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A Bezier Curve Based Free Collision Path Planning of an Articulated Robot

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ABSTRACT

The main objective of this paper is to find a path for the robot arm from its given start point to its desired goal point in an automated manner without collision with the obstacles. This paper investigates the problem of path planning for a 5 axis robot, operating in environment with obstacles whose boundaries are enveloped by cubic shape. The path planning approach presented is developed in the robot joint space and consists of three steps. The first step is to used Bezier curve technique , the second step is to generate a sufficient number of intermediate points in Cartesian space along Bezier curve and the third step is to convert the coordinate of the generated intermediate points from it's Cartesian space into joint space and move the robot arm along the free collision generated path.

This work is not limited to theoretical studies or simulations, experiments have been run with various tests, on a LabVolt R5150 robot to assess the real efficiency and usability of the adopted method. The method applies to robots in a fixed and known environment. A number of experiments were carried out to test the ability of the robot arm to reach it's goal without collision. Experiment results verify the effectiveness of the method developed in this paper.

Keywords: Free collision path planning, Articulated robot, Bezier curves, Joint space

اعتماد مفهوم منحنى بيزر لتخطيط مسار خال من الاصطدام بالعوائق لروبوت ممفصل

الخلاصة

ان الهدف الاساس من هذا البحث هو تخطيط مسار لروبوت ممفصل ذا خمسة محاور وبشكل مؤتمت وخال من التماس او الاصطدام بالعوائق الموجودة في محيط العمل بعد تعريف نقطتي بداية ونهاية المسار. اعتمدت الطريقة المقترحة في هذا البحث ثلاثة خطوات لتوليد المسار , حيث من خلال المرحلة الاولى تم تطبيق مفهوم بيزر لاشتقاق وتوليد المنحنيات المطلوبة (المسارات) في حين تم تقسيم المنحنيات ضمن المرحلة الثانية الى عدد ملائم من التقسيمات استنتجت من خلالها النقاط البينية الملائمة والتي تقع على المسار المستنتج, اما المرحلة الثالثة فمن خلالها تم تحويل

الاحداثيات الديكارتية للنقاط البينية المستنتجة الى احداثيات مفاصل الربوت لقيادة ذراع الروبوت ضمن المسار المقترح دون الاصطدام بالعوائق.
لم يقتصر البحث على الاشتقاق الرياضي والمحاكات وانما اشتمل على عدة تطبيقات عملية وباستخدام الروبوت LabVolt R5150 لاختبار كفاءة وفاعلية الطريقة المقترحة حيث تم التطبيق في بيئة ثابتة ومعرفة من خلال عدة تجارب لاختبار قابلية وصول الروبوت للهدف دون الاصطدام بالعوائق, واثبتت جميع التجارب نجاح وفاعلية الطريقة المقترحة لتوليد المسار.

INTRODUCTION

A manipulator without sensors has no ability to avoid obstacles in its workspace and it has to be taught every point on its trajectory , so that the arm may be free from collision as the arm moves along desired path from a start point to a goal point. This path is stored and used each time the manipulator is moved from the start to the goal points. Obviously, this method is only good in cases of repetitive tasks where there is no variation in the position of either the start or the goal point [1].

Bezier curves have several advantages for geometric modeling. The first and last control points are coincident with the endpoints of the curve segment. The curve is also tangent to the first and last edges of the control polygon and the curve generally follows the shape of the control polygon, making it intuitive to modify. Bezier curves can also be strung together, providing automatic continuity between the endpoint of one Bezier curve and the starting point of another Bezier curve [2].

BEZIER CURVES

Bezier curves have become the foundation of parametric freeform curve and surface geometry in CAD and visualization . A Bezier curve is defined by a series of two or more control points. The control points make up what is called the control polygon. Linear segments that connect the ordered series of control points form the control polygon [3].

