FEASIBILITY STUDY ON ROBOT OFF-LINE PROGRAMMING AND SIMULATION USING MATLAB TOOLS; SIMMECHANICS AND SIMULINK PACKAGES

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ABSTRAK

Sejak kurun ke 19, pembangunan robot di dalam industri pembuatan telah bertambah dengan cepat dan ini memerlukan penjejakan kembali sejarah pembangunan robot oleh pembuat robot bagi melihat bagaimana robot berkembang sehingga ke hari ini. Berdasarkan kepada keperluan, robot dikatakan akan mengambil alih tugas pekerja disebabkan oleh beberapa faktor seperti kebolehannya melakukan kerja dengan efektif, mengurangkan kos dan melakukan tugas yang tidak dapat dilakukan oleh manusia. Objektif kajian ini adalah untuk mendapatkan pembelajaran mengenai program-luar robot dan simulasi menggunakan MATLAB SimMechanics dan Simulink. Adalah diharapkan kajian ini dapat membantu para pengajar dan pengkaji di dalam bidang yang berkaitan kerana MATLAB digunakan secara meluas di dunia di dalam pelbagai bidang. Hasil daripada kajian ini menunjukkan bahawa MATLAB SimMechanics boleh melakukan program-luar dan simulasi 3D untuk mendapatkan faktor mekanikal seperti sudut cantum, pecutan sudut, daya reaksi dan tork kiraan. Manakala SpaceLib kemudian digunakan untuk mendapatkan kedudukan dan program bagi setiap bahagian robot berdasarkan kepada satu sistem koordinat di dalam bentuk matriks.

ABSTRACT

Since 19th century, the development of robot in manufacturing industry have been increased rapidly, thus require the need to track down the historical development of robots by robot manufacturers that brings the robot function like todays. Due to demand, robot is said to be replacing human labour because of some factors such as its capability to do work effectively, reducing cost and task that human cannot do. In this research, a feasible study on robot off-line programming and simulation using MATLAB SimMechanics and Simulink packages will be the main objective. This project will be addressing about the development of robot modeling and simulation in the SimMechanics. It is aimed that this approach will be helping the academician and researchers in the related field because MATLAB is widely used in the world in various application.The result of this project shows that it is possible to do programming and 3D simulation using SimMechanics in order to obtain mechanical variables such as joint angle, angular acceleration, reaction force, and torque. SpaceLib program is then used to obtain the desired location and program each robot link to the respective coordinate system in matrix form.

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CHAPTER 1

INTRODUCTION: ROBOT AND PROGRAMMING

1.1 Research Background

Robots are believed to take the human work task in the future due to the demand and safety they offer. This phenomenon can be predicted if we take a look in our environment especially in manufacturing and industry. Movie industry for an example had launched a new action series, "I, Robot" that showing us the future that we will be living with the help of robot, have going beyond our expectation. Equipped with artificial intelligence that can be easily being mounted into a robot, this is not impossible because numerous researches are rapidly increased on the specified subject.

The term of the robot was first been introduced by a Czech dramatist, Karel Capek in 1921 of "Rossum's Universal Robots" that referring to a perfect and tireless worker performing manual labor jobs for human beings. Since Asimov raised the word robotics in his science fiction stories about robot 1940's, people began to think and design robot. Japanese defined robot as an all-purpose machine equipped with a memory device and a terminal and capable of rotation and replacing human labor by automatic performance and movement. Another good definition was made by the Robot Institute of America, that robot is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools or specialized device, through variable programmed motions for the performance of a variety of tasks [Antti, 1989][Fu K.S et al, 1987].

That is in short, a robot is a reprogrammable general-purposes manipulator with external sensors that can perform various assembly tasks, possessing intelligence associated with its control and sensing system [Fu K.S et al, 1987].

According to Joseph, there are Three Laws of Robotics remain worthy design standards [Engelberger, J.F, 1983][3]:

1. A robot must not harm a human being, nor through inaction allow one to come to harm.

2. A robot must always obey human beings, unless that is in conflict with the first law.

3. A robot must protect itself from harm, unless that is in conflict with the first and second laws.

Future robots are likely to have a greater number of attributes similar to human such as having greater sensor capabilities, more intelligence, higher level of manual dexterity and also limited degree of mobility. Although today robot does not behave like humans, there is no denying that the technology is moving in a direction to provide those machines with human capabilities.

