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Optimizing Joint Angles of Robotic Manipulator using genetic Algorithm

F.Y.C. Albert[1], S.P. Koh[2], C.P. Chen[3], S.K.Tiong[4], S.Y.S. Edwin[5+]

Department of Electronic & Communication Engineering
Universiti Tenaga Nasional, Km 7, Jalan Kajang-Puchong
43009 Kajang, Selangor

Abstract. This paper would presents the formulation and application of a genetic algorithm based strategy for the determination of optimizing joint angles in a given search space for 3 armed planar manipulator system that would contribute to a productive and a quality way of material handling and processing. The system would adopt the advantage of Genetic Algorithm (GA) to optimize its performance in terms of path control and accuracy. Once a path is being generated and given as input to the robot, the manipulator's end tip moves along that specified path. The main idea of this paper is to design a continuous path model for the indigenously developed 3 armed planar manipulator during its maneuvering from one point to another point or during pick and place operations in a workspace avoiding all the obstacles in its path of motion. The paper presents simulation results obtained based on the information of the target's position and the manipulator orientation.

Keywords: path control, genetic algorithms, inverse kinematics, manipulator.

1. Introduction

This research is to develop an artificial intelligent 3 armed planar manipulator. This planar manipulator can be used to facilitate various operations undertaken in manufacturing industry. For example, tasks such as assembly of components and flexible material handling operations can be more efficiently carried out using redundant manipulator instead of non-redundant manipulator. Moreover, redundant manipulator robots make manufacturing systems more flexible and these systems become capable of handling more complex operations.

Based on the literature, many researchers have worked to develop theories, algorithms and research being pursued for the important of path control problems. In path planning problems, the number of feasible paths between the initial position and final position of a robot is often very large, and the goal is not necessarily to determine the best solution, but to obtain a good one according to certain requirements and certain constraints. From the literature, various search methods have been developed (e.g., calculus-based methods, enumerative schemes, random search algorithms, etc.) for the robot path-planning problem. Enumerative schemes are not effective when the search space is too large to explore all the paths. Random search algorithms are probabilistically complete, but may take a long time to find a solution. In their study, Pin and Culioli [1] have applied a projected sub gradient algorithm to solve the minimax problem for joint torque distribution optimization, but the run time was long and the result obtained was a local minimum. Chen and Zalzala [2] have applied Genetic Algorithmic approach to multi-criteria motion planning of mobile manipulator systems. Traveling distance and path safety were considered criteria for the mobile robot path planning. The emphasis of the study was placed on using GA to search for global optimal solutions and solve the minimax problem for manipulator torque distribution. Various simulation results from two examples show that the proposed GAs approach performs better than the conventional search methods. Similarly, Sexton and Gupta [3] have carried out comparative evaluation of GA and back-propagation for training neural networks (NNs) for five chaotic time series. Their results show that the GAs is superior to Back-

[+] *E-mail address*: (albert@uniten.edu.my, johnnykoh@uniten.edu.my, chaiphing@uniten.edu.my, siehkiong@uniten.edu.my, edwin@uniten.edu.my).

Propagation in effectiveness, ease-of-use and efficiency for training NNs. For every problem considered, the GA approach was found to provide statistically superior solutions in less CPU time.

A significant amount of research also has been reported regarding to the trajectory planning for redundant degree of motion freedom robot manipulators [4, 5]. However, most of them are based on the analytical methods of inverse kinematics employing a pseudo-inverse of the Jacobian matrix. Doyle and Jones [6] proposed a path-planning scheme that uses GA to search the manipulator configuration space for the optimum path. The result indicated that the GA generates good path solutions. Davidor [7] applied genetic algorithm (GA) to the trajectory generation by searching the inverse kinematics solutions to pre-defined end-effector robot paths. Pires and Machado [8] proposed an evolutionary method which optimizes the robot structure and the required manipulating trajectories. They described how an optimal manipulator minimizes both the path trajectory length and the ripple in the time evolution, without any collision with the obstacles in the workspace. An algorithm containing a genetic algorithm and a pattern search is introduced to design the optimal point-to-point trajectory planning for a planar 3-DOF manipulator. Genetic algorithms have been shown to be effective in solving NP-hard problems, thus they are often used for path planning [9].

