Path planning optimization for mechatronic systems with the use of genetic algorithm and ant colony

A Tsagaris¹,*, G Mansour²,*

¹Department of Automation, Technological Educational Institution of Thessaloniki, Greece
²Laboratory for Machine Tools and Manufacturing Engineering, Mechanical Engineering Department, Aristoteles University of Thessaloniki, Greece,

Email: tsagaris@autom.teithe.gr, mansour@eng.auth.gr

Abstract. Path planning optimization of mechatronic systems is a very important field of research that has been growing rapidly in recent years. Coordinate measuring machines (CMM), robotic arms, CNC machines, are often using a big amount of points to control the path planning. Within these efforts, some encouraging results are presented in this work on the optimization of path planning. By integrating ant colony techniques into genetic algorithm, path optimization can be reached up to 50% instead of the simple genetic algorithm. At the same time, the calculation of the optimal solution that makes this technique even more efficient is accelerated. From measurements made in a simulation model, reductions in overall trajectories were recorded up to 40% in cases where the number of points exceeded 500 while the optimal path planning time was reduced by up to 20%. In real-system implementation these values are slightly reduced due to the real-time execution of the movements. This integration makes the proposed technique particularly attractive in cases where are path planning between a large number of points and the calculation time is required to be small.

1. Introduction

In the last years the number of systems using path planning has increased in many areas. They are used in industrial applications, in medical applications, in agriculture, transport, etc. In very large scale of applications, path planning optimizations have many uses such as: pick and place objects, assembling, painting and many others.

For the optimization at the last years is a shift from computational optimization algorithms to methodologies based on the modeling of various natural and biological processes inspired by the animal kingdom. Research is focused on stochastic heuristic algorithms inspired by biological, social and natural phenomena, because problems occurring in nature are difficult combining optimization problems. These problems present a large number of local best solutions that make their resolution quite difficult with classical methods. With stochastic heuristic algorithms the finding of optimal solution is through a repetitive process, where through the iteration one or more solutions are created by the algorithm to meet the optimal requirements.

Basic features of algorithms that use nature's phenomena are firstly that they model a social, physical or biological phenomenon, secondly that have a kind of stochasticity using parallel structures that allow the creation of parallel solutions and finally that they are adaptable to the environment in which they operate each time. On the other hand, some drawbacks are that they are stochastic
algorithms which means that they may not find the perfect solution, but an optimal within the given margins. These margins can be time or a set of values. They use evaluation functions that create high computational costs. They usually have a large number of parameters which are important in the evolution of calculations and the optimal solution approach as well as require adequate regulation [1].

The fact that the heuristic algorithms are based on the repeatability of their function creates an additional problem that has to do with the different solutions depending on the initial given conditions. So the same algorithm can give different results depending on the initial conditions. Thus, interventions are often made in the initial conditions of these algorithms to best effect the results. In this research is presented a methodology of a hybrid algorithm that intervenes exactly at this point. A meta-heuristic algorithm (ant colony) is used to optimize the initial conditions of a heuristic algorithm (genetic). The aim is that this combination will lead to the final optimization of the result beyond the results of the application of a simple model of genetic algorithms. The results of the algorithm are implemented with the help of point-to-point simulation programs in the space that is based on robotic systems, CNC machine tools, CMM systems, and mechatronics systems that incorporate path planning. An application like this could be the optimized operation of these systems [2].

2. State of the art

Path planning is applied in many cases both in industry and engineering. Examples of applications include drones, welding machine, robotic vehicles, production and assembly lines and computer technologies [3]. Gasparetto and Zanotto have stated that there is no limitation to the kinematic model of the execution of a path and that the time of the path is determined in advance by means of optimization techniques [4]. On the other hand, the path planning technique proposed by them did not require enforcement. Also, the kinematic model constraints are taken into account in the optimal path planning phase defined by the robot motion before the algorithm is executed [4].

