DEVELOPMENT OF A SMART FACTORY PROTOTYPE IN CONTEXT OF INDUSTRY 4.0

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ABSTRACT

The disruption caused by digitalization and the Internet, the increase in labour costs and the demand for a better work-life balance have led to the emergence of the fourth industrial revolution or also called Industry 4.0. In this work, a smart factory prototype was developed to showcase the application of digitalization, data exchange, Internet of things, system integration and usage of ICT in a manufacturing system, in order to automatically produce a customized product. The smart factory concept was specified by a system model showing the system's elements and its dependencies. A prototype was constructed by retrofitting a modular trainer with Industry 4.0 elements while using currently available components such as RFID, PLC and network components, which was connected to a local area network with an Internet connection. A SCADA software was used as the backbone of the system to interface various devices for monitoring, control, and data exchange to a database. It was also used to build a user interface for local and remote access through the Internet. Evaluations based on the VDMA Industry 4.0 Toolbox were conducted in terms of functionality and Industry 4.0 application level. The prototype managed to increase its Industry 4.0 application level from 0.3 to 2.3 from a maximum level of 4.0 according to the VDMA toolbox. In conclusion, the smart factory prototype that was developed by retrofitting an existing system can be used to showcase the concept of Industry 4.0 to improve understanding on Industry 4.0.

ABSTRAK

Perubahan teknologi akibat digitalisasi dan Internet, peningkatan kos buruh, dan permintaan untuk keseimbangan hidup yang lebih baik, telah membawa kepada pengenalan revolusi perindustrian ke-empat atau Industri 4.0. Dalam penyelidikan ini, sebuah prototaip kilang pintar telah dibangunkan untuk menunjukkan applikasi digitalisasi, pertukaran data, *IoT*, integrasi sistem, dan penggunaan *ICT* untuk menghasilkan produk yang disesuaikan secara automatik. Konsep kilang pintar dizahirkan melalui satu model sistem yang menunjukkan elemen-elemen sistem dan kebergantungannya. Sebuah prototaip telah dibina dengan mengubahsuai beberapa alat latihan modular dengan elemen-elemen Industri 4.0 dan dengan menggunakan komponen sedia ada seperti RFID, PLC, dan komponen rangkaian seterusnya disambungkan ke rangkaian kawasan tempatan dengan sambungan Internet. Perisian SCADA digunakan sebagai tulang belakang sistem untuk menghubungkan pelbagai peranti untuk pemantauan, kawalan, dan pertukaran data ke pangkalan data. Ia juga digunakan untuk membina antara muka pengguna untuk akses setempat dan akses luar melalui Internet. Penilaian menggunakan *VDMA Industry 4.0 Toolbox* telah dijalankan dari segi kebolehfungsiannya dan tahap aplikasi Industri 4.0. Prototaip tersebut telah berjaya meningkatkan tahapnya dari 0.3 ke 2.3 daripada tahap maksimum sebanyak 4.0 mengikut penilaian VDMA. Kesimpulannya, prototaip kilang pintar ini telah dapat dibangunkan dengan mengubahsuai sistem sedia ada dan ia dapat digunakan untuk mempamerkan konsep Industri 4.0 untuk meningkatkan pemahaman berkaitan Industri 4.0.

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LIST OF PUBLICATIONS

1. **SMART FACTORY REFERENCE MODEL FOR TRAINING ON INDUSTRY 4.0**
   5th International Conference on Advances in Mechanical Engineering (ICAME 2017), Ao Nang Villa Resort, Krabi, Thailand, August 16-18, 2017
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2. **SPECIFICATION OF PRINCIPLE SOLUTION FOR A SMART FACTORY EXEMPLIFIED BY ACTIVE STRUCTURE**
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5. **CONCEPTION OF LOGISTICS MANAGEMENT SYSTEM FOR SMART FACTORY** (as Co-Author)
   Published in International Journal of Engineering and Technology (UAE), vol. 7, no. 4, pp. 126-131, 2018

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LIST OF SYMBOLS AND ABBREVIATIONS

3D	-	Three Dimension
AC	-	Alternating Current
ADS	-	Automation Device Specification
ADTEC	-	Advanced Technology Training Centre
AI	-	Artificial Intelligent
API	-	Application Programming Interface
AR	-	Augmented Reality
ASEAN	-	The Association of Southeast Asian Nations
CAD	-	Computer Aided Manufacturing.
CONSENS	-	Conceptual Design Specification Technique for the Engineering of Complex Systems
CPS	-	Cyber-Physical System
DC	-	Direct Current
DFKI	-	*Deutsches Forschungszentrum für künstliche Intelligenz* - German Research Centre for Artificial Intelligent
DPM	-	Digital Power Meter
ERP	-	Enterprise resource planning
ETP	-	Economic Transformation Program
GDP	-	Gross domestic product
GTAI	-	Germany Trade and Invest
HMI	-	Human Machine Interface
ICT	-	Information and Communication Technology

