Journal of Achievements in Materials and Manufacturing Engineering

VOLUME 29 ISSUE 2 August 2008

The comparison of elastic band and B-Spline polynomials methods in smoothing process of collision-free robot trajectory

D. Reclik*, **G. Kost**

Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland

* Corresponding author: E-mail address: daniel.reclik@polsl.pl

Received 19.03.2008; published in revised form 01.08.2008

Manufacturing and processing

ABSTRACT

Purpose: The main reason of this paper was to prepare the system, which tests the use of elastic band for smoothing the collision-free trajectory. The aided robot off-line programming system is based on NURBS and B-Spline curves. Because there is a lot of information in references about using elastic band algorithm, authors decided to compare these two methods. The most important criterion in robotics is having the smoothest possible robot trajectory, so as a standard there the NURBS curves (C^2 smooth class) were used.

Design/methodology/approach: Pascal language compiler was used for research. All algorithms were coded in this programming language and compiled. Results were set in Microsoft Excel worksheet.

Findings: Results show that calculations, which were made with B-Spline method, have taken less time than calculations based on elastic band curves. Moreover, the elastic band method gave the smoothest curves but only in geometrical sense, which is less important (the first and second derivate are not continuous, which is the most important issue in presented case). That is why it was found that using the B-Spline algorithm is a better solution, because it takes less time and gives better quality results.

Research limitations/implications: The MS Windows application was created, which generates smooth curves (in geometrical sense) by marking the interpolation base points which are calculated by the collision-free movement planner. This application generates curves by using both presented methods - B-Spline and elastic band. Both of these curves were compared in regard of standard deviation and variance of B-Spline and elastic band.

Practical implications: Because the elastic band algorithm takes a lot of time (three times longer than B-Spline) it is not used in the final application. The authors used B-Spline method to make smoother and optimized trajectory in application for off-line collision-free robot programming.

Originality/value: This is a new approach, which describes the comparison between elastic band and B-Spline polynomials methods in collision-free robot trajectory.

Keywords: Robotics; Mechatronics; NURBS curves; B-Spline; Elastic band method

1. Introduction

This paper has been worked out as a result of the detailed analysis of the references connected with the collision-free robot movement planning in its workspace. The most important thing was to create the computer aided for off-line robot programming system. The main purpose of the created system was that, it should determine the collision-free robot trajectory from starting point to the ending one. First, B-Spline curves and NURBS polynomials (Non Uniform Rational B-Spline) were used. Although those methods allow to get smoother and optimized robot trajectory, the authors decided to use another algorithm to make sure that the B-Spline and NURBS method are the best and the most beneficial methods. The time, which is needed to obtain the smoothest robot trajectory, is the most important criterion. Because there is a lot of information in references about elastic band algorithm, the authors decided to compare these methods [13-17].

2. Elastic band algorithm

The elastic band method consists of the force potential and continuous strain methods. In the off-line robot programming system, both methods, B-Spline and elastic band, are used for converting the initial broken path (the staircase function) into the smooth robot movement trajectory. They do not provide the collision-free robot trajectory. Because the created system must operate in 3-dimensional space, the comparison between presented methods should be made in all Cartesian coordinates. However, authors decided to make comparison in 2-dimensional plane because only it also allows judging the speed of both methods. Moreover, the time search in the 3D space is saved.

The authors decided to present in this paper only the most interesting issue - the numerical implementation. One can find the mathematical basis of elastic band algorithm and B-Spline curves in references [10-13].

The generalized formula of elastic force, which causes the path strain, was divided into two (x and y) components. Thanks to this, it was possible to calculate the force value and position change in x and y direction. Superposition of those two vectors (x and y) gives total translation of i-th point on the surface. The elastic force F_{el} equations for x_i and y_i coordinates are shown below [13, 14]:

$$F_{el}(x_i)=k_{el}\left(\frac{x_{i-1}-x_i}{\sqrt{(x_{i-1}-x_i)^2+(y_{i-1}-y_i)^2}}+\frac{x_{i+1}-x_i}{\sqrt{(x_i-x_{i+1})^2+(y_i-y_{i+1})^2}}\right)$$

