2014 2nd International Conference on Technology, Informatics, Management, Engineering & Environment
Bandung, Indonesia, August 19-21, 2014

Integration of Cyber-Physical Systems Technology with Augmented Reality in the Pre-Construction Stage

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***Abstract*—Cyber-Physical Systems (CPS) is a computerized networking system that integrates with physical processes. The lack of theoretical foundation in CPS has resulted with this study, which aims to provide a holistic view of Cyber-Physical Systems and its integration with Augmented Reality (AR) as a decision support tool in the pre-construction stage. It will then discuss the problems that arise and propose the use of location aware mobile augmented reality handheld system as a support tool to provide users with an intuitive information visualization of local network infrastructures**

Keywords—Cyber Physical Systems; Augmented Reality; Pre-Construction Stage; Underground networks

I. INTRODUCTION

Construction management involves the management control of cost, time and quality under a strategic framework which includes the planning, coordinating, directing, scheduling, monitoring and controlling of the entire construction project; from the pre-construction, construction, and post-construction management phase [1]. The conditions for every construction stage are constantly changing, and to survive in this challenging industry, companies must develop and improve continuously based on knowledge of both the environment and of one's own work [2]. In the UK, the buildability is the extent to which the design of a building facilitates ease of construction subject to the overall requirements for the completed building while in the US, it is known as constructability, defined as the optimum use of construction knowledge and experience in planning, engineering, procurement and field operations to achieve overall project objectives [3]. See **Fig 1**

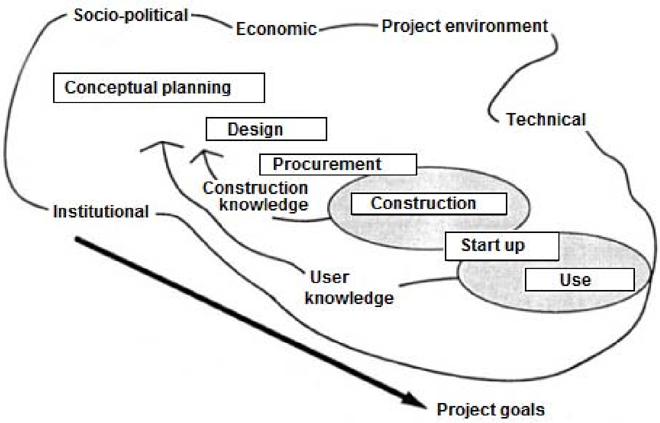

Fig. 1. The wider framework of buidability [3]

A clinical decision support system based on Cyber Physical System [4] have been shown to be efficient, easy to handle, safe, reliable and cost effective. However, their full implementation in construction management has been limited due to multi-tasking and the large scale of a given project at each construction stage. The survey indicates that 83% of the respondents agreed that a constructability problem begins before the actual construction [5]. See **Fig 2**

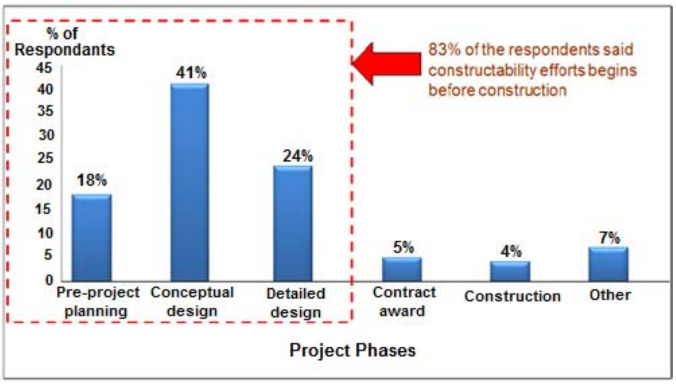

Fig. 2. Constructability efforts typically begin [5]

This work was financially supported by Fundamental Research Grant Scheme (FRGS Grant No: 4F388) under Ministry of Education, Malaysia.

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Fig 3 identifies the specific concern at pre-construction stage as locating utilities, right of way and drainage pattern. It is the highest number of occurrence that emerged 18 times out of 100 identified buildability problems [6]. **Table I** shows a total of 100 buildability problems that was collected from 30 projects and companies.

