

DESIGN OF INTEGRATION FRAMEWORK TOWARDS INDUSTRY 4.0: FROM SHOP FLOOR TO CLOUD

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Lee Yoon Ket^{1*}, Chiew Tsung Heng¹, Ong Jia Jan¹, Chang Kai Ming¹,
Chan Tai Wei², Chan Wah Beow³, Eyo Geak Loo⁴

¹ Department of Mechanical Engineering, Tunku Abdul Rahman University College, Jalan Genting Kelang,
53300 Setapak, Kuala Lumpur, Malaysia.

² Business Development & Data Analysis Department (BDDA), Asia Roofing Industries Sdn. Bhd. (subsidiary of Ajiya Berhad),
No.4, Jalan Sungai Pelubung 32/149, Seksyen 32, 40460 Shah Alam, Selangor, Malaysia.

³ Engineering Department, Asia Roofing Industries Sdn. Bhd. (subsidiary of Ajiya Berhad), No. 4, Jalan Sungai Pelubung 32/149,
Seksyen 32, 40460 Shah Alam, Selangor, Malaysia.

⁴ Centre for Technology Research, Innovation and Sustainability (C-TRIS), Asia Roofing Industries Sdn. Bhd.
(subsidiary of Ajiya Berhad), No. 4, Jalan Sungai Pelubung 32/149, Seksyen 32, 40460 Shah Alam, Selangor, Malaysia.

*Corresponding author: leeyk@tarc.edu.my

ABSTRACT

The capability of the fourth industrial revolution in fulfilling the ever-changing demand of customers has attracted great attention from the small medium enterprises. Industry 4.0 is one of the ideal solutions to advance the manufacturing to a new level to tackle the high variation in productions of roofing industry. A three-layer Industry 4.0 integration framework, adoptable by a considered roofing company was proposed in this study. A conceptual mechanical designs of automated stacking systems also have been proposed to automate the considered stacking process in the roofing company to minimize the manual labour workforce. The proposed framework realized the complete integration from field layer to the Cloud system using Automation Markup Language and OPC Unified Architecture technologies as the communication backbone. The feasibility of the proposed framework was demonstrated through experiment conducted on an experimental system model where the Google Cloud, the OPC UA-AutomationML server, and a microcontroller-controlled system was used as the enterprise layer, communication layer, and the field layer, respectively. The success of integration was proven by controlling the light intensity and ON/OFF status of a physical LED through the Cloud. For future works, the proposed framework could be implemented on a simulated model of real-time prototype or a real-time manufacturing line to test its robustness.

Keywords: AutomationML, Cloud, Industry 4.0, Integration, OPC UA

1.0 INTRODUCTION

The fourth industrial revolution has become the main interest of the world especially the small medium enterprises (SMEs) and multinational corporations. The essence of Industry 4.0 that allows the manufacturers to cope with the ever-changing demand greatly attracts the interest of the roofing industries that require a series of manufacturing processes in their production lines to produce a wide range of roofing with different types of profiles, sizes, materials composition, and number of layers in order to cater various purposes and users, from residential houses to industrial commercial buildings. The presence of high variability in the demand that involved multiple manufacturing processes posed a great challenge to the roofing industries. Consequently, the fourth revolution is desirable to satisfy the ever-changing demands of users by advancing the overall manufacturing

structures to the next level. A similar challenge was faced by the roofing industries in Malaysia. Although a national policy on Industry 4.0 (MITI, 2018) was launched by the government to drive the revolution of the manufacturing sectors in Malaysia, majority of the performed works observed in the industries were limited to digitalization of data and big data analytic (Hizam-Hanafiah and Soomro, 2021). In addition, many architectures and models of Industry 4.0 have been introduced (Pethig *et al.*, 2017; Tantik and Anderl, 2017; Xun and Seung, 2019) but the practical application of such models in roofing industries was still inadequate.

A roofing company based in Malaysia was considered and studied in this work. The considered roofing company manufactures various types of roofing products with different lengths in a manufacturing line. The main concern of the

considered roofing company is the transferring and stacking processes of roofing products that relied on an extensive labor workforce due to heavy weight and to avoid deflection, especially for long length roofing products. Moreover, a flipping process is also required to stack the roofing products in an odd and even arrangement. However, this high number of workers is not cost efficient as the quantity of annual orders for such a long length of roofing products is relatively low. Furthermore, the manual labor transfer process also led to low efficiency in terms of time. Hence, an automation in the stacking process including the flipping feature is desired.