(1)

$$F_{el}(y_i)=k_{el}\left(\frac{y_{i-1}-y_i}{\sqrt{(x_{i-1}-x_i)^2+(y_{i-1}-y_i)^2}}+\frac{y_{i+1}-y_i}{\sqrt{(x_i-x_{i+1})^2+(y_i-y_{i+1})^2}}\right)$$

where:
k_{el} – correction coefficient from 0 to 10 range

The comparison between B-Spline and elastic band should be carried out in the same conditions; therefore the correction was equal to 1 in both cases. In order to allow the collision-free pathway through robot workspace, there was necessary to define the potential repulsive forces, which are connected with roadblocks interaction on the robot motion. The repulsive forces are defined as following:

$$F_{odp}(x_i)=\begin{cases} k_{odp}(\rho_0-\rho)^l\dfrac{\partial\rho}{\partial x}(x_i) & if\quad \rho<\rho_0 \\ 0 & if\quad \rho\geq\rho_0 \end{cases} \qquad (2)$$

where:
$F_{odp}(x_i)$ – the repulsive force, which caused path strain for x_i point,
k_{odp} – the positive coefficient, which control the force value in every iteration,
l – the coefficient controlling the repulsive force,
ρ_0 - the limited distance from the closest roadblock, from which the force start to work
ρ - the distance from the closest roadblok, which is calculate in given path point.

Figure 1 shows graphical display of presented problem.

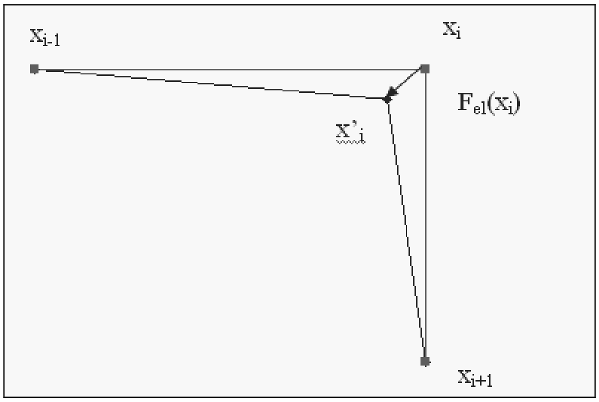

Fig. 1. Elastic force interaction

3. B-Spline and NURBS method

Interpolated curves [6-9], based on Berstein-Bézier polynomials, NURBS curves and B-Spline, are composite functions. The base of generating those curves is a basis function, which gives the proper shape of the 2-dimentional curve with set parameters when it is suitable for linking up. Because basic functions are defined by the time, therefore, one can found that the curve, which comes from the junction, is also indirectly defined by the time. Therefore, to determine the interpolated curve of robot movement on collision-free trajectory, at first, there must be provided the total time of movement duration. This time (of movement duration) is indicated as a base unit-it means that the movement lasts from 0 to 1 in time interval, that is from 0 to 100% of real time. Because the NURBS mathematical algorithm is very popular, therefore the procedure of realization of that algorithm is described in this paper. First, it is necessary to determine the kinematic pair during creating the polynomial of flexible interpolated function. Because the movement on curve must last from 0 to 1, the interval time from that range is interpolated kinematic pair. To accept the right number of interpolated kinematic pair, the degree of interpolated polynomial n and number of ordinary points of interpolation are defined. After having defined the kinematic pairs of interpolation, it is possible to determine the basic function component of rational B-spline polynomial (NURBS). Defining the basic functions must be done iteratively, because to determine the basic function of any degree, at first the basic function of lower degree must be defined. That's why defining the basic functions starts from determining the basic function of 0 degree, which is defining as follows: for set time interval are 1, while for others time interval are 0. Basic functions of higher degrees are defined by using the following formula [7]:

$$\chi_{i,p}(t) = \frac{t - t_i}{t_{i+p} - t_i} \cdot \chi_{i,p-1}(t) + \frac{t_{i+p+1} - t}{t_{i+p+1} - t_{i+1}} \cdot \chi_{i+1,p-1}(t) \tag{3}$$

where:
p – is in turn: 1, 2, 3 … until to value of polynomial degree n

Having computed values of basic functions, the points' coordinates of interpolated polynomial X(t), Y(t) are determined as a superposition of values of particular Cartesian co-ordinate system. In case of conventional B-spline polynomial, the values of coordinates are determined as product sum of basic functions and coordinate values of basis points P, in a way as it is shown below:

$$X,Y(t) = \sum_j \chi_{j,n}(t) \cdot P(x,y)_j \tag{4}$$

To determine the rational B-spline polynomial (NURBS) the authors must have taken into consideration the importance of the base points P, which are indicate as w. Knowing the importance of basic points one can determine particular coordinates of interpolated polynomial by using below formulas:

$$X,Y(t) = \frac{\sum_j \chi_{j,n} \cdot P(x,y)_j \cdot w_j}{\sum_j \chi_{j,n}(t) \cdot w_j} \tag{5}$$