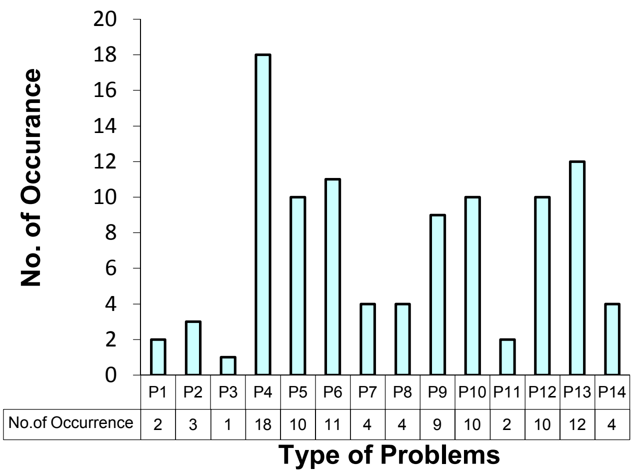

Fig.3. Frequency of buidability problems occurred [6]

TABLE I. NUMBER OF OCCURRENCE IN COLLECTED BUILDABILITY PROBLEMS

No.	Type of problems	No. of Occurrence
P1	Impact of weather	2
P2	Storage requirement	3
P3	Traffic control requirement	1
P4	Utilities, right of way and drainage pattern	18
P5	Availability of materials, equipment or manpower	10
P6	Techniques/sequence of construction	11
P7	Accessibility	4
P8	Tolerance needs	4
P9	Unpractical design details	9
P10	Lack of standardisation or repetition	10
P11	Poor design information	2
P12	Incomplete design details	10
P13	Unsafe design	12
P14	Complex design	4

II. RESEARCH APPROACH

The research approach in this paper focus towards the integration of different systems with the same aim to visualize the information to end users [7]. The details in the discussion will provide a clearer picture to the user of the system to be developed in various aspects including system definition, enabling technologies and also the system architecture.

III. SYSTEM DEFINITION

A. Cyber-Physical Systems (CPS)

Generally, Cyber-Physical Systems (CPS) are integrations of computerized network system and physical processes[8]. The ability to interact with, and expand the capabilities of the physical world through computation, communication and control is a key enabler for future technology developments [9]. Bi-directional coordination is a key feature of a CPS approach with the presence of integration concept like 'cyber-to-physical' bridge and 'physical-to-cyber' bridge as shown in **Fig 4** [10].

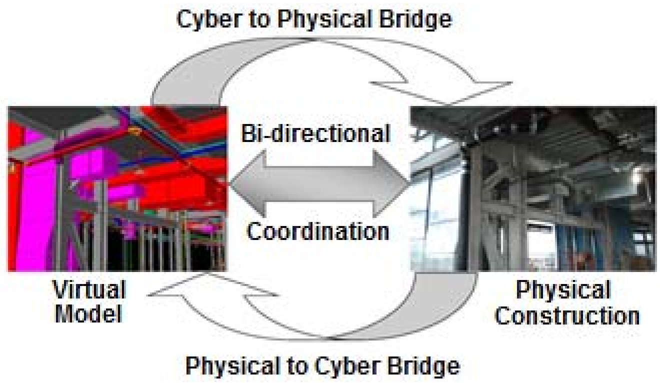

Fig. 4. Cyber-Physical Systems Integration Concept[10]

Presently, a precursor generation of CPS, referred to as embedded systems, has been applied to several industry sectors such as transportation, critical infrastructure, healthcare, defense systems and tele-physical operation and consumer electronics [11]. **Fig 5** shows the establishment of Cyber-Physical Systems term starting from era 1900's to 2000's [12].

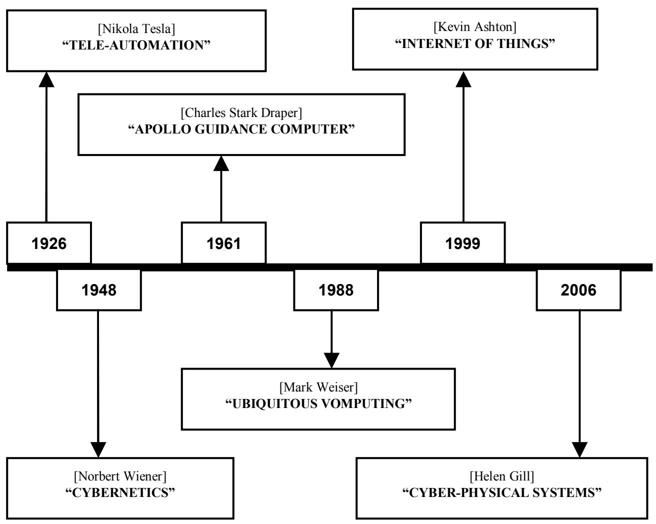

Fig. 5. Establishment of Cyber-Physical Systems [12]

B. Augmented Reality Technology (AR)

Augmented Reality (AR) is a system that supplements the real world with virtual objects/informations that appear to coexist in the same space as the real-world [13]. Augmented reality is related to the concept of virtual reality (VR) [14] which is a part of the support system to the CPS approach. **Fig 6** shows the VR spectrum where there is Augmented Reality based on the real world with virtual elements inserted in the Mixed Reality; where virtual and real elements are mixed up [15]. It has a potential to revolutionize the real information delivery channels to end users and become the latest innovation toward information visualization [16].