Bezier curves have an associated degree. The degree, m, of a Bezier curve is:

$$m = n - 1$$

where n is the number of control points. Thus, a first degree Bezier curve has two control points; a second degree Bezier curve has three control points, etc. Examples of Bezier curves are included in figure 1. The control polygons are shown as lines connecting the control points. The shape of the Bezier curve is completely defined by the location of the control points. By moving the control points, the curve changes in a unique, mathematically defined manner [4].

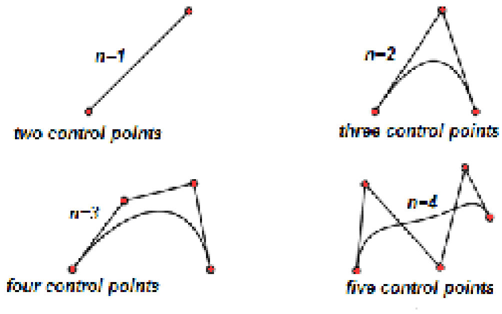


Figure (1). Bezier Curves.

In this work the property of Bezier curves which that the curve pass only through the start and the end control points and it does not pass through the intermediate control points, has been invested to plan free collision robot path by considering the start and the end control points as the initial and the goal position of the robot path while the other control points are considered as obstacles as clearly defined in the next section.

OBSTACLE DESCRIPTION

Obstacles may have polygonal or any other shape. However, it is not particularly desirable to have the manipulator pass very close to the obstacle boundaries, and thus the smallest cube which bounds an original obstacle has been used in this work to approximate the obstacle. Every point on the robot arm has to be located outside the cubic obstacle to ensure a collision free trajectory with that obstacle.

PATH PLANNING PROCEDURE

In order to move the robot arm from the start point to the goal point in the presence of obstacles, a sequence of joint angles along the path have to be determined [5]. The problem of finding a feasible collision free path, from Start to Goal, can be solved by applying Bezier technique, a number of intermediate points will be found and used for path planning.

The adopted path planning method to move the arm through a number of intermediate points to reach the desired goal point is illustrated in the following steps:

Step one : input Cartesian coordinates of Start point, Goal point and obstacles
Step two: considering the previous points as a control points of a Bezier curve
Step three: applying Bezier curve techniques $P(t) = \sum_{i=0}^{n} P_i B_{i,n}(t)$
Step four: partitioning the generated curve into sufficient intermediate segments and points
Step five: convert the Cartesian space of each generated intermediate point into joint space

Step six: move the robot arm through the generated joints spaces from the start point towered the goal point

Path planning cases:

One of the objectives for path planning in the Cartesian space is to minimize the distance between the starting point and goal point [6]. As Robot path can be represented by dotted line and the position of various nodes can be expressed by P_i, which means that the robot arm can move along the dotted lines and complete the path. P_i represent the intermediate nodes that the robot must pass through. When the robotic arm moves, the path can be represented by a serious of nodes P_i. So, the primary problem in Cartesian coordinate space path planning is how to generate a series of intermediate nodes between the beginning (Start) and the end (Goal) of path, which is identified by nodes P_i . In this work the intermediate nodes of the robot path have been generated using Bezier curve techniques by identify it's control points and it's degree equation (1). Mathematically a parametric Bezier curve of nth-degree is defined by:

$$P(t) = \sum_{i=0}^{n} P_i B_{i,n}(t) \qquad ....(1)$$

As an example, given the control points P0.P1, P2, P3, the cubic Bezier curve can be defined as:

$$P(t) = \sum_{i=0}^{3} P_i B_{i,3}(t) \qquad ....(2)$$

Where

$$B_{0,3}(t) = (1-t)^3, B_{1,3}(t) = 3t(1-t)^2 \ , B_{2,3}(t) = 3t^2(1-t) \ , B_{3,3}(t) = t^3$$

are the Bernstein polynomials of degree three.

After the generation of the intermediate nodes of the robot's trajectory, then the simplest path between these nodes is the straight line segments to guide the robot arm along the desired free collision path, by considering that the control points as obstacles .

