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AN APPROACH OF DEPENDABLE LOGIC CONTROLLER FOR PICK AND PLACE ROBOTIC SYSTEM IN COMPUTER INTEGRATED MANUFACTURING SYSTEM

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Bachelor of Electrical Engineering (Control, Instrumentation and Automation)

June 2014

I hereby declare that I have read this report entitle "An Approach of Dependable Logic Controller for Pick and Place Robotic System in Computer Integrated Manufacturing System" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation) with Honours.

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AN APPROACH OF DEPENDABLE LOGIC CONTROLLER FOR PICK AND PLACE ROBOTIC SYSTEM IN COMPUTER INTEGRATED MANUFACTURING SYSTEM

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A report submitted in partial fulfilment of the requirement for the degree of Bachelor of Electrical Engineering (Control, Instrumentation & Automation) With Honours

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2014

I declare that this report entitle "An Approach of Dependable Logic Controller for Pick and Place Robotic System in Computer Integrated Manufacturing System" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	…………………………
Name	:	NURRAFIDAH BINTI MOHAMMAD RASHID
Date	:	…………………………

Specially dedicated:

To my beloved family members,

Supervisor,

All lecturers,

And my dear friends

For their encouragement, support, motivation and patience throughout my journey of education.

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ABSTRACT

The increase in demand of safety-critical systems in manufacturing process has led to the increase in its complexity. Verification process need to be done to ensure the correctness of the controller designed. A necessary procedure should be carried out to ensure that the designed system is dependable during the entire operation. In this report, a robotic pick and place system is used as an application in designing a dependable logic controller. Before designing the controller, procedure such as determining the logical behaviour and its definition of states must be achieved for the pre-post conditions to be valid. After the pre-post condition is defined, the Boolean mathematical model is generated in terms of input and output relationship from the pre-post condition. Then the next stage is to design the dependable logic controller by using PLC ladder diagram approach. The dependability aspects described in this report is focused on the safety properties of the logic controller. The designed controller is verified with a model checking tool which is Symbolic Model Verifier (SMV) software. The function of the model checking tool is to verify the correctness of the mathematical model and whether the designed logic controller meets the specification written. The specifications or properties are referred to various studies done on Computational Tree Logic, CTL specifications. The result of the SMV software is either TRUE or FALSE. If the result is TRUE, it means that the system meets the specification written. If the result is FALSE, means that the system is not behaving as what it was specify and a counterexample is generated. Counterexample shows the path or state that violates the specification for the user to identify in the model of the whole system. As a conclusion, the system verified satisfies all the properties and the designed controller is dependable.

ABSTRAK

Peningkatan dalam permintaan sistem keselamatan yang kritikal dalam pembuatan industri telah mengakibatkan dalam peningkatan sistem yang padat. Ia juga telah menyebabkan langkah-langkah yang wajar perlu diambil untuk menghasilkan alat pengawal yang selamat. Dalam laporan ini, sistem robotik ‘Angkat dan Letak’ digunakan sebagai satu aplikasi dalam merekabentuk satu alat pengawal logik yang mampu beroperasi secara kendiri. Sebelum bermula merekabentuk alat pengawal itu, langkah-langkah seperti mengenal pasti sifat logik dan status definisi bagi membentuk keadaan ‘pre-post’ yang sah. Selepas mengenal pasti keadaan ‘pre-post’, bentuk matematik ‘Boolean’ di reka daripada syarat ‘input & output’ keadaan ‘pre-post’. Langkah seterusnya ialah merekabentuk alat kawalan logik yang mampu beroperasi secara kendiri. Alat kawalan yang dinyatakan dalam laporan ini memfokuskan tentang cirri-ciri keselamatan dalam mengawal sesuatu keadaan. Rekabentuk itu kemudian disahkan untuk mengenal pasti sama ada reka bentuk itu mengikut spesifikasi dan objektif sebenar yang telah di tetapkan. Spesifikasi dirujuk dalam beberapa penyelidikan spesifikasi ‘Computational Tree Logic, CTL’ yang telah di buat oleh penyelidik-penyelidik. Spesifikasi itu kemudian digunakan untuk mengenalpasti kebenaran alat kawalan logic itu dalam perisian SMV. Keputusan SMV sama ada BENAR atau SALAH. BENAR bermaksud sistem itu mengikut spesifikasi yang ditentukan. SALAH bermaksud sistem itu tidak berkelakuan yang sepatutnya dan ‘counterexample’ akan ditunjukkan. ‘Counterexample’ ini bertujuan untuk memberitahu pengguna di mana salahnye dalam sistem yang menyebabkan sistem itu tidak mengikut spesifikasi. Kesimpulannya, sistem telah disahkan BENAR mengikuti spesifikasi yang ditentukan dan alat kawalan tersebut boleh dipercayai.

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CHAPTER 1

INTRODUCTION

This chapter discusses about the project background, problem statement, objectives for this project, scope that limits the area being discussed and outline for this report.