Industrial robots are now being focused due to its capabilities and advantages especially in the aspect of how factories run. Yet too many robots are become too expensive and too complicated. There is no doubt that the use of robots will be the key to growth in manufacturing in the next decade and more companies using robots will boost their productivity.

It is seems that in the last twenty years, the cost of a universal robot has hardly increased, yet labor cost have quadrupled. In year 1981, Unimation Inc claimed that the hourly cost of a robot was about 30% of labor cost in the US automotive industry whereas in 1966 the costs were similar [Harley, John, 1983].

Why do we use robot in industry? The principle advantage of a robot is its flexibility such as;

1. Able to cope with different products on one line as market demand changes

2. Able to be re-programmed to suit minor modifications or when a completely new model been introduced

This availability offers the high-volume manufacturers in a way of coping with change in volume or type, and for the small manufacturers for the chance of a big jump in productivity while continuing to produce in small batches, such that in some cases, he may be able to compete with much larger companies. Table 1 shows the main advantages of robots.

Table 1.1 Main advantages of robots [Harley John, 1983]

1	Improvement in productivity through the use of robots	94.00%
2	Stabilization of product quality and improved job efficiency	69.70%
3	Improve labor safety	52.80%
4	Changing workers attitudes	51.40%
5	Shortage of laborer and skilled workers	45.00%
6	Increased flexibility of production system	39.70%
7	Progress of engineering and technology of robot	37.30%

Modern industrial arms have increased in capability and performance through controller and language development, improved mechanisms, sensing, and drive systems. In the early to mid 80's the robot industry grew very fast primarily due to

large investments by the automotive industry. The benefits of robots to industry include improved management control and productivity and consistently high quality products.

As manufacturing moves to become more responsive environment with products having shorter life cycles and batch quantities reducing in size, robot programming times become critical, and hence an area to be addressed in order to seek improved productivity. *Off-line programming* is an approach that could reduce the required skill levels of a programmer, reduce the programming times, allow the operator a 'natural' interface with which the operator would conduct the task in the real world, and reduce the boredom factor [Boud, A.C.; Steiner, S.J. ,1997][Naylor, A et. al, 1987].

Due to *on-line programming* have some deficiencies, *off-line programming* becomes popularly used in the industries. We can find one of the developments using the MATLAB® software in robot technology in the "Simulink-Based Robotic Toolkit for Simulation and Control of the PUMA 560 Robot Manipulator" [Dixon, W.E. et. al, 2001]. The PUMA 560 robot manipulator is developed by using the MATLAB®/Simulink based platform that can be easily be executed on the LINUX or Win32-based operating system. The toolkit represents a graphical user-friendly nature that allowing the toolkit can be customizing in real-time simulation without writing any code. It is also give the users to easily incorporate additional functionality and hardware through the simple block diagram interface that Simulink provides thus providing the flexibility for easily modifying component for increased functionality.

There are also some off-line programming software available whether made individually by research or provided by the robot manufacturers. Some of the software developed by the researchers is as mentioned above, SRTK, ROBOSIM, SPACELIB, RRS, WorkSpace, RoboWorks etc. Table 1.2 shows the example of robot manufacturers that provided along the off-line programming software with their robots.

Table 1.2 Robot manufacturers and its off-line programming software

No	Robot Manufacturers	Off-line programming software
1	ABB	RobotStudio
2	Fanuc	RoboGuide
3	Motoman	MotoSim
4	Kawasaki	PC-Roset
5	Adept	Adept DeskTop
6	Staubli	Staubli Studio

1.2 Robot Programming

In the global competition for the manufacturing industries, there are some aspect that has to be concerned such as productivity, cost reduction and also product flexibility. In this subject, there has exist a number of *on-line programming* and *off-line programming* that are spoke to be able to reduce for the mentioned problem.

The number of industrial robots that have been applied in the manufacturing production and other areas in the past decade is significantly smaller than the number predicted at the beginning of the decades. This is due to some of problem such as programming of robot for various tasks in not the least trivial problem and thus bringing the word *"off-line programming"* catches researcher's eye for further investigation and research rather than "*on-line programming"* that is time-consuming process and not very efficient in a flexible manufacturing environment [Leondes C.T and Shirinzadeh B. , 2001]. Furthermore, the *''on-line''* programming technique requires the use of the actual robot which is physically put through the desired sequence of actions.

