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Optimize Path Planning for Medical Robot in Iraqi Hospitals

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Abstract

This paper presents a study for optimal performance of a robot to be used in human surgery (Laparoscope device). He was done in Al-Sader educational hospital in maysan Governorate. The robot was manufactured by Karel Storez company. Connecting linkages were increased to get seven degrees of freedom.

The optimal performance was obtained by using genetic algorithm method to choose the optimal path planning in the working area, this was done by making an integrated computer program through MATLAB language (R2013a).The results of best path planning would shorten length without hitting any obstacle, assuming the surrounding environment will be variable, the position and obstacle shapes would be random. We found that the best path planning in every environment depends on objective function. The practical side was made in laboratory of the Research Unit of Automation and Robotics in the Control and Systems Engineering Department, University of Technology. The robot used was the Lab-Volt Servo Robot System Model 5250 (RoboCIM5250).

Keywords: Laparoscope , Path Planning, Optimization method.

المسار ألأمثل للإنسان ألآلي ألمستخدم في الأغراضِ الطبيةِ في ألمستشفيات ألعراقية

الخلاصة

تناولت هذه الرسالة دراسة تصميم امثل لموديل مختار للإنسان الآلي المستخدم في مجال الجراحة البشرية (جهاز التنظير البطني الجراحي) المستخدم في مستشفى الصدر التعليمي في محافظة ميسان و المصنع من قبل شركة (KAREL STOREZ) من خلال زيادة عدد درجات الحرية لتصل سبعة درجات الحرية.

تم الحصول على اداء امثل وذلك باستخدام طريقة الخوارزمية الجينية لأختار المسار الأمثل في مجال العمل المحدد وبوجود العوائق أمام حركة Tip of End-effectorالموجودة في الذراع الميكانيكي للموديل الجديد الذي استخدم في هذه الرسالة وتم ذلك بإنشاء برنامج حاسوبي متكامل عن طريق لغة (MATLAB R2013a) وكان الحصول على أفضل مسار والذي يكون الأقصر طولا وبدون الاصطدام بأي عائق وتم الافتراض أن البيئة المحيطة تكون متغيرة وكذلك مواقع و أشكال العوائق بحيث تكون عشوائية, فقد تم الحصول على أفضل مسار في كل بيئة بالاعتماد على (Objective Function). وتم اجراء الجانب العملي في مختبر وحدة الانسان الآلي والاتمتة في قسم هندسة السيطرة والنظم / الجامعة التكنولوجية وكان الروبوت المستخدم هو The Lab-Volt Servo Robot System Model 5250(RoboCIM5250)

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INTRODUCTION

Minimally invasive surgery (MIS) or laparoscopy typically involves the use of special surgical instruments with an observation of the surgical field through an endoscope,[1]. Path planning can be defined as “the determination of a path that a robot must take in order to pass over each point in an environment,[2]. Genetic Algorithm was applied to provide optimal path and select the shortest path in predictable environment which will be able to handle static obstacles. **Gonchar,etal (2000) [3]**, used simulations in path planning and motion control for medical robot with six degrees of freedom (DOF), determining the optimum or near optimum configuration of the robot manipulator. Louaï, et al (2003) [4],investigated a two-step strategy to optimize the most critical settings of an Robot-assisted Minimally Invasive Surgery (RMIS). The first step relies on a patient-dependent modeling of the intervention by the surgeon that is transformed into an optimization problem where criteria such as visibility and dexterity. The second one, referred to as the pose planning problem, aims at guaranteeing a collision-free operation of the robot throughout the intervention by properly assigning stationary extra flexibility at the beginning of the intervention. Wael (2013)[5],studied the effect of trajectory planning method duration time on correct dynamic response selection of six degrees of freedom micro-robot intended for surgery applications using two different methods of trajectory planning with different four duration times (5, 10, 20 and 60 sec). The kinematic equations of motion were obtained using Denavit-Hartemberg parameters representation.

The main objectives of the work are the experimental and theoretical investigations to: identify the sequences of steps and type of methods necessary to implement a path planning for medical robot (Laparoscope).Seven degrees of freedom are achieved by using Genetic Algorithm method (GA) to give the optimal path planning when moving the manipulator from initial point to goal point according to a given workspace.

Model of The Surgical Robot (Laparoscopic Surgery)

Taken the surgical robot (Laparoscopic Surgery) in Iraq hospitals in AL SADER education hospital in MYSAN governorate made by KAREL STOREZ company, all the details of laparoscopic surgery system shown clear in Figures (1) and the information given in Table (1).

