Smooth Path Planning Using Interpolation in Motion Control Camera

Angelina Efrina Prahastaputri 13523060[1,2]
Program Studi Teknik Informatika
Sekolah Teknik Elektro dan Informatika
Institut Teknologi Bandung, Jl. Ganesha 10 Bandung 40132, Indonesia
[1]13523060@std.stei.itb.ac.id, [2]efrinaprahastaputri@gmail.com

***Abstract*—Motion control cameras are recently used in entertainment industries especially in filmmaking and videomaking. Motion control cameras utilize a motion control system to create complex movements that are almost impossible to done manually by humans. Motion control cameras' system uses interpolation principles in calculating path for the camera movement. This paper will analyze which type of interpolation is the best to generate smooth and accurate path planning.**

***Keywords*—Motion control camera, interpolation, movements, path planning.**

I. INTRODUCTION

In this vast era of digitalization, many industries have used technology to better help with their production, the entertainment industry is not an exception. The entertainment industry has grown so large and rapidly, especially in filmmaking or videomaking. Such industries require innovative, creative, and trendy content to get the market's attention. One of the key parts of filmmaking or videomaking is the cinematography. Cinematography becomes very important to capture the essence of innovation and creativity of the content.

There are many tools in cinematography, but the most important tool is the camera. The type of camera that has been recently used by many filmmakers or video makers are motion control cameras. Motion control cameras allow filmmakers and video makers to go beyond the traditional ways of moving cameras manually and can create shots that are much smoother, more stable, and more creative. Because of that, there is no time lost building complicated makeshift camera rigs and there is more ability to control the camera movement [4].

Motion control software is used in motion control cameras to create paths for the camera to move. In this paper, we will explore the smooth path planning process using interpolation for interpolated motion in motion control cameras. Interpolation is one of the applications of Gauss elimination in numerical method [3] and we will discuss its importance in path-planning process in motion control cameras.

II. THEORETICAL BASIS

A. Polynomial Interpolation

One of the applications of Gauss elimination in numerical method is interpolation. Given n+1 data points, (x_0, y_0), (x_1, y_1), …, (x_n, y_n), a polynomial function $y = p_n(x)$ that interpolates or passes all points can be found with the highest order of $p_n(x)$ is n. This function can then be used to find or predict the value of y at x = a by evaluating $y = p_n(a)$.

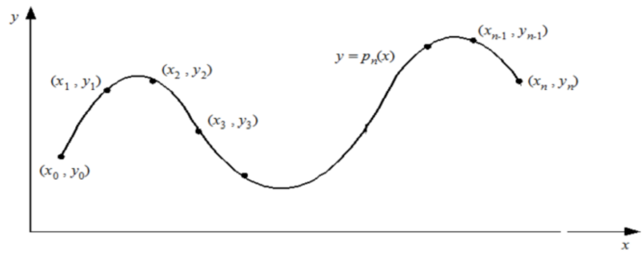

Figure 2.1 Several Points Interpolated by A Polynomial Function
https://informatika.stei.itb.ac.id/~rinaldi.munir/AljabarGeometri/2023-2024/Algeo-07-Aplikasi-SPL-2-2023.pdf

If there are two data points, (x_0, y_0) and (x_1, y_1), the polynomial function that interpolates both points is $p(x) = a_0 + a_1x$ or a linear function.

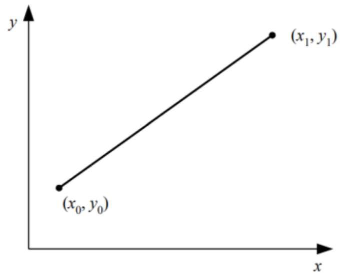

Figure 2.2 Linear Interpolation
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If there are three data points, (x_0, y_0), (x_1, y_1), and (x_2, y_2), the polynomial function that interpolates all points is $p_2(x) = a_0 + a_1x + a_2x^2$ or a quadratic function.

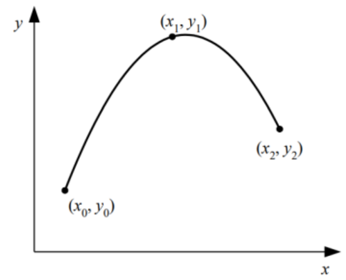

Figure 2.3 Quadratic Interpolation
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If there are four data points, (x_0, y_0), (x_1, y_1), (x_2, y_2), and (x_3, y_3), the polynomial function that interpolates all points is $p_3(x) = a_0 + a_1x + a_2x^2 + a_3x^3$or a cubic function.