ID	-	Identification
IEC	-	International Electro-Mechanical Commission
IIS	-	Internet Information Services
IO	-	Input Output
IoS	-	Internet of Services
IoT	-	Internet of Things
IoTDS	-	Internet of Things Data & Services
IP	-	Internet Protocol
IPv4	-	Internet Protocol Version 4
IPv6	-	Internet Protocol Version 6
IT	-	Information Technology
JSON	-	JavaScript Object Notation
LAN	-	Local Area Network
M2M	-	Machine to Machine
MES	-	Manufacturing Executing System
MITI	-	Ministry of International Trade and Industry
MIPS	-	Million Instruction Per Seconds
MPS	-	Modular Production System
MQTT	-	Message Queuing Telemetry Transport
MSSQL	-	Microsoft SQL Server
NKRA	-	National Key Results Area
OPC	-	Open Platform Communication
PC	-	Personal Computer
PLC	-	Programmable Logic Controller
RAMI 4.0	-	Reference Architectural Model *Industrie* 4.0
RFID	-	Radio-Frequency Identification
RMK	-	*Rancangan Malaysia Ke-*

RS 232 - Recommended Standard 232

RS 485 - Recommended Standard 485

SAP - Systems Applications and Products in Data Processing

SCADA - Supervisory Control And Data Acquisition

SFC - Sequential Function Chart

SMI - Small Medium Industry

SOP - Standard Operating Procedure

TCP/IP- - Transmission Control Protocol/Internet Protocol

TLS - Transport Layer Security

TVET - Technical and vocational education training

USB - Universal Serial Bus

UTHM - *Universiti Tun Hussein Onn Malaysia*

V - Volt

VDMA - *Verband Deutscher Maschinen- und Anlagenbau* (Mechanical Engineering Industry Association)

VR - Virtual Reality

WIP - Workpiece in Progress

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CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia is well-known as a manufacturing hub. One of the factors behind this is its cheap labour cost. Cheap labour has always been favourable in comparison to a highly automated system which needs a huge amount of initial investment and skilled workers. Due to this, manufacturers often move their production operation to countries with cheaper labour costs [1,2]. Among the problems that arise is the migration of labours between countries, causing disruption in the receiving countries' labour market and social ecosystem [3]. With the increase of awareness and movement of labour organizations in countries that used to provide cheap labour including Malaysia, the demand for higher wages [1], better working environment and better work-life balance [4] have been increasing, when then increases production cost [5]. Furthermore, governments of countries that used to provide cheap labour including Malaysia has implemented various pro-labour related policies such as minimum wages [1,6] and introduced several stringent labour-related laws. This seemed to affect Malaysia, which used to be a manufacturing hub because of its affordable labour [7]. If the increase of wages is not aligned with the increase in productivity [6], manufacturers will need to move to a country that could provide cheaper labour with more productivity in order to stay competitive [2] such as China [8] or adopt to use automation [1]. This will affect the regional economy especially if multinational companies pull out their investment.

Additionally, the buying habits of consumers are changing rapidly [7,9]. e-commerce is swiftly taking over conventional shopping [10,11]. Online shopping is getting more popular [9,10] as consumers can review the item they want to buy [12], compare prices and purchase them at the click of a mouse. At the same time, the product life cycle is getting shorter [13–17] in which products are constantly updated every now and then and the introduction of new models or versions is becoming faster [18,19]. The idea of mass customization [4,14,20–22] of products is not far away as people nowadays want exclusivity [13]. Other than that, social media today has already become part of our lives and influences many things. Nowadays, a lot of disruption has occurred that is caused by advancement in technologies and new inventions [5,7,14] and all of these are available with an affordable price tag [22–24]. This is also supported by the existence and advancement of information and communication technology (ICT) infrastructures and software development [5] such as the high-speed Internet, large data centres and various intelligent software or applications [23,25].