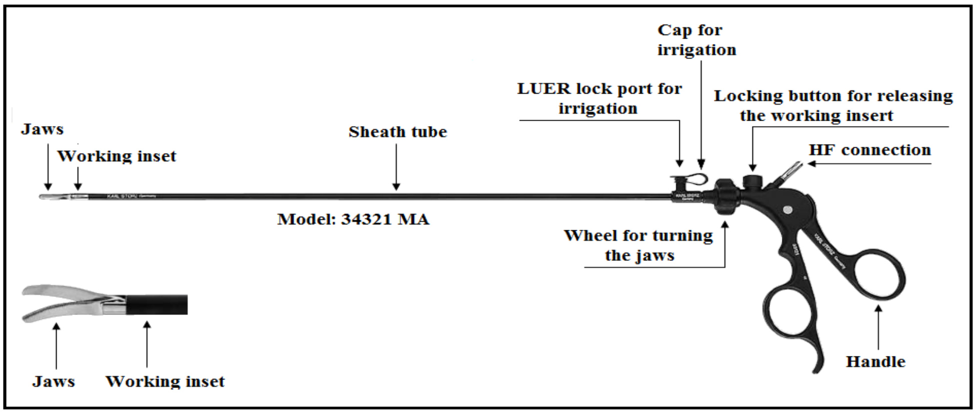


Figure (1) The laparoscope in Al Sader Education Hospital,

Size 5 mm, Length36 cm [6].

Table (1) Laparoscopic Forceps - KARL STORZ,Model34321 MA,[7].

Product Name	Description
KAREL STOREZ Design Handle	rotating, dismantling, insulated, with connector pin for unipolar coagulation, length of jaws 20 mm, serrated, spoon-shaped jaws, curved, size 5 mm, length 36 cm
Three Parts Dismentle Structure	-
Types of Jaws	Many types for different operation function for customer demand
Size Diameter	3.5mm, 5mm, 10mm
Working Length	360mm , 400mm , 450mm
Materials	Stainless steel for shaft, Plastic for knob and handle
Plug for LUER-Lock	connector for cleaning, black, autoclavable

Kinematics Analysis of Surgical Robot(Laparoscopic)

The surgical robot under consideration has seven DOF and a redundant one for tool replacement. The end effector has 3 rotations Roll, Pitch and Yaw as shown in Figure (2). The kinematics analysis for the robot is performed using the Denavit-Hartenberg representation. A schematic diagram assigning all the joint axes is represented in Figure (3).

The seven DOF manipulator kinematic parameters are derived using Denavit-Hartemberg formulation shown in Table (2).

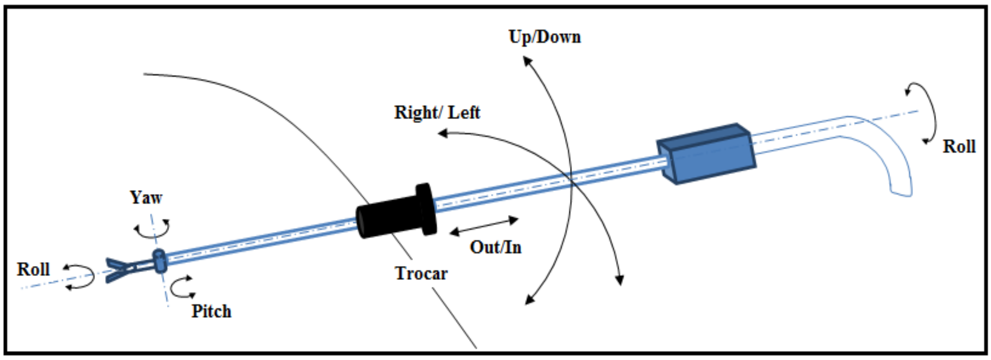


Figure (2) A Simulated Laparoscopic with a Seven Degrees of Freedom

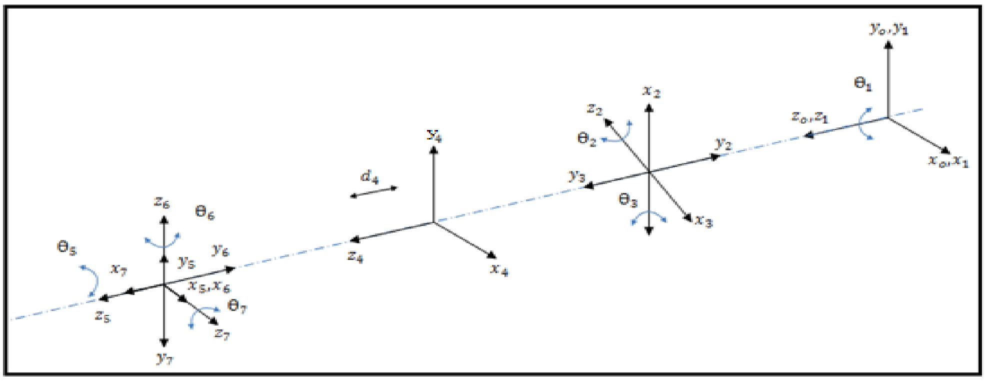


Figure (3) All Frames of Manipulator

Table (2): Denavit-Hartenberg Parameters

i	**α_{i-1}**	**a_{i-1}**	**di**	**θi**
1	0	0	0	θ_1
2	-90	0	L_1	θ_2
3	180	0	0	θ_3
4	-90	0	L_1-d_4	0
5	0	0	L_3	θ_3
6	-90	0	0	θ_6
7	-90	0	0	θ_7

Forward Kinematics

In the forward kinematics for a robot mechanism (laparoscope) in a systematic manner, one should use a suitable kinematic model.