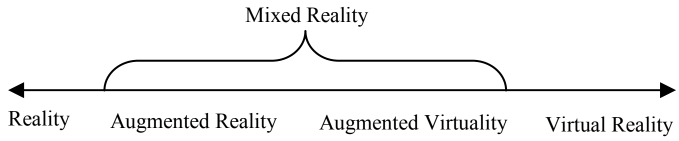

Fig. 6. Spectrum of Augmented Reality[15]

IV. Enabling Technologies

A. Cyber-Physical Systems

In Cyber-Physical Systems, four key components in enabling technologies that enhance bi-directional coordination are described below:

1) Virtual Prototyping

Virtual prototyping is the exploitation of simulation processes for the testing, evaluation and modification of prototypes in virtual design environments [17]. Virtual prototyping involves creating digital models in 3D, 4D, nD and also VR which have enhanced facilities for further exploration attributes and behaviours, and the investigation of 'what-if' scenarios [18] enabling identification and correction of any problems before construction.

2) Wireless Sensors

The radio frequency identification (RFID) technology is a wireless sensor technology which is based on the detection of electromagnetic signals by tags and readers [19]. Compared with wired sensors, it offers increased flexibility in terms of placement, reduced cost of installation and maintenance.

3) Mobile Devices

Mobile devices, such as smartphones and tablets, proliferate in today's corporate environments [20]. With a small computer device, information can be read and written on a display screen. For example, tablet PCs are capable of accommodating several kinds of information which can be used to navigate models forquick entry of construction data. Besides that, most of mobile devices have external features for data capture such as barcode scanners and RFID readers. Another important feature of mobile devices is the wireless connectivity. Data captured using mobile devices can be transferred wirelessly to a local or remote server.

4) Communication Networks

The communication network is one of the most important technology for enhancing bi-directional coordination in order to transfer and exchange of information between mobile and fixed devices [21]. Some communication networks being used include the internet, wireless local area network (WLAN, Wi-Fi) [22] and the wireless personal area network (WPAN) comprising ultra wide band, Zigbee [23] and Bluetooth [24].

B. Augmented Reality

The key enabling technologies components of Augmented Reality are briefly explained below:

1) Media Representation

AR systems use more varied media representations including text, symbol and indicator, 2D image, 3D wireframe, 3D data and model and also animation which each represents a class of information with common characteristics.

2) Input Mechanism

In AR systems, virtual information is presented to the user to add to the real world scene and thus the information content is what matters. For this reason most of the tasks in using an AR system are information accessing, rather than virtual content (object) manipulation and editing as in a typical VR or 3D CAD environment. Thus the input mechanism is primarily considering object manipulation tasks as a major feature in AR systems.

3) Output Mechanism Continuum

Output mechanism refers to the devices, used to support presentation of content and system responses to the user. Displays in AR need not be only visual but also creating audio displays for AR [25]. Almost all work in AR has focused on the visual sense: virtual graphic objects and overlays. But the augmentation might apply to all other senses as well.

4) Trackers

Accurate registration and positioning of virtual objects in the real environment require accuracy in tracking the user's head as well as sensing the locations of real objects in the environment. The biggest single obstacle to building effective AR systems is the requirement of accurate, long-range sensors and trackers.

V. Systems Architectures

A. Cyber-Physical Systems

The critical issue is how to integrate the virtual models with the physical building components so that there can be bi-directional coordination between them for a variety of purposes. System architecture has been developed to demonstrate the application of the CPS approach (shown in **Fig 7**) which are explained as follows:

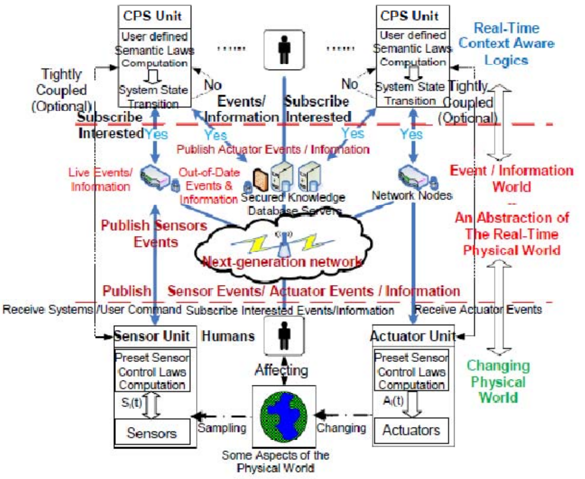

Fig. 7. System Architecture of Cyber-Physical Systems[26]

1) *Sensing Layer*

The sensing layer consists of sensors which monitor different aspects of the construction process. Depending on the type of sensor used, this layer can also provide the construction personnel access to control decisions.

