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Cyber physical systems: A smart city perspective

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ABSTRACT

Cyber-physical system (CPS) is a terminology used to describe multiple systems of existing infrastructure and manufacturing system that combines computing technologies (cyber space) into the physical space to integrate human interaction. This paper does a literature review of the work related to CPS in terms of its importance in today's world. Further, this paper also looks at the importance of CPS and its relationship with internet of things (IoT). CPS is a very broad area and is used in variety of fields and some of these major fields are evaluated. Additionally, the implementation of CPS and IoT is major enabler for smart cities and various examples of such implementation in the context of Dubai and UAE are researched. Finally, security issues related to CPS in general are also reviewed.

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1. INTRODUCTION

Due to the recent advancements in technology, computation and communication features of devices are being pushed into physical systems which interact and respond to stimulus coming from the surrounding environment. This is due to the advent of rapid growth in networked computing technologies. These embedded technologies have given rise to cyber physical systems.

According to a researcher, Asadollah *et al.*, cyber physical systems are a type of complex engineering system that brings together physical, processing and interactivity parts. A computing and communication core is needed to compute, control, coordinate, monitor and integrate in the physical systems [1]. According to another researcher, Anand *et al.*, cyber physical systems are intelligent systems created using low power wireless network sensors that are used to interface between physical space and cyber space [2]. Another researcher, Chaâri *et al.*, defines cyber physical systems are made of sensors which have very less processing and built-in storage capabilities. These sensors are increasingly becoming smaller with advancements in engineering technology and are integrated into larger industrial systems [3]. The advent of internet of things (IoT) and cloud computing having enabled these CPS devices to increase their capabilities by taking advantage of the cloud-based storage and processing.

In summary, the cyber physical systems (CPS) can be viewed as a contributing factor towards the fourth industrial revolution. These systems are constructed by integrating production, sustainability and customer satisfaction. The system per se is made up of appliances, machines, robots and complete industrial

environment connected to the Internet, which will enable all industrial network infrastructure and applications to take advantage of being connected to Internet at all levels of the industry. The biggest advantage provided by this, is the possibility of processing and analyzing significantly large information flows from production and auxiliary processes [4, 5].

CPS is made up of cyber-which are used to define intelligent systems being used and physical-meaning methodologies to sense, observe, manipulate and interact with the physical space. CPS are being prevalently used in various industries including, but not limited to, entertainment, transportation, smart energy grid, medical, and evacuation support. A new paradigm in CPS is the concept of IoT, which is turning out to the be fundamental element for creating smart cities [6]. The technology of these systems is depending on application software's, which are built into devices and the major operations of these application is not processing data but may have other purposes. Some examples include cars, medical devices, energy meters, and smart transportation systems.

The cyber physical system consists of the physical environment of users; interfaces between the physical and digital; and cyber space consisting of servers and networks as shown in Figure 1. The physical space refers to the physical elements that need to be physically monitored or controlled in a real environment. The cyber space refers to the embedded devices consisting of sensors that process information and communicate with their distributed environment with the use of actuators. The interfacing is done either using sensors or actuators with more intelligence, which are used to convert forms of energy to electricity [7]. Due to the recent advancements in technology, computation and communication features of devices are being pushed into physical systems which interact and respond to stimulus coming from the surrounding environment. This is due to the advent of rapid growth in networked computing technologies. These embedded technologies have given rise to cyber physical systems.