$$ {}^0_1T=\begin{bmatrix} c\theta_1 & -s\theta_1 & 0 & 0 \\ s\theta_1 & c\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad ;{}^1_2T=\begin{bmatrix} c\theta_2 & -s\theta_2 & 0 & 0 \\ 0 & 0 & 1 & l_1 \\ -s\theta_2 & -c\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^2_3T=\begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & 0 \\ -s\theta_3 & -c\theta_3 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad ;{}^3_4T=\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & l_2-d_4 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^4_5T=\begin{bmatrix} c\theta_5 & -s\theta_5 & 0 & 0 \\ s\theta_5 & c\theta_5 & 0 & 0 \\ 0 & 0 & 1 & l_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad ;{}^5_6T=\begin{bmatrix} c\theta_6 & -s\theta_6 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -s\theta_6 & -c\theta_6 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^6_7T=\begin{bmatrix} c\theta_7 & -s\theta_7 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -s\theta_7 & -c\theta_7 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

The forward kinematics are from the base, Frame(0) to the tip of end- effector frame (7) .

$$ {}^{base}_{end-effector}T={}^0_7T={}^0_1T\,{}^1_2T\,{}^2_3T\,{}^3_4T\,{}^4_5T\,{}^5_6T\,{}^6_7T $$

$$ {}^0_7T=\begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

p_x = $-s_3$ (L_3 +L_2 –d_4) …..(1)

p_y = $-c_3$ $(L_3 + L_2 - d_4)$ …..(2)

$p_z = 0$ …..(3)

Inverse Kinematics

In this paper using Algebraic solution approach was used. That is to determine the value of angles and distance (d_4).

$${}^{0}_{7}T={}^{0}_{1}T\,{}^{1}_{2}T\,{}^{2}_{3}T\,{}^{3}_{4}T\,{}^{4}_{5}T\,{}^{5}_{6}T\,{}^{6}_{7}T$$

$$[{}^{0}_{1}T\,{}^{1}_{2}T\,]^{-1}\,{}^{0}_{7}T={}^{2}_{3}T\,{}^{3}_{4}T\,{}^{4}_{5}T\,{}^{5}_{6}T\,{}^{6}_{7}T$$

$$\theta_1 = A\ \tan2\ (-p_x, p_y) \pm (A\ \tan2\ (\sqrt{p_x^2 + p_y^2 - L_1^2}, L_1) \quad …..(4)$$

$$\theta_2 = A\ \tan2\ (A, B) \pm (A\ \tan2\ (\sqrt{A^2 + B^2 - C^2}, C) \quad …..(5)$$

$$\theta_{13} = A\ \tan2\ (-p_x, -p_y) \pm (A\ \tan2\ (\sqrt{p_x^2 + p_y^2 - L_1^2}, L_1)$$

$$\theta_3 = \theta_{13} - \theta_1$$

$$d_4 = [L_3 + L_2 - (c_1^2 p_x^2 + 2c_1 p_x p_y s_1 + s_1^2 p_y^2 + p_z^2]^{1/2} \quad …..(6)$$

$$c_5 = \frac{-c_1 c_{23} r_{13} + c_2 s_{13} r_{23} + s_2 s_{33}}{s_6}$$

$$\theta_5 = A\ \tan2\ (\sqrt{1 - {c_5}^2}, c_5) \quad …..(7)$$

$$-s_2 c_{13} r_{13} + s_2 s_{13} r_{23} + c_2 r_{33} = -c_6$$

$$\theta_6 = A\ \tan2\ (\pm\sqrt{1 - {c_6}^2}, -c_6) \quad …..(8)$$

$$s_7 = \frac{-s_2 c_{13} r_{12} + s_2 s_{13} r_{22} + c_2 r_{32}}{s_6} = C$$

$$c_7 = \sqrt{1 - C^2}$$

$$\theta_7 = A\ \tan2\ (\sqrt{1 - {c_7}^2}, c_7) \quad …..(9)$$

Optimization Path Planning

Optimization problem is defined as values of the variables that minimize the objective function while satisfying the constraints. The optimization problems are centered with three factors: an objective function (which is to be minimized or maximized), a set of unknown or variables that affect the objective function,[8].

Optimization Path Planning Based Genetic Algorithm

Genetic Algorithms intuitively use randomness to generate a solution in a more intelligent manner than the probabilistic road map method and faster than another path planning methods,[9]. The strength of this method is that it allows to explore and exploit the best solutions by two operators, which are selection and genetic reproduction [10].

Figure (4) depicts a framework to represent Path Planning. As shown, a model of the map of robot workspace area including the location of robot, obstacles and free space area known as configuration space, must first be created. In configuration space, all possible configurations of robot a represented. Then, the configuration space will be modeled by defining the free space area to construct a graph that represents the connectivity of the space. This graph is constructed by using an appropriate algorithm that presents the connectivity of the graph which also known as graph search optimal path using GA. Finally, the Path Planning algorithm is applied with in this graph to find a feasible path for the robot to reach the goal.