This paper proposes a conceptual mechanical design of automated stacking systems to automate the considered stacking process. In addition, this paper also proposes an Industry 4.0 integration framework based on the Reference Architectural Model Industry 4.0 (RAMI 4.0) model that is able to be adopted by the considered roofing company. The proposed framework would allow the complete integration from shop floor to Cloud system in which the automated stacking system would respond in correspondence to the orders received through the Cloud system.

2.0 CONCEPTUAL DESIGN FOR AUTOMATED STACKING SYSTEM

An on-site primary study was conducted to ensure the feasibility of the designs, by considering: (i) the on-site available space, (ii) the weight and sizes of the roofing products, and (iii) the holding force of the vacuum suction cup.

The main purpose of the primary study was to determine the suitable number of vacuum suction cups in order to hold certain sizes of roofing products with respective weight. The dimension of the overall conceptual designed system was also estimated through the primary study to ensure that the overall designed system would be able to fit into the available spaces in the factory. Based on the study through on-site measurement and review of specification of products, the total maximum weight of the roofing product with a length of 20 m is 115.418 kg. By setting a vacuum level of 0.3 bar, a diameter of 100 mm for suction cup, and the total load of a product with 20 m in length = $2390.88/4$ N (assumption; number of lifter modules = 4), the number of suction cups required per module was calculated. The proposed suction cup lifter for a single module comprises ten suction cups and arranged evenly in two columns with five suction cups per column. More than one lifter module could be used depending on the length of the roofing products. The considered safety factor for a module is four to avoid any immediate threat if any malfunction occurred in one of the vacuum cups.

Three conceptual designs were proposed through the extensive research on the market available mechanisms and technologies, e.g. flipping using multi-layer conveyors, slotting discs, L-beam flipper, overhead lifters, and guided rails. The overall conceptual designs of the stacking system were produced using the SOLIDWORKS software and the vacuum suction mechanisms (Jaiswal, 2017) were utilized in the proposed designs. The Quality Function Deployment (QFD) tool was used to determine the product design specifications by considering the safety, size, installation, maintenance, quality, and reliability. The final conceptual design was chosen for the considered roofing company based on the Pugh analysis matrix.

2.1 Final Conceptual Design

Figure 2-1 depicts the final conceptual design for the automated stacking process. A linear gantry system with vacuum suction lifter module was proposed for the transportation of the products. The foam rubber type of suction cup was proposed as it could provide suction grip evenly on uneven surfaces. A series of resting tables was proposed for the flipping process in the zone A. Two L-beams were proposed to perform the flipping mechanism on the resting tables as shown in Figure 2-2. The incoming roofing products could be lifted by the gantry system, transferred and stacked at zone B. The series of roller beds at the zone B was used to transfer out the stacked products as outgoing products. This design required lower cost as no robotics arms were used but still able to provide the ease in transferring out the stacked products.

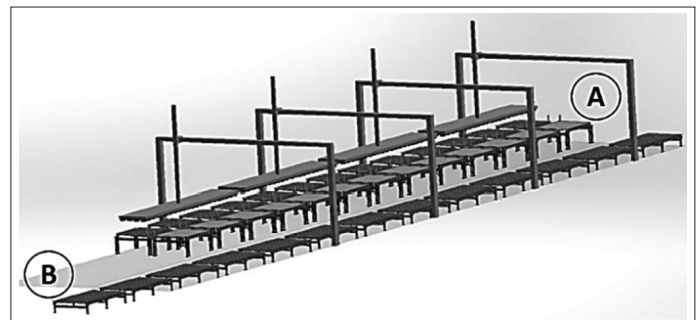


Figure 2-1: Third conceptual design of automated stacking system



Figure 2-2: The flipping process was demonstrated: (a) resting table with two L-beams, (b) product on roller table being flipped up, (c) the flipped up product received by two L-beams of resting table, and (d) the product flipped and located on the resting table

3.0 PROPOSED INTEGRATION FRAMEWORK

The proposed conceptual design of the automated stacking system could be controlled through industrial controllers such as programmable logic controllers (PLCs) or other industrial microcontrollers. An Industry 4.0 integration framework based on the RAMI 4.0 model that enabled the complete integration from shop floor to Cloud system was proposed. In general, the RAMI 4.0 is a reference architecture model for Industry 4.0 that describes the fundamental requirements to comply with the Industry 4.0 systems by linking the system lifecycle, value stream, hierarchy, and functional layers (Xun and Seung, 2019).

