DEVELOPMENT OF A GENETIC ALGORITHM CONTROLLER FOR CARTESIAN ROBOT

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This thesis is especially dedicated to my beloved parents.

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It is my hope that this thesis would contribute to the organizations in furthering their research.

ABSTRACT

In some daily tasks such as drilling, laser marking or spot welding application, the Cartesian robot is requested to reach with its hand tip to a desired target location. Such tasks become more complex if it has to handle multiple points in shortest travelling time and space. It is with these reasons that this study was conducted with the primary objective to develop a computational intelligent system that would contribute towards encouraging a productive and quality way of material handling and processing. The objective of this project is to design, develop and optimize the performance of a Cartesian robotic arm in terms of its positioning and speed to perform spot welding application. The genetic algorithm (GA) will be introduce, it will be able to look for the optimum sequences to solve its path planning via evolutionary solutions. GA will determine the best combination paths in order to minimize the total motion of welding time in shortest travel distance. The new algorithm is tested and implemented in this Cartesian robot. Laser pointer will replace the spot welding torch for the demonstration purpose in this project. This project involves in developing a machine learning system that is capable of performing independent learning capability for a given tasks. The design and development of this project will involve two major sections. First section concerns about the hardware construction, wiring and testing. Second section involves software design to control the movement of the robot for the spot welding. The hardware design can be categorized into two aspects i.e. the electrical design and mechanical design. The electrical design involves wiring of control components such as the stepper motor controller, input and output devices as well as the power supply and the safety devices. Finally, the developed algorithm will been tested and implemented into in this Cartesian robot system.

ABSTRAK

Untuk tugasan harian seperti penggerudian, *'laser mark'* atau applikasi kimpalan titik, robot kartesian adalah disuruh untuk mencecah objek pada lokasi tertentu dengan menggunakan tip pada lengannya. Tugasan itu akan menjadi rumit jika ia hendak mengendalikan pelbagai kerja jenis titik pada masa yang singkat dan jarak yang terdekat. Untuk tujuan ini, kajian ini dijalankan dengan matlamat utama untuk menghasilkan sebuah sistem pintar komputasi yang dapat menyumbang kepada peningkatan produktiviti dalam pengendalian dan pemprosesan bahan yang berkualiti. Secara umumnya, objektif kajian adalah untuk merekacipta, membina dan mengoptimumkan prestasi sistem kartesian robot untuk kedudukan dan kelajuannya dalam mengendalikan applikasi kimpalan titik. Algoritma genetik (GA) akan diperkenalkan dan ianya berkeupayaan untuk mengoptimumkan jujukan robot dalam menyelesaikan rancangan pergerakan robot melalui penyelesaian evolusi. GA akan menentukan kombinasi pergerakan yang paling baik demi meminimumkan jumlah masa kimpalan dalam jarak yang terdekat. Algoritma baru ini diuji dan dilaksanakan untuk kartesian robot ini. Penunjuk laser yang menggantikan alat kimpalan titik telah digunakan dalam projek ini untuk tujuan demonstrasi. Projek ini melibatkan pembangunan sistem mesin belajar yang berupaya untuk menunjukkan kebolehan untuk ditugaskan belajar secara tersendiri. Rekacipta dan pembangunan projek ini melibatkan dua bahagian. Bahagian pertama melibatkan pembangunan perkakasan, pendawaian dan ujian. Bahagian kedua melibatkan rekaan perisian untuk mengawal pergerakan paksi robot untuk melakukan kimpalan titik. Rekaan perkakasan dikategorikan kepada dua bahagian iaitu rekabentuk elektrikal dan mekanikal. Rekaan elektrikal melibatkan pendawaian komponen seperti kawalan stepper motor, peranti masukan dan keluaran, sistem bekalan kuasa dan peranti keselamatan. Akhirnya, algoritma yang dibangunkan ini telah diuji dan berjaya dilaksanakan dalam sistem kartesian robot.

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CHAPTER I

INTRODUCTION

1.1 Introduction

A Cartesian coordinate robot is an industrial robot whose one or more principal axes of control are linear. They move in a straight line rather than rotate. Among other advantages is that this mechanical arrangement simplifies the robot control arm solution. Cartesian robots are being widely employed in industrial applications such as automobile spot welding or assembling lines that handle a variety of car models. In order to avoid the risk factor in spot welding application, various steps can be taken. One of the prominent method is by substituting the human hands with the robotic arm in handling these dangerous and hazardous environments.

