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Bézier Curve Interpolation Model for Complex Data by Using Neutrosophic Approach

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Abstract

Since certain data are ignored owing to noise, coping with the complex data with neutrosophic features is problematic. This paper suggests a neutrosophic set strategy for interpolating the Bézier curve to overcome this issue. Thus, depending on the neutrosophic set notion, this work introduces the Bézier curve interpolation method for neutrosophic data. Using the neutrosophic set and its attributes, the neutrosophic control point is specified first. After that, the Bernstein basis function is linked to the control point and yields a neutrosophic Bézier. This curve is then shown using an interpolation approach that includes curves indicating membership, indeterminacy, and non-membership. Before the conclusion of this article, there is a numeric example and an algorithm for developing the neutrosophic Bézier curve using interpolation. Based on the results obtained, the neutrosophic set can deal with the complex data by treating all data including the uncertainty data as indeterminacy membership functions. In conclusion, this model can be used for real applications involving big data analysis.

Keywords Neutrosophic Set, Interpolation Approach, Bézier Curve, Neutrosophic Control Points, Complex Data

INTRODUCTION

To deal with the issues of sophisticated uncertainty, Zadeh [1] proposed the core notion of fuzzy set theory. A few years later, Atanassov [2] introduced the intuitionistic fuzzy set (IFS), a fuzzy set theory extension that combines the grade of membership, non-membership, and uncertainty. Approaching the intricate problem with intuitive and fuzzy characteristics is tough, and it is not frequently investigated in the scope of geometric modeling. Various studies utilizing datasets and splines have been fully completed in [3-11]. The neutrosophic technique was devised by Florentin Smarandache [12] as a mathematics approach to the principle of neutrality that works with complex data. The neutrosophic set (NS) idea is defined by membership degrees, non-membership, and indeterminacy. In this sense, a neutrosophic set refers to the resolution and depiction of challenges involving many domains. An element in neutrosophic set theory can have true, false, and indeterminate membership degrees all at once. This enables the modeling of more sophisticated types of uncertainty and indeterminacy, such as circumstances in which a statement might be membership and non-membership simultaneously. Some researchers have also used geometric modeling to apply neutrosophic set approaches [13-14, 25-29].

In this study, complex data will be modeled using the neutrosophic set approach and the Bézier function. According to Ayasdi [23], complex data is also known as "big data sets". He also noted that even a tiny data set is complex and tough to work with. "Data that is difficult to interpolate is also classified as complex data" by Ayasdi [23]. According to ETL tools [24], "complex data is big data with unclear information”. Therefore, an outcome of the citations obtained is complex data used in this paper can be described as large, hard to deal with, and a little ambiguous.

The purpose of this research is to create a geometric model that can handle complex data, with a focus on neutrosophic Bézier curve interpolation. Before building the neutrosophic Bézier curve, the neutrosophic control point must be defined using the neutrosophic set and its characteristics. These control points are used with the Bernstein basis function to generate neutrosophic Bézier curve models, which are then rendered via interpolation. The following is the format for this paper. The first section of this research offered background information. The neutrosophic principle and the neutrosophic control point (NCP) are depicted in Section 2. Section 3 shows how to interpolate the neutrosophic Bézier curve (NBC) using NCP. Section 4 offers both a mathematical illustration and an NBC visualization. The characteristics of the curve, as well as the technique utilized to build it, are also examined. Part 5 will bring this investigation to a close.

PRELIMINARIES

This section explains NSs, including the fundamental notion of NS and the NCP. In fuzzy systems, the intuitionistic set can accommodate limited details but not unclear or distorted data [12]. “There are three memberships: a truth membership function, T, an indeterminacy membership function, I, and a falsity membership function, F, with the parameter "indeterminacy" added by the NS specification” [12].

Definition 1 [15] Let X be the domain of conversation, with a component in X indicated as x. The neutrosophic set (NS) represents an item and NS is denoted as $\hat{A}$.

$$\hat{A}=\{\langle x:T_{\hat{A}}(x),I_{\hat{A}}(x),F_{\hat{A}}(x)\rangle|\ x\in X\} \tag{1}$$

where the functions $T,I,F:X\to]^{-}0,1^{+}[$ define, respectively, the degree of membership (or truth), the degree of indeterminacy, and the degree of non-membership (or falsehood) of the element $x\in X$ to the set $\hat{A}$ with the condition;

$$0^{-}\le T_{\hat{A}}(x)+I_{\hat{A}}(x)+F_{\hat{A}}(x)\le 3^{+} \tag{2}$$

There is no restriction to the value of $T_{\hat{A}}(x), I_{\hat{A}}(x)$ and $F_{\hat{A}}(x)$