This work is not limited to theoretical studies or simulations, experiments have been run with various tests, on a LabVolt R5150 robot at university of technology to assess the real efficiency and usability of the proposed technique. The method applies to robots in a fixed and known environment. A number of experiments were carried out to test the ability of an stationary revolute robot to reach it's goal without collision.

1-Environment with single obstacle : in this case three nodes [start, obstacle and goal] as shown in the Table(1), have been modeled to generate 2^{nd} order Bezier curve according to the equation (3) :

$$P(t) = \sum_{i=0}^{2} P_i B_{i,2}(t) \qquad ....(3)$$

Table (1) Physical environment coordinates of single obstacle case.

	START P0	OBSTACLE P1	GOAL P2
X-coordinate	150	300	150
Y-coordinate	50	250	350
Z-coordinate	100	200	400

According to the mathematical formulae of Bezier curve (3) and the coordinate of the control points Table (1) the 2nd order Bezier curve can be generated and represented as illustrated in Figure (2) using Matlab software.

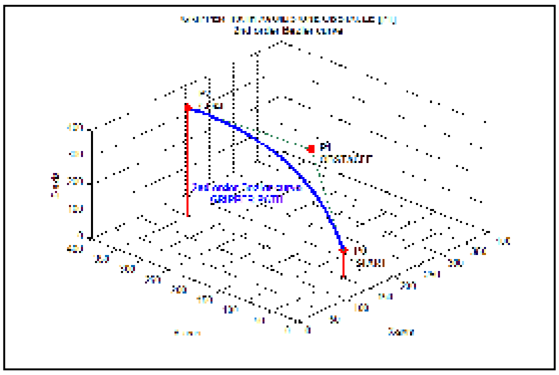
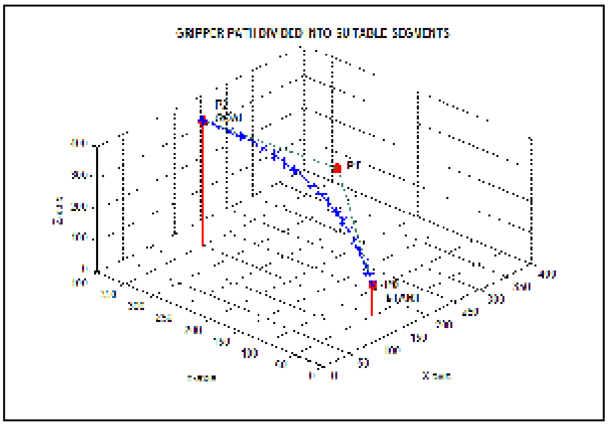


Figure (2) 2nd order Bezier curve.

The generated Bezier curve [2nd order] can be reshaped by sufficient intermediate nodes Figure (3) with suitable increment to guide the robot arm through these nodes to reach the desired goal.



Intermediate nodes (generated)

P_i	X-.	Y-	Z-
P1	150	50	100
P2	164.25	69.75	110.25
P3	177	89	121
P4	188.25	107.75	132.25
P5	198	126	144
P6	206.25	143.75	156.25
P7	213	161	169
P8	218.25	177.75	182.25
P9	222	194	196
P10	224.25	209.75	210.25
P11	225	225	225
P12	224.25	239.75	240.25
P13	222	254	256
P14	218.25	267.75	272.25
P15	213	281	289
P16	206.25	293.75	306.25
P17	198	306	324
P18	188.25	317.75	342.25
P19	177	329	361
P20	164.25	339.75	380.25
P21	150	350	400

Figure(3) Intermediate points on the curve.

2-Environment with two obstacles: for two obstacles environment, four nodes [start, 1st obstacle, 2nd obstacle and goal] have been defined and modeled as a control points to generate 3rd order (n-1) Bezier curve , the coordinates of the four point are illustrated in the Table (2) .

Table (2) Physical environment coordinates of two obstacles case.