In order to display how the algorithm works, many different trajectories, which have random chosen basic points, were shown. The main property of generated curves is the degree of matching to basis points. If the higher degree of interpolated polynomial n is taken, the generated curve is more standing-off from the basic points. Enlarging the degree of interpolated polynomial causes reduction of curve's inflexion, what finally makes that the curve has soft round.

4. Comparison of elastic band and B-Spline methods in smoothing process of robot trajectory

To make the comparison between those two methods [7, 8, 9], there was necessary to determine the trajectory of robot movement. The trajectory was determined by using the collision-free movement planner. The determined trajectory is shown in Figure 2. Findings were entered into a program which smoothes the trajectory by using B-Spline and elastic band algorithms. The comparison of the results is shown in Figure 3.

Because the analysis were leaded with the same initial conditions and the same correction coefficient, the differential time in getting satisfied results by using both methods was determined. To get the right results in trajectory quality authors decided to compare the basis points (generated by using elastic band method) with points of B-Spline curve, which are close to i-th point of elastic band trajectory. Thanks to this solution, the minimal trajectory difference, which helps in determining the variance error, was determined. (Fig. 4).

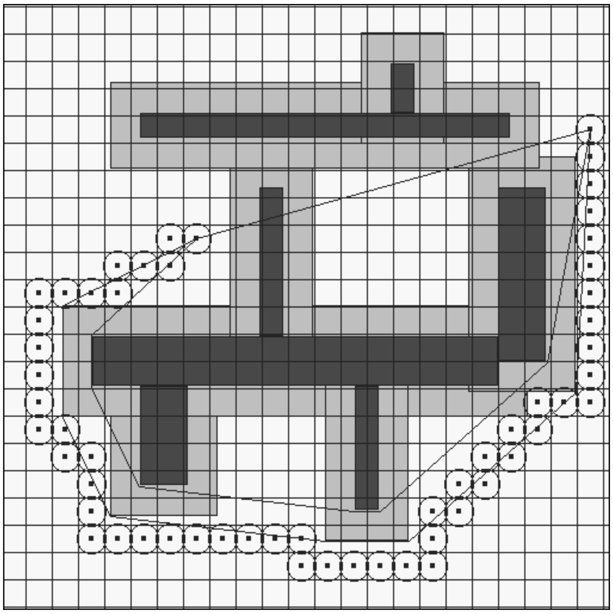

Fig. 2. Basic collision-free trajectory

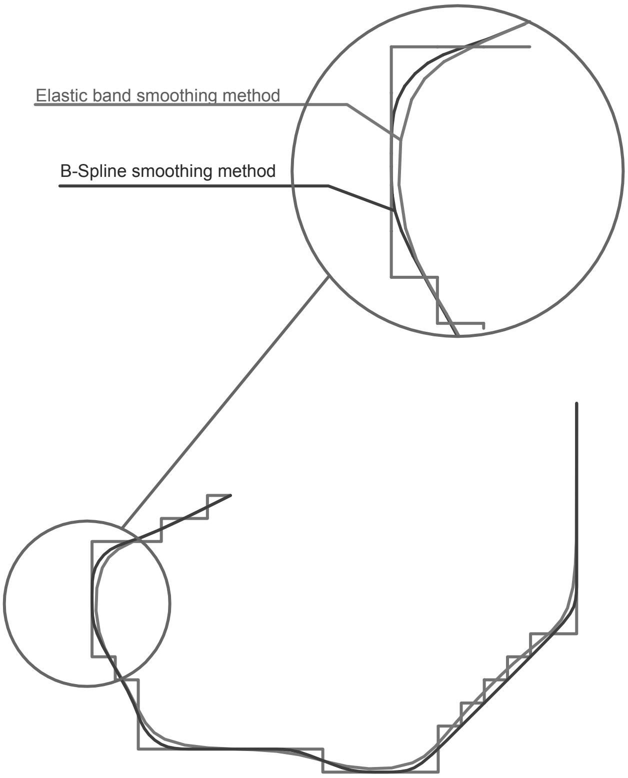

Fig. 3. Comparison of elastic band and B-Spline methods

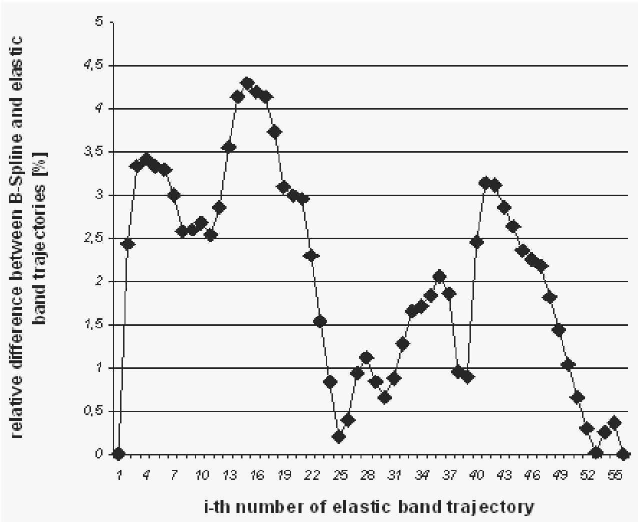

Fig. 4. Minimal trajectory difference

5. Conclusions

The received differential time of calculation indicates clearly that the received smooth trajectory by using elastic band is slower than using B-Spline algorithm. Moreover, Bezier functions can also provide the continuous derivative, what allows using C^2 curves for robot steering. The curve of this class (C^2) has continuous second derivative. Therefore, it is possible to obtain the robot acceleration graph, which is the most important and needed thing in drive control [3-5].

References

[1] K. Foit, Introduction to use of virtual reality visualizations in the exploitation and virtual testing of machines, Journal of Achievements in Materials and Manufacturing Engineering 25/2 (2007) 57-60.