In the work of L. Qu et. al., a method of finding the optimum path of a part measuring with Coordinate Measuring Machine (CMM) is presented. The proposed method is using a genetic algorithm with a greedy selection crossover GSX technique, which reduces the total path of the end effector, resulting in a decrease in the total measurement time [5]. An automated device operate in place away from the coordinate measuring machine (CMM) and uses optimization techniques to affect the operating costs and programming time [6]. Introducing a control model of the points involved in the measurement focuses on a strategy for automatic measurement by correctly combining measurement points and tracking points in a logical sequence. The algorithm selects and processes control points along the measurement path and creates a control program. As far as the test result is concerned, it shows that the generated measurement program meets DMIS and can lead the machine to perform all measuring functions correctly. With this method the measurement times are reduced by about 30% compared to the conventional method [6].

Syed Hammad Mian and Abdulrahman Al-Ahmari present the optimization of the time of measuring one part in a Coordinate Measuring Machine (C.M.M.). In terms of efficacy and time of measurement, a genetic algorithm, a simulated annealing method and a brute force method are used to calculate the optimal measurement sequence of the individual surface-recesses of the piece [7]. Tuncer and Yildirim are using an advanced GA to design robust mobile robot routes through the use of a new mutant operator to avoid inaccessible paths and early convergence [8]. Nakhaeinia and Karasfi proposed a similar project, which develops a behavioral approach. This approach uses intelligent techniques, like fuzzy logic, to make mobile robots avoid collision in unknown and dynamic environments [9]. Hybrid GA is also used to cope with multi-stage path programming. The GA-based approach is a very promising tool for path planning, although its computational efficiency needs to be improved. Taking into account the football robots, Zhang, Lu and Song have developed an artificial field potential algorithm to program the dynamic path in which both targets and obstacles move [10]. To solve the minimal local problem, a simulation annealing algorithm (SA) has been incorporated into the method.
The geometric design of Cartesian spatial robotic arms [11] is presented by Sagris et al, using an algorithm with a hybrid model. This hybrid model integrates a genetic algorithm with a quasi-Newton algorithm and a method of handling constraints. The methodology is implemented in an open loop space robot with three rotating joints. The design parameters focus on the robot base, the robot links and the robot joint angles. The optimal calculated solution places the end-effector of the robot in the preset positions, while avoiding unique configurations. The same optimization algorithm is used in [12] to align the cloud point, without user involvement. A collision avoidance algorithm was used by Gigras and Gupta [13], where an ant colony algorithm was configured to find the optimum path for reaching a destination. Mansour et al. present a CNC expert system that optimizes the machining process by deciding the optimum path. Genetic algorithms are using to optimize the path planning in the shortest possible time. The CNC system is able to select the best path between the possible cutting paths with the use of a CAD product model. The efficiency of CNC machining is greatly improved and the cutting time is reduced [14].

3. Methodology
The aim of this work is the development of a hybrid path planning optimization algorithm. By combining intelligent techniques, an overall optimization is achieved in the movement of systems using spatial mechanisms. The methodology is applied to a number of mechatronics systems, such as robotic arms, CMM machines, CNC machines, which are concentrated on optimizing their path planning. Fields of interests in this paper are optimization of path planning using genetic algorithms and ant colony techniques, comparison of hybrid optimization model with simple genetic algorithm, mapping of the mathematical model of performance of difference of optimization from the use of the hybrid model and the development of graphic simulation modelling, off-line programming and automatic machine code generation for use in robotic arms and CMM metering systems.

Optimization tools explore the ability to develop hybrid algorithms that rely on or combine stochastic optimization methodologies, deterministic methodologies, and search engine optimization methods either at the same time or in combinations of these. Thus, a hybrid algorithm combining a genetic algorithm, an ant colony technique and a method for controlling the boundaries of variables was developed. In its application, it was tested on various problems of robotic arms, where, exploiting the advantages of individual methodologies, it succeeded in identifying optimal solutions to the problems of the path planning both in calculating the shortest path and in optimizing the execution time of the algorithms. Applications have shown that optimized times are also verified in real-world
testing, making this methodology very effective and in real-world orbital guidance systems for mechatronic systems. The proposed methodology is shown in the figure 1.