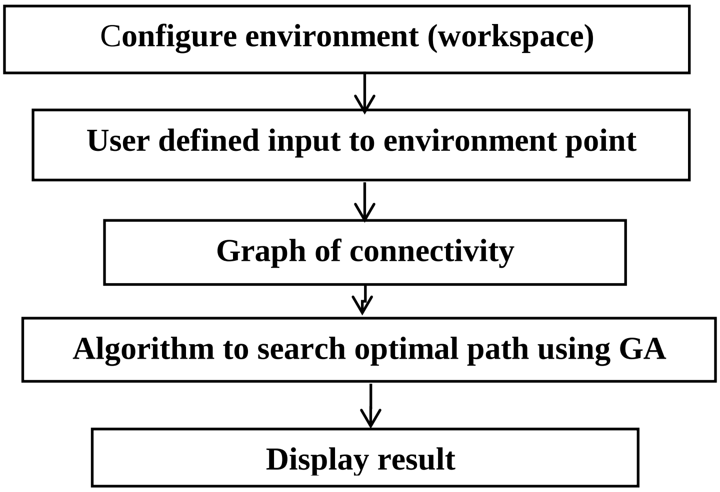


Figure (4) The Framework To Find Optimal Path

Genetic Representation

This section explains the details of the internal structure of the GA and describes its implementation which is represented in the flowchart of GA Figure (5). To evaluate the operation of GA the performance of the following parameters must be calculated:

Initialization

We must create an initial population with a predefined population size. The population contains number of individuals (i.e., chromosomes).

Fitness Function

The fitness function will lead the search towards the optimal solution. The optimal path is the shortest path between the starting and goal point, the fitness function is responsible on finding this path, [2]. The length of the feasible path is compute as shown in Equation (10).

$$r_{(i)} = \sqrt{(x_{(i+1)} - x_{(i)})^2 + (y_{(i+1)} - y_{(i)})^2} \qquad \text{…..(10)}$$

The shortest path helps computing the total number of steps the robot need to take until reaching the end point. The objective function of the overall path can be expressed as shown in Equation (11).

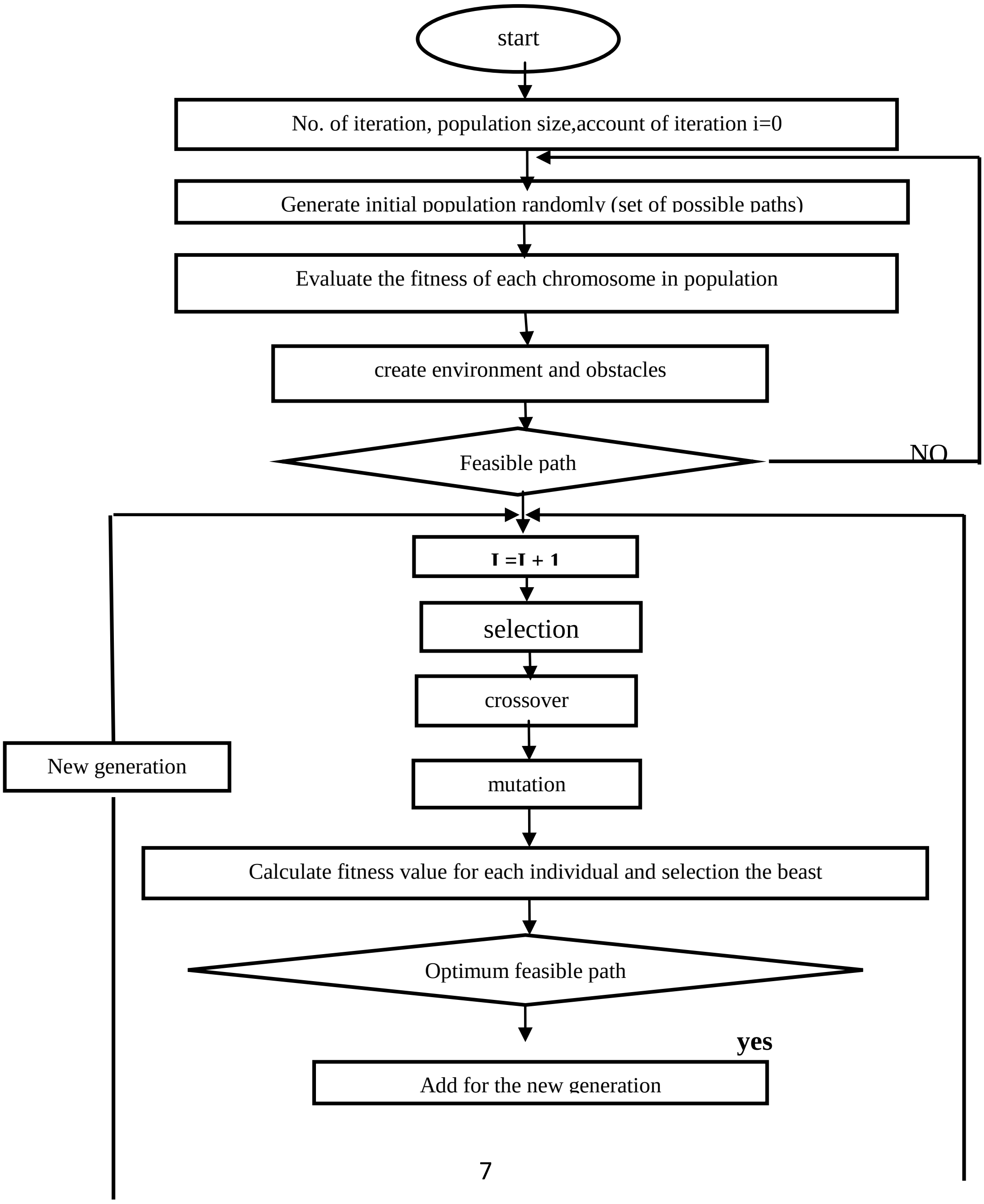
$$r_{total} = \sum_{i=1}^{n} r_{(i)} \qquad \ldots..(11)$$

Where:

n is the number of points on the path from start point to goal point, $\boldsymbol{r}_{(i)}$ is the distance between two points, $x_{(i)}$ and $y_{(i)}$are robot's current horizontal and vertical positionsrespectively,$x_{(i+1)}$ and $y_{(i+1)}$ are robot's next horizontal and vertical positions. The fitness function (F) is the inverse of the total distance which is Euclidean distance.