Programming means the generation of algorithms and data. Hunt have been outlined five objectives of structured programming that are needs to be considered and fulfilled before any of robot programming are done [Hunt, V.D, 1983];

1. Program readability and clarity
2. Increased programmer productivity
3. Reduced testing time
4. Reliability
5. Maintainability

According to Lee et al, there are four main categories in robot programming techniques available [Lee et.al, 1990];

1. Manual on-line programming that physically teaching a robot the desired trajectory through interaction with a teach pendant or other similar devices and also known as 'teach by showing' or 'lead-through' programming.

2. Use of explicit robot programming languages where entire motion cycle of the robot is specified explicitly by a computer program containing specific commands.

3. Task-level programming that needs the robotic arm to be command in order to perform certain task using various artificial intelligence techniques.

4. Off-line programming that combining computer simulations and graphics to produce a desired trajectory plan without need for physical direct access to the manipulator or its movement that also include the calculations and its corresponding differential motions.

On-line programming is a robot program that a robot is being physically moved through the task by an operator.

Lewis F.L said that computer-integrated manufacturing operations require off-line programming and simulation in order to layout production facilities, model and evaluate design concepts, optimize motion of devices, avoid interference and collisions, minimize process cycle times, maximize productivity, and ensure maximum return on investment [Lewis, F.L. et. al, 1999]. There are some software (e.g., ROBCAD and SILMA) provides support for 3D workable layouts including robots, end effectors, fixtures, conveyors, part positioners, and automatic guided vehicles.

What actually does the off-line programming means? Eberhard explained that off-line or indirect programming means generating a robot program freed from a robot control or a programming device, remote from the industrial robot's workplace, for instance in central programming development [Eberhard R. and Behrens A., 1996].Off-line programming involves use of a high-level robot programming language. This allows writing and editing programs in a language which is closer to the operator's language than to the machines. Off-line programming can be based on an explicit programming language or on a 'world modeling'; implicit or 'model-based' language.

Illija have been done some good research to do robot off-line programming using a personal computer and robots modeling by AutoCad also simulate using the 3D Studio program packages [Nikolic, I.Z and Maksic, V, 1995]. She modeled some robot such as PUMA robot, SCARA robots and also educational robots by the AutoCad and then simulating the robot animation by the 3D Studio program packages without the need for specialized robot packages that results in cheaper cost than depending on the available software.

Numerous off-line programming have already been developed nowadays. Programming of the robot for various tasks in production can be done in two ways in the real system, either that requiring industrial robot to be mounted in the place of working environment or by animation using off-line programming method. These two methods are requiring significant financial means but the off-line programming system for the robot programming has the main advantages to enables prediction and avoidance of possible numerous collision situations, before robot introduction to the

real system. The needs to buy a special programming packages and the corresponding hardware also required here thus bringing the choices to the customers to think the appropriate or suitable software to meet their needs. Time and costs for robot introduction for education and training on the programming systems for the person who will be conducting the robot are also items to be considered. These factors effect for slower introduction of robot in smaller and medium size companies.

The use of off-line programming and simulation system to program industrial robots enabling the shift of programming creation and optimization away from production thereby offers the possibility to reduce down times in production. Furthermore, by using the Off-line programming, a simulation program can be adapting and simulating variety of scenarios and processes of a robot specific task. Thus, this will be optimizing the process and do not affect the production cell flow.

Hodges claimed that there are some advantages that off-line programming offers [Hodges, Bernard, 1992];

1. Improved robot and programmer safety;

   (a) Programmer is remote from a potentially hazardous environment.

   (b) The programmer and the robot are not placed at risk by the accidental operation of the wrong controls, as when the robot is very close to the workpiece.

   (c) Operator eyes need not to be close to the tool point to achieve the desired accuracy of positioning. Conventional programming places the operator in a vulnerable position inside the working envelope. High-precision task require this risk period to be long and continuous, particularly if the program consists of several hundred points. Control mistakes, operator fatigue and errors induced by visual problems such as restricted view and eye strain can easily cause mistakes in the program and poor accuracy.