The current trend of Industry 4.0 could be a way to adapt to the various trend that is currently arising such as trend related to the Internet or as mentioned above and can be a solution to problems such as labour cost, demand for a work-life balance or as mentioned above [5,8,26,27]. The Industry 4.0 trend was initially the German government's initiative to establish Germany as the main provider of advanced manufacturing solutions [4,20,23,28]. Although the term Industry 4.0 was first coined by the Germans, other countries such as Japan, the United States, and China have also been looking into the concept under different names [4,5,17,27,29,30]. Industry 4.0 is commonly associated to the Cyber-Physical System (CPS), Internet of Things (IoT), smart factory, and Internet of Service (IoS) according to [31] in which digitalization, data transfer between systems and the Internet are the focal point [4,5,20, 23,25,32]. Advanced manufacturing and automation are interconnected using ICT [9,26,27,32–34] and linked worldwide through the Internet [4,9,30,32]. The aim is to optimize the whole value chain [33]. It is called Industry 4.0 because it is said to be the fourth revolution [23] in the industry after the introduction of steam power and mechanization in the first revolution, mass production line and electricity in the second revolution and computer and automation in the third revolution [4,20,22,23]. Among its applications are the smart factory, smart and customized products, smart logistics, smart home, office or buildings, smart mobility, and smart energy and environment monitoring or smart grid [4,22,25,32].

Industry 4.0 could be the solution in maintaining Malaysia as a manufacturing hub, thus boosting the regional economy because it depends on highly automated and interconnected systems rather than cheap labour [8]. The role of workers will change to be more technical, dynamic and flexible. This will increase the income per capita and is hoped to provide a better and balanced work to life quality [4,35]. On the other hand, Small and Medium Industries (SMI) could also benefit from this revolution because it will make them more productive [19] and they can reduce their labour cost and increase their profits [20]. Furthermore, SMIs usually do not need a very complex system, which makes it easier to maintain [34]. With Industry 4.0, SMIs could subscribe to many useful services from the cloud, thus saving costs on software and ICT equipment [5,25,29]. This will give more opportunity for SMIs to use ICT in their production [4,29].

Industry 4.0 is currently being defined [9,31,36] and no concrete definition currently exists [2,23,32,37]. Thus, industries, solution providers, academicians, researchers, and policymakers are currently in discussion and are researching on Industry 4.0 [9] to set a clear path, standards and fundamentals for the fourth industrial revolution [22]. Therefore a clear understanding and approach to Industry 4.0 are still lacking [30,31]. One of the challenges is to create awareness and make people understand the benefits of this revolution [30]. Other than that, the investment in new technology will be huge [27,37] and without the economic scale, it would be unworthy [26]. Before this revolution is fully implemented, it is wise to understand this revolution mainly to prepare the future workforce to handle such technology [30,34]. To better understand the concept of Industry 4.0, a prototype is needed to show its concept, how it works, how it can be implemented, and to investigate and proof whether the concept can be implemented and is viable [4]. With a prototype, it will be easier to evaluate the concept and to prepare the future generation with the necessary skills and knowledge needed to operate and maintain this system [34].

The aim of this work is to understand the fundamental vision of Industry 4.0 and develop a smart factory prototype that can be used to showcase and educate people on the concept of Industry 4.0. The prototype is aimed to show the basic concepts of Industry 4.0 such as digitalization, mass customization, data exchange and connecting a production line to the Internet. The prototype was developed by upgrading an existing production trainer and using currently available components [4,14] to show that the Industry 3.0 system could be upgraded to a certain level. This prototype was aimed to be used to understand Industry 4.0 better or help people, especially students and academicians, to have a better overview of Industry 4.0. It can also be used for various training purposes or evaluation by interested parties involved with Industry 4.0.

1.2 Problem Statement

With the increase in labour cost [6,38] and demand for a better life to work quality [1,5], Malaysia needs to break away from its current industrialization policies, adopt new and advanced technologies and look into Industry 4.0 seriously [7,8]. As Industry 4.0 is still new in Malaysia, it is wise to start preparing for the revolution to come by understanding its fundamentals [8]. The key is to understand how Industry 4.0 works and how it could be implemented, especially by upgrading existing systems. The lack of experts and skilled workers in this field means slow progress towards fully implementing Industry 4.0 and this is a big problem as Malaysia will be left behind. Thus, it is important to develop an Industry 4.0 prototype to understand it further and to evaluate the future of Industry 4.0.

The initial cost of implementing Industry 4.0 is very high which is a problem. Most technical providers will recommend new hardware or solutions. This means scrapping old hardware and investing in new systems. Working solutions are currently being made available day by day [8], but the cost is too high and cannot be afforded by the small-medium industry or training institutes [15]. The lack of funding means the lack of equipment, making it hard to train the future workforce with the necessary knowledge and skill competencies. The limited and currently available reference model that shows only part of the concept or application of Industry 4.0 makes it hard for a training institute to invest in this new equipment. It is also harder and less effective to teach students, especially technical and vocational students, to understand this topic when they have to imagine a complex system in their head without a reference model. Therefore, upgrading a currently existing system using currently available components seems to be the best way in terms of cost and time.