The initial population for GA is pre-calculated by an ant colony algorithm and help to find an optimal solution. Therefore, GA is more efficiently activated by the ant colony algorithm. This hybrid methodology is based on the GA techniques. Unlike conventional search techniques, GA does not use a single search point, but a population of points called individuals. Each individual represents a possible solution to the problem. In these algorithms, the population is constantly evolving into the best areas of the search space, using techniques such as selection, passage and mutation.

4. Experimental results
Experimental measurements included execution of a Traveler Salesman Problem (TSP) algorithm to find the optimum path between numbers of points. The TSP algorithm was first implemented only with GA, and then implemented using the hybrid algorithm presented above. Thus, the optimization achieved with the use of the hybrid algorithm was calculated. Experimental data was performed in two different cases.

In the first case is used a simulation model developed in a matlab programming environment. Using a different set of parameters, the hybrid and GA were compared. The sets of data included different number of points, population for the genetic algorithm and generations for the Genetic Algorithm. The results are shown below.

Figure 2 shows the percentage of optimization of the hybrid algorithm in relation to the simple GA, for 300 points and 10000 iterations of generations of the genetic algorithm. The calculation time improves to over 5% while the evaluation function is optimised to about 4%. In the case of 300 points and 1000 iterations of genes of the genetic algorithm, the calculation time improves to over 22% while the evaluation function is optimized to about 12%. On the x-axis is showing the number of the population.

![Figure 2. a) Points 300 and 10000 Genes, b) Points 300 and 1000 Genes.](image)

Figure 3 shows the percentage of optimization of the hybrid algorithm in relation to the simple GA, for 700 points and 10000 iterations for the generations of the genetic algorithm. The calculation time is improved to about 18% while the evaluation function is optimized to about 10%. In the second case

![Figure 3. a) Points 700 and 10000 Genes, b) Points 700 and 1000 Genes.](image)
for 700 points of path planning and 1000 iterations for generations of the genetic algorithm, the calculation time is improved to about 26% while the evaluation function is better to about 34%.

Figure 4 shows the percentage of optimization of the hybrid algorithm in relation to the simple GA for 1000 points and 10000 iterations for the generations of the genetic algorithm. The calculation time is improved to about 22% while the evaluation function is optimized to about 15%. In the second case for 1000 points of use of path planning and 1000 iterations related to the generations of the genetic algorithm, the calculation time is improved to about 29% while the evaluation function is optimized to about 47%.

![Figure 4](image)

**Figure 4.** a) Points 1000 and 10000 Genes, b) Points 1000 and 1000 Genes.

In a second phase the hybrid algorithm was applied in real conditions using a CMM machine. In order to evaluate the method in real time, the algorithm was tested on a SCIROCCO-RECORD CMM machine developed by Brown & Sharpe DEA Company. The CMM consisting of three sliding joints and two rotating joints (figure 5).

![Figure 5](image)

**Figure 5.** Brown & Sharpe DEASCIROCCO-RECORD.

The results showed that for 300 points of path planning and 10000 iterations for generations of the genetic algorithm, the CMM execution time is improved to about 5% (compared to 7% of the simulation model) while the evaluation function calculated from software is better to about 4%. In the case of 700 points with 10000 iterations, 25% optimization (compared to 18% of the simulation model) is observed in the actual execution, while with the use of 1000 points and 10000 iterations, the time is optimized by 40% (compared to 22% of the simulation model).

5. **Conclusion**

In this paper a hybrid path-optimization algorithm combining ant-colony with genetic algorithm is presented. The ant colony prepares the initial GA population and provides it with GA to start with
optimized initial population. The final performance of the model, with the appropriate parameterization, gives optimal path planning results. Testing of the algorithm was done in solving the classic TSP problem. From measurements made using simulation model, it was observed that as the number of points used is increased and the number of GA repeats decreases, both the optimization rate of execution time and fitness function for the distance calculation are increased. This means that the hybrid algorithm is ideal for cases where many points are for identification and the results must be the optimum in short time. The experimental measurements have shown that the path planning optimization can be reached up to 50% instead of the simple genetic algorithm. At the same time, the calculation of the optimal solution that makes this technique even more efficient is accelerated. From measurements made in a simulation model, reductions in overall trajectories were recorded up to 40% in cases where the number of points exceeded 500 while optimal path planning time was reduced by up to 20%.

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