It is with these reasons that this study was conducted with the primary objective to design and develop a new low-cost, high-efficiency Cartesian robotic arm for application such as spot welding. A new evolutionary computation method using Genetic Algorithm (GA) to control and optimize the system performance in terms of its positioning and speed that would contribute towards encouraging a productive and quality process will be developed. GA operates on populations of candidate controllers, initially selected from some distribution. This population of

candidate controller is repeatedly grown according to crossover, mutation and other GA operators and then culled according to the fitness function.

The competition between different companies regarding price and performance of the Cartesian robot and control system has been the most important motivation. In case of cost saving on robotics equipments, the solution is an alternative. It also to aware national interest in science and technology and this constitutes a prerequisite for an inventive society.

1.2 Problem Statement

The problem can be stated as: Given a Cartesian robot with a spot welding torch (laser head as replacement of torch), a set of known fixed coordinates with the initial and final configurations, find a coordinated motion plan for the laser head from its initial to final configuration and optimizing the overall time taken for the laser head to perform the spot welding.

To give an idea of the complexity of the problem, let's consider a number of n coordination points and one origin points for the laser head to be fixed at positions (x_0, y_0). For this application, the search space is a discrete space and there are ($n!$) permutation scheme of the close routes or path that this robot has to go through. GA will be the search algorithm to find the best or approximate optimization solution for the shortest path and time in this problem.

The above mentioned problem is actually the same as the well-known "Traveling Salesman Problem (TSP)" that of finding the shortest closed tour through a given set of cities visiting each city exactly once. The objective function is the sum of the Euclidian lengths of all edges among the salesman's route. The Euclidean [40] distance between points P ($p_1,p_2,\ldots,p_n$) and Q ($q_1,q_2,\ldots,q_n$) in Euclidean n-space is defined as:

$$\sqrt{(p_1-q_1)^2+(p_2-q_2)^2+\ldots+(p_n-q_n)^2}=\sqrt{\sum_{i=1}^{n}(p_i-q_i)^2} \qquad (1.1)$$

The developed Cartesian robot is scheduled of a route for the spot welder to perform welding on a work piece. In this robotic application, the "cities" are points to weld, and the "cost of travel" includes the time for retooling the robot (single machine job sequencing problem).

Thus, given a set of points C = $\{c_1, c_2, \ldots, c_k\}$, for each pair ($c_i$, c_j), i≠j, let d(c_i, c_j) be the distance between point c_i and c_j. Solving the TSP entails finding a permutation π' of the points ($c_{\pi'(1)},\ldots,c_{\pi'(k)}$), such that

$$\sum_{i=1}^{k} d(c_{\pi'(i)}, c_{\pi'(i+1)}) \le \sum_{i=1}^{k} d(c_{\pi(i)}, c_{\pi(i+1)}) \qquad \forall \pi \neq \pi', (k+1) \equiv 1 \qquad (1.2)$$

The size of the solution space, q is given in equation 1.2 for $n > 2$, where n is the number of points. This is the number of Hamiltonian cycles in a complete graph of n nodes, that is, closed paths that visit all nodes exactly once.

$$q = \frac{1}{2}(n-1)! \qquad (1.3)$$

For a laser head with n number of coordination points, the numbers of possible solutions / routes are $n!$ where n = the number of points are given in Table 1.1. Therefore, an evolutionary solution such as genetic algorithm is introduced to optimize the performance and solve the path planning sequences problem in shortest time.

No. of Points (n)	Number of Solutions
5	120
10	3628800
50	3.04E+64

Table 1.1: Number of possible solutions

1.3 Project Aims and Objectives

The main objective of this project is to design and develop a new low-cost, high efficiency Genetic Algorithm (GA) controller used in Cartesian robotic arm for spot welding application. To achieve this objective, the following works will be carried out during the research period:

1. To design and develop the hardware of the proposed robotic system. This includes both its electrical and mechanical components.
   (a) The electrical components consist of two Parker Compumotor OEM750X micro stepping drive/controller as the main controller, an electrical protection system, a power distribution system, input/output modules, an electro-pneumatic-based Z axis, two stepper motors with encoder feedback system and a laser pointer that will replace the spot welding torch for demonstration purpose in this project.
   (b) The mechanical components of the proposed robotic system consist of two lead screw drive systems for both X and Y axes, a jig and fixture module and a mechanical base.
2. To develop a machine-learning system and program via a new genetic algorithm that is capable of performing the following analysis:
   (a) Reliably and consistently learn and repeat a given tasks.
   (b) Ability to look for the optimum sequences via genetic algorithm evolutionary solutions.
3. To develop a PC-based control simulator for the proposed system using Visual Basic and Microsoft Excel as the database to simulate and evaluate the possible solution for path planning process. Simulation package consists of a graphical user interface (GUI) where it links and directs the flow of the working process. It is a medium to allow interaction between the hardware, GA control system and database. In this simulation package, the input data will be stored and learned in the database. The data from database can be extracted to be processed and executed via the hardware. This simulator is capable to control the I/O module, robot learning module, a manual output trigger module, a home routine and a process module.