Another challenge in developing or upgrading a system into a smart factory system using currently available components is to identify which Industry 4.0

application can be implemented, which off-the-shelf components can be used and how to integrate various systems to work together [5]. There is also an issue on how to connect them to the Internet. Integration of various systems especially from different kinds of manufacturers is a complicated task. Thus, an interface is needed that could interconnect various systems and components preferably using a common way to exchange data.

1.3 Objectives

The main aim of this research was to develop a working Industry 4.0 smart factory prototype as suggested in [4,14,27,39] by upgrading an existing system and using currently available technology that can be used to train students on Industry 4.0. The objectives of this research were as follows:-

(i) To derive a domain-spanning principle solution for a smart factory prototype in the context of Industry 4.0 and implement Conceptual Design Specification Technique for the Engineering of Complex Systems (CONSENS).

(ii) To develop, assemble, integrate and interface a smart factory prototype in the context of Industry 4.0 including its user interface by retrofitting an existing system.

(iii) To evaluate the smart factory prototype in terms of functionality using the *Industrie 4.0* toolbox of the Mechanical Engineering Industry Association (VDMA).

1.4 Scope and Limitation

This work is focused on developing a smart factory prototype to show the basic application of Industry 4.0, especially the concept of mass customization, data exchange and remote access through the Internet. This is as suggested in [4,5,14,27] and to be showcased and used as a training aid. The scope of this research was thus limited to developing a smart factory prototype by upgrading an existing modular production trainer and use currently available components to limit the cost. This research was divided into three phases. The first phase was to derive a domain specific principle solution and to implement a conceptual principle model using

CONSENS [40] to create a system model. Creating a model would ease the development process. It was to give an overall view of the system before attempting to build it.

The second phase was to upgrade an existing production trainer by reassembling it according to its new function and integrating all of its components until it became fully functional. In this project, a smart factory system was set up with a modular and decentralized production concept [14,17] and was equipped with Radio-Frequency Identification (RFID) technology [41]. Products that were assembled by this prototype were modular in form or in other words, can be mix and match to give consumers the liberty of choosing what they want. It was controlled by PC-based controllers which were interconnected in a local area network (LAN) managed by a router with an Internet connection. A server that hosted a supervisory control and data acquisition (SCADA) software and database was also hooked up to the LAN. The SCADA was used as an interface to display, monitor and control the system either locally or through the Internet. The SCADA software was the backbone of the whole system used to integrate all the components and provided an interface between the systems to a database. Lastly was to evaluate the system in terms of functionality and to determining the level of Industry 4.0 it has achieved. For this, the Toolbox *Industrie* 4.0 of VDMA was used [36]. This prototype was later used to train students and showcased to get feedbacks. Other than that, an observation on the skill sets needed to operate, develop and maintain the system was conducted.

In this research, not all of the nine pillars of Industry 4.0 were adapted. Rather, it was limited to the existing system and the components available at hand. It focused on the digitalization of signals, IoT for monitoring, cloud services, data exchange and integrating various systems. It also showed the concept of a modular product. Thus, big data and analytics, simulation, augmented reality (AR), and additive manufacturing was not covered directly in this project as they are big topics and they could be a research topic on its own. To cover the topic of data analytics, new algorithms need to be created. The simulation includes the development of software that could mimic the physical world and requires a lot of animation. This is also the case for augmented reality. As for additive manufacturing, with the current equipment, it is not viable to include 3D printing in this prototype. Another important topic and a big concern in Industry 4.0 is cybersecurity. As the topic itself is a big topic on its own, it was not covered in this research although basic security was implemented. Other than that, a digitalized mimic of the physical world was not implemented but the input and output signals of various components were displayed on the HMI. Again, to develop a mimic of the real world requires a lot of animation and software development and is more suitable for a software developer. The relevant scope of this work is as follows:

(i) The smart factory prototype consisted of two parts: A domain specific principle solution with a conceptual model developed by implementing CONSENS and a working prototype.

(ii) The prototype was developed by upgrading an existing system using currently forehanded available parts and components to limit the cost. It consisted of three production stations equipped with RFID technology and using Industrial Ethernet.

(iii) The system including the controllers and server were interconnected with each other through a LAN managed by a router connected to the Internet. The server hosted the SCADA software and database.

(iv) The SCADA software was used as the backbone of the system to interconnect them together and link it to a database. An interface for local and remote access for displaying, monitoring and controlling data was also developed using this software.