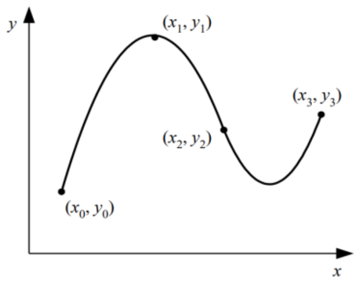

Figure 2.4 Cubic Interpolation
https://informatika.stei.itb.ac.id/~rinaldi.munir/AljabarGeometri/2023-2024/Algeo-07-Aplikasi-SPL-2-2023.pdf

With the exact same method, we can make higher n order polynomial function that interpolates n + 1 data points. By substituting (x_i, y_i) into the polynomial function, $p_n(x) = a_0 + a_1x + a_2x^2 + \dots + a_nx^n$, we will get linear equations, and its solutions can be found by using Gauss elimination. [8]

B. Spline Interpolation

Spline interpolation is used to create a smooth curve that passes through all data points by dividing the data into smaller segments and fitting a polynomial to each segment. There are linear, quadratic, and cubic spline interpolation. The commonly used one is cubic spline interpolation. [3]

Given data points, (x_0, y_0), (x_1, y_1), …, (x_n, y_n), an interpolating cubic spline fit through the data points, piecewise cubic polynomial approximate the data between two consecutive points. The interpolating cubic spline is given by

$$\begin{aligned} f(x) &= a_1x^3 + b_1x^2 + c_1x + d_1,\ x_0 \le x \le x_1 \\ &= a_2x^3 + b_2x^2 + c_2x + d_2,\ x_1 \le x \le x_2 \\ &\vdots \\ &= a_nx^3 + b_nx^2 + c_nx + d_n,\ x_{n-1} \le x \le x_n \end{aligned}$$

Cubic spline interpolation uses cubic polynomials for each segment of the data, resulting in a continuous curve with its first and second derivatives are also continuous. Thus, creating smooth continuous curve. [4]

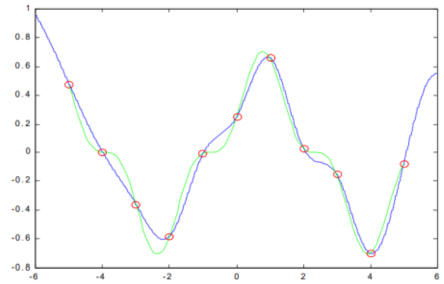

Figure 2.5 Cubic Spline Approximation of $[\sin(x) + \cos(x)]^{3/4}$
https://web.archive.org/web/20090408054627/http://online.redwoods.cc.ca.us/instruct/darnold/laproj/Fall98/SkyMeg/Proj.PDF

C. Motion Control Camera

Motion control cameras are specialized cameras that utilize motion control systems that enable filmmakers or video makers to create precise, repeatable, and programmable camera movements. Motion control cameras utilize robotics and computer controls to perform camera movements that seem impossible to achieve manually by humans. Motion control cameras ensure precision, in position, speed, accuracy, and timing, of the camera movement, allowing repetition of camera motions with the exact same consistency. [8]

Figure 2.6 Bolt High Speed Camera Robot
https://cinecrane.com/bolt-motion-control/

D. Motion Control Software

Motion control refers to the methods used to precisely regulate and control the movement and position of mechanical systems. [6]

Motion control software is a critical component in managing and executing precise, repeatable, and coordinated movements in motion control systems. It acts as the "brain" of the system, enabling the integration and operation of hardware components like motors, actuators, sensors, and controllers. This software is the key to achieving precision, synchronization, and efficiency in automated systems.

Motion control software provides multiple features and functions such as trajectory or path planning, real-time control of the system, multi-axis coordination and synchronization, real-time feedback and compensation, and customization of the system and programming environment.

Motion control software calculates the optimal path for movement, ensuring smooth and efficient transitions between points. Path planning involves determining the velocity, acceleration, and deceleration profiles to minimize vibration, maintain precision, and avoid overshooting.

Real-time control ensures that the system can dynamically adjust to changes in conditions or inputs during operation. If an obstacle is detected or if there are variations in the load, the software can modify the movement parameters to maintain accuracy and safety.

Many motion control cameras involve multiple movement axes. The software synchronizes these axes to work harmoniously, enabling complex operations like 3D positioning, and robotic arm movements, which are commonly performed by motion control cameras.

The system also provides real-time feedback to the software, which uses this data to adjust for errors such as positioning errors, velocity errors, and many other errors.

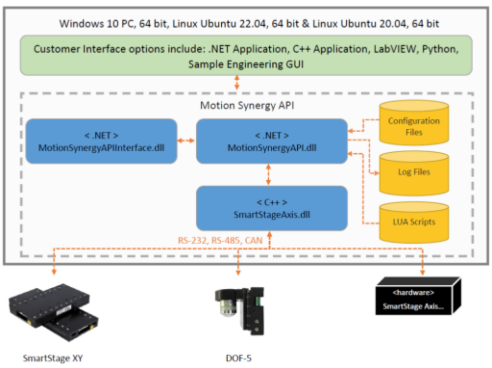

Figure 2.7 Motion Control Software: Motion Synergy API Architecture
https://dovermotion.com/products/motion-control-software-motion-synergy-api

III. ANALYSIS

A. Interpolated Motion

Interpolated motion is called for when the path that an object takes through space is important. One simple improvement that simulates interpolated motion is to very finely set the velocity on each axis, both axes will start and stop at about the same time. [2]

Interpolated motion is important for creating smooth and continuous camera paths in path planning. Interpolated motion utilizes the interpolation principles to generate smooth path for the camera movement. A path is considered smooth if it is continuous and precise.

