DESIGN AND VERIFICATION OF PICK AND PLACE ARM MODEL BY USING PETRI NET

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DECLARATION

I declare that this thesis entitled “DESIGN AND VERIFICATION OF PICK AND PLACE ARM MODEL BY USING PETRI NET 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 : .....

Name : .....

Date : .....

APPROVAL

I hereby declare that I have checked this report entitled “DESIGN AND VERIFICATION OF PICK AND PLACE ARM MODEL BY USING PETRI NET” and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature : .....

Supervisor Name : .....

Date : .....

DEDICATIONS

To my beloved mother and father

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ABSTRACT

In this era of modernization, demands for industrial robotics technologies like Articulated robots, Cylindrical robots, Cartesian robots and SCARA robots are increased from days to days to improve consistency, productivity, efficiency and safety of workforce, reduce complexity and human errors. The performance of pick and place robot arm is increasing with the implementation of model checking technique in its development stage. However, the state explosion problem will be happened during the system verification since the state variables grows exponentially as the degree of freedom of the pick and place arm system increases. The first objective of this project is to design the petri net models for the pick and place arm system by using Hierarchical Petri Net Simulator. Next objective is to identify the incidence matrix of the petri net models. The last objective is to identify the structural and behavior properties of the petri net models. 3 petri net models with different in state variables are designed through translating of the real-life pick and place arm mechanism. The incidence matrix of the petri net models show the releasing and accepting of the tokens from the places via activation of transitions. The structural properties which includes the invariants are identified for each petri net model. The behavior properties which includes reachability, deadlock, boundedness and reversibility are verified for each petri net model. Among 3 petri net models, model B is the best because it is deadlock-free, having the largest amount of reachable and reversible markings. Therefore, model B has the best performance compared to model A and model C. From the results, model B can be concluded that the risk for the breakdown to occur is the least among these 3 models.

ABSTRAK

Era modenisasi hari ini, permintaan untuk teknologi robotik industri seperti robot Artikulasi, robot silinder, robot Cartesian dan robot SCARA dinaikkan dari semasa ke semasa untuk meningkatkan konsistensi, produktiviti, kecekapan dan keselamatan tenaga kerja, mengurangkan kerumitan dan kesilapan manusia. Prestasi memilih dan meletakkan lengan robot semakin meningkat dengan pelaksanaan teknik pemeriksaan model dalam peringkat pembangunannya. Walau bagaimanapun, masalah letupan sesuatu keadaan akan berlaku semasa pengesahan sistem kerana pemboleh ubah keadaan tumbuh dengan pesat apabila tahap kebebasan dan sistem lengan memilih dan menempat meningkat. Objektif pertama projek ini adalah untuk merekabentuk model petri bersih untuk sistem lengan memilih dan menempat dengan menggunakan Hierarchical Petri Net Simulator. Objektif seterusnya adalah untuk mengenalpasti matriks kejadian model petri net. Objektif terakhir adalah untuk mengenal pasti ciri struktur dan tingkah laku model petri net. 3 model petri net dengan pemboleh ubah keadaan yang berbeza direka bentuk menerusi menterjemahkan mekanisme sistem lengan memilih dan menempat. Matriks kejadian model petri net menunjukkan pelepasan dan penerimaan tanda-tanda dari tempat melalui pengaktifan peralihan. Ciri-ciri struktur yang termasuk invarian dikenalpasti untuk setiap model petri net. Ciri-ciri tingkah laku yang merangkumi kebolehcapaian, kebuntuan, ketinggalan dan kebolehulangan ditentusahkan untuk setiap model petri net. Antara 3 model petri net, model B adalah yang terbaik kerana ia bebas daripada kebuntuan, mempunyai tanda-tanda yang boleh dicapai dan boleh diterbalikkan. Oleh itu, model B mempunyai prestasi terbaik berbanding model A dan model C. Dari hasilnya, model B dapat disimpulkan bahawa risiko pecahan proses berlaku adalah yang paling kecil di antara 3 model ini.