2. Postprocessors enable a variety of types of robots to be programmed from one workstation.

3. The system permits verification, assisted by the graphical simulation system, of robot programs in terms of positional data and program logic. This may include input/output signals for control of peripheral equipment, the processing of sensory inputs, path control informations and programming structures such as loops, branches and wait instructions, and the inclusion of previously written subroutines.

4. In off-line programming the robot program is developed, partially or completely, without requiring direct use of the robot, which can remain in production while its next task is being programmed. This makes the use or robots economic for small batch production, and increases the economic viability of the robot installation.

5. The use off-line programming enables complete automation system to be planned, built up and modified to suit the desired requirements. This can include the layout of machine tools, materials handling devices such as bowl feeders and conveyors system, as well as the evaluation of different robots and their individual positioning and work envelope considerations.

6. Off-line programming allows data built up in CAD and production control systems to be incorporated into the design of the robot installation.

Engineers always found themselves in problem that when they are trying to synchronize the virtual and the real situation in manufacturing process. Although there are many of offline simulation programming been introduced by many manufacturers especially for robot such as workspace, roboguide, roboworks etc, some may still have experience about synchronizing the virtual and real process due to testing has become the bottleneck for CAE (Computer Aided Engineering)

purposes since testing data is not in a form that can be readily absorbed by CAE as Mr. Doug Marinaro, vice president of Software and Consulting, at MTS Systems Corp. in Minneapolis.

Many of automobile manufacturers are interested in the Off-line programming method and believe that it can help to reduce their manufacturing time losses and effectiveness. For example, big car company such as Audi, BMW, Ford, Mercedes, Opel, Renault, PSA, Volvo and VW have initiated the RRS or Realistic Robot Simulation in 1992, to obtain modules that able to precisely simulate the motion behaviour of the robots[Vollman, Karl, 2002][R.R. Waiboer et.al, 1995]. The robot controller manufacturers, ABB, Comau, KUKA, Fanuc, Renault Automation, Siemens and VW also the simulation system manufacturer Dassault Systems, Deneb, Silma and Tecnomatix were all interested in this interesting project.

The objective of RRS project is to achieve a good accuracy in the cycle time, possibility to use several controllers in one cell, data consistency between real and virtual time, the interface are able to support continuous development and far-reaching requirement and capable and compatible with older version of simulation system.

The aim of this work is to perform the off-line programming of industrial robot by simulation which is done by using MATLAB® Simulink, SimMechanics packages and MATLAB programming. This is a simple and easy approach for Off-line programming of the robot to know its movement, forces etc. We will build a converter that can convert program data for a specific robot in the MATLAB® environment to do the same task required and then simulates the task then analyzing it.

Figure 1.1 shows the hierarchical structure for task planning and off-line programming for strategies of task planning and programming. We will be focusing in the *Geometric Modeling* of CSG in this project as the strategies for off-line programming.