	START P0	1st OBSTACLE P1	2nd OBISTACLE P2	GOAL P3
X-coordinate	150	150	300	150
Y-coordinate	50	200	250	350
Z-coordinate	100	300	200	350

According to the mathematical formulae of Bezier curve (2) and the coordinate of the control points (Table 2) the 3rdorder Bezier curve can be generated and represented as illustrated in Figure (4) using Matlab software.

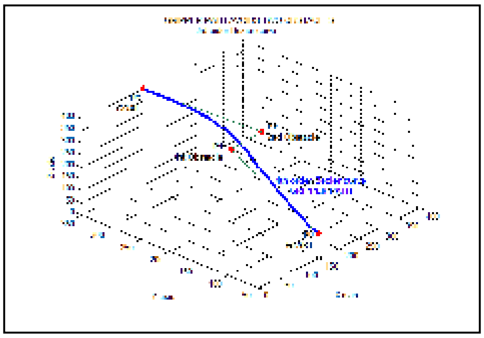
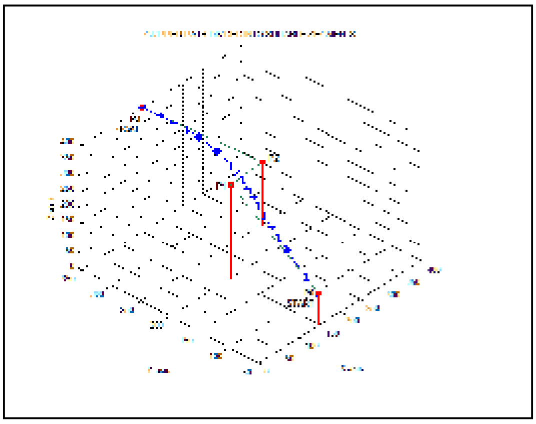


Figure (4) 3rd order Bezier curve.

The generated 3rd order Bezier curve can be divided and reshaped by sufficient intermediate nodes Figure (5) with suitable increment to generate a free collision path to move the manipulator to the desired goal,



Intermediate nodes (generated)

P_i	X	Y	Z
P1	150	50	50
P2	151.0688	71.76875	71.76875
P3	154.05	92.15	92.15
P4	158.6063	111.2563	111.2563
P5	164.4	129.2	129.2
P6	171.0938	146.0938	146.0938
P7	178.35	162.05	162.05
P8	185.8313	177.1813	177.1813
P9	193.2	191.6	191.6
P10	200.1188	205.4188	205.4188
P11	206.25	218.75	218.75
P12	211.2563	231.7063	231.7063
P13	214.8	244.4	244.4
P14	216.5438	256.9438	256.9438
P15	216.15	269.45	269.45
P16	213.2813	282.0313	282.0313
P17	207.6	294.8	294.8
P18	198.7688	307.8688	307.8688
P19	186.45	321.35	321.35
P20	170.3063	335.3563	335.3563
P21	150	350	350

Figure (5) Intermediate points on the curve.

3- Environment with three obstacles: for three obstacles environment, five nodes [start, 1st obstacle, 2nd obstacle, 3rd obstacle and goal] were defined and modeled to generate 4th order (n-1) Bezier curve , the coordinate of the five points are illustrated in the Table (3).

Table (3) Physical environment coordinates of three obstacles case.

	Start P0	1st Obstacle P1	2nd Obstacle P2	3rd Obstacle P3	Goal P4
X-coord.	150	150	300	300	150
Y-coord.	50	200	250	300	350
Z-coord.	100	300	200	400	400

According to the mathematical formulae of Bezier curve (4) and the coordinate of the control points (Table 3) the 4th order Bezier curve can be generated and represented as illustrated in Figure (6) using Matlab software.