(v) The smart factory prototype was able to produce a final product that is modular using the mix and match concept and is able to produce up to eight (8) variants without any reprogramming to show the concept of customization.

(vi) The evaluation was to test the functionality of the system, the level of Industry 4.0 compliance according to a toolbox by VDMA.

(vii) In this research, not all of Industry 4.0 pillars were implemented, for example, the cybersecurity of the system was covered, the digitalized mimic of the physical world was not developed and none of the data obtained for example the digitalized signals was analysed. Among others, this is because to include all of the Industry 4.0 pillars in one prototype will involve a lot of time, cost and effort and the goal of this research is to develop a prototype using currently available components to minimize the cost.

1.5 Significance

Industry 4.0 is the next revolution and has yet to be widely implemented [22]. Therefore, the potential for such a system is still vast. Furthermore, to compete globally [4,7] the implementation of Industry 4.0 is crucial [4,7] as the local market shares are limited and this is a great opportunity [8]. The smart factory is one of the applications of Industry 4.0 [4]. With the winds of change present in the global economy through a better supply chain and changes in consumers' buying habits, countries that do not take action will be left behind. Malaysia has taken a step forward by introducing the National Industry 4.0 Policy Framework launched by the prime minister in 2018. This makes Industry 4.0 a national agenda. This policy was published by the Ministry of International Trade and Industry (MITI) [7]. According to this policy, the manufacturing sector in Malaysia contributed 22% of the Gross Domestic Product (GDP) in the last five years with over two million employees in this sector. With the emergence of new technologies at a more affordable cost [23,24], machines and automated systems will replace humans. With a smart factory, mass customization, higher productivity, and products with good quality can be produced at a reasonable cost [5,19]. This means that cheap labour is no longer an investment factor [8,22] and investors are looking for countries that could provide the technical know-how and skilled workers to develop, operate and maintain such systems. To do this, an awareness campaign to increase the understanding of Industry 4.0 must be carried out, for example, using a prototype.

From a survey conducted by Acatech, 84% of the respondents agreed that Industry 4.0 has a potential future [42]. A survey by the Germany Trade and Invest (GTAI) indicated that 81% of the respondents responded with 'yes' to the question of whether Industry 4.0 will offer new opportunities [43]. The survey showed that Industry 4.0 has a vast potential and will create new opportunities or a business model that will one day influence the industrial world. The Malaysian government has targeted an annual GDP growth rate of 5.1% under the 11th Malaysian Plan (RMK-11) for the manufacturing sector [7]. This shows that manufacturing is an important element of the economy.

Although the smart factory is highly automated and it seems like machines and robots are filling the employment list, skilled workers are still needed to operate and maintain these automated machines [20]. Skilled workers mean higher income that will make the economy flourish [35]. Another aspect related to Industry 4.0 is the Economic Transformation Program (ETP) in the sectors of electrical and electronics [44]. The target is to revitalize the industry, accelerate higher yields and prepare the industry to respond to external shocks such as any decline in global demand. This is to move the industry away from manufacturing activities towards higher-value activities such as design, assembly, packaging and the provision of total solutions. Industry 4.0 gives the opportunity to do this. Manufacturing will be automated and time can be focused on research and designing new products [4].

According to the National Industry 4.0 Policy Framework, among the challenges faced by Malaysia are the lack of awareness, the need to enhance the skill of workers and the high cost of investment [7]. Therefore, it is important to expose trainers and academicians with Industry 4.0-related technologies and skills to develop the know-how and expertise in this field. After that is to train the current and future workforce to adhere to these changes [7,8]. By doing this, students can have an oversight of what is to come. Educators need to understand Industry 4.0 so that they could incorporate this concept into their teaching syllabus [30]. All of this must be done at an affordable cost and possibly by using equipment that is already available on the shelves. One way is to upgrade existing systems with Industry 4.0-related technologies.

Therefore, this prototype is significant to create awareness to understand Industry 4.0 better. This is to see how it works and whether Industry 4.0 is relevant. It is also to identify the relevant skills needed and adapt the current curricular for training as suggested in [4,34].

1.6 Thesis Organization

This thesis is organized as follows. CHAPTER 1 highlights the background of this project, problem statement, objective, scope and its significance. CHAPTER 2 deliberates on available literature on Industry 4.0, smart factory and CONSENS. CHAPTER 3 explains the methodology used in developing this prototype, the design, and the evaluation method. CHAPTER 4 explains the result of this research which is the prototype itself including the CONSENS Model, the operation flow and

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