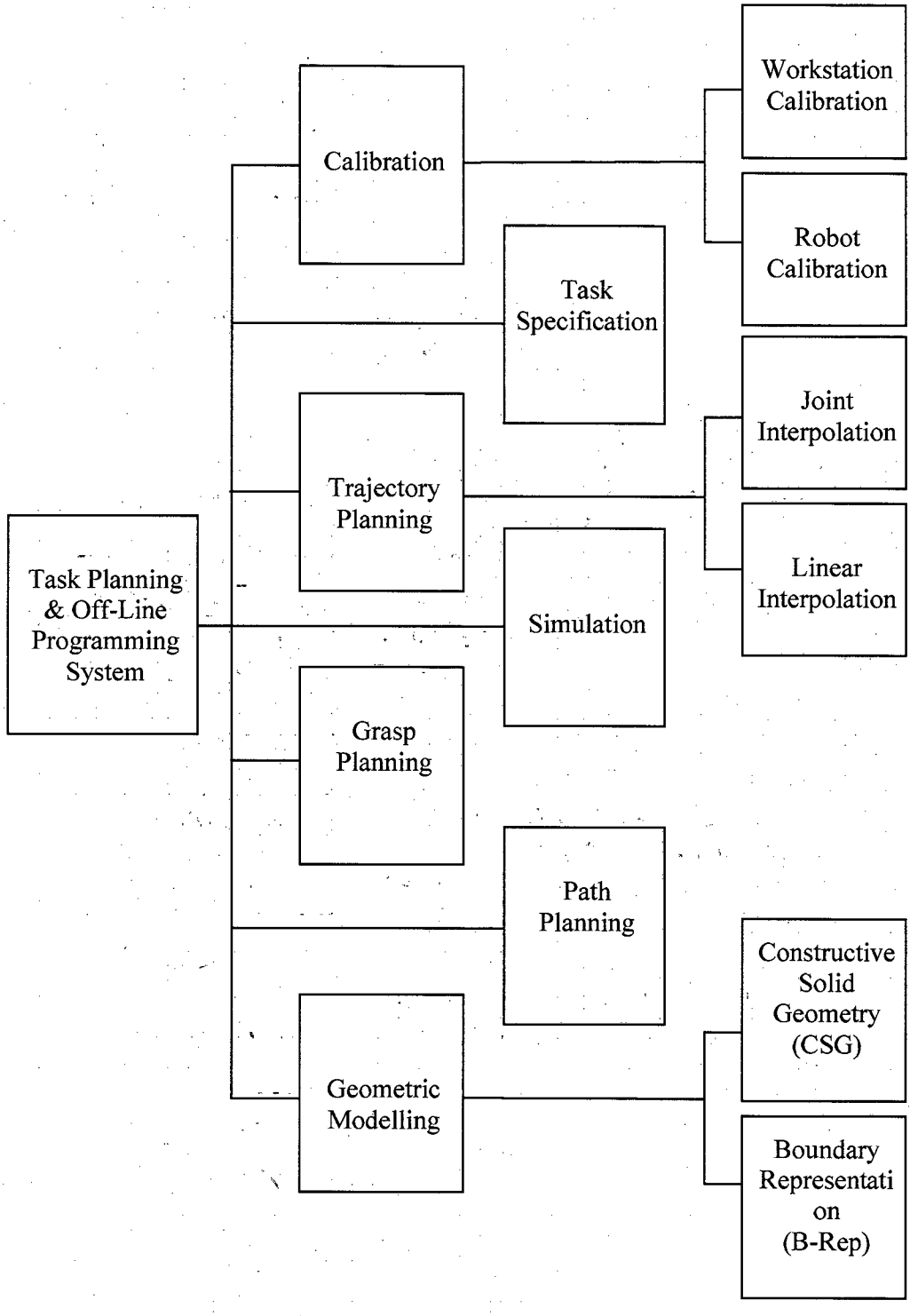

Figure 1.1 The hierarchical structure for task planning and off-line programming [Harley John, 1983]

