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Abbas Shahzadeh, Abbas Khosravi, Troy Robinette, Saeid Nahavandi

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Smooth Path Planning using Biclothoid Fillets for High Speed CNC Machines

Abbas Shahzadeh[a], Abbas Khosravi[a], Troy Robinette[b], Saeid Nahavandi[a]

[a] *Deakin University, 75 Pigdons Road, Waurn Ponds VIC 3216, Australia*
[b] *ANCA Motion, 1 Bessemer Rd, Bayswater North VIC 3153, Australia*

Abstract

In high speed Computer Numerical Control (CNC) machines, cut velocities greater than 60 metres per minute and accelerations higher than 2g are used. In such high feedrates and accelerations, even a small discontinuity in curvature or in tangency can result in jerk spikes and consequently in machine vibrations, poor cut quality and decreased lifespan of the equipment. To prevent these consequences, using path smoothing techniques is necessary. Many path smoothing methods have been proposed in the literature to eliminate toolpath discontinuities. However the usage of almost all of these techniques is limited to purely linear toolpaths. In this paper a new path smoothing method using biclothoid fillets is introduced. The proposed method can be used to convert any given path consisted of lines and arcs to a curvature continuous path. The generated path is arc length parameterised which makes it easy to interpolate. The distance between the G2-continuous path and the original toolpath is limited to an adjustable tolerance. The proposed method has been tested on a CNC laser cutting machine and the results are reported. The main contribution of this paper is a fillet fitting method which is not limited to line to line transitions. The proposed smoothing fillets can be fitted between two arcs or a line and arc as well. A comparison with Bezier fillets, shows that using the proposed method results in a smoother curvature profile, higher feedrates and shorter cycle times.

Keywords:
CNC, path planning, corner smoothing, jerk, G2 continuity, clothoid

1. Introduction

Standard part programs processed by CNC controllers, define toolpaths which are composed of several lines and arcs [1]. At each line to line, line to arc or arc to arc transition, careful considerations are required to ensure that the physical limits of the machine are not exceeded. For example when the machine is moving at a constant feedrate, at the point where two successive non-tangent linear moves meet, there will be a sudden change in the velocity of the participating joints. Therefore, the controller has to foresee these transition points and reduce the path velocity to limit the side effects of a step change in the velocity. Similarly at line to arc and arc to arc transitions, even when the two moves are completely tangent, curvature discontinuities have to be addressed. Any discontinuity in the curvature results in a step change in acceleration and consequently in a jerk spike which can have detrimental effects on the quality of cut.

The same issue needs to be addressed in path planning for mobile robots and also in highway and railway design. The problem can be explained in a more tangible way in the context of wheeled vehicles. Imagine a car which is being driven on a road. For moving on a straight line, the angle of the front wheels with the chassis of the car needs to be zero. However for turning on a circular bend with a radius equal to 15 metres, for a typical car, the angle of the front wheels has to be about 10 degrees. In a non-standard road where a straight line segment is immediately followed by a circular bend, the driver will have to change the angle of the front wheels from zero to 10 degrees instantaneously which is physically impossible. So in order to follow the road, the car has to stop, reorient its front wheels and start moving again [2]. To prevent cases like the given example, smoothing curves like clothoids are used in highway and railway design. The role of the smoothing curves is to prevent sudden changes in the curvature and to eliminate curvature discontinuities.

In the case of CNC machines, there are two modes of operation known as 'Exact Stop Mode' and 'Continuous Mode' [1]. In the 'Exact Stop Mode', discontinuities in the toolpath do not make any difference in the overall performance. The reason is that in this mode, the machine stops after each move and before starting the next move. However in the 'Continuous Mode', in order to have a jerk-limited smooth movement, planning a curvature continuous path without any discontinuities in curvature or tangency is necessary.

As mentioned before, the same problem has been studied for mobile robots and autonomous vehicles [2, 3, 4, 5].

Email addresses: abbas.shahzadeh@research.deakin.edu.au (Abbas Shahzadeh), abbas.khosravi@deakin.edu.au (Abbas Khosravi), troy.robinette@ancamotion.com (Troy Robinette), saeid.nahavandi@deakin.edu.au (Saeid Nahavandi)