Faculty of Manufacturing Engineering

FLEXIBLE ROBOT CONFIGURATION CELL IN MANUFACTURING INDUSTRY

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DECLARATION

I declare that this thesis entitled "Flexible Robot Configuration Cell in Manufacturing Industry" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
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Date	:	....

APPROVAL

I hereby declare that I have read this dissertation and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature : ………………..

Supervisor Name : Ir. Dr. Muhamad Arfauz bin A. Rahman

Date : ………………………..

DEDICATION

I dedicate this thesis :

To my beloved husband, Muhammad Nur Hilmi bin Mohammad Hatta

To my supportive father, Osman bin Talib

To my lovely and caring parents, Rosidah binti Ramli

And to my beloved sisters and brothers.

Who always picked me up on time and encouraged me to go on every adventure, especially this one.

ABSTRACT

Manufacturing configuration work is a very tedious process that relies on the way a system is determined and the experience of the person involved. This work is also based on the requirements set by the user. In this research work, the development of flexible approach for configuring robot work cell in manufacturing industry is presented. An articulated robot with six (6) degree of freedom (DOF) is taken as reference to represent the configuration layout because it is one of the most widely used robot in industries. The purpose of this research is to develop a new flexible approach for easy configuring robot work cell with minimal configuration time, less human or expert involvement and at little or no further investment. The different emerging strategies which focus on the configuration work has been highlighted and reviewed. In this work, a variant-shaped configuration concept with its mathematical equation for both workspace area, A_w and the manufacturing throughput time, MTT of each configuration layout have been developed. Later, a configuration framework with a set of rule selection has been created for further development of a graphical user interface (GUI) of flexible configuration model (FlexCoM). The developed FlexCoM would be used in determining the ideal robot work cell while satisfying the user requirements. Matlab and CATIA V5 software where it involves the CATIA VBA and macro tools were used in this research work. The developed FlexCoM has been tested and evaluated by three (3) different industries where the outcome of this research showed that the developed FlexCoM could assist design engineers in minimizing the configuration time, optimizing the human and expert involvement as well as capitalizing the available resource for investment while conducting robot work cell configuration work in the future. This research hopes that the industry will benefit from the outcome by having the ability to optimize the configuration system and to minimize the risk of investment.

ABSTRAK

Kerja konfigurasi pembuatan adalah satu proses yang memerlukan ketelitian yang sangat tinggi di mana kerja ini bergantung pada cara sistem ditentukan dan pengalaman orang yang mengendalikan sistem yang terlibat. Kerja ini juga berdasarkan keperluan yang ditetapkan oleh pengguna. Dalam laporan ini, kerja mengenai pembangunan kaedah yang fleksibel untuk mengkonfigurasi sel kerja robot dalam industri pembuatan dibentangkan. Articulated Robot dengan enam (6) darjah kebebasan diambil sebagai rujukan untuk mewakili susun atur konfigurasi kerana ia adalah salah satu robot paling banyak digunakan dalam industri. Tujuan penyelidikan ini adalah untuk membangunkan kaedah konfigurasi yang baru dan fleksibel yang dapat mengkonfigurasi sel kerja robot dengan masa konfigurasi yang minimum, penglibatan manusia atau pakar yang kurang dan risiko pelaburan yang minimum. Strategi baru yang menumpukan pada kerja-kerja konfigurasi telah diserlahkan dan dikaji semula. Dalam kerja ini, satu konsep konfigurasi yang terdiri dari pelbagai bentuk bersama ayat matematik seperti kawasan ruang kerja dan masa pembuatan pemprosesan untuk setiap susun atur konfigurasi telah dibagunkan. Kemudian, satu rangka konfigurasi bersama satu set pilihan peraturan telah dicipta untuk digunakan dalam pembentukan satu grafik perantraan sistem dan pengguna untuk model konfigurasi yang fleksibel (FlexCoM). FlexCoM yang dibangunkan akan digunakan dalam menentukan sel kerja robot yang ideal sambil memenuhi keperluan pengguna. Matlab dan perisian CATIA V5 di mana ia melibatkan CATIA VBA dan alat makro telah digunakan dalam kerja-kerja penyelidikan ini. FlexCoM yang telah dibangunkan ini, telah diuji dan yang dinilai oleh tiga (3) industri yang berbeza dimana hasil kajian ini menunjukkan bahawa FlexCoM yang dibangunkan dapat membantu jurutera rekaan dalam meminimumkan masa konfigurasi, mengoptimalkan penglibatan manusia dan pakar serta memanfaatkan sumber yang tersedia untuk pelaburan ketika melakukan konfigurasi sel kerja robot bekerja di masa depan. Kajian ini berharap bahawa industri akan mendapat manfaat daripada hasil kerja ini dengan mempunyai keupayaan untuk mengoptimumkan sistem konfigurasi dan meminimumkan risiko pelaburan.