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LIST OF SYMBOLS AND ABBREVIATIONS

HiPS	-	Hierarchical Petri Net Simulator
EOFM		Enhanced Operator Function Model
AlPiNA	-	Algebra Petri Net Analyzer
PEP	-	Programming Environment based on Petri Nets
Yasper	-	Yet Another Smart Process Editor

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CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the industrial automation applications are growing rapidly in performance, size and complexity. Industrial automation can be defined as the ability to handle processes and machineries in an industry to replace the manpower with the use of control system like robots, sensors, actuators, processors or controllers. The growth of industrial automation can be explained by industrial revolution.

Industry 4.0 was introduced by representatives from various fields to empower the competitiveness of German in the manufacturing industry. Industrial revolution in different fields can be distributed into 4 stages so far which are field of mechanization (1st industrial revolution), field of intensive use of electrical energy (2nd industrial revolution), field of widespread digitalization (3rd industrial revolution), field of smart machine and product (4th industrial revolution which also called as "Industry 4.0"). According to the principle of Industry 4.0, there are 2 development directions can be followed for future project which includes huge application-pull and exceptional technology-pull.

Huge application-pull encourages a remarkable need for changes depends on different operative framework conditions. The project work should be made changes such as shorten the development periods, increase individualization of products, increase flexibility, reduce organization hierarchy and increase resource efficiency. In the other hand, exceptional technology-pull has been practiced our daily life like Apps, smartphones, laptops and 3D printer but these technologies are not widely spread into industry. Therefore, extensive approach in field of industry should be carried out. These approaches include mechanization and automation increment, digitalization and networking and miniaturization. Hence, Industry 4.0 has catalyzed the development of industrial robots [1].

Since the industrial world these days is facing many technological changes which has increased the demanding of premium quality products and services that can only be accomplished by a high level of productivity, therefore industrial automation is implemented in fulfilling the requirements of companies to face globalization and productivity task. Industrial automation is moving towards extraordinary productivity spurred by excellent in energy efficiency, suitable standards, and better structure. With the development of SCADA, DCS and Process Instruments have made automation more reliable and powerful. Industrial automation also contributes in reducing the cost from employee's salary and bonus. Cost to employ a robot is much cheaper when comparing the spend on the maintenance, energy and repair. With the higher production and lower production cost can produce more affordable goods for consumers [2].

Besides, the industrial automation also increases human safety by minimizing contribution of human being in dangerous working environment like hazardous chemicals, heavy objects, back-breaking labor, poor air quality and extreme temperature.

1.2 Motivation

In new era of globalization, the new development situation and tasks have made our industries extremely urgent to establish a new manufacturing system featuring standardization, modularization, network and intelligence. With the concept of Industry 4.0, global market of production nowadays has gone through a dramatically changes on the manufacturing system from manually into integrated autonomous machines [1]. These changes include shorter product life cycle, variation in the order income and customized products demanding which can lead to inclining in robot quality and declining in robot prices from years to years as shown in Figure 1.1 and Figure 1.2. Figure 1.3 shows that the demands of industrial robot are increased significantly from 2012 with prediction for future.

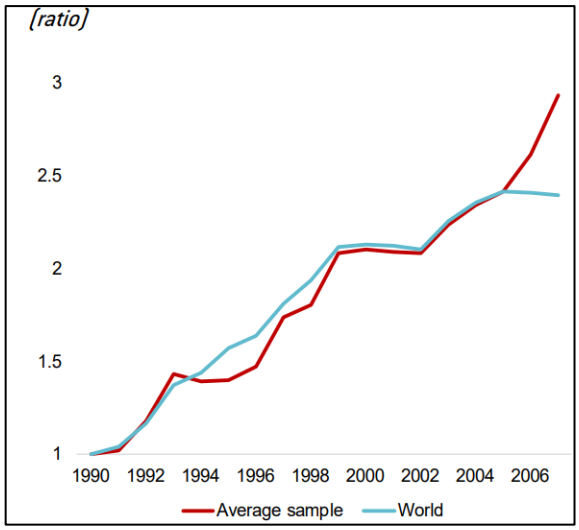

Figure 1.1: Quality of Robots Analysis 1990 - 2006.