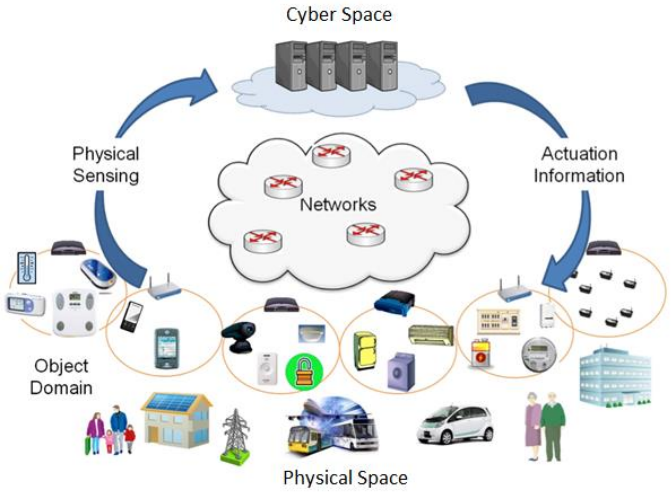

Figure 1. The cyber physical system [8]

2. THE IMPORTANCE OF CPS AND IoT

A subsidiary of the CPS is IoT, which is a large network of different interconnected objects that have a unique identity and can be referenced using IP or MAC addresses. The devices encompass different sensors, actuators, intelligent devices, RFID enabled devices and smart mobile devices, communicate using de-facto popular protocols. The IoT is growing to be a technology that is used to create a system consisting of cooperating smart autonomous physical-digital objects which are complemented by using sensors and actuators. Furthermore, relevant processing, storage and networking capabilities are also available in IoT systems [9]. The IoT architecture is a basis for the successful design and implementation of CPS. These IoT infrastructure consisting of protocols and API are used to facilitate the collection, management and processing of large amount of data. The implementation can be at a local or global level which aids connectivity using technologies like Wi-Fi, fiber, cellular networks and in the future, 5G. With large scale IoT based CPS, Cloud Computing infrastructures and platforms can be effectively used to provide flexible cloud-based processing power. These infrastructures also provide virtualization capabilities and large capacity storage for the data produced by the sensors. Another enabler would be the big data/ analytics which

is considered as the brain of the IoT. This system processes the data sent by the sensors and actuators, correlate it with other sources of information and produces intelligence information that can be derived as actions in the physical space. The characteristics of IoT devices are very challenging; as these devices have essential impact on the services provided. Following are some of the characteristics of IoT devices [10]: they should have the capability to be adapt to contexts or situations that may arise sue to change in external environments and situations.

They should have self-configuration capabilities allowing multiple devices to interact with one another to accomplish the assigned role. They should be able to communicate with other devices and the infrastructure by supporting interoperable communication protocols. They should have a unique identifier and unique identity so that these system interfaces allow passing data with users and their environment. They have to be integrated into the network so that they can communicate and exchange sensor data with other devices and systems.

3. DOMAINS AND APPLICATIONS OF CPS

CPS are becoming increasingly prevalent in today's society. These systems are being used on a daily basis such as smart homes, traffic control systems, automotive systems and energy systems. These types of systems are also used in high-tech domains like aviation systems, medical technology, weapons systems, manufacturing sector and chip fabrication, among other industries. The following section provides an overview of the various CPS application domains according to their functionality.

3.1. Health care and medicine

The domain of health care and medicine is used to address the relevant health aspect of a patient. Technologies related to home care, smart operating room, and smart medical devices, are various opportunities in this domain. These devices aid monitoring of the patient health by increasing the connectivity of medical devices with network devices which, in effect provides continuous patient monitoring. The current trend in this domain is towards creating energy efficient systems that provide real-time visualization of patient data along with seamless capability of plugging in new sensors with interoperable medical devices. One such device is an infusion pump, which is used to inject a required medicine into a patient. These infusion pumps are normally administered automatically to release a controlled amount of medicine. The major functions of such a device are to deliver the medicine based on the schedule and whenever a patient may request for the medicine, have the intelligence to prevent any undesired situations that may occur during the medicine infusion and, monitor and notify personnel of the undesired conditions which may arise [11]. With the advent of wearable smart devices which are interacting with its surrounding environments by capturing and providing health data, personalized healthcare can be provided to improve the quality of life. Therefore, these systems help in creating health awareness which in effect helps people detect and address diseases that may arise in their daily life and routine [12]. Helpful systems and robots can be used to prolong and ease living for seniors without external aid and can alert external health bodies in case of emergency health events.