In the proposed integration framework, two vital technologies, namely; the Automation Markup Language (AutomationML) and Open Platform Communications Unified Architecture (OPC UA) were utilized as the backbone of the communication and data exchange. The AutomationML (IEC, 2014) is an open and neutral XML-based object oriented data modelling language that realizes the data exchange

between multiple fields including the mechanical engineering, control programming, electrical design, communication and management systems throughout the lifecycle of a production system (Luder *et al.*, 2010; Schleipen *et al.*, 2014). It is able to close the data exchange gap of heterogeneous autonomous engineering tools in industry by extending, adapting and merging the existing standardized data formats (Xun *et al.*, 2018). On the other hand, the OPC UA is a client-server mechanism that is able to realize the interconnectivity and interoperability by serving as the communication interface for heterogeneous network fields in industry. The works of Xun *et al.* (2018) and Fuchs *et al.* (2020) explained the details of AutomationML and OPC UA. Technically, the overall proposed integration framework consists of three layers, namely; (i) enterprise layer, (ii) communication layer, and (iii) field layer; complied with the RAMI 4.0 model, as shown in Figure 3-1.

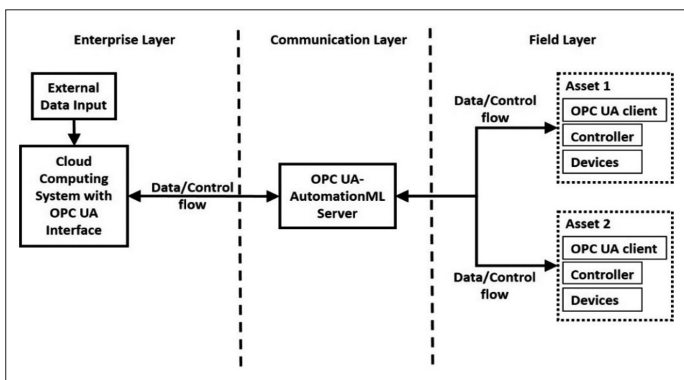


Figure 3-1: The proposed integration framework from field level to Cloud system for roofing industry

3.1 Enterprise Layer

A Cloud platform accessible by all parties would be used in this layer. The management team, engineers or human operators could provide any control commands at this layer through the Cloud platform to alter or adjust the operation or field devices state. External databases or files could be input, saved and backed up into the Cloud platform. These input and updates also would be reflected in the field devices. An OPC UA client is required to be established at this layer to connect with the OPC UA-AutomationML server at the communication layer. In short, all information provided by the OPCUA-AutomationML server at the communication layer could be displayed and acquired in the enterprise layer to allow the decision making of users. Conversely, users also could change the operation states in the OPC UA-AutomationML server.

3.2 Communication Layer

The communication layer is vital in the overall framework as it acts as a bridge to connect the enterprise and field layers. The OPC-UA-AutomationML server acquires and hosts the overall information of the assets in the field layer. It is also able to enable the information flow to any connected external clients such as the enterprise layer and vice-versa. For example, the information of a robotic arm system could be acquired from the server and passed to the Cloud system in the enterprise layer. The order of products could also be acquired from the Enterprise layer

to activate suitable number of lifter modules for the respective length of products.

3.3 Field Layer

The filed devices and their respective controllers are considered in the field layer. These field devices would be defined as the assets of a manufacturing line. For example, the robotic arm systems, roller bed systems and flipping systems as well as their respective controllers such as PLCs or microcontrollers of the automated stacking system for the roofing products can be considered as the assets. Respective interface such as OPC UA client for each controller of field devices is required to be established in order to be able to communicate with higher layer.