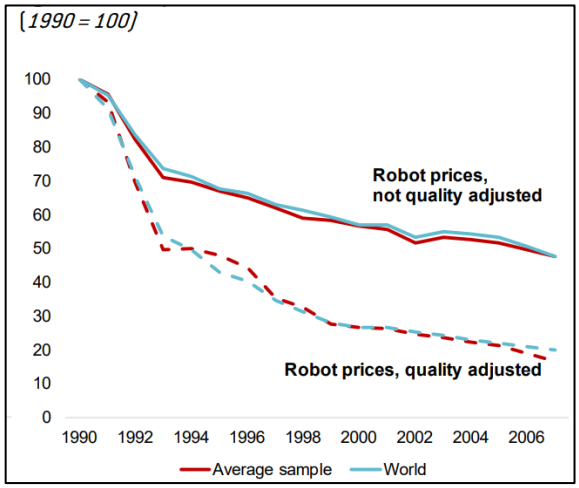

Figure 1.2: General Price for Robots 1990-2006.

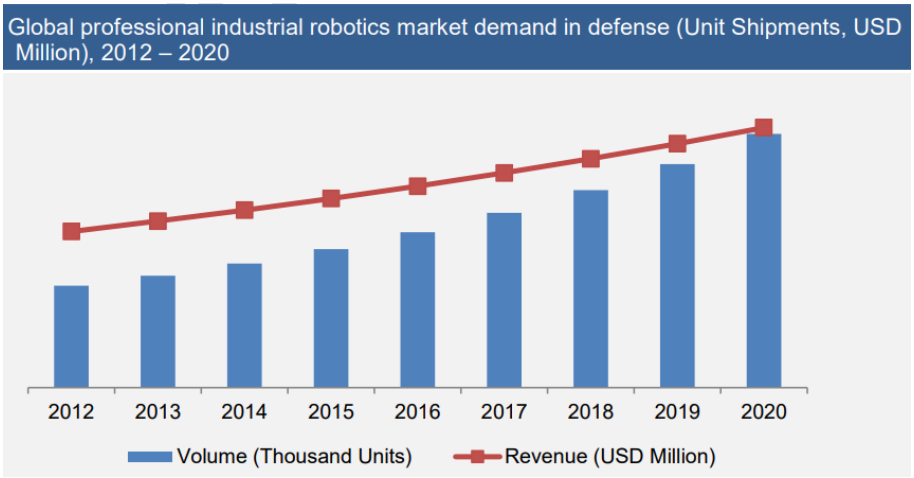

Figure 1.3: Global Professional Industrial Robot Market Demand in Defense 2012-2020 [3].

Along the growth of industrial robot, pick and place robots play important roles in process like assembly, inspection, quality controlling, packaging and sortation. This causes the pick and place robots become more competitive on the market. Since the assigned tasks for the autonomous pick and place robots increase, the complexity of the application for the pick and place mechanism also increases. This can cause the errors occur in the mechatronics control system which controlled by LLD due to more suitable to sequential control but not logic control rather than PN. In pick and place application, there are few commons errors may cause failure to the operation of robot includes:

- Underestimation of payload and inertia requirements.
- Overtasking to an industrial robot.
- Underestimation of cable management issues.
- Neglection of some application element before choosing a robotics system.
- Misunderstanding on the accuracy and repeatability factors.
- Choosing a robotics system based solely on control system rather than mechanical system.

As the results of occurrence of these errors, the industrial production and safety of employees may be influenced. This may lead to high losses from penalty on the project completion time delays. Moreover, higher maintenance fees on the machine may be applied to the company and this also can cause deficit in a company's account. Instead to develop a high-quality industrial robot with lesser errors, verification and validation steps must be taken seriously on its development process.

1.3 Problem Statement

State space approach, the most common way in modeling a large degree of freedom system may lead to state explosion problem since its tuple size for the combinations of state variables are grew exponentially [4, 5].

The large degree of freedom in a pick and place system cause the verification process of the system become challenging since there are a huge number in the possible combinations of actuators motions. Hence, petri net approach is introduced in this paper to prevent the state explosion problem of the pick and place arm system with multiple degree of freedoms.