$$P(t) = \sum_{i=0}^{4} P_i B_{i,4}(t) \qquad \text{................(4)}$$

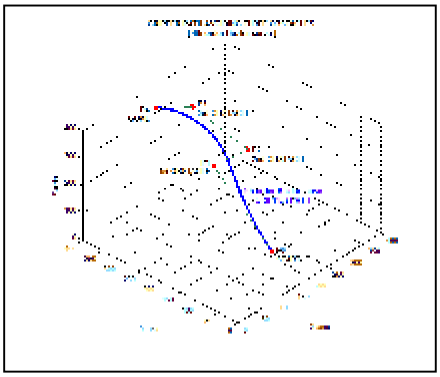
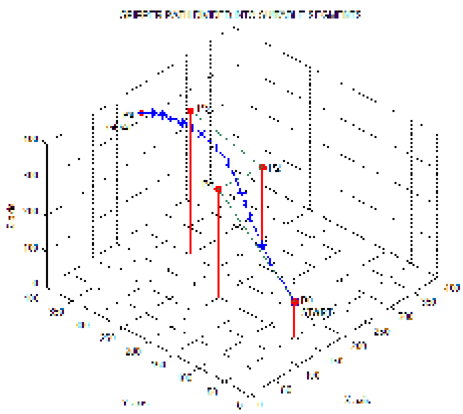


Figure (6) 4th order Bezier curve.

The generated 4th order Bezier curve can be divided and reshaped by sufficient intermediate nodes with suitable increment to generate a free collision path to move the manipulator to the desired goal, as shown in Figure (7).



Figure(7) Intermediate points on the curve.

Intermediate nodes (generated)			
P_i	X	Y	Z
P1	150	50	100
P2	152.0544	78.54938	135.7931
P3	157.47	104.39	164.29
P4	165.2044	127.7994	187.0431
P5	174.32	149.04	205.44
P6	183.9844	168.3594	220.7031
P7	193.47	185.99	233.89
P8	202.1544	202.1494	245.8931
P9	209.52	217.04	257.44
P10	215.1544	230.8494	269.0931
P11	218.75	243.75	281.25
P12	220.1044	255.8994	294.1431
P13	219.12	267.44	307.84
P14	215.8044	278.4994	322.2431
P15	210.27	289.19	337.09
P16	202.7344	299.6094	351.9531
P17	193.52	309.84	366.24
P18	183.0544	319.9494	379.1931
P19	171.87	329.99	389.89
P20	160.6044	339.9994	397.2431

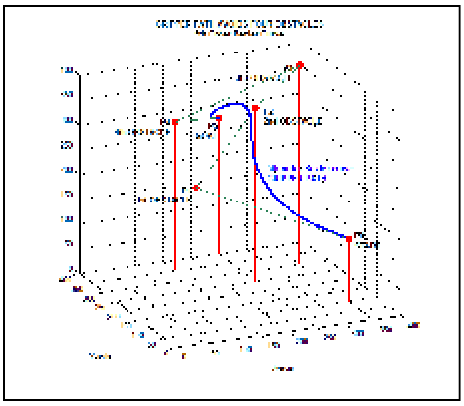
4- Environment with four obstacles: for four obstacles environment, six nodes [start, 1st obstacle, 2nd obstacle, 3rd obstacle, 4th obstacle and goal] were defined and modeled as a control points to generate 5th order (n-1) Bezier curve , the coordinate of the six points are illustrated in the Table (3) while the mathematical formulation of the 4th order Bezier curve as in equation (5).

Table (4) Physical environment coordinates of three obstacles case.

	Start P0	1st Obst. P1	2nd Obst. P2	3rd Obst. P3	4th Obst. P4	Goal P5
X-coord.	350	100	250	350	150	250
Y-coord.	100	150	250	300	350	400
Z-coord.	125	250	350	400	300	275

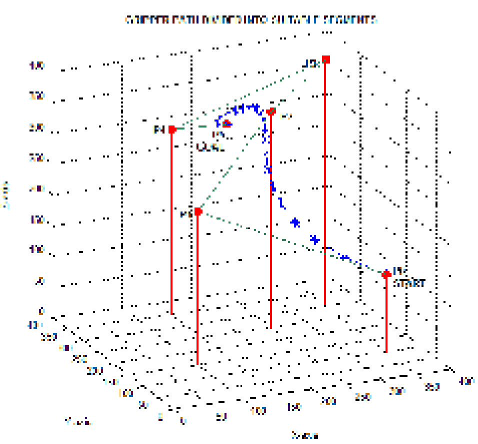
$$P(t) = \sum_{i=0}^{5} P_i B_{i,5}(t) \qquad \dots 5$$

using data listed in Table (3) and equation (5) the 5th order Bezier curve can be represented as shown in Figure(8).