The Euclidean distance between starting and goal point is the length of the line segment connecting them. The fitness function used in this study is:

$$F = \frac{1}{r_{total}} \qquad \ldots..(12)$$



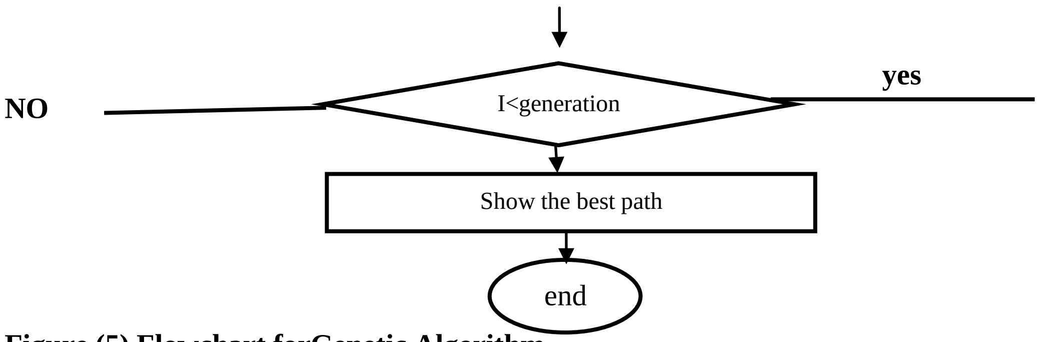


Figure (5) Flowchart forGenetic Algorithm

(iii) Environment

Boundaries for obstacles area are formed by their actual boundaries plus a safety distance that is defined with consideration to the size of the robot. The obstacles are putting randomly but carefully placed such that they keep some distance from the starting point and the goal point to make sure that the robot has some space to move in the begging.

(iv)Selection Process

Selection is the stage of a genetic algorithm in which individual genomes are chosen from a population for later breeding (recombination or crossover). We used elitism method which biased random selection procedure based on fitness.

(v) Crossover Operator

To better explore potential solutions GAs was employed a crossover operator, which mimics the reproduction process. The crossover techniques used here is single point crossover and the crossover.

(vi) Mutation

After a crossover is performed, mutation take place. This is to prevent falling all solutions in population into a local optimum of solved problem. Typically mutation will involve swapping two randomly selected bits in a chromosome.

(vii) Generation Algorithm

Generation algorithm is used to increase the population and help to prevent the stagnating at local optima. Then the new generated population must be checked for infeasibility. If the number of generated path is still insufficient a new population is generated. This process is repeated over again until the desired number of feasible path is reached.

Experimental Work and Procedure

The implementation and applying of optimization path planning using program of genetic algorithm must be applied experimentally to provide guarantee for the robot motion, from the optimal path and pass through the way point and parameters values which contain lengths and angles for each robot joints. These values that obtained from experimental work will be the optimum parameters for this robot. In this study the experimental work will be applied on the Lab-Volt RoboCIM shown in Figure (6).

Figure (6)The Lab-Volt Servo Robot SystemModel 5250(RoboCIM5250)

The Lab-Volt RoboCIM software is used to simulate and control the operation of the Servo Robot and external devices, and create programs.

- RoboCIM workspace is created and adjusted the dimension of work space and change robot position Figure (7) and Figure (8).
- The start and goal points are determined and the free points in the environment of robot are defined, Figure (9).
- An obstacle is added to the workspace by giving the limitations of these obstacles.
- The program of robot motion using is created and run either in the text programming mode or the icon programming mode.

Icon program: allows you to create and run simple task programs, with the aid of icons and graphical tools (no typewriting required).

Text program: allows you to create and run simple and complex task programs, by typewriting all necessary commands Figure (10).

- Then the real system is connected.