3.2. Smart electric power grid

This category is an essential critical infrastructure that is necessary for the survival of a nation. A smart grid implementation enables a normal electric grid to be a cyber-physical system. The efficiency and reliability of existing energy girds can be improved by implementing smart grids. These systems have features that help in autonomous monitoring, diagnosis, responding to energy demand and enhanced communication [13]. The system consists of power plants which generate energy, storage facilities to store this energy and transmission facilities to transmit this energy to end users. Also present in this system are self-replenishing energy sources like large fields of wind turbines and solar panel fields. Also included are the energy management and distribution facilities in smart home and smart buildings. The smart grid is actually a distributed, cooperative and customer interactive network which is used to do real-time monitoring of usage in terms of load, understand distribution of the energy efficiently and thus plan the usage level of the energy for the consumers [14]. This is possible due to the presence of two-way flow of information between the consumer and the utility provider. Due to this interaction, decisions can be made to switch between multiple energy sources present in the grid that leads to further grid exploration, power quality monitoring and prevention of potential outage of energy systems. Also, part of the smart grid is the water distribution system, which integrates monitoring of water quality for hardness and impurities. Also involved in this system, is the detection of water force and levels of water distribution which aids in better leak detection. An essential component for creating a smart grid is a smart meter used for creating an automatic meter reading system (AMR) [15]. These devices collect fine grained energy consumption data and wirelessly transfer to

reading devices. These AMR devices will remain operational for extended period of time and can enable remote collection of consumption data of electricity and water. This has several advantages like reducing the cost of reading meters and reducing manual reading errors. Real time monitoring of the system can enable utilities to better respond to demand changes.

3.3. Intelligent transportation

This domain relates to the usage of advanced technologies for improving safety, coordination and services in traffic management. Sensors find real-time information which is fed to a computation system and then communicated to the actuators to provide the efficient traffic management. The system is created by integration of vehicles, sensors, pedestrians, road side units (RSUs) and traffic management centers. Intelligent transportation enables real time monitoring of traffic and enables optimal traffic management and collision avoidance [16]. The implementation is done by the use of vehicle-to-vehicle (V2V) communications and vehicle-to-roadside (V2R) communications. Some of the problems addressed by these systems include, reducing traffic accidents, avoiding and reducing congestion, fuel efficiency and improving general transportation safety [17]. The presence of intelligent systems, wireless modules and the presence of many numbers of sensor in these vehicles, is used effectively to create this kind of a CPS. Other implementations include new solutions which can be applied to autonomous vehicles that can successfully navigate to a destination. The autonomous vehicles will have new guidance and safety systems which will be integrated into the electronic on-board systems already present in modern day vehicles, connect wirelessly to the manufacturer, and offer third-party services via the internet. These vehicles can have open-source software, which is an issue, as they will have software from a variety of vendors [18].

3.4. Air transportation

Enhanced safety is a primary objective of air transportation systems. There has been significant progress in many dimensions of the air transportation system, but still there is a need to enhance the safety capabilities to enhance safe navigation and tracking functionality [19]. To achieve this safety, distributed control using sophisticated air traffic management systems in going to be a significant element of future systems. This in turn, is going to give rise to more challenges as the interaction between aircraft and radar towers are going to increase significantly, which can inhibit and limit the overall capability of the current system. The enhancement will include the use of satellite technology over radar towers to conduct air traffic control. Satellite navigation will provide pilots with precise locations of surrounding aircrafts. Another implementation is the advent of unmanned aerial vehicles (UAV) or also called drones. The technologies used in UAVs are being increasingly adopted into civilian aircraft systems, making them increasing smarter. These technologies increase the physical awareness of aircrafts and thus will have a major impact on air traffic in near future and systems used to manage air traffic. This is giving rise to a concept called as NextGen air transportation systems [20].