2) *Device Layer*

This layer consists of the client devices such as tablet PCs or smart phones through which the end user can interact with the system. This layer serves two purposes;provides access to sensed data from the sensing layer and enables the entry of information through the user interface.

3) *Communication Layer*

This layer contains the Internet and wireless communication networks such as wireless personal area networks (WPAN), wide area networks (WAN) and local area networks (LANs). These communication networks connect mobile and other devices to allow for collaboration and information sharing between construction personnel on site and with the design offices of the consultants. The communication networks also allow the data collected through the mobile devices to be transferred through the Internet to the database in the contents and application layer.

4) *Contents and Application Layer*

The contents and application layer contains the local database, database server and the control application. This layer stores, analyses and is constantly updated with information collected from both the communication and actuation layers. The control applications use the sensed data from the database to make control decisions which can be visualized using the virtual prototype in the actuation layer.

5) *Actuation Layer*

The actuation layer contains the virtual prototype which is accessed through the user interface. The virtual prototype enables the user to visualize how the sensed information affects the system. The user interface enables the user to visualize and monitor the sensed information from the contents and storage layer. The user can also embed control decisions into the virtual prototype using the mobile devices in the device layer.

B. Augmented Reality

Fig 8 describes the main tasks in an augmented reality application. First one is the image capture. Information about the environment is captured by the camera, this information will be used as the background image for the augmented scene. When the positioning of the user is performed by image processing techniques the image captured by the camera will serve as a source for this task. The second task is the tracking of the user position. Apart from the purely augmented reality tasks, other processing tasks can be required in order to build the corresponding augmented reality scene. Rendering of the augmented reality scene is the fourth task. Last one is the visualization in the output device. Different client-server architectures can support this process, the following figure shows both extremes, any alternative in the middle will be valid.

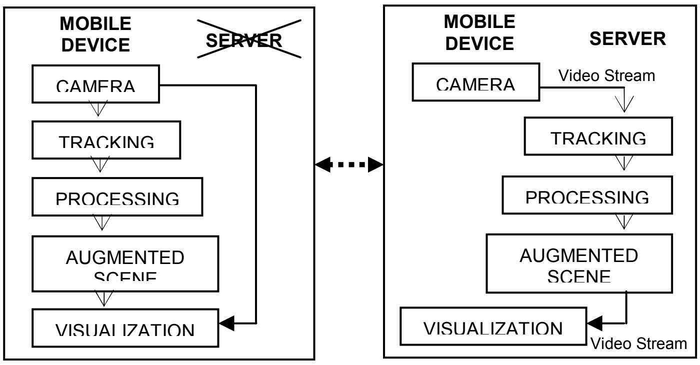

Fig. 8. Architecture layer of Augmented Reality (adapted by [27])

VI. APPLICATION SCENARIOS

There are two scenarios presented in this paper to show the practical application of the CPS approach and integration of CPS concept with augmented reality based approach.

A. Potential Integration of Cyber-Physical Systems in Construction Industry

Systems integration has been identified as one of the key approaches to help the construction industry to improve productivity and efficiency [28] and offers opportunities for enhancing construction project delivery process. The integration of CPS approach involves several key aspects like the development of an effective mechanism for facilitating real-time coordination between the virtual model and the physical construction, designing the positioning of the most appropriate sensor types and other instrumentation that will enable real-time data collection and aggregation and a plan for laboratory-scale experiments to explore bi-directional coordination between the virtual model and a small physical prototype. This will involve placing sensors on key physical components, tracking the status of the components in the physical prototype and developing mechanisms for reflecting changes simultaneously in both the virtual model and the sensed data in the physical prototype [11] . See **Fig 9**