In addition, there are number of algorithms, strategies and their variations that are currently being used for solving complex optimization problems. GA has been applied widely in the systems in order to optimize the desired objectives. GA represents one of the artificial intelligence algorithms that are used to improve performance in the systems. GA is a technique for efficiently finding near optimal or approximate solutions relating to optimization and difficult problems through a set of techniques operation which are selection, crossover, and mutation. Such techniques are principles of evolutionary biology applied to computer science.

Furthermore, GA based search and optimization techniques also have recently found increasing use in machine learning, robot motion planning, scheduling, pattern recognition, image sensing and many other engineering applications. This research paper addresses the problem of determining optimal joint angles for a robotic system performing a specified task using GA. GAs have proven their robustness and usefulness over other search techniques because of their unique procedures that differ from other normal search and optimization techniques. The techniques are GAs work with coding of a parameter set, not the parameters themselves and GAs search from a population of points, not a single point. Moreover, GAs use payoff (objective function) information, not derivative or other auxiliary knowledge and GAs use probabilistic transition rules, not deterministic rules.

Various methods of determining the robot trajectory have been proposed and researched in recent years. For example, Monteiro and Madrid [10] have used GA to plan the stages of the trajectory of a robot arm. They have proposed the use of GA to plan a trajectory with obstacle avoidance and implement joint space using classical GA. Pires and Machado [11] have used GA to generate collision free trajectories for robotic manipulators with the objective to minimize the path length and ripple in time evolution of robot positions and velocities. They have used direct kinematics for this purpose and have presented results for several redundant and non-redundant robot manipulators. Watanabe et. al. [12] has described a method for the path planning of an omnidirectional mobile manipulator by applying an evolutionary strategy. Initial and final orientations and arrival time are specified in advance. The approach automatically selects points in a wide range of data points, minimizing or maximizing the total cost function, which consists of several sub-cost functions such as motion smoothness, movable range of joint, singular orientation etc. The points are then used to form a trajectory by fitting in B-spline curve. In their recent paper, Choi et. al. [13] have used GA for trajectory optimization and applied it to biped robots. They have proposed a method to find optimal via-points using GA which minimizes the sum of deviation of velocities and acceleration as well as jerk to obtain continuity on the entire trajectory interval and energy distribution. The continuous velocity and acceleration at the via points ensure a smooth biped walking.

Makino et. al. [14] have proposed the development of a motion planning system which yields an optimal work pass for an autonomous agricultural vehicle in a farm land. Their system consists (make up) of two parts: Global path planning and Local motion planning. The global path planning component works to acquire an optimal work path for the whole field. In this case, the optimal work path is the lowest traveling cost from a start point to a goal point. The local motion planning component acquires the optimal path and plans an optimal control policy in a headland. These components are implemented with simulated annealing, TABU search, GA and reinforcement learning algorithm.

A review of literature shows that various researchers have mainly optimized velocity, acceleration, path length etc. for the determination of optimum trajectory. This research paper proposes a path planning method using GA which searches the manipulator configuration for optimum joint angles.

A planar of three degree of freedom manipulator system has been chosen for this study in order to test the reliability of the proposed algorithm.

2. Problem Formulation

Generally, the initial and target position would be given by the user. The problem is to find the optimum end finger tip value and the optimum joints angles as a function of the goal (wrist position *x, y* and orientation *θ)* for the robot manipulator to reach the final positions.

This would be performing by using the GA to optimize the problem. Let $\{\theta_1, \theta_2, \theta_3\}$ be the joint angles of a 3-link serial manipulator with link lengths $\{L_1, L_2, L_3\}$. The problem consists of locating a specific path that requires the least amount of angle amongst several possible paths. It is evident that the end effector, in moving between any two specified end points, can follow a variety of paths. All such paths require different amounts of angle depending upon the distance covered.

3. Methodology

In this paper, the synthesis of genetic algorithm and inverse kinematics would be implemented. The approach method algorithm is depicted in Figure 1.