3.5. Emergency response

Emergency response is, when public safety and health is compromised due to natural or man-made calamities, and when a system is in place to address these issues. A CPS enabled emergency response system is one which can conduct unmanned search and recovery in hostile environments. Most of the CPS robots are autonomous, self-learning or remotely operated by controllers [12]. These systems provide fast emergencies services due to use of distributed, low-power sensors which have a dedicated communications and control space. These systems require nodes to collect information so that the situation can be assessed and informed to emergency teams. Normally these situations are very fluid and ever changing in nature. Due to this, the system has to be robust, efficient, adaptive and use all resources at its disposal very efficiently.

3.6. Smart manufacturing

Smart manufacturing systems are the one which combine the information technology (IT) and operation technology (OT), present in a factory or manufacturing unit. The system uses software and on floor robots and automated technologies to enhance the productivity while goods are being manufactured. This CPS systems is giving rise to Industry 4.0, which is manufacturing for the future. In this type of industry, production technologies will give rise to different work flows in the industry and enhance different forms of collaborative efforts. The focus of Industry 4.0 is to add networked software to machines which in effect gives benefits like machine-to-machine communication, so that human work can be reduced and efficiency is increased. Another benefit, is in the form of predictive maintenance of machines and appliances. Status reports generated by these machines can enable predictive maintenance and also enable remote repair [4]. A final benefit is the engagement of the user with the system. Users can provide data into a mechanical system to create new value and further enhance services provided by the system.

3.7. Smart building

The concept of automating a building with respect to installing sensors, actuators and distributed control systems, gives rise to smart building systems. These systems make use of sensors to control the heating, ventilation and air conditioning (HVAC) system to provide a suitable and energy efficient building. Also controlled are the lighting systems of the building, such that only desired areas are lit up only when needed. Another prime system which is monitored is the fire prevention systems to ensure the safety of the residents [21]. The whole purpose of designing a smart building is to provide a smart living atmosphere for the residents. This is done by autonomous learning by the system where the living patterns are monitored. Smart building needs to be sustainable for a long period of time, hence the systems have to adapt to technological and social changes.

4. SMART CITIES USING CPS

The concept of smart cities has been developed by combining several domains like smart buildings, emergency response, intelligent transportation and smart grids. Smart cities are wide scale CPS with sensors continually looking at occurrences happening in the cyber and physical world. This in turn affects the actuators in changing the urban environment in suitable ways [22]. These systems are implemented to improve urban and city life, which is increasing at a very rapid rate.

Urban cities need to redesign and retool the infrastructure in the city as the increasing population is putting pressure on its existing infrastructure [23]. These challenges include how to efficiently use critical resources like energy, water and food. Quick growth of cities is a hindrance to the sustainable development of the city if the necessary infrastructure is not in place. This in effect, leads to the stagnant growth of a city. To make a city smarter, the city will have to be redesigned and retooled, but this is not easy for existing old cities like London wherein some of the existing infrastructure is old and dilapidated. The redesign is not an easy as the city itself is centuries old and any change is practically impossible. An example is the presence of centuries old building and roads that cannot be easily replaced.

Security and emergency response is a key beneficiary of this collaboration in the smart city environment. Citywide CCTV networks that integrate the resources of both public and private organizations will be combined with automation to identify and track threats and incidents in real time [24]. Health care will benefit from faster response to emergencies, as well as personal health care data from wearable devices, telemedicine, and artificial intelligence diagnosis. Energy is another important factor; smart cities react fluidly and instinctively to fluctuating energy demands, the availability of alternative energy sources, and infrastructure failures. This improves efficiency, reduces costs, lowers greenhouse emissions, and benefits the interconnected infrastructure itself.