1.4 Project Scope

The project scope of the entire computational intelligent robotic system can be illustrated using the diagram as shown in Figure 1.1. The proposed project has the following system features:

- The robot can be taught easily for any required motion. This is known as the machine learning system.
- Incorporating a new genetic algorithm to optimize robot's path planning for performing spot welding process.
- Able to look for the best combination and optimum path solutions.
- Applicable for precise positioning.
- Flexible and user friendly applications in laboratory as well as in industry.
- The machine can adapt to small variations in position, hence increased accuracy and cover a larger working area.

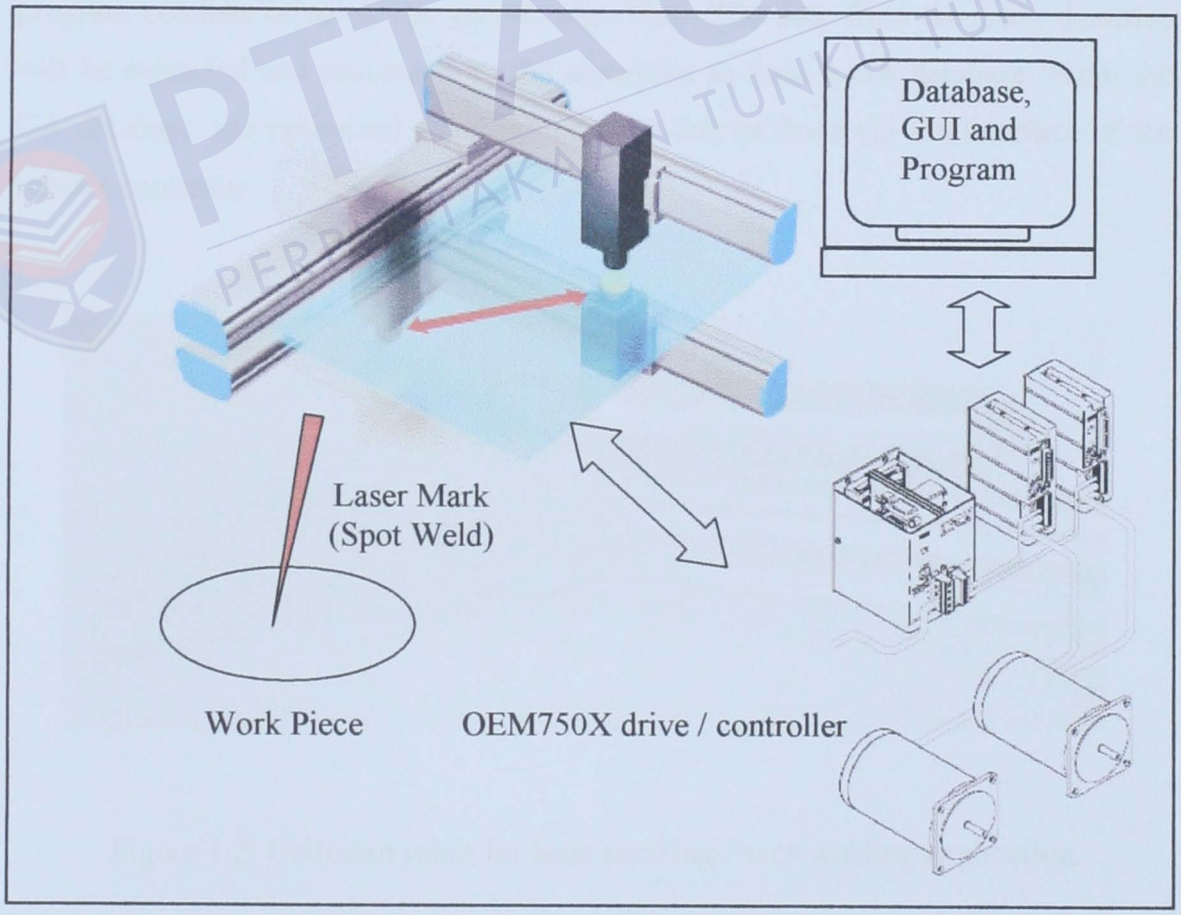

Figure 1.1: A typical genetic algorithm control system for Cartesian robot

1.5 Overview of the Project

The optimization of the spot welding process is the task of finding the best combinational paths for spot welding through a given set of vertices. A method is presented to minimize the total motion time taken for spot welding operation. The method uses a coordination diagram and trajectories planner that can easily be implemented in the Cartesian robot as shown in Figure 1.2.