Figure(8) 5th order Bezier curve.

The generated 5thorder Bezier curve can be divided and reshaped by sufficient intermediate nodes with suitable increment to generate a free collision path to move the arm to the desired goal, as shown in Figure (9).

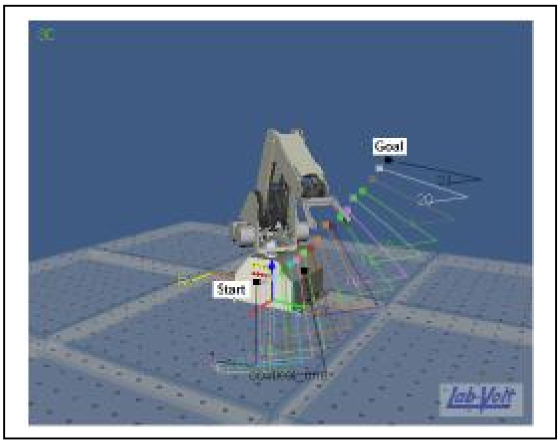


Figure(9) Intermediate Points on the curve. Simulation

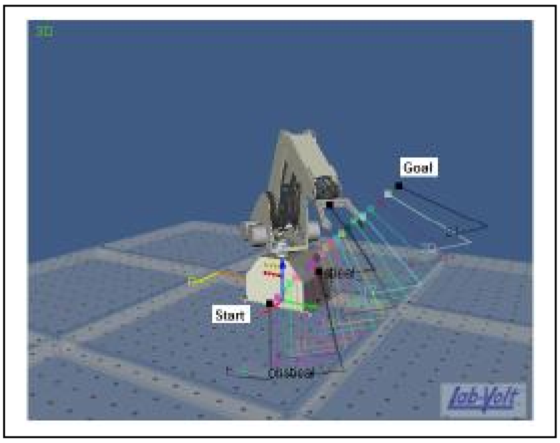
Intermediate nodes (generated)			
P_i	X	Y	Z
P1	350	100	125
P2	296.944	113.629	155.5915
P3	260.6065	129.073	184.7165
P4	237.8681	145.739	212.1218
P5	225.808	163.136	237.528
P6	221.7285	180.859	260.6445
P7	223.1795	198.589	281.1845
P8	227.9827	216.079	298.8798
P9	234.256	233.152	313.496
P10	240.4381	249.689	324.8475
P11	245.3125	265.62	332.8125
P12	248.0322	280.93	337.3478
P13	248.144	295.64	338.504
P14	245.6126	309.798	336.4405
P15	240.8455	323.461	331.4405
P16	234.7168	336.718	323.9258
P17	228.592	349.664	314.472
P18	224.3522	362.388	303.8235
P19	224.4185	374.977	292.9085
P20	231.7764	387.498	282.8538
P21	250	400	275

Simulation

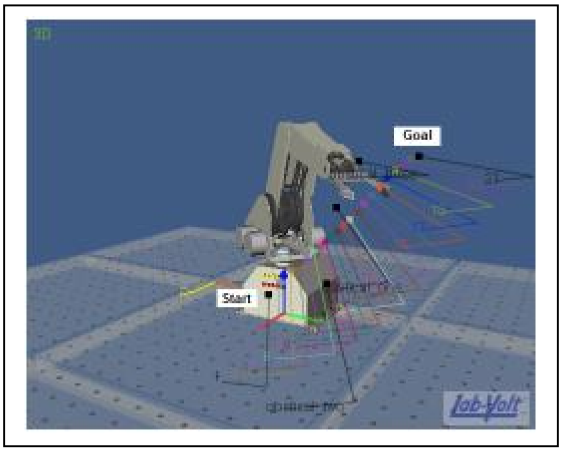
A number of experiments were simulated to test the ability of an stationary 5 axis revolute robot to reach it's goal without collision with the obstacles presents in it's work space using the generated data of the planned paths as the input to RoboCIM software. The adopted procedure gives good results by avoiding the collision with the obstacles during it's movement from the start point to the goal in all the simulated cases as shown in the Figure (10).