5. SMART CITY IMPLEMENTATION IN UAE

Relating to smart cities, Dubai and UAE in general is considered as a test bed and live laboratory for implementing CPS in a large scale. As the city is still developing and growing, the implementation of smart sensors and actuators is not a major retool or redesign of the city in itself. There is a major push from the leaders of the country to implement CPS citywide in Dubai and to make the city, the smartest city in the world before the start of Expo 2020. The primary focus is on smart buildings, transport, energy and water to enable increase in happiness of citizens, residents and visitors of the city. Another vision by the leaders is to turn 80% of the government services to smart services by 2018 in the public sector with a focus on health, education and innovation [25]. Some of the major initiatives happening in Dubai related to CPS and IoT are illustrated in the following section. Dubai silicon oasis authority (DSOA), is an integrated free zone technology park in Dubai, has partnered with Huawei, to implement and install the first smart street solution in the Middle East region at Dubai silicon oasis. The smart street solution consists of a digital signage system that displays news and other information in real-time. The system consists of a wireless system that provides Internet access.

Also, present, is a closed-circuit television system that is used for monitoring and proving safety using intelligent surveillance. Sensors are placed throughout to monitor external temperature and air quality. The system is considered to be scalable and additional services and capabilities can be added with minimum cost and in time. The Smart Street Solution is centrally controlled and allows greater energy efficiency and management [26]. Etisalat, one of the leading telecom providers in the UAE, is currently building enablers for a successful IoT implementation in the UAE by enhancing the fixed and mobile infrastructures, and also improving the ecosystem for a number of solutions [27]. The company has further made investments in some of the core components to this venture. The support provided by Etisalat is in fields like smart parking, waste management, and traffic management and smart surveillance systems for general users to industrial IoT

solutions such as energy management and big data solutions. Intel and DSOA, have announced the inauguration of Intel's Ignition Lab [28]. The lab is located in the Dubai Technology Entrepreneurship Centre (DTEC), a technology incubation center belonging to DSOA. The lab will collaborate and will be used by local subsidiaries in promoting novel IoT developments including, but not limited to, collaborating with these companies to develop smart CPS solutions and the development of smart cities, smart homes, and smart transportation. Plans are in place for household appliances that use consumable supplies, such as washing machines, vacuum cleaners and refrigerators, through IoT sensing and payment capability, to detect when to order new supplies, and then place the order, and execute the payment, with an alert message to homeowners so they can approve or cancel the order [29]. A decree has been passed in the UAE for all financial sectors to implement blockchain technology [30]. This technology can help the governments boost security in the financial system by securing and facilitating transactions in the fast-growing Islamic capital market. The Industrial CPS is of particular significance due to the sheer number of oils, gas and petrochemical organizations across the region. At a time, when the oil price is low, the presence of interconnected industrial systems produces much efficient networks [31].

The industrial CPS is implemented in an offshore oil and gas facility in UAE, wherein the assets are monitored, connecting the people with real-time data using predictive analytics for problem diagnosis. This in effect, has given the company a total saving of $30 million per year. Du, another telecom provider of the UAE is enabling smart technologies powered by IoT to deliver 100 smart initiatives and 1,000 smart services to Dubai residents and visitors over the next three years. Du are working with partners [32] to enable solutions for its customers such as smart meters, global and local inventory management, and smart vending machines, to be implemented in a variety of industries across the city and the country. To implement its IoT network, Du has incorporated LoRa, a new technology [33]. Dubai electricity and water authority (DEWA) has started planned for and started building its new headquarters. The new building is named Al-Sheraa (Arabic for sail), will be the tallest, largest, and smartest net zero energy building (ZEB) in the world. The building will use the latest technologies including IoT, big data and open data, and artificial intelligence (AI). Robots will be used for cleaning and to provide security services. A smart app will alert the employees about the time they should leave their homes based on the traffic [34].

The same app can be used to book parking spaces and meeting rooms. It can be also used by visitors to easily reach the building and meeting rooms. Al-Sheraa will use state-of-the-art building management tools. It will feature a control center which will allow essential systems to operate and will shut down non-essential systems, including air conditioning and lighting. The road and transports authority (RTA) of Dubai is planning to implement intelligent roads and traffic systems. As part of this, traffic lights will automatically turn to green, whenever an ambulance or emergency vehicle approach the signals. Another aim of this system is to reduce the traffic congestion and bottleneck on the roads and produce much efficient road systems. The successful implementation of this system will reduce the greenhouse gas emissions as start and stop of vehicles will be considerably reduced.