The development of the control system can be divided into standard spot welding program and an optimization program as illustrated in Figure 1.3. The standard spot welding software consists of a graphical user interface (GUI) where users can input objects data. The program is responsible to learn and store the data into the main database. The data includes vector coordinates and motion parameters such as speed, acceleration, welding delay and stopping delay. The main database can be extracted and used for basic sequential spot welding. The optimization program consists of using the genetic algorithm. The data from the main database will be extracted and processed by the algorithm to form a GA database. From the GA database, the optimized welding operation can be done via the interface of the robot's controller.

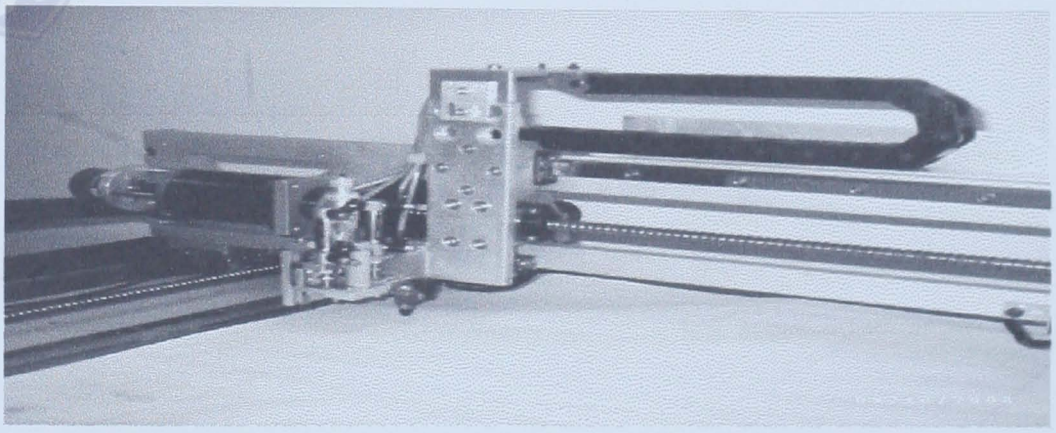

Figure 1.2: Cartesian robot for laser marking / spot welding application

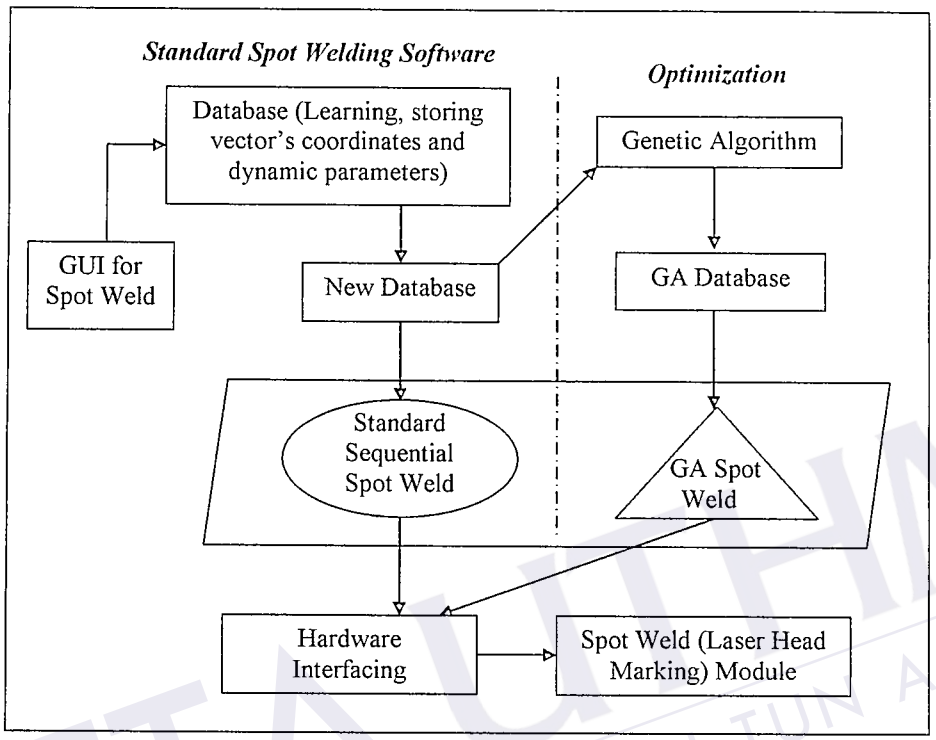

Figure 1.3: Block diagram of genetic algorithm controller for Cartesian robot

1.6 Project Contributions

The following items have been designed and developed for this project.