The first step is to encode the global angle θ_1, θ_2, θ_3, represented in real number or real coded as strings [15]. After the encoding process, the GA would proceed to initialize a population of solutions randomly, and then improve it through repetitive application of selection, crossover and mutation operators.

The GAs uses a stochastic sampling which is also called the roulette wheel selection method. This sampling method selects parents from the current population according to a spin of a weighted roulette wheel. The fitness function is formulated based on the difference from target object to the end-effector. The value of the fitness function would exponentially reduce if the difference is small. The fitness of the solution is expressed as in equation (1).

Fitness:

$$F = \sum \tag{1}$$

Fitness for Collision:

$$f1 = \begin{cases} N \times 10 & \text{collisions} \\ 0 & \text{no collisions} \end{cases}$$

N = No of via or intermediate point collision

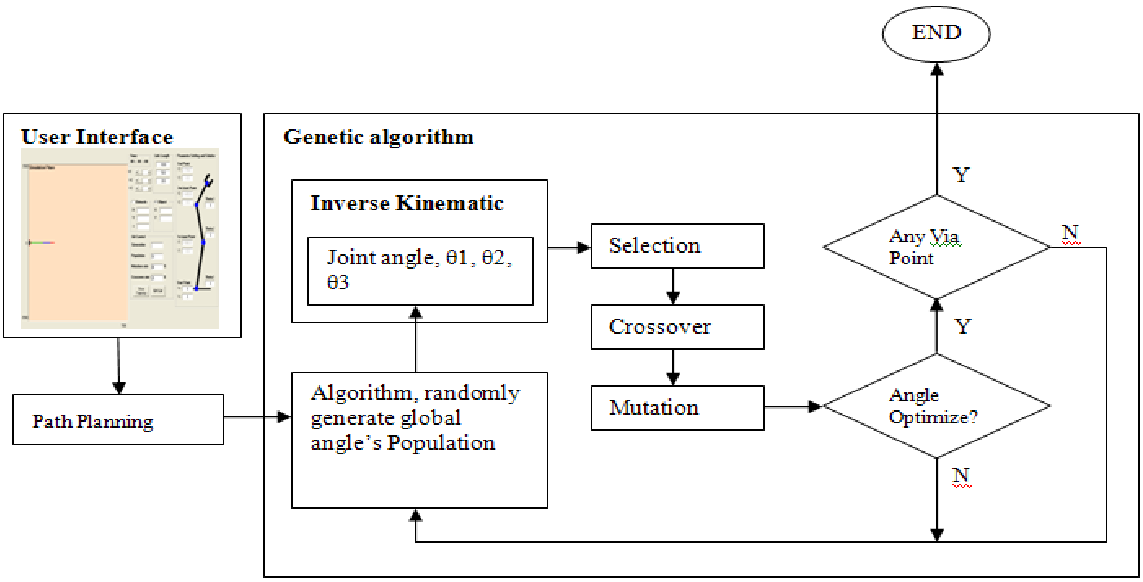

Fig. 1: Block diagram of inverse kinematics and genetic algorithm

Fitness of total angle:

$$f2(\theta) = f1 + \sum_{k=1}^{3} \sum_{m=0}^{n+1} abs(\theta_{k,m} + \theta_{k,m-1}) \tag{2}$$

k = number of link
m = total via point

Total Fitness:

$$F = e^{-\beta(f1 + f2)^{\gamma}} \tag{3}$$

β and γ = control parameter

The parents were selected based on their fitness, where whoever with greater fitness would be most likely to be selected for breeding. The Dynamic Multi-Layered Chromosome Crossover (DMCC) is used in the crossover operation to produce two offspring from the selected two parents. The new proposed crossover operator would be dynamically selecting for two points and would determine operation to produce two offspring from the selected two parents. The new proposed crossover operator would be dynamically selecting for two points and would determine the layers which to be applied with the crossover operation. Every gene that between the two points would be swapped among the parents strings, to create two new offspring. The DMCC operation process is illustrated in Figure 2. For mutation operation, a random gene would be selected to be mutated. The mutation would choose the best string or individual from the populations (parents). This process would change the value of the selected gene from the individual string.