4.0 FRAMEWORK IMPLEMENTATION AND PRELIMINARY TESTING

Figure 4-1 shows an experimental system model corresponding to the proposed framework shown in Figure 3-1. For the enterprise layer, the Google Cloud platform was used to keep the MySQL Workbench database. The MySQL Workbench is also able to read the external data such as the sales order of roofing products in Comma Separated Values (.CSV) files format and update the database accordingly. For example, MySQL Workbench could read the received orders from the customers in .CSV format, and update the respective database.

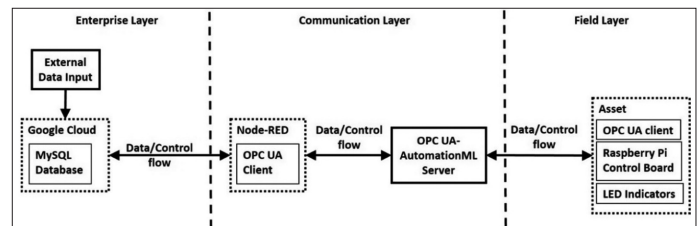


Figure 4-1: The proposed integration framework from field level to Cloud system for the experimental system model

The communication layer consists of two important elements: (i) Node-RED, and (ii) OPC UA-AutomationML server. The Node-RED was used to acquire the order data from the Google Cloud platform and to establish the OPC UA client as shown in Figure 4-2. The creation of the OPC UA client allowed the connection between the Enterprise layer and the OPC UA-AutomationML server. The client was used to send/receive OPC UA service request/response messages to/from the OPC UA-AutomationML server. This server was created based on the developed hierarchy of all related assets from AutomationML Editor, by using AML2OPCUA tool (developed by Fraunhofer IOSB) and acted as the backbone to connect both enterprise and field layers through OPC UA networking.

For the field layer, the LED indicators and its respective controller, the Raspberry Pi control board were used as the field devices in the experimental system model as shown in Figure 4-3. An OPC UA client was created using Python programming in the Raspberry Pi control board to realize the connectivity between the field layer and the OPC UA-AutomationML server. Any data or command change in the Cloud or server could alter and update the status of field devices in the client and vice-versa. A control command on the field devices, such as turning ON/

OFF and changing the light intensity of the LED indicator was input into the Cloud through MySQL workbench (Figure 4-3). The status of changes could be observed through the UaExpert client tool and the physical field device, the LED indicator.

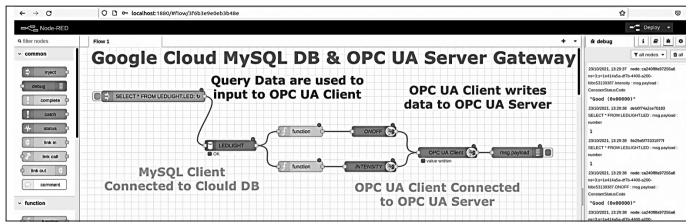


Figure 4-2: The developed Node-RED program used in the experimental system model

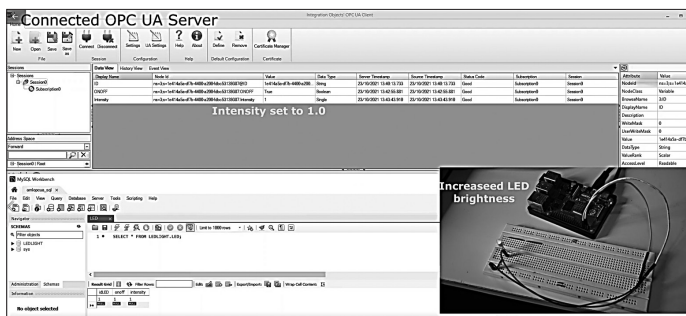


Figure 4-3: The connected physical LED indicator with the OPC UA-AutomationML server to the Google Cloud platform for the experimental system model

Experiment was conducted to test the connectivity of the proposed integration framework by varying the data in the Google Cloud platform through the MySQL Workbench to turn on/off the LED and change the light intensity of the LED. For the ON/OFF status of the LED, two commands were used where the value of 0 indicates the OFF status while the value of 1 indicates the ON status. On the other hand, the range of value between 0.1 and 1 were used to adjust the light intensity of the LED. The value of 0.1 indicates a very low intensity (dim light) while the value of 1 indicates a very high intensity (bright light). For the ease of comparison, only 3 sets of results with values of 0.1, 0.5 and 1 were used in the light intensity experiment.