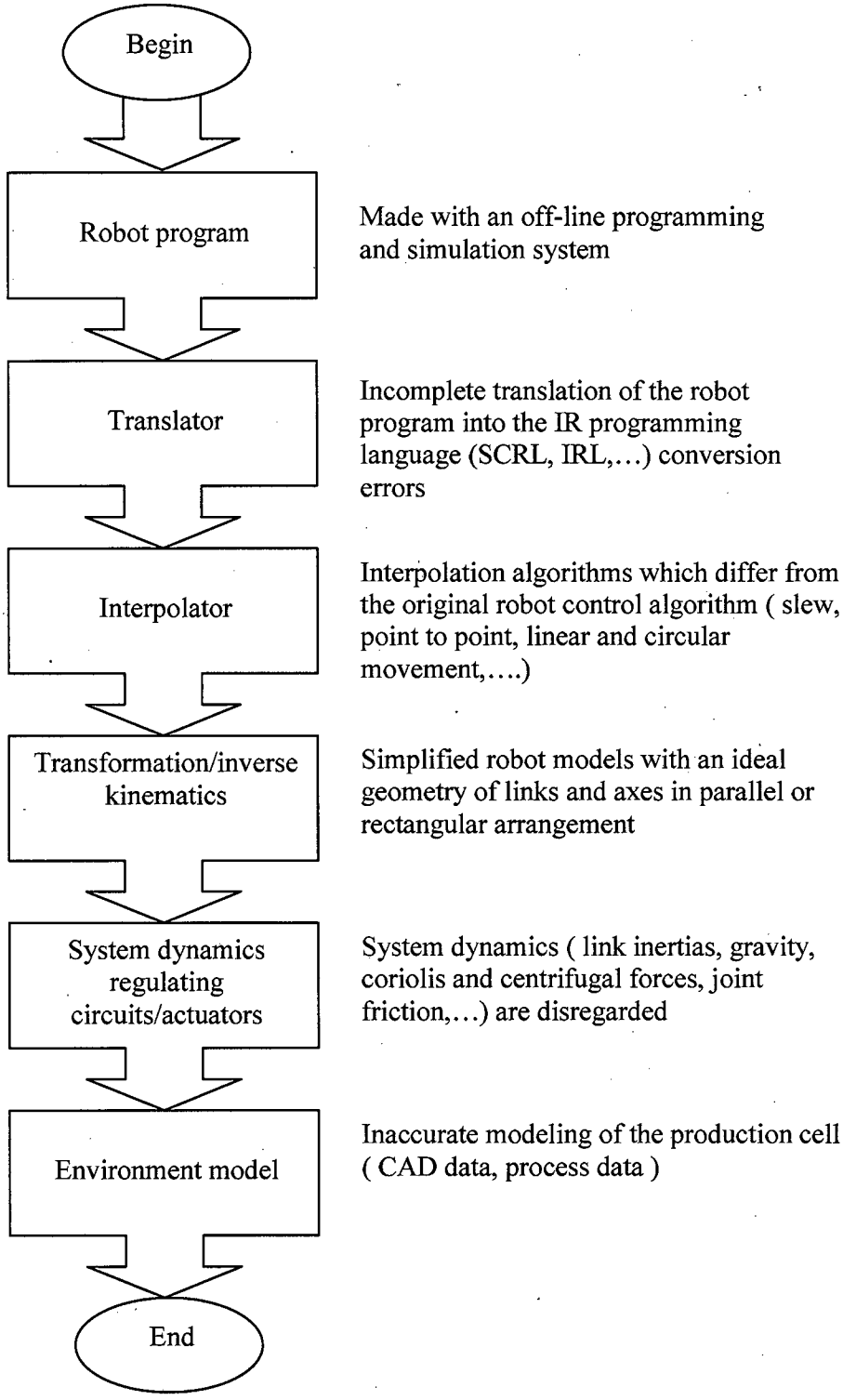

Figure 1.2 Program flowcharts: conversion of a simulated robot program

The transformation (inverse kinematics) and motion interpolation of the original robot control software are integrated into the off-line programming system thus enable to achieve and improved path accuracy and other more realistic time-dependent characteristics, such as path accuracy, path velocity or cycle time (Project RRS: Realistic Robot Simulation) [Vollman, Karl, 2002].

1.3 Research Objective

The purpose of this project is to provide a feasibility study on off-line programming and simulation using MATLAB especially focused on SimMechanics and Simulink packages.

In order to achieve the project main objectives, there are some task that have to be done. The overall structure of the project will be basically based on following:

1. Reviewing the basic of robot development including the advantages and disadvantages of on-line programming and off-line programming method.

2. Understand the basic principle of robot modeling and simulation using SimMechanics and Simulink library blocks.

3. Understand how robot programming is done for data calculation of kinematics and dynamics (using SpaceLib software).

4. Evaluating the result obtained from the simulation to define the capability of SimMechanics and Simulink for robot modeling and simulation.

The project will be discussing and analyzing existing robot arm model in the SimMechanics packages for off-line programming purposes and also will be including below mentioned items;

1. Editing and reconstructing the existing Manutec R3 robot arm model in SimMechanics demo library to obtain its mechanical variables.

2. An experiment to implement and built a new SCARA robot model using the parameter obtained from the SCARA robot specification and measurement from laboratory to determine how robot model are built in the SimMechanics

3. Run a robot program model using SpaceLib to identify the mechanical variables and robot kinematics that can be used for off-line programming purposes

1.3 Research Scope

The scope of the project encompasses the advantages of off-line programming using MATLAB are weighed by using the SimMechanics and Simulink packages. The existing demo of robot arm model are discussed and analyzed. A simple comparison with look-alike software of Dymola for the robot arm model is handled to identify the differences and advantages. Then the robot arm model is edited in such a way to find the other mechanical variables that SimMechanics can offer. In addition, an experiment to identify the process of building geometrical structures and 3D visualization of a robot models without any simulation to obtain its mechanical variables will be conducted. In the aspect of robot programming, we will not building any of computer program or software but only using existing software of SpaceLib for analysis and discussion.