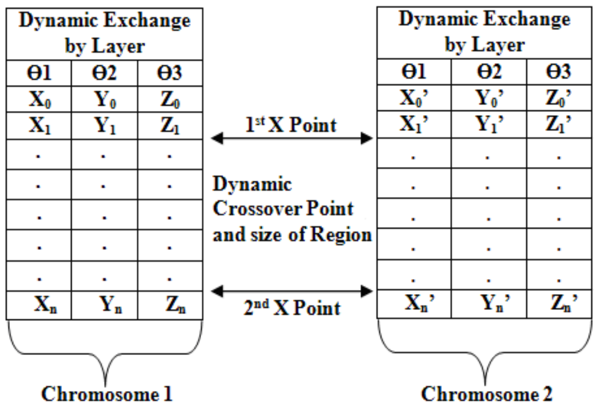

Fig. 2: DMCC operator operation

The fitness of the new breeding generation after the crossover and mutation operations would be evaluated. Consequently, the current good ranked individual would be replaced with the best fitness offspring. This generational process would be done iteratively until the termination condition is met. The process would be terminated if a solution is found that satisfies the minimum criteria that can be either the minimum end point accuracy or the maximum number of generations assigned.

4. Preliminary Result

A GUI simulator package has been developed to evaluate the continuous path planar manipulator, as depicted in Figure 3. It would based on the object target provided by the user and the obstacle contour then generate the specify path in the workspace and try to obtain the unknown joint angles of the manipulator. The simulation has been carried out using the GA parameters as given in Table I and Table II.

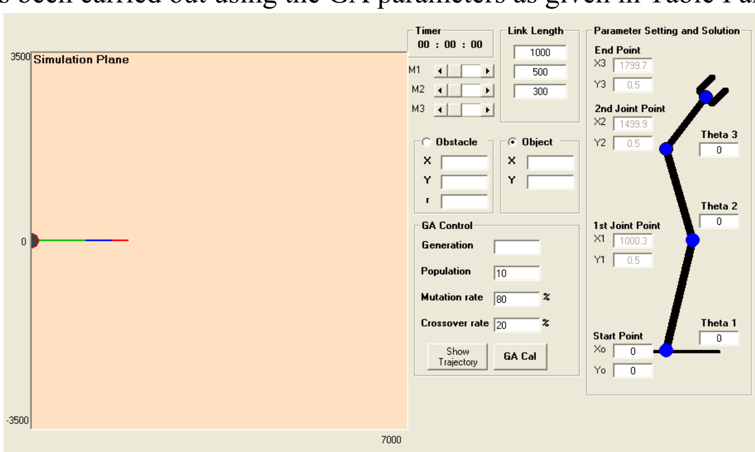

Fig. 3: GUI Simulator package.

TABLE I: GA PARAMETER FOR PATH WITHOUT OBJECT COLLISION

Simulation Parameter	Value
Population, p_o	100
Chromosome length/layer	20/2
Selection Method	Stochastic
Crossover Rate, p_c	80%
Mutation Rate, p_m	5%
Mutation Point, m_p	2
No. of Best Chromosomes Kept, k_b	1
Crossover Type	DMCC

TABLE II: GA PARAMETER FOR PATH WITH OBJECT COLLISION

Simulation Parameter	Value
Population, p_o	100
Chromosome length/layer	20/2
Selection Method	Stochastic
Crossover Rate, p_c	80%
Mutation Rate, p_m	5%
Mutation Point, m_p	2
No. of Best Chromosomes Kept, k_b	1
Crossover Type	DMCC

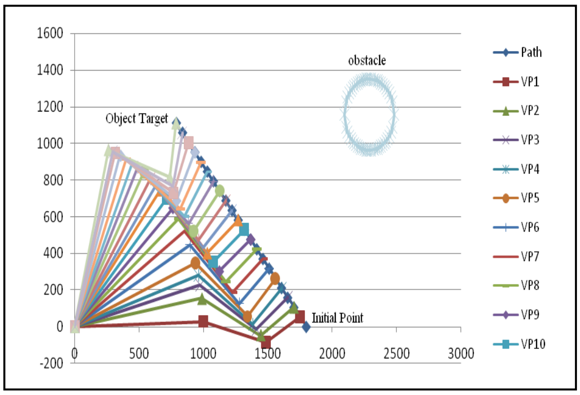

Fig. 4: Simulation for continuous path planar manipulator without obstacle.