[2] K. Białas, Comparison of methods of reduction of vibrations, Journal of Achievements in Materials and Manufacturing Engineering 25/1 (2007) 87-95.

[3] S.F. Chan, R. Kwan, Post-processing methodologies for offline robot programming within computer integrated manufacture, Journal of Materials Processing Technology 139 (2003) 8-14.

[4] A. Klimpel, A. Lisiecki, A.S. Klimpel, A. Rzeźnikiewicz, Robotized GMA surfacing of cermetal deposits, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 395-398.

[5] Tutorial materials from FANUC 100iB technical operators training, Astor, 2006.

[6] G. Kost, R. Zdanowicz, Modeling of manufacturing systems and robot motions, Proceedings of the 13th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2005, Gliwice–Wisła, 2005, 347-350.

[7] E. Chlebus, The CAx techniques in engineering of production, WNT, Warsaw, 2000 (in Polish).

[8] I. Dulęba, The algorithms and methods of a mobile and stationary manipulators movement planning, Academic Press EXIT, Warsaw, 2001 (in Polish).

[9] G.G. Kost, The safety movement robot planning based on grading function and Markov Chains stationary, Silesian University Press, Gliwice, 2004 (in Polish).

[10] E. Demaine, S. Gweightwasser, Introduction to Algorithms, MIT Press, London, 2002.

[11] A. Morecki, J. Knapczyk, The basis of robotics. Theory and manipulators elements, WNT, Warsaw, 2001 (in Polish).

[12] K. Kozłowski, P. Dutkiewicz, W. Wróblewski, The Robots modeling and controlling, PWN, Warsaw, 2003 (in Polish).

[13] Z. Fortuna, B. Macukow, J. Wąsowski, The numerical methods. University handbooks, PWN, Warsaw, 1999 (in Polish.)

[14] E. Majchrzak, B. Mochnacki, The numerical methods. Theoretical foundations, practical aspects and algorithms, Silesian University Press, Gliwice, 2004 (in Polish).

[15] J.C. Latombe, Robot motion planning, Kluwer Academic Publishers, Boston/London, 1993.

[16] K.H. Rosen, Discrete mathematics and its applications, Second Edition, McGraw-Hill Publishing, New Jersey, 1991.

[17] J. Boissonat, J. Budric, K. Goldberg, Algorithmic Foundations of Robotics V, Springer tracts in advanced robotics 7, Springer-Verlag, Berlin-Heidelberg, 2004.

[18] G. Kost, The safety movement robot planning based on grading function. Macines Engineering 10 (2005) 165-182 (in Polish).