicycle framework that uses methods of video processing to perform automatic vehicle detection. The viability of this mechanism was then demonstrated by evaluating the implementation of its prototype. Initial results showed that good accuracy was obtained by operating at standard frame rates while real-time detection was able to be performed with reduced frame rates. Figure 10 is a graphical representation of this cyber-physical bicycle model.

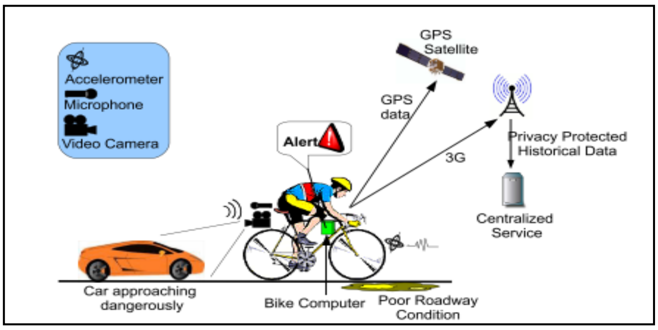

Figure 10 Cyber-Physical Bicycle (Smaldone et al., 2011)

In order to avoid threats and attacks that will result in safety implications such as physical harm and even a loss of human life, providing safety for vehicles is critical in intelligent applications of vehicular cyber-physical systems (VCPS) **(Melo Jr. et al., 2013)**. An application was addressed this particular need for security by analysing the reliability and completeness of the safety requirements that would be implemented in CPS. Authors have identified the specific requirement for VCPS which integrate both cyber and physical requirements. This method successfully enhanced security by providing clearer vision in VCPS. The security requirements for VCPS is tabulated in Table 1.

Table 1. VCPS security requirements (Melo Jr. et al., 2013)

Security issue	Cyber requirements	Physical requirements
Confidentiality	Personal and private information shall be protected;	The communication among sensors, controllers and actuators shall be protected as necessary;
Integrity	The integrity of received data and its transmission shall be verified; The integrity of hardware and software components shall be verified;	The integrity of tamper proofing storage devices shall be verified; The integrity of control and feedback data shall be verified; The integrity of the firmware of sensors, controllers and actuators shall be verified;
Authentication	System access by users or external actors shall be authenticated as necessary;	Sensors shall be authenticated before sending sensing data; Controllers shall be authenticated before sending actuation commands;
Active security	Mechanisms like intrusion and misbehavior detectors shall be implemented for both cyber and physical components; Mechanisms like fault detectors shall be considered, mainly on physical components;	

To promote the production of smart car models, Jha and Sukthankar suggested the use of machine learning approaches to learn stochastic models of interaction between humans and vehicles **(Jha & Sukthankar, 2011)**. The accuracy of automobile models can be enhanced by using current psychological theories regarding human behaviour. The authors recommend using a mixture of randomized and statistical approaches to validate automotive CPS. For instance, human beings typically are not ideal route planners for a given set of obstacles. Instead, the improved prediction is obtained by making assumptions based on the path prediction model on self-centred features which are known to influence human steering preferences.

4. CONCLUSIONS

Compared to conventional embedded systems, CPS is expected to bring about enhancements in numerous aspects such as in efficiency performance, protection, reliability, robustness, adaptability and many more. Put another way, CPS give the promise of systems that can respond faster, more accurately, more efficiently and more effectively. For instance, vehicular CPS or VCPS has the potential to prevent fatal car accidents by virtue of a fast response. In the medical industry, the adoption of robotic surgery could provide higher accuracy. Zero net energy buildings with better quality are also another possibility with CPS. Nevertheless, extensive research on enhancing the security of CPS is required to maintain privacy and protect lives. As a result, research in CPS would significantly ameliorate the fundamental efficiency of virtually any engineered device while also improving the quality of our daily lives in the process.

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