1.4 Objectives

The objectives for this project are:

1. To design the petri net models for the pick and place arm system by using Hierarchical Petri Net Simulator (HiPS)
2. To identify the incidence matrix of the petri net models by using Hierarchical Petri Net Simulator (HiPS).
3. To identify the structural and behavior properties of the petri net models by using Hierarchical Petri Net Simulator (HiPS).

1.5 Project Scope

In this project, I model the process of the pick and place arm system by converting each of the state variables from real life pick and place mechanism into petri net. In modeling, I designed 3 models of the pick and place arm system with different amount of states. The incidence matrix for each model is identified to understand on the process sequence of the system from the petri net model. Then, the structural and behavior properties are identified for the 3 models. Lastly, the best model among the 3 models is chosen with proper facts.

1.6 Outlines

Chapter 1 discussed on the definition, revolution and importance of industrial automation to operators and industrial machines which can improve productivity and machine efficiency, increase human safety and product quality and reduce company expenses. By motivation from the quality demands of the manufacturing industry, this project is carried out to implement the modeling process of pick and place arm system via petri net approach. The state explosion problem can be solved through this approach. With the ease of using software HiPS, the verification and validation on the properties of the petri net models can be carried out. Chapter 2 will discuss on the theoretical backgrounds and literature reviews by referring to the past research papers, journals and books. Chapter 3 describes the flow of project and tasks to be accomplished by using suitable methods. In Chapter 4, the results obtained are

recorded with analysis, synthesis and evaluations. In Chapter 5, conclusion and future works are discussed based on this project.

CHAPTER 2

LITERATURE REVIEW

2.1 System Modeling

Engineered systems nowadays integrate heterogenous of complex subsystems. For example, a pick and place arm system may consist of several combinations of motions which performed with the contributions of software, mechanical and electronics parts. Hence, there are numerous of transducers like limit switches, ultrasonic sensors, reed sensors or photoelectric sensors and actuators like electrical actuators, pneumatics actuators, hydraulic actuators or supercoiled polymers are used to accomplish loading and unloading tasks assigned by programmer. System development and enhancement for the pick and place mechanism are challenging because its complex combinations of motions which can span manifold engineering disciplines. This may cause engineers to have difficulties in specifying, designing, simulating and analyzing the system via design tools. The iterations of motions become much more insufficient to be constructed by simple mathematical equations [6]. The general development lifecycle of an engineering system can be illustrated as in Figure 2.1 [7].

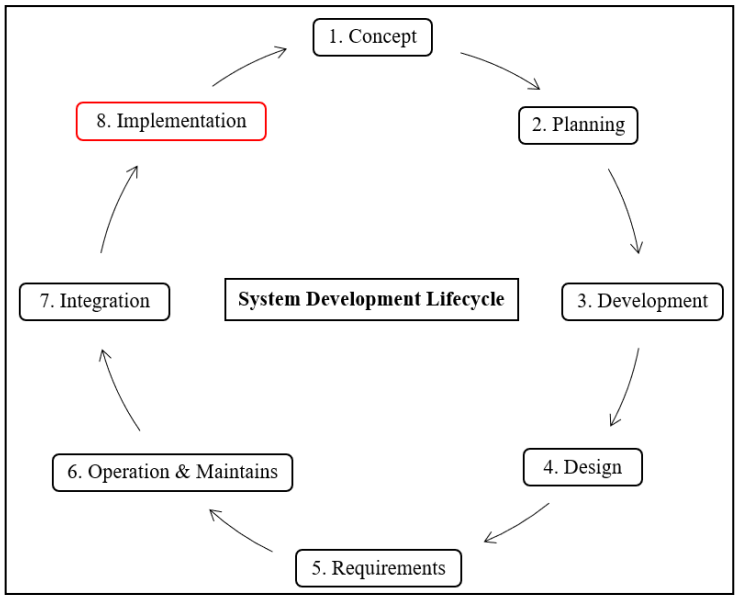

Figure 2.1: Engineering System Development Lifecycle.