1.1 PROJECT BACKGROUND

The era of present day manufacturing systems with its hard-wired inter-connection of manufacturing cells is slowly passing out and replace by software controllers such as Programmable Logic Controller (PLC) [17]. The present manufacturing system serves the purpose of reducing the cost and increase dependability of the system. With the increasing demand of dependable control system, safety properties are the upmost important that needs to be considered.

Dependability can be defined as 'the trustworthiness of a computing system which allows reliance to be justifiably placed on the service if delivers [1]. The characteristic of dependability also include reliability, availability, safety and security. The number of states and properties associated is proportional to the increasing complexity of the system.

To determine the correctness of the system or the dependability of the system, a formal method approach is introduced. One of the technique in formal method is model checking. Formal method approach is intended to verify safety-critical applications, security-critical applications, financial reasons and legal reasons. This gives an advantage to better and more precise understanding of the model and implementations.

When designing a dependable controller, it is crucial to ensure that the controller works the same as the robotic operation itself. The defined specification is the characteristic of the dependability of the controller such as safety, reachability and resettability.

In conclusion, it is an utmost important that a designed controller is being verified to ensure the correctness of the design meets the specification properties especially in manufacturing line to avoid any fault from happening during operation.

1.2 PROBLEM STATEMENT

In today's fast growing technology, PLC has made it possible for automation systems to become larger and hence, increase the complexity of the algorithms implemented in logic controllers increases. At the same time, the demands on dependability are increasing due to rising user-awareness, stricter legislation and especially new application areas of automatic control. This increases the vulnerability in the development of the systems, especially in systems with safety responsibility faults that must not occur because it may lead to high costs, human injuries and also could causes material damages.

Furthermore, according to [13] it has become necessary to re-examine how and why safety cases are built in order that we might provide a means for managing their inherent complexity and reduce production costs. Thus this is also the motivation for this proposed project.

To ensure the safety of the system, the correctness of the operation model and controller needs to be verified by model checking technique with safety specifications. Safety specifications are properties defined from the operation itself. The properties are satisfied if all behaviour is acceptable and this indicates that the design verified is correct.

As a technique of formal verification, model checking is suitable because by model checking the formal check of the operational model is performed automatically. Therefore, the proposed project is intended to introduce a dependable logic controller for a robotic pick and place system provided with safety properties verified with Symbolic Model Verifier (SMV) software.

1.3 PROJECT OBJECTIVES

1. To determine the logical behaviour of a robotic pick and place system by using pre-post condition table.
2. To design the Boolean mathematical model of the robotic pick and place system in terms of input-output relationship.
3. To design a logic controller and verify its dependability for the robotic pick and place system.

1.4 PROJECT SCOPE

This project focuses on determining the logical behaviour of the existing Computer-Integrated Manufacturing (CIM) model, known as ‘Souvenir Assembly Line (CIM 40)’ refer Appendix 1, which only focus on Workstations 1, located at the Centre of Robotics, Innovation and Automation (CERIA) laboratory in ‘Universiti Teknikal Malaysia Melaka (UTeM)’. The Boolean mathematical model is generated from the logical behaviour of a robotic pick and place system of Workstation 1. In addition, a ladder diagram is used to design the logic controller for the system. The formal method approach for verification is model checking technique by using Symbolic Model Verifier (SMV) software. The dependability of the logic controller is verified with specifications such as safety properties and it is verified using the SMV software. The verification process and analysis only include the result of the verification, either True or False. The counterexample generated from the false result is not discussed in the report.

1.5 REPORT OUTLINE

In Chapter 1, the problem statement, objectives and scope of research is defined and discussed. The scope of research is defined based on the objective and problem statement and to limit the area of research. In Chapter 2, the theories and research work of other researches related to this project are discussed. Relevant research works that are useful in achieving the objectives are also discussed in Chapter 2. Chapter 3 discusses the methodology needed to achieve the objectives. The procedures to achieve the objectives are also described in this chapter. Objective 1 and 2 is achieved also in this chapter. In addition, the designed controller is also included in this chapter. Chapter 4 is the result of verification using SMV software with its analysis and further discussion. Chapter 5 is the overall conclusion for this project and recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses about the referred theory for this project and also related research works done by previous researchers related to this project.

2.1 RESEARCH THEORY

The demand on new technology is increasing due to the convenience it provides especially in automated manufacturing system where it has improved much aspects such as time consumption, dependability, reliability, safety, maintainability and availability of the system. The current automated manufacturing system has much improved where hard-wire is replaced by PLC that is easily change to meet the specifications and condition of the system and also to reduce cost instead of building a new controller [17].

Many systems in the industry are based on safety-critical system. Safety is defined by the process to be controlled in an automation system that needs to be limited to states in which no people or machines are harmed [2]. But in [3] it is also stated that there is no such thing as absolute safety, and therefore safety should be define in terms of acceptable loss. PLC is a unique type of computer used in automation systems [4] and has made it possible as a controller to control safety-critical system. Generally speaking, they are based on sensors and actuators which have the ability to control, monitor and interact with a particular process or a collection of processes, refer to Figure 2.1 [5].