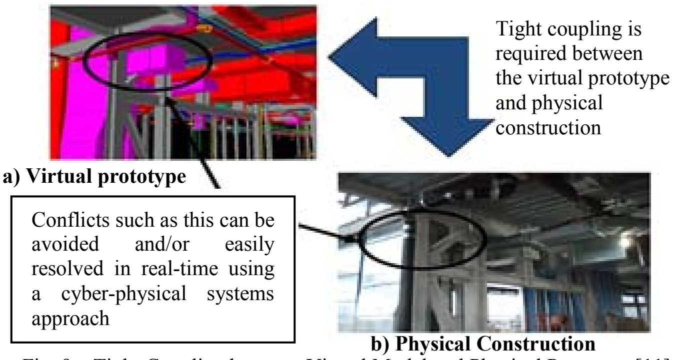

Fig. 9. Tight Coupling between Virtual Model and Physical Prototype [11]

B. *Integration of CPS Concept with Mobile Augmented Reality Handheld Location-Aware*

The evolution of Augmented Reality (AR) technology based on devices such as Ultra Mobile PCs (UMPC), PDAs or Smart phones has experienced a transformation towards more user-accepted handheld systems [29]. See **Fig 10**. The increasing availability of AR on such consumer platforms and the technology's capability of enhancing real-world vision with graphical representations of hidden objects, and abstract information make it a powerful tool. Underground utility companies rely on geographic information systems (GIS) to manage their underground infrastructure [30]. The geospatial data from the GIS cannot be directly visualized using AR, since it consists of a collection of geo-referenced features such as 3D scenes composed of polygons, and other visual elements in a multi-stage pipeline [31]. This makes it a challenge to visualize geospatial data from GIS using AR technology on existing mobile devices such as Smart phone

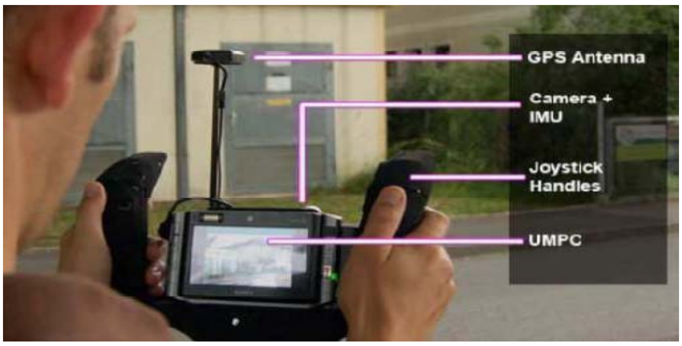

Fig. 10. Lightweight AR device designed for outdoor use and delivering field workers an augmented view with geospatial content [30]

The development of an outdoor handheld augmented reality system providing users with an intuitive visualization of the local underground network infrastructure and abstract information such as a view of geospatial data and residence boundaries or safety buffers [32]. These features and related information indirectly provide initial information to the stakeholder in order to speed up the work on the field in line with the performance of the work in its early stages. See **Fig 11**

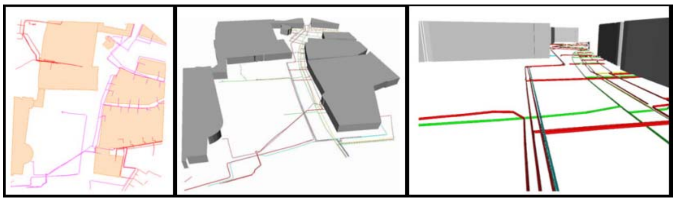

Fig. 11. Left 2D view of Geospatial data and Middle and Right 3D model around the residence and underground infrastructure networks [32]

VII. Discussion

The development of Cyber-Physical Systems, poses a huge challenge due to its complexities. A variety of issues need to be solved at different aspects of system design to ease the integration of the physical and cyber worlds [33]. Currently, the existing research challenges are summarized from various viewpoints in [8][34]. In the last few years, this emergence of CPSs has attracted significant interest, and will continue to be of interest for the years to come. Developing CPSs requires a new science of characterizing and controlling dynamic processes across heterogeneous networks of sensors and computational devices. Basically, the widespread applications of CPSs require breakthroughs in the research of theoretical and technical support

VIII. Conclusion

This paper provides a concept of Cyber-Physical Systems in order to give a better understanding of the system and how it can be implemented in pre-construction industry by integrating it with augmented reality (AR) technology to make decisions in real-time.. Mobile augmented reality handheld location-aware is one potential application utilizing the concept of CPS with the integration of augmented reality approach. Further study on the prototype system will be conducted in this research. A proof of concept prototype system will be developed and evaluated with selected end users to validate the effectiveness of this design. Comprehensive and large-scale simulations will also be conducted to examine the efficiency and scalability of the proposed approach under various environmental dynamics.

Acknowledgment

This work was financially supported by Universiti Teknologi Malaysia Fundamental Research Grant Scheme (UTM-FRGS Grant No: 4F388) under Ministry of Education, Malaysia.

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