6. SECURITY CHALLENGES

All CPS are connected to system networks, private network and or the Internet. Due to this aspect, security is considered as a major requirement in CPS. The security can range from physical security to securing the data while in transmission and it depends on the areas of application and services where the CPS is being used. Necessary security mechanisms and policies need to be in place to access these security requirements. The major challenges faced by the CPS are given in the following section: i) Confidentiality: This refers to the protection of data that is stored or transmitted [35]. Only authorized people or processes are allowed to view the data, ii) Integrity: This refers to the property of the data being free from tampering [36]. Only authorized people or process are allowed to edit the data and measures have to be completed, so that data, while being transmitted does not get tampered with and changed, iii) Authentication: This measure is put in place to ensure that the data sender or producer is properly identified. Only a process or person with proper credential system should be allowed to produce or send data, iv) Access Control: This measure ensures that the systems or data is only available to the authorized people. All other interaction requests are rejected by the system, v) Non-repudiation: A measure put in place to complement authentication. This ensures that the data producer cannot deny the fact data originated from the person or process, vi) Dependability: This refers on the trustworthiness of the system. This measure ensures that system performs the required functionality without degradation of performance and results, vii) Safety: This refers to very important feature of system which should not pose any danger to users during its operation. This measure is highly critical in manufacturing industries with heavy machinery, and viii) Privacy: This refers to when personal information and data from resources are not disclosed to unauthorized parties [37].

All these security challenges are applicable to smart cities where the cyber physical systems are not only used by the citizens but also can be manipulated by potential hackers. As the CPS are ingrained into the daily operations of the city, even a minor manipulation or hack of the system can cause major issues which can even lead to life threatening situations [38]. Some examples of these could be autonomous vehicles colliding into pedestrians, and manipulation of smart grids causing power outage in the whole city. Some of the attacks conducted against CPS [36] include *deception attacks*, where false information like incorrect data is sent from the sensors or controllers. Sensors can be physically compromised or comprised using software. Another attack is the *DoS attacks*, where the system is brought down or made slow by compromising the communication channel. An effect would be that controllers do not receive sensor data. Also prevalent is the *network isolation attack*, where a set of nodes are comprised and isolated from the network [39]. This attack can cause packets coming into or going from this region, to be dropped. The attack on CPS is classified to short and long duration attacks. The short attacks are where services are disrupted immediately whereas the long duration is where the goal is not to disrupt services immediately, but to setup up a distributed attack to be launched at a later time. One such attack happened recently involving millions of IoT devices in a DDoS attack which brought DNS servers hosted by Dyn [40]. These devices are still unpatched and can be used in future attacks. Researchers are extensively looking at CPS intrusion detection techniques (IDS) to avert such incidents [41]. Various types of IDS devices which can do behavior-based detection, knowledge-based detection, host-based auditing and network-based auditing are currently being looked at.

7. CONCLUSION

The cyber-physical system (CPS) encompasses current and upcoming digital infrastructures used in the design of engineered systems that is being used for existing and future technologies. These systems are expected to make an important impact on the interactions with the physical world. Smart cities are a way of the future and more and more countries are converting major cities to smart cities to handle the rapid urbanization and stress put on the resources of the city. CPS and IoT are big enablers which will increase the quality of services and ultimately benefit the environment as they are implemented in smart cities throughout the world. CPS is actually a convergence of various technologies consisting of embedded systems, distributed systems and real-time systems which aid in the development of energy efficient networking with the help of microcontrollers, sensors and actuators. CPS as a system must function as dependable, safe, secure, and efficient and address security concerns like privacy, confidentially and availability.

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