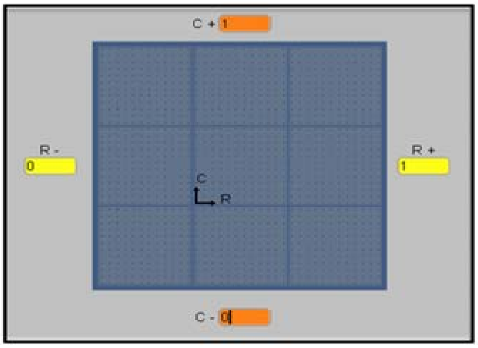
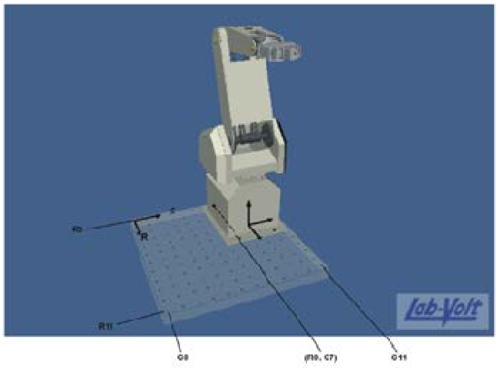
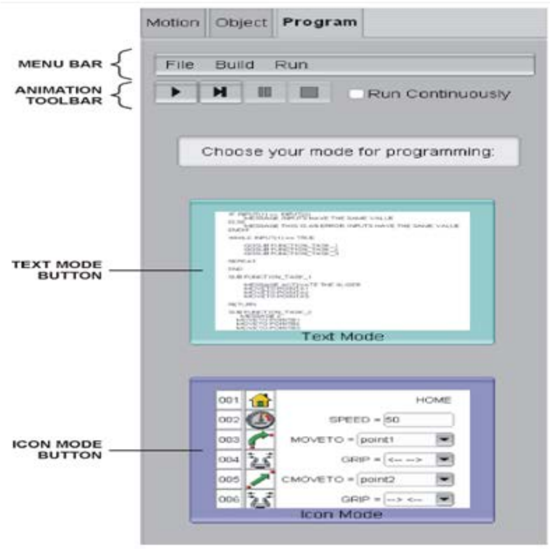

C + 1
R - 0
R + 1
C - 0

Figure (7) Setting the Work Surfaces of Robot.



Figure(8) Change Robot Position in the Work Space.



001 HOME
002 SPEED = 50
003 MOVETO = point1
004 GRIP = <-- -->
005 CMOVETO = point2
006 GRIP = --> <--

Figure (9) Preface Program of Robot

Figure (10) The RoboCIM5250 Connected with Components

Genetic Algorithm Program Results and Discussions

The first environment: Table (3), shows the computed results using Genetic Algorithm (GA) with various generations. The best distance value was achieved after each run and the generation number where this value was found. The program results of the Genetic Algorithm(GA)show that shortest generated path (distance) with the length of (24.21) at generation (60) as shown in Figure (11).Figure (12) shows the increasing in the number of generation gives the shortest path with the same number of population size and gives less distance of path.

Table (3) Program Results For The First Working Environment Using (GA)With Population Size 100.

Exp.	Generation No.	Distance
1	20	33.49
2	25	30.46
3	35	24.44
4	40	24.29
5	50	24.22
6	60	24.21

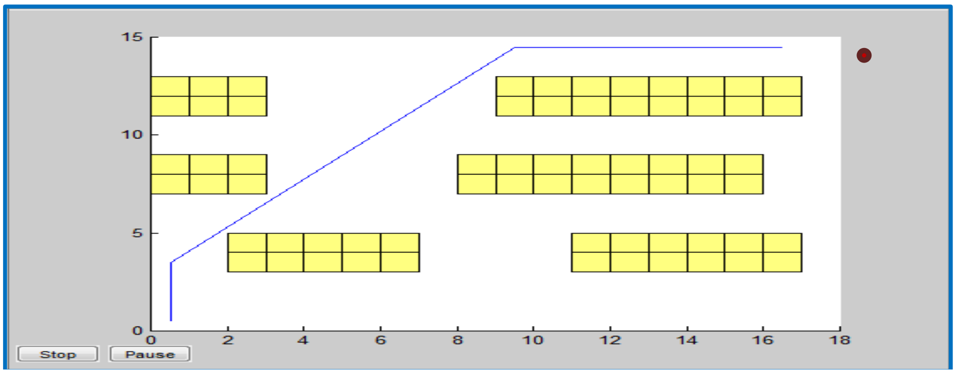


Figure (11) Feasible Path For The First Working Environment Using GA(60 Iterations)

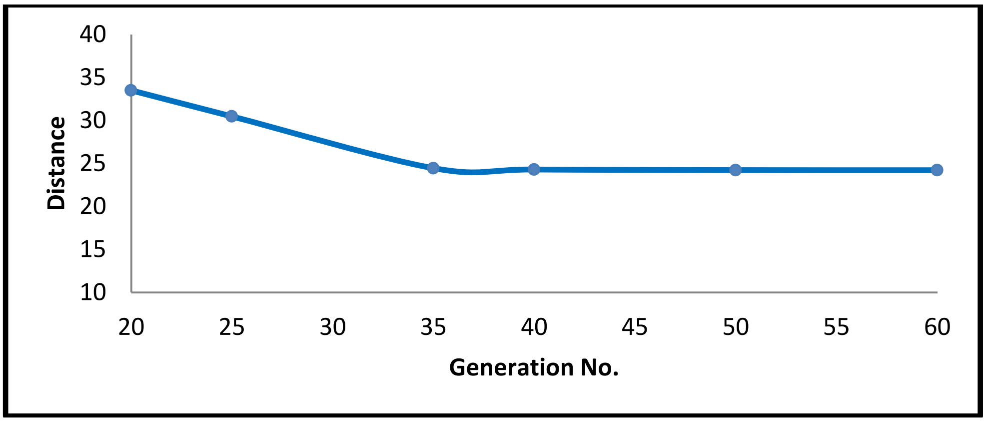


Figure (12) Convergence Process For GAwith The Environment

The second environment: The position, shapes and number of obstacles are shown in Figures (13) to (18). The program results show that shortest generated path of the second environment is (22.52) with generation (400)see Table (4) and Figure (18). It was found the program can be successful in both simple or complex environment but in complex environment the number of generation will be increased to obtain the optimal path with the same number of population size for each case.