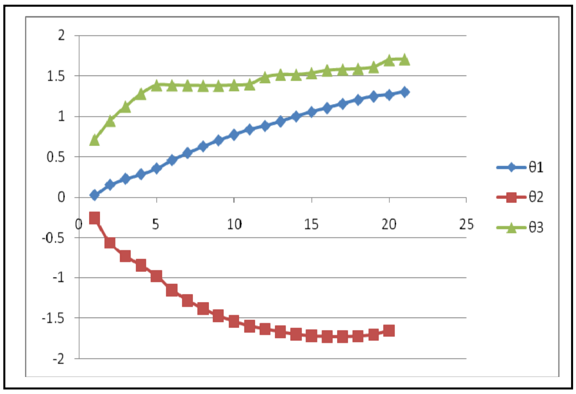

Fig. 5: Joint angle versus via points for continuous path planar manipulator without obstacle.

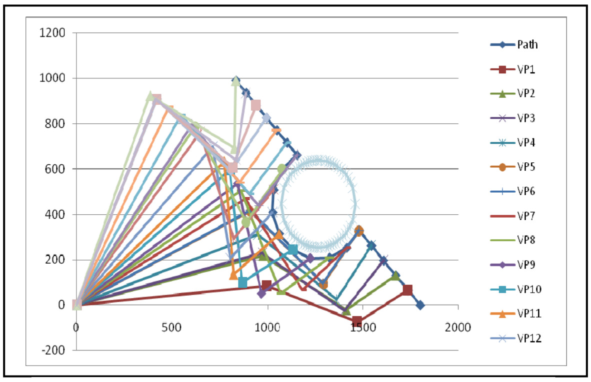

Fig. 6: Simulation for continuous path planar manipulator with obstacle.

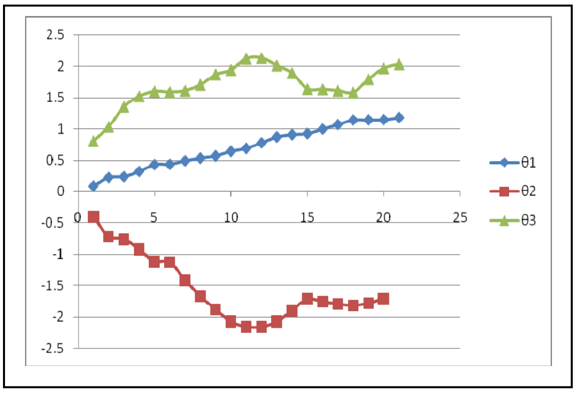

Fig. 7: Joint angle versus via points for continuous path planar manipulator with

From the simulation, the path is continuous and move smoothly from the initial condition to the final condition where the target object is placed, when there is no obstacle or the obstacle is outside the manipulator workspace as depicted in Figure 4. The number of generations required for solving the problem for continuous path planar manipulator without object collision is 500. Figure 6 shows the continuous path planar manipulator with object collision. From the Figure 4 can be observed that, the path is continuous, move smoothly and avoiding the obstacle from collision in the manipulator workspace. The initial condition and the final condition where the target object was placed are same as depicted in Figure 3. The number of generations required for solving the problem for continuous path planar manipulator with object collision is 2000.

5. Conclusion

The proposed algorithm is applicable and useful when dealing with complex path control such as spot welding and laser scanning in automation systems. In this work, a simulator package has been successfully developed to test and evaluate the performance of the planar manipulator. The results indicate that the problem is solved for the system by implementing GA. The proposed method exhibits improved search speed and approximate solution. Future work includes further testing and improving the algorithm for more complex robots, task and incorporating with the real constraints.

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