For the ON/OFF status experiment, the data or command of either 0 or 1 was input into the MySQL Workbench. The new data would update the database in the Google Cloud platform. This updated data would then be written to the OPC UA-AutomationML server through the established OPC UA client in the NodeRED. The updated data or status in the OPC UA-AutomationML server was observed through the UaExpert client tool. The new status in the server would be acquired by the OPC UA client and change the status of the physical LED indicator through the Raspberry Pi control board. The same flow of procedure was applied for the light intensity experiment. The results for both experiment were summarized in Table 4-1 and Table 4-2 respectively.

Based on the results in Table 4-1 and Table 4-2, it was clearly observed that the connectivity of the proposed integration framework from the Cloud to the field devices has been

established successfully. These preliminary experiment proven that the data able to flow from the Cloud and update the status of the physical field devices. According to the observation in Table 4-1, the LED indicators in the field layer can be turned ON/OFF by updating the status through the Cloud. A similar observation also has been recorded in the light intensity experiment where the physical LED indicator was able to successfully respond, corresponding to the light intensity set through the Cloud. The success of the preliminary experiment has proven the feasibility of the proposed integration framework. This feasible framework could be used as the fundamental reference and be adapted into the roofing company by adding necessary assets at the shop floor such as the PLC, motors and sensors of automated stacking systems to form the connection to the enterprise layer. Engineers and top management team would be able to monitor and manage the shop floor processes through the considered Cloud system.

Table 4-1: The summary of results for the LED ON/OFF status experiment

Data/command in the Google Cloud platform	Status observed in OPC UA-AutomationML server through UaExpert client tool	Status of physical LED indicator
0 (OFF)	0	Light off
1 (ON)	1	Light on

Table 4-2: The summary of results for the light intensity of LED indicator experiment

Data/command in the Google Cloud platform	Status observed in OPC UA-AutomationML server through UaExpert client tool	Status of physical LED indicator
0.1	0.1	Very dim
0.5	0.5	Moderate intensity
1	1	Very bright

5.0 CONCLUSION AND FUTURE WORKS

This study proposed a three-layer integration framework for the industrial process control system of the roofing industry towards the Industry 4.0. In the proposed framework, the OPC UA and AutomationML technologies were utilized as the vital communication and bridging between the enterprise and field layers. Two experiment were conducted on the experimental system model and the obtained results proven the connectivity from the Cloud system at the enterprise layer to the physical LED indicators at the field layer, through to the AutomationML-OPC UA server at the communication layer. The proposed framework also suggested the feasibility in applying any of the conceptual designs for automated stacking systems as the asset of the field layer. For future works, the proposed framework could be applied on a real-time prototype or industrial manufacturing line to test its robustness. Furthermore, it also could be extended to incorporate other elements in the manufacturing management system such as the manufacturing execution system.

6.0 ACKNOWLEDGEMENTS

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PROFILES



TS. DR LEE YOON KET is a principal lecturer of the Mechanical Engineering Department in the Faculty of Engineering and Technology, Tunku Abdul Rahman University College (TAR UC). He completed his PhD at Queen University of Belfast, U.K. in 2004. In 2017, Ts. Dr Lee has registered under the Engineering Council U.K. as a member of Institute of Mechanical Engineers with the title of Chartered Engineer. Besides, Ts. Dr Lee also registered with Malaysia Board of Technologists in the Manufacturing and Industrial Technology area with the title of Ts. in 2018. Ts. Dr Lee possesses 7 years of industrial working experiences and 8 years of academic experiences. His research interests mainly focus on application of Industry 4.0 to SMI, Autonomous system and Manufacturing planning and control. Currently, Ts. Dr Lee is leading the Centre of Autonomous and Robotics Research in TAR UC that focuses on applications of Industry 4.0.
Email: leeyk@tarc.edu.my