Table (4) Program Results For The Moderate Working Environment Using GA With Population Size 100.

Exp #	Generation No.	Distance
1	25	33.17
2	100	25.24
3	150	24.28
4	200	23.25
5	300	22.65
6	400	22.52

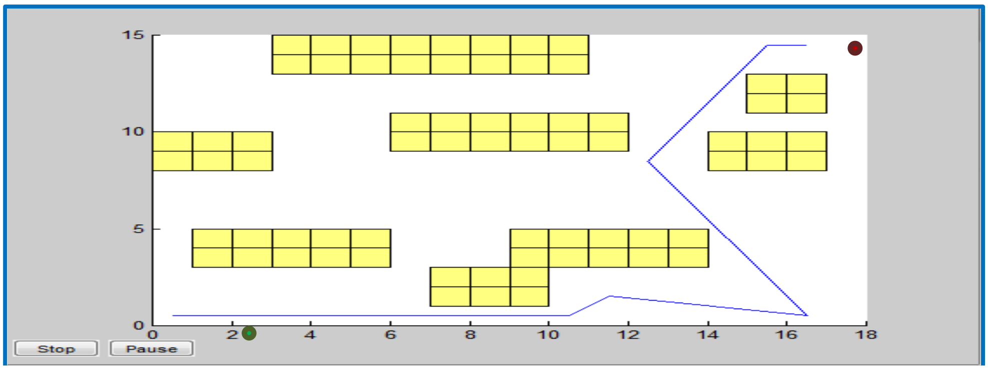


Figure (13) Feasible Path For The Moderate Working Environment Using GA(25 Iterations)

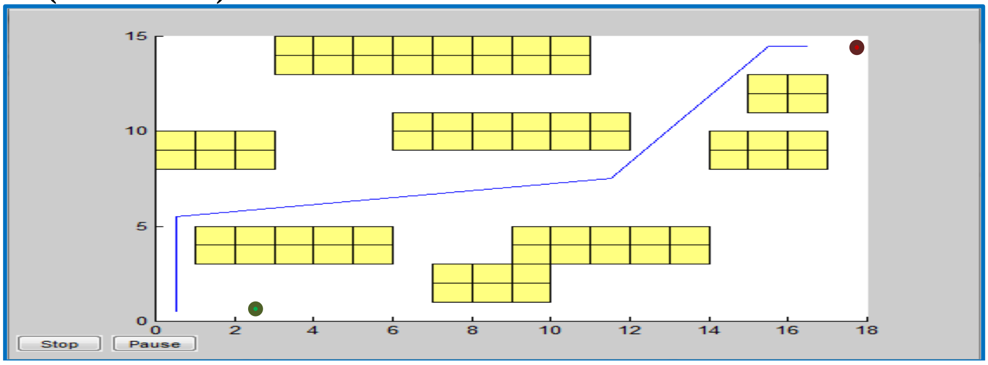


Figure (14) Feasible Path For The Moderate WorkingEnvironment Using GA(20 Iterations)

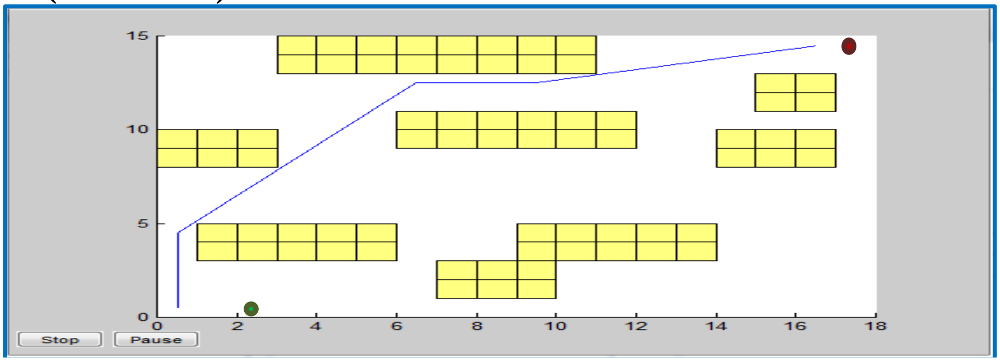


Figure (15) Feasible Path For The Moderate Working Environment Using GA(100 Iterations)