Motion control cameras have multiple movement axis which enable them to move accurately and precisely. There are multiple motions that can be created with motion control camera with multi-axis.

The first motion is point-to-point motion. It is the simplest form of motion; it moves each axis independently to reach the target position. For example, to move from point (0,0) to point (100, 200), in millimetres, the X axis will move 100 mm, and once it has reached its position, the Y axis will move 200 mm. Moving two segments independently is typically the slowest method to get from one point to another, so this form of point-to-point motion is rarely used.

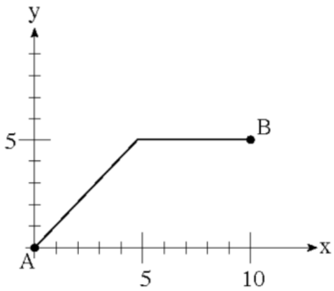

Figure 3.1 Point-to-Point Motion
https://dovermotion.com/resources/motion-control-handbook/interpolated-motion/

A variation of point-to-point motion is blended motion. To create a blended move, the controller overlaps, or blends, the move profiles of two axes. As one axis ends its move, the other axis begins its move, without waiting for the previous axis to fully stop. A user-specified “blend factor” defines the location, time, or velocity value at which the second axis should begin moving.

Blended motion produces a radius, rather than a sharp corner, when the motion changes direction. Applications such as dispensing and cutting may require blended motion if the part or item being tracked has rounded corners. And even if a radius (curve) is not required at the corner of a move, blended motion provides the benefit of keeping the axes moving, avoiding the deceleration and acceleration time required to stop and restart as the motion abruptly changes direction.

A more common type of motion for multi-axis systems is linear interpolation, which coordinates motion between the axes. With linear interpolation, the controller determines the appropriate move profile for each axis so that *all axes* reach the target position at the same time. The result is a straight line which is the shortest path between the start and end points. Linear interpolation can be used for 2-axis and 3-axis systems.

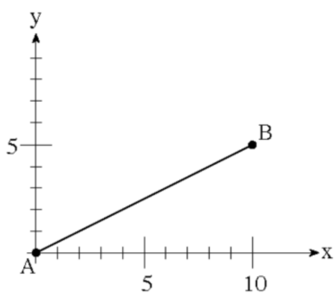

Figure 3.2 Linear Interpolation Motion
https://dovermotion.com/resources/motion-control-

handbook/interpolated-motion/

But linear interpolation and other high-order interpolation have less accuracy because there might be unusual behavior on the endpoints of the interpolation.

This behaviour usually can be handled by using cubic spline interpolation to create a better path and generally smoother path. [2] [5]

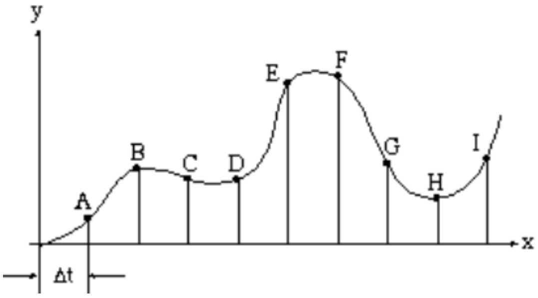

Figure 3.3 Cubic Spline Interpolation Motion
https://dovermotion.com/resources/motion-control-handbook/interpolated-motion/

IV. EVALUATION

The use of spline interpolation, specifically cubic spline interpolation in motion control camera has several advantages. Cubic spline interpolation able to generate smooth and continuous camera paths that are critical for cinematic and high-speed filming. The key strength of spline interpolation lies in its ability to provide C^2 continuity**,** ensuring smooth transitions in both position and velocity without abrupt changes. This is particularly beneficial in filmmaking and videomaking, where camera movements need to be precise and fluid to create high-quality visual content.

However, there are some challenges associated with spline interpolation. One such challenge is Runge's phenomenon where higher-order polynomials may lead to oscillations in the motion trajectory or path, especially when dealing with large number of data points. While cubic splines generally can handle this issue, careful attention must be paid when selecting the degree of the spline to avoid undesirable artifacts in the motion path.

Another challenge is the computational cost associated with real-time path adjustments. Although cubic spline interpolation generates smooth results, the real-time execution of complex paths can strain system resources, particularly in systems with multiple axes or high-speed movement. Therefore, a balance between interpolation complexity and computational efficiency must be maintained to ensure optimal real-time performance.

V. CONCLUSION

Motion control camera utilizes the principal of interpolation and spline interpolation within its motion control system. Each type of interpolation and spline interpolation has its own advantages and disadvantages. But in general, cubic spline interpolation by far produces the smoothest path compared to other types of interpolation and spline interpolation for the camera movement so it can maintain precision and accuracy.

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Through this paper, the author hopes it can bring more knowledge for the author and also for the readers on better understanding about smooth path-planning using polynomial interpolation in motion control camera.

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PERNYATAAN

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Bandung, 2 Januari 2025

Angelina Efrina Prahastaputri 13523060