- A new genetic algorithm controller for Cartesian robot to perform path planning for laser marking / spot welding application. A novel machine control technique via evolutionary solution has been successfully designed and developed.
- Traveling Salesman Problem (TSP) has implemented in this robot for finding the shortest closed path and time through a given set of coordinate points visiting each point exactly once. Using genetic algorithm (GA), a good fitness function has been designed, tested and real time implementation to its control functionality with various types of input configurations.

- A customize user friendly GUI simulator package and control system have been developed to test the genetic algorithm and to run the machine hardware.

1.7 Thesis Layout

This thesis consists of five chapters. In Chapter 1, the importance and demands of robots in industries are discussed. This chapter includes the aims and objectives, and general overview of the project and project's contribution.

Literature reviews of related subjects in this project are summarized in Chapter 2. This chapter reviews the general background on industrial robots, components of a robot, types of robot configurations, drive systems, as well as types of controllers and software. This chapter also reviews the recent development in genetic algorithm as well as other intelligent control techniques such as neural networks, hill climbing algorithm and simulated annealing. Basic genetic operators and control parameters used in connection with such algorithm are also introduced.

Chapter 3 give a detail descriptions on the methodology used in this project. This chapter will provide a better view of how the project was carried out and following integration of the complete system. This chapter explains the development, construction and the implementation of the GA control system to the hardware. The design of electrical, mechanical, electro-pneumatic system and the genetic algorithm optimization method and simulator package are also described in details.

Chapter 4 explains how the analysis and testing techniques are carried out. The system's performance, abilities of the project, the means to improve or optimize using GA and the effect of GA control parameters and operators are also discussed.

The final chapter involves conclusion, recommendations, and future improvement that can be introduced to the system to widen its functionality and usage.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

In order to design and develop this project, knowledge, study and research are the important aspects to be concerned. This chapter is about comparison and selection of the best designing technique. The objective of this chapter is to give an idea and to figure out the solution for the entire problems that will rise during the project development.

2.2 Modern Technology of Robots

A robot is a machine constructed as an assembly of joined links so that they can be articulated into desired positions by a programmable controller and precision actuators to perform a variety of tasks. Robots range from simple devices to very complex and intelligent systems by virtue of added sensors, computer, and special features (Robotics & Automation, 2000).

Generally, a complete robot will consist of an arm, end effectors, actuators, a controller and special peripherals such as sensor, which the robot controller can control or at least exchange information with.

The controller contains almost all the technological advances that have made robots viable. The controller consists of:

- One or more microprocessors as a central processing unit.
- Memory containing programs written by the robot supplier, and with a room for programs and data entered by the end user.
- Input/output devices through which the computer receives and transmits information.

Actuators powered by a particular form of drive systems move the joints of manipulator. Common drive systems used in robotics are hydraulic drive, electric drive and pneumatic drive.

An end effector is defined as the special device that connected to the manipulator's wrist to enable the robot to accomplish a specific task. Because of the wide variations in task that are performed by industrial robots, the end effector must usually be custom engineered and fabricated for a specified job (Groover, 1987). Figure 2.1 below illustrates the possible components of a robot system.

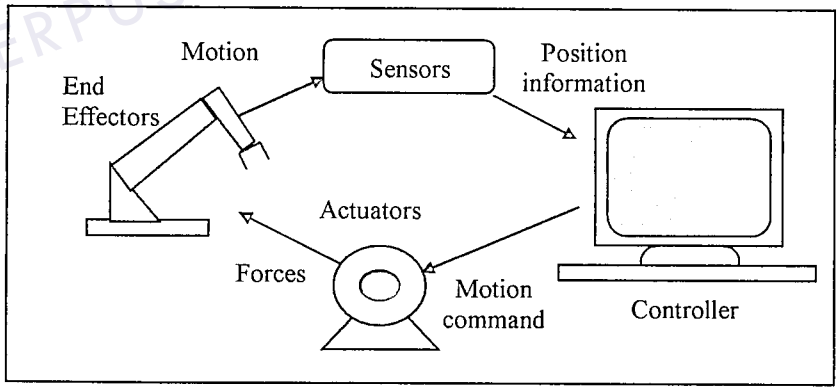

Figure 2.1: Components of a robot system

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