There are 3 major parts of implementing process in system development which are modeling, design and simulation. Modeling is the abstract model development of a system where different perspective of that system is presented by each model. In modeling, a system is represented by using graphical notation based on Unified Modeling Language. Models define and show the properties of the system. Design is creation of artifacts according to the desired functionality. Simulation demonstrates the behavior of a system model in a particular environment. Simulation is a basic design analysis step that tend to attract insight on the design properties and to approach testing of the system design. We can understand a system deeper through dissection or partitioning into smaller and more readily analyzed compartments.

Models can be expressed in some modeling language either has strong semantics or a weak semantics. A modeling language with strong semantics has a clear and unambiguous meaning while modeling language with weak semantics has only adopted with block diagram notations without specific meaning. This means a weak semantics model is hard to analyze but it is commonly used to informally link design concept with human beings. Among modeling languages of engineering system design, mathematical modeling and graphical modeling are frequently used to describe the process of the system. The models can be classified as deterministic model and stochastic model. Deterministic model will come out with the same outputs from a given inputs. However, stochastic model will come out with a distribution of possible outputs[8].

Mathematical modeling is a deterministic way that often used to understand the internal mechanisms of a real system via translate the processes involved into mathematical operations [9]. According to Bellomo and Preziosi[10], a mathematical model can be defined as a set of mathematical expression which can be used for calculating the time-space evolution of a physical system. In mathematical modeling, the system can be expressed as differential equations, integral equations, difference equations, Boolean expressions, interpolation or linear equations.

On the other hand, graphical modeling is a stochastic method where a family of probability distributions are represented in terms of direct or indirect graph. With the use of graphical modeling, humans can understand clearer into a system compared to mathematical modeling. This would help the nonknowledge-based users easily to build rather than recognize every process in the system. The graphical approaches that

frequently used are Bayesian network and Markov network. However, Bayesian network and Markov network methods require mathematical knowledge base in probability distribution of statistical operations [6, 7, 8]. Therefore, petri net modeling, a graphical modeling method is introduced in this paper.

2.2 Petri Net

Petri net is a graphical modeling tool (named after Carl Adam Petri) that usually used to model various field of system instead of engineered system such as business flows and biological networks. It is widely used for the designation and investigation of concurrent, deadlock, asynchronous and allocated dynamical system. A Petri net structure is a four-tuple with mathematics expression: Net, N = {P, T, I, O} where $P = \{p_1, p_2, \ldots, p_n\}$is a finite set of places ○, $n \geq 0$. $T = \{t_1, t_2, \ldots, t_m\}$ is a finite set of transitions □, $m \geq 0$. Meanwhile, the set of places are disjointed with the set of transitions, $P \cap T = \emptyset$. $I: T \rightarrow P^{\infty}$ is the input function, a protraction from transition to the places. $O: T \rightarrow P^{\infty}$ is the output function, a protraction from transition to the places. Places can be symbolized as states, resources or conditions that need to be available before an action can be implemented. Transition can be symbolized as actions. A petri net graph is a depiction of a petri net structure as a bipartite directed multigraph such that each arc is coordinated from a component of a set (either place or transition) to a component of other set (either place or transition). However, the exchange on the sequence among places and transitions can lead to totally different net. The net is worked like data flow diagrams when its primarily is based on motions which represented by transitions. On the other hand, the net is worked like automata when its primarily is based on conditions which represented by places. System developers are always slotting the elements that representing a single system component on a cycle which would help to understand the net.

In petri net, a marking is to assign a number of tokens to the respectively place where a token is an original concept which can be allocated and expected to occupy in the place of petri net. The marking, M also defined as an n-vector, $M = (M_1, M_2, \ldots, M_n)$, where $n = |P|$. The quantity of tokens in place, p_i *is* M_i, $i = 1, \ldots, n$. On a petri net graph, tokens are illustrated by small dots ● in the places of a petri net [9, 10].

According to the firing rule of petri net, a transition fires by eliminating tokens from its input places. Then, it creates the new tokens and allocated into its output