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LIST OF ABBREVIATIONS

AI	-	Artificial Intelligence
AIP	-	Artificial Intelligence Planning
ASRP	-	Assembly System Reconfiguration Planning
DE	-	Differential Evolution
DOF	-	Degree of Freedom
FlexCoM	-	Flexible Configuration Model
FLP	-	Facility Layout Planning
FMS	-	Flexible Manufacturing System
FraRWCC	-	Framework for the Robotic Work Cell Configuration
GUI	-	Graphical User Interface
IDEF0	-	Integrated Definition for Function Modelling 0
IDEF3	-	Integrated Definition for Function Modelling 3
IFR	-	International Federation of Robotics
IJASM	-	International Journal Agile and Management System
LMTT	-	Manufacturing Throughput Time Limit
LCT	-	Line Cycle Time
MCE	-	Manufacturing Cycle Efficiency
NIST	-	National Institute of Standards and Technology, United States of America
OTM	-	OSHA Technical Manual
PC	-	Personnel Computer
RAS	-	Reconfigurable Manufacturing System
RCT	-	Robot Cycle Time
RMS	-	Reconfigurable Manufacturing System
SPSS	-	Statistical Package for the Social Sciences
VBA	-	Visual Basic for Applications

LIST OF SYMBOLS

A_{safew}	-	Safe Area
A_W	-	Workspace Area
C	-	Clearance for the Worker Movement in a Worker Cell
C_1	-	Configuration with both dual and mirror condition
C_2	-	Configuration without dual and with mirror condition
C_3	-	Configuration with dual and without mirror condition
C_4	-	Configuration without both dual and mirror condition
C_T	-	Configuration Condition
L	-	Length
LA_w	-	Workspace Area Limit
LMTT	-	Manufacturing Throughput Time Limit
L_{opt}	-	Optimum Robot Work Cell Configuration Layout
L_{safe}	-	Safe Length
L_{xsafe}	-	Safe Length at X-axis
L_{ysafe}	-	Safe Length at Y-axis
Max L	-	Maximum Length
Max W	-	Maximum Width
$\min(A_w)$	-	Minimum Workspace Area
min(MTT)	-	Minimum Manufacturing Throughput Time
mm	-	Milimeter
MTT	-	Manufacturing Throughput Time
N_c	-	Number of Configurations
N_{oc}	-	Number of Optimum Configuration
N_r	-	Number of Robot Use
$P_{(1-10)}$	-	Coefficients
sec	-	Second
t_i	-	Inspection Time
t_m	-	Move Time
T_m	-	Manufacturing Throughput Time
t_p	-	Process Time
t_q	-	Queue Time
W	-	Width
W_{safe}	-	Safe Width
Y	-	Length of the Robot Tooling And Work Piece
X	-	Length of Robot Arm

LIST OF PUBLICATIONS

The following are the list of journal publications of this research work:

1. Osman, N. S., A. Rahman, M. A., Abd. Rahman, A. A., Kamsani, S. H., Bali Mohamad, B. M., Kamsani, S. H., Mohamad, E., Zaini, Z.A. & Ab Rahman, M. F. (2017). Configuring Robot Work Cell based on Multi-Shaped Layout Approach. International Journal of Automotive and Mechanical Engineering (IJAME). 14(4):4826-4845.
2. Osman, N. S., A. Rahman, M. A., Abd. Rahman, A. A., Kamsani, S. H., Bali Mohamad, B. M., Kamsani, S. H., Mohamad, E., Zaini, Z.A. & Ab Rahman, M. F. (2017). Configuring Robot Work Cell in Manufacturing Industry. International Journal of Agile Systems and Management (IJASM). 10(3/4), 295-320.
3. Osman, N. S., A. Rahman, M. A., Abd. Rahman, A. A., Kamsani, S. H., Bali Mohamad, B. M., Kamsani, S. H., Mohamad, E., Zaini, Z.A. & Ab Rahman, M. F. (2017). Development of an Automated Configuration System for Robot Work Cell. Journal of Advanced Manufacturing Technology (JAMT), 11(1 (1)), 113-128.
4. A. Rahman, M. A., Osman, N. S., Boon, C. H., Poh, G. L. T., Abd. Rahman, A. A., Bali Mohamad, B. M., Kamsani, S. H., Mohamad, E., Zaini, Z.A. & Ab Rahman, M. F. (2016). Configuring Safe Industrial Robot Work Cell in Manufacturing Industry. Journal of Advanced Manufacturing Technology (JAMT), 10(2), 125-136.
5. Development of Mathematical Models for Determining Optimal Robot Work Cell - Journal of Mechanical Engineering (JAMT) – Waiting for Feedback.

The following are the list of conference proceeding publications of this research work:

1. Osman, N. S., A. Rahman, M. A., Abd. Rahman, A. A., Bali Mohamad, B. M., & Kamsani, S. H. (2017). Optimization of multiple robot configuration pattern using

shape variant approach. Innovative Research and Industrial Dialogue.

2. Osman, N. S., A. Rahman, M. A., Abd. Rahman, A. A., Bali Mohamad, B. M., & Kamsani, S. H. (2017). Determination of the Optimal Workspace and Manufacturing Throughput Time for Configuring Robot Work Cell. In Proceeding of Mechanical Engineering Research Day 2017.

3. Osman, N. S., Rahman, M. A. A., Rahman, A. A., Kamsani, S. H., Mohamad, B. B., Mohamad, E., & Zaini, Z. A. (2017). Systematic Approach in Determining Workspace Area and Manufacturing Throughput Time for Configuring Robot Work Cell. Transdisciplinary Engineering: A Paradigm Shift, 959.

4. Osman, N. S., Rahman, M. A. A., Rahman, A. A., Kamsani, S. H., Mohamad, B. B., Mohamad, E., Zaini, Z.A., Ab Rahman, M.F. and Mohammad Hatta, M. N. H. (2017). Automated platform for designing multiple robot work cells. In IOP Conference Series: Materials Science and Engineering (Vol. 210, No. 1, p. 012061). IOP Publishing.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Nowadays, manufacturing industry has faced a new environment where all the manufacturing competitors around the world have similar opportunities due to the globalization (Koren, 2010). Competition may happen even though they are producing similar functional products but located in different parts of the world (Wadhwa, 2012). Therefore, particular attention on productivity and quality of the products should be emphasized in order to satisfy customer demands (Lueth, 1992; Dalotă, 2011) as well as to win the manufacturing competition. As the result, an automated manufacturing system is required for this type of environment.

Automated manufacturing system has more advantages compared to the traditional system, i.e., they are more efficient and flexible and also may produce quality products rapidly and effectively, may decrease human errors, and also decrease the workload of the employees (Gardner, 1985; Mishev, 2006). Therefore, many manufacturing companies have started investing more in the automated manufacturing system (Ross, 1981; Mittal et al., 2017).

Thereafter, flexible manufacturing system (FMS) becomes a high demand for dealing with the global competition, rapidly changing technology and manufacturing organization. Also for settling the increasing trend in customer's demand for a greater variety, high quality and competitive cost (Choudhury et al., 2008; Altmann et al., 2017). One of the primary benefit of having FMS is manufacturing company may have the ability to reconfigure their current manufacturing system with a new convenient manufacturing system quickly in future (Abdi, 2009; A. Rahman & Mo, 2012c; Wu et al., 2015). This work will present a part of work towards the development of FMS.

Industrial robot plays a vital technology for FMS (Jain et al., 2015) and it has been used widely in several fields following the rapid development of the industrial technology, like the assembly, material handling, welding, spray painting, glazing or machine tending (Adrisano et al., 2007), drilling, cutting, transportation, stacking, measuring, laser processing (Morel, 2004; Li, 2006; Xiangquan et al., 2008) amongst others.