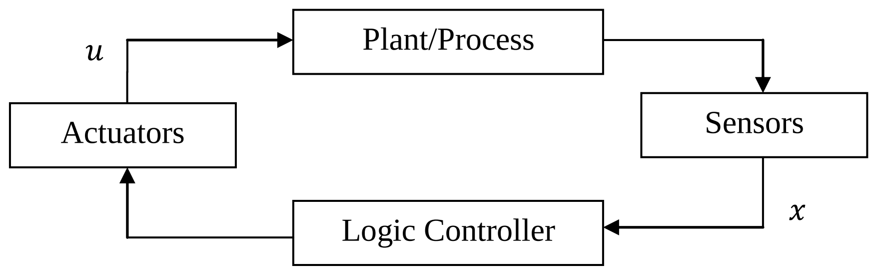

Figure2.1: Control system architecture

For this project, a formal method approach is introduced to verify the program of a robotic pick and place system part of a Computer-Integrated System (CIM), which runs on OMRON SYSMAC CJ1M Programmable Controller. This formal method approach uses Symbolic Model Verifier (SMV) as a tool for model checker to perform the software design evaluation effectively and automatically.

Referring to Figure 2.2, model checking is a technique for verifying correctness of the properties of finite-state systems, such as automation system. The properties are expressed as temporal logic formula [18]. Temporal logic expresses the ordering of events in time by means of operators that specify properties such as “p will eventually hold”.

In contrast, this model checker software has its own drawbacks which are state space explosion and expressiveness which is hard to deal with parameterized system. State space explosion occur when there are too much memory required.

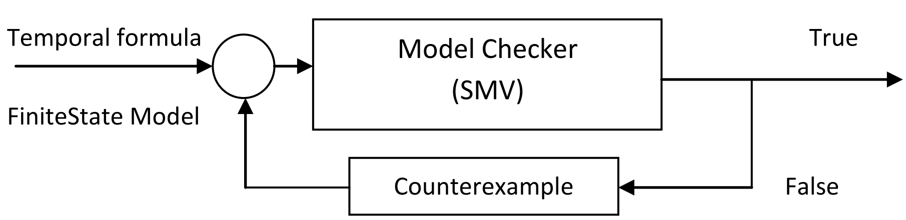

Figure 2.2: Operation of the model checker and its relationship [10]

Formal verification means to automatically explore all behaviours of the component, to check whether or not the specification is fulfilled [6]. To formally verify a design system, a formal specification is required. The formal specification can be viewed as an unambiguous abstraction of the implementation; for instance it might state that a certain combination of inputs always leads to a certain combination of outputs [7]. The specifications contain safety requirements such as lack of deadlocks and any similar critical states that could cause the system to break down. The specifications are determined by the pre-condition and post-condition of the software routine. The pre-condition expresses the requirements that a call of the routine must satisfy, for the routine to guarantee the corresponding post-condition. The post-condition expresses properties that are ensured in return by the execution of the call [7].

The term safety is also used to describe a system that implement the required safety functions necessary to achieve, by itself or with other safety-related systems, or external risk reduction facilities, the necessary safety integrity for the required safety functions [8]. The work procedure for the specification properties is as follows. Firstly, determine the safe state. Next determine the conditions for the safe state. Third, write the structured safety specification and lastly, amend if needed [9].

As shown in Figure 2.3, the safe state is determined by the behaviour of the controller in its operating state and safe state. If the machine are supposed to operate in the operating state and the safe state is denote when it is not operating. Means that the machine is not supposed to operate after the operating state.

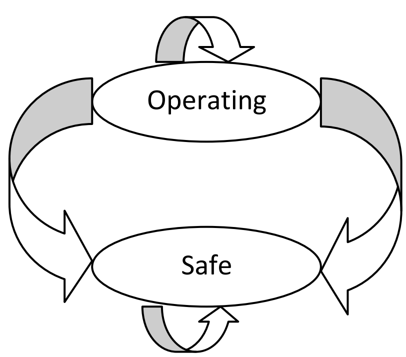

Figure 2.3: State diagram showing the states of the basic safety software component [9]

The specification for the model checker, SMV is written in Computational Tree Logic or CTL, created by Clarke et al [19], a propositional temporal logic of branching time. The syntax of CTL is defined recursively using a path quantifier, a temporal operator, Boolean operands and smaller CTL formulae.

Since CTL is defined on paths, each formula must have a *path quantifier*. There are two path quantifiers [20]:

- *A* (for all paths): The formula is said to hold at a given state if for all paths from the state, the clause following *A* is true.
- *E* (there exist a path): The formula is said to hold at a given state if there exists a path from the state where the clause following *E* is true.

Since, CTL is a temporal logic, there are four forward time temporal operators:

- *G* (Globally): The clause following the *G* operator holds true globally in the future.
- *F* (Finally): The clause following the *F* operator holds true sometime in the future.
- *X* (Next state): The clause following the *X* operator holds true next state.
- *U* (Until): The clause preceding the *U* operator must hold until the clause succeeding the operator holds (along all paths of concern).

Once the property is written in CTL, verification can be performed by traversing the design finite state machine to ensure that it is a model of the property formula.