DR CHIEW TSUNG HENG is currently a Programme Leader for Mechatronics Engineering programme and senior lecturer in Department of Mechanical Engineering, Faculty of Engineering and Technology, Tunku Abdul Rahman University College (TAR UC). His research interest is in the motion control system of machine tools, industrial automation and robotic technologies, and Industry 4.0. He received the PhD, MSc in Manufacturing Engineering, and Bachelor in Manufacturing Engineering (Robotics and Automation) from Universiti Teknikal Malaysia Melaka. Dr Chiew has 4 years of teaching experience and is now actively involved in industrial collaboration research and projects. He is the core member of the Centre of Autonomous and Robotics Research in TAR UC that is focused on the applications of Industry 4.0. Recently, Dr Chiew has registered under the Engineering Council U.K. as a member of Institute of Mechanical Engineers with the title of Chartered Engineer.
Email address: chiewth@tarc.edu.my



DR ONG JIA JAN is currently a Senior Lecturer in the Department of Mechanical Engineering, Faculty of Engineering and Technology, Tunku Abdul Rahman University College. He completed his PhD in 2016 and MEng (Honours) Mechatronic Engineering in 2009 at University of Nottingham Malaysia. Since 2017, Dr Ong has been registered under the Institute of Engineering and Technology (IET) U.K. as a Member of IET. Dr Ong possesses 4 years of industrial working experience and 2 years of academic experiences. His research interest area is in Industry 4.0, image data compression, encryption, error correction and minimal instruction set computer.
Email address: ongj@tarc.edu.my



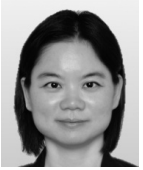
DR CHANG KAI MING is currently a Senior Lecturer in the Department of Mechanical Engineering, Faculty of Engineering and Technology, Tunku Abdul Rahman University College. His research interest is in robotics, automation and networking for Industry 4.0. He received his PhD in Electronics and Electrical Engineering, MSc in Bionanotechnology and MEng Mechanical Engineering (Mechatronics) from the University of Southampton, U.K. Dr Chang has 2 years of teaching experience and is a core member of the Centre of Autonomous and Robotic Research (CASRR) in TAR UC. Dr Chang is a member of the IMechE, IET and IEEE. Current projects involve automated vehicles and computer vision for remote monitoring and control of manufacturing activities.
Email address: changkm@tarc.edu.my



MR. CHAN TAI WEI is the Head of Business Development and Data Analysis at Asia Roofing Industries Sdn. Bhd. He completed his Master of Engineering in Electrical and Computer Engineering at University of Nottingham in 2014. He had 3 years of experience in corporate finance and advisory, and 5 years in manufacturing of metal building materials. In 2019, Mr. Chan Tai Wei was certified as TRIZ consultant by Malaysia TRIZ Innovation Association. He has also been invited to speak for prominent events such as International Greentech & Eco Products Exhibition & Conference Malaysia 2021, Pesta MyTRIZ 2018 – TRIZ on Corporate Strategies, Asia-Pacific Digital Technology Symposium 2017, etc. In Asia Roofing Industries Sdn. Bhd., Mr. Chan Tai Wei is in charge of strategizing and driving the business performance and sustainability, planning and implementation of Digital Transformation towards Industry 4.0, and advising the management team on new business developments and corporate exercises such as partnerships, joint-ventures, merger and acquisitions.
Email address: chantw@ajiya.com



MR. CHAN WAH BEOW joined Asia Roofing Industries Sdn. Bhd. in 1992. He has 30 years of industrial experience and is currently the Head of Production (Metal Frame division) and Engineering of the company. In 2019, he was certified as Level 2 TRIZ Practitioner by Malaysia TRIZ Innovation Association. He is also involved in the Industry 4.0 - Digitization project in collaboration with TARUC.
Email address: arisgtp@ajiya.com



TS. EYO GEAK LOO is the Head of Centre for Technology Research, Innovation and Sustainability (C-TRIS) at Asia Roofing Industries Sdn. Bhd. She completed her engineering degree at the University of Malaya in 2000. She has 22 years of industry experience in manufacturing, quality assurance, product development and process improvement. In 2019, she was certified as Level 2 TRIZ Practitioner by Malaysia TRIZ Innovation Association. In 2021, she is registered with Malaysia Board of Technologists with the title Professional Technologist (Ts.). Currently Ts. Eyo leads the company's projects on Industry 4.0 initiatives, including process automation, shop floor digitization and ERP integration. She is also involved in the Industry 4.0 - Digitization project in collaboration with TARUC.
Email address: eyogl@ajiya.com