The report is divided into five chapters. The first chapter begins with the introduction to the concept of off-line programming and simulation. The second chapter is further supplements background knowledge on the off-line programming

and simulation that have been done by other researchers. An introduction to the SimMechanics will be included for reference and acknowledgement. While the third chapter will be the project methodology after which the result are reviewed and discussed. Lastly, based on the discussion of the result, conclusions are drawn and recommendations are provided.

1.4 Research Methodology

In this paper, we are trying to solve robot "*Off-line programming and simulation problem using SimMechanics*" by modeling the robot arm from the robot specification and then create a simple translator program in MATLAB based on the robot controller that is also can be a feasible study to do programming with any type of robots. A detailed explanation of project methodology will be on chapter 3.

To solve this project, we split it into some smaller parts;

- An overview on some literature studies on robot off-line programming, modeling and simulation including information on MATLAB SimMechanics packages.
- A comparison with on-line programming and other available off-line programming software.
- An analysis on the robot modeling and simulation using the robot arm model demo on the MATLAB SimMechanics packages and some comparison to the Dymola software model.
- Analysis of SpaceLib robot programming for position and orientation for the robot motion for its capability to simulate any given parameter for the specified motion.

1.5 Thesis Organization

The design and development of the robot has taken into deep parts of its. Occupied with artificial intelligence that enabling the robot to make decision, appropriate task and accurately doing their work task, this is proving that robot capabilities going beyond our expectation. The current and possible future applications of robots are moving in the direction to provide us with more capabilities like those of humans. Manufacturing industries especially, should take these advantages to perform and upgrade their product quality and enhancement by integrating robot into their work environment.

The two reason of selecting robot for production is to reduce labor cost, and to perform work that is boring, unpleasant, or hazardous for human beings. Use of the industrial robot, which became identifiable as a unique device in the 1960s, along with the Computer Aided Design (CAD) systems, and Computer Aided Manufacturing (CAM) systems, characterizes the latest trends in the automation of the manufacturing process. These technologies are leading industrial automation through another transition for where the scope is still unknown.

In the aspect of system development in manufacturing, robot off-line programming are more beneficial than on-line programming to such factors as reduce time-consumption, error prediction and reducing cost. Off-line programming systems are important both as aids in programming present-day industrial automation as well as platforms for robotics research. This will be focused in the next chapter that introducing the background knowledge and literature reviews of MATLAB and SimMechanics in the aspect of off-line programming. This will be followed by chapter 3, where the research problem statement will be highlighted. Chapter 4 will be including the research methodology. As for chapter 5, the modeling, simulation and programming of two kinds of robot, Manutec R3 and Yamaha YK600X SCARA robot will be explained briefly then the simulation result of these two robots are explained and discuss in chapter 6. Finally, the research conclusion for this research will be included in chapter 7.

CHAPTER 2

BACKGROUND KNOWLEDGE AND LITERATURE REVIEW

2.1 MATLAB and SimMechanics in "*off-line programming*"

In the last decade, the growth of industrial robot has not been nearly as rapid as predicted. The primary reason can be said that the robots are still too difficult to use [Craig J.J, 1989]. This phenomenon is then slowly changed in a direction to commercially use robot in terms of using their capability to do some difficult task. One of the actions taken is that robot manufacturers and individual research are increasing in a way to ease robot usage that is not only user-friendly, but can also improving user's time and cost to whoever used it. Off-line programming software can be said as one of the solution to robot manufacturers and researchers for this problem because its capability to reduce cost, time saving and other advantages its offer. Numerous type of software has been introduced in the development of off-line programming. In this project, off-line programming with MATLAB is focused.

This chapter generally reviews some of the works in the field of off-line programming associated with MATLAB SimMechanics. In the area of off-line programming with MATLAB, introduction on MATLAB SimMechanics will be reviewed first. Then, since the package is still new, any existing example of package usage or user feedback will be noted. This is followed by a review of some works related to the SimMechanics.