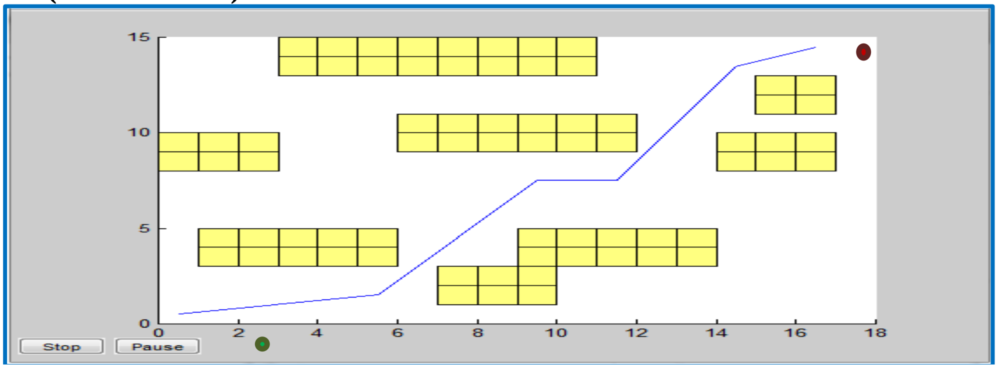


Figure (16) Feasible Path For The Moderate WorkingEnvironment Using GA(150 Iterations)

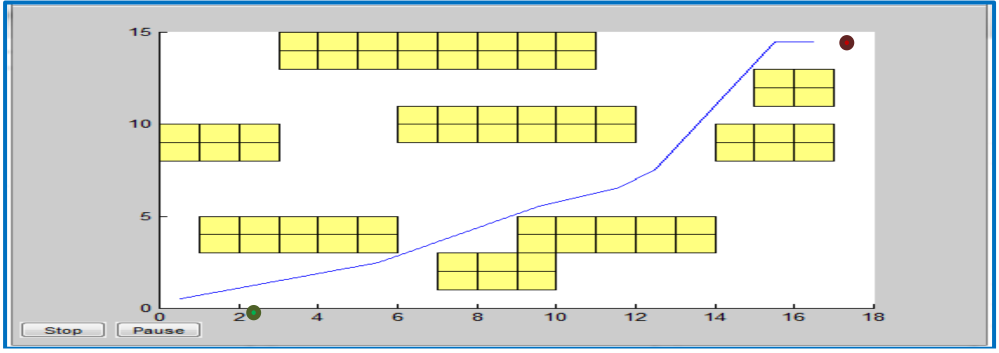


Figure (17) Feasible Path For The Moderate Working Environment Using GA(300 Iterations)

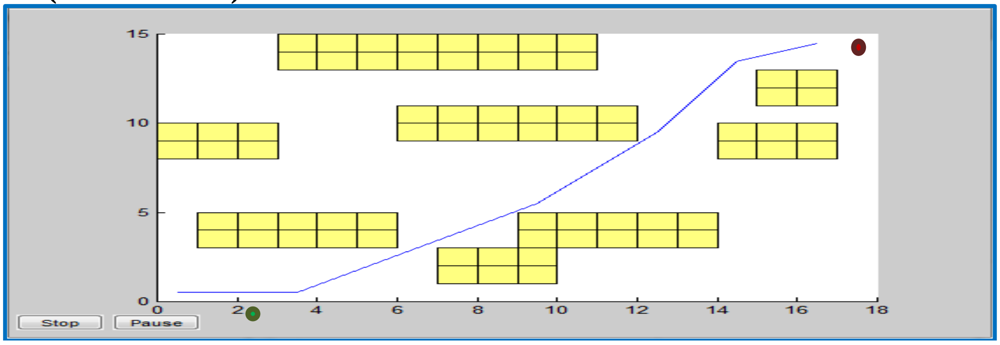


Figure (18) Feasible Path For The Moderate Working Environment Using GA(400 Iterations)

Experimental Results and Discussions

After the optimal results are obtained and entered the results on the robot software and simulationruns then connected practically. By applying the experimental procedure; the optimal parameters of robot are presented.

The optimization results of coordinates for robot in each position points are shown in tables (5) to (6):

Table (5) The Optimization Values of Cartesian Coordinates For Robot At Each Point. (All Unites In mm)

Point	x-value	y-value	z-value	Pitch	Roll
1	1.5	-280	47.5	-180	-179.69
2	41.5	-225	47.5	-180	-169.55
3	146.5	-170	47.5	-180	-139.25
4	256.5	105	47.5	180	-67.74

Table (6) The Optimization Values of Articular Coordinates For Robot At Each Point. (All Unites In Degrees)

Point	Base	Shoulder	Elbow	Wrist Pitch	Wrist Roll
1	-89.69	6.63	-117.62	110.98	0.31
2	-79.55	1.98	-128.32	126.34	10.45
3	-49.25	1.45	-129.2	127.75	40.75

4	22.26	6.45	-118.23	111.79	112.26

Conclusions

The conclusions that are extracted from the present study are as following:

1. In this study we presented the idea of using Genetic Algorithm (GA) approach to solve the optimization path planning problem in environment with variable number of generation. This idea shows that the proposed approach is effective and efficient in handling different types of tasks environments.
2. Genetic Algorithm (GA) will determine the way point accurately. It can help to choose the near points or the optimal points and ignore unfeasible points. This technique of Genetic Algorithm (GA) gives the unique optimal path.
3. We proposed a simplified fitness function which utilizes the path length.
4. We explored the performance of the evolutionary process with various number of generations.
5. We increased the number of generation to obtain a shortest and smoother path that is safer in both types of environments.
6. With increasing the complexity of the environment the number of generation must be increased with fixed population size.

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