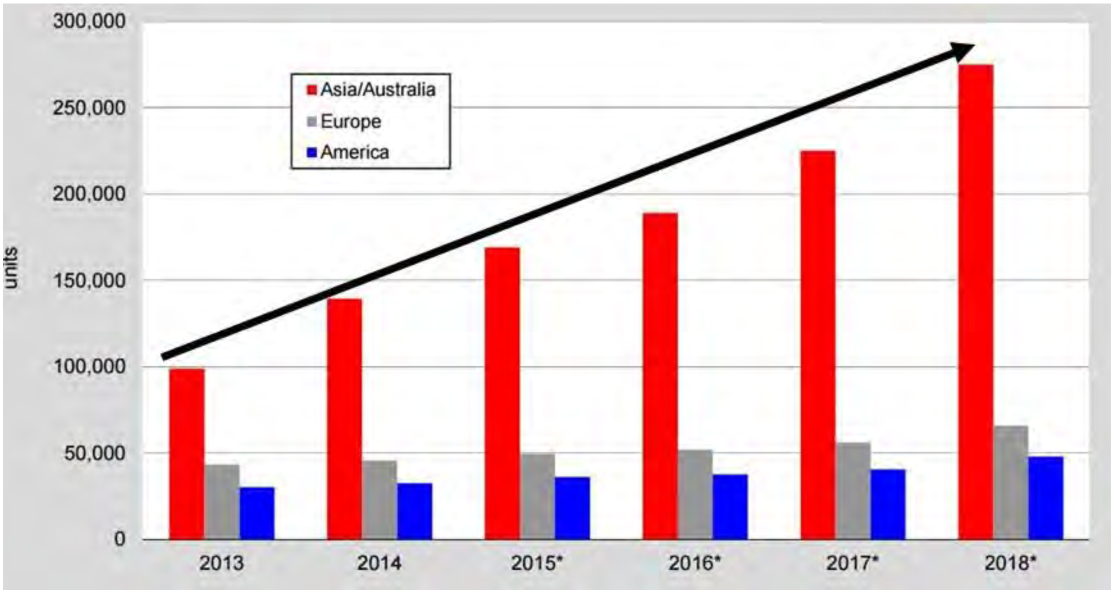

Figure 1.1: Worldwide Annual Supply of Industrial Robots (IFR, 2015)

Figure 1.1 presents the latest statistic issued by the International Federation of Robotics (IFR) in its 2015 World Robotics report. The utilization of industrial robot in manufacturing industry is shown to be increasing from 2013 to 2016. Following the current trends, they predicted that by 2018, global sales of industrial robots will grow on average by at least 15% yearly (IFR, 2015).

Increased demand of industrial robot has led the manufacturing industry encountered a new challenge in reconfiguring their current robot work cell as well as their future cell appropriately (Bojinov et al., 2002; Scholer et al., 2017). In addition, current market situation is unpredictable and frequently changes depending on customer demands (Koren et al., 1998; A. Rahman & Mo, 2010, 2012a, 2012b, 2012c; A. Rahman et al., 2016; Abdi et al., 2018) which is can also contributed to the challenge in configuration work.

Configuration work is referred to the laying out process where it is important to give profound impact on the performance of a particular system, not only on the adaptability to market demands, but also on reliability, productivity, product quality, and cost. Therefore, it is essential to understand the impact of proper selection of robot cell configuration for gaining an optimal performance (Koren et al., 1998).

Current configuration studies repot that a few vital parameters has been challenged in creating the optimal configuration layout. The parameters involve configuration time and cost, human and expert involvement and future investment (Bojinov et al., 2002b; Reinhart & Krug, 2010; A. Rahman & Mo, 2010, 2012a, 2012b, 2012c; Pellegrinelli et al., 2014; Spensieri et al., 2016).

In this work, a new flexible approach for configuring the current and future robot work cell for manufacturing industry was proposed where it may assist in improving the configuration time and cost, optimizing the human and expert involvement as well as capitalizing the available resource for investment.

1.2 Problem Statement

The manufacturing industry has become more competitive in providing high quality products or services to satisfy the customer needs. Automated manufacturing system with flexible automation is in demand in any industry which it could deal with the current market