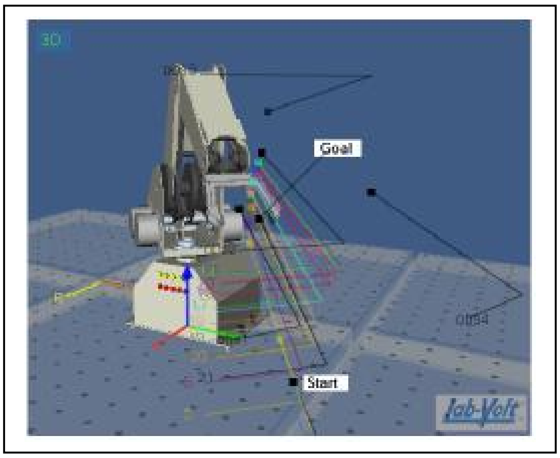
a-Simulation of case one



b-Simulation of case two



c-Simulation of case three



d- Simulation of case four

Figure(10) Simulation cases of the adopted procedure using RoboCIM software.

EXPERIMENTS

A number of experiments were carried out to test the ability of the robot to reach it's goal without collision with the obstacles. The adopted method has been tested in real environment in the university of technology for four different cases using a Lab-Volt R5150 5 axis robot arm, the adopted model gives good results for all the tested cases as shown in the Figure (11).

Figure (11) Testing of the LabVolt R5150 using the adopted method.

CONCLUSIONS

In this paper a free collision path planning strategy for revolute robots of five axes has been adopted and tested which makes use of safe knowledge of the infeasible joint space due to the obstacles in the workspace. By applying Bezier techniques, curves with different orders are used to generate a path of a sequence of intermediate points to reach a final goal.

We believe that the solution developed in this paper will make the use of Bezier techniques more useful in applications of robot path planning in known environments (obstacles) with out collision. The generated paths (Bezier Curves) would have to be completed by partitioning it into sufficient segments to generate

intermediate nodes that arm to follow by a sequence of joint angles to reach the goal.
By testing the adopted procedure with several different cases, we found that it is an efficient, accurate, and effective.

REFERENCES

[1].Ihn Namgung, " Application of quadratic algebraic curve for 2D collision free path planning and path space construction", International Journal of Control, Automation, and Systems, Vol.2, No.1, pp107-117, 2004.

[2]. Ji-wung Choi, Renwick E. and Gabriel H, " Smooth path generation based on Bezier curves fot autonomous vehicles", Proceeding of the world congress on engineering and computer science, San Francisco, Vol.II, 2009

[3].Ji-wung Choi, Renwick E. and Gabriel H., "Continuous curvature path generation based on Bezier curves for autonomous vehicle", International Journal of Applied Mathematics, Vol.40 No.2 , 2007.

[4].M.Abbas, E. Jamal and J.M. Ali, " Bezier curve interpolation constrained by a line", Applied Mathematical Science, Vol.5, No.37, pp 1817-1832, 2011.

[5]. Vaclav Hlavac, " Manipulator trajectory planning", Czech Technical University in Prague, http://cmp.felk.cvut.cz/~hlavac, 2006.

[6].H.C.Fang, S.K.Ong and A.Y.C.Nee," Interactive robot trajectory planning and simulation using Augmented Reality", Robotics and Computer-integrated Manufacturing, Vol.12, pp 227-237 , 2012.