NS chooses a value from a true standard or a quasi-subset of $]^{-}0,1^{+}[$. However, in technological contexts, the true interval's value $[0,1]$ will be used because $]^{-}0,1^{+}[$ will be impossible to employ in real-world applications such as scientific and engineering difficulties. As a result, membership value utilization is

$$\hat{A}=\{\langle x:T_{\hat{A}}(x),I_{\hat{A}}(x),F_{\hat{A}}(x)\rangle|\ x\in X\} \text{ and } T_{\hat{A}}(x),I_{\hat{A}}(x),F_{\hat{A}}(x)\in[0,1] \tag{3}$$

There is no restriction to the value of $T_{\hat{A}}(x), I_{\hat{A}}(x), F_{\hat{A}}(x)$. Therefore,

$$0\le T_{\hat{A}}(x)+I_{\hat{A}}(x)+F_{\hat{A}}(x)\le 3 \tag{4}$$

Definition 2 [3,4] Let $\hat{A}=\{\langle x:T_{\hat{A}}(x),I_{\hat{A}}(x),F_{\hat{A}}(x)\rangle|\ x\in\hat{A}\}$ and $\hat{B}=\{\langle y:T_{\hat{B}}(y),I_{\hat{B}}(y),F_{\hat{B}}(y)\rangle|\ y\in\hat{B}\}$ be neutrosophic components. Thus, $NR=\{\langle (x,y):T(x,y),I(x,y),F(x,y)\rangle|\ x\in\hat{A},y\in\hat{B}\}$ is a neutrosophic relation between $\hat{A}$ and $\hat{B}$.

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Definition 3 [3,4] A Neutrosophic set $\hat{A}$ in space X is a neutrosophic point (NP) and $\hat{A}=\{\hat{A}_i\}$ where $i=0,...,n$ is a set of NPs where there exists $T_A : X \to [0,1]$ as truth membership, $I_A : X \to [0,1]$ as indeterminacy membership, and $F_A : X \to [0,1]$ as false membership with

$$T_A(\hat{A}) = \begin{cases} 0 & if\ \hat{A}_i \notin \hat{A} \\ a \in (0,1) & if\ \hat{A}_i \hat{\in} \hat{A} \\ 1 & if\ \hat{A}_i \in \hat{A} \end{cases} \tag{5}$$

$$I_A(\hat{A}) = \begin{cases} 0 & if\ \hat{A}_i \notin \hat{A} \\ b \in (0,1) & if\ \hat{A}_i \hat{\in} \hat{A} \\ 1 & if\ \hat{A}_i \in \hat{A} \end{cases} \tag{6}$$

$$F_A(\hat{A}) = \begin{cases} 0 & if\ \hat{A}_i \notin \hat{A} \\ c \in (0,1) & if\ \hat{A}_i \hat{\in} \hat{A} \\ 1 & if\ \hat{A}_i \in \hat{A} \end{cases} \tag{7}$$

Neutrosophic Control Point (NCP)

A control point is a specific point or group of points in computer graphics and mathematical modeling that governs the shape or behavior of a curve, surface, or another geometric object. In this work, control points are a group of points used to identify the outlines of an NBC. It is also important in geometric modeling for deriving and fabricating smooth curves. The concept of NS and its attributes are used to define NCP in this section. According to research [16-18], the fuzzy set concept is used to build fuzzy control points.

Definition 4 NCP is described as a collection of point $n+1$ that denote a locations and values and is used to represent the curve and is indicated by

$$\begin{aligned} \hat{B}_i^T &= \left\{\hat{b}_0^T, \hat{b}_1^T, ..., \hat{b}_n^T\right\} \\ \hat{B}_i^I &= \left\{\hat{b}_0^I, \hat{b}_1^I, ..., \hat{b}_n^I\right\} \\ \hat{B}_i^F &= \left\{\hat{b}_0^F, \hat{b}_1^F, ..., \hat{b}_n^F\right\} \end{aligned} \tag{8}$$

Where $\hat{B}_i^T$, $\hat{B}_i^I$ and $\hat{B}_i^F$ are neutrosophic control points for membership truth, indeterminacy, and falsity respectively, and the controlling polygon vertex or control points are designated beginning with 0 to n.

INTERPOLATION OF NEUTROSOPHIC BÉZIER CURVE (NBC)

A Bézier curve is a parameterized curve with a polynomial equation of parameters used in modeling and defined by its controlling polygon [19, 20]. The total amount of points necessary to describe a polynomial determines its degree [21]. As seen in the definition below, combining fuzzy control points with the Bernstein polynomial or basis function yields a Bézier curve. The mathematical representation of the Bézier curve was introduced by Piegl and Tiller [22]. The difference between non-NBC and NBC is NBC will use the mathematical representation of non-NBC and then blend with NCP which was defined in **Definition 4.** The NBC is constructed using NCP and **Definition 1**, which is then merged in a geometric model with the Bézier blending function. The mathematical expression for NBC using the interpolation procedure is as follows:

Definition 5 Let

$$\hat{B}_i^T = \left\{\hat{b}_0^T, \hat{b}_1^T, \ldots, \hat{b}_n^T\right\}; \hat{B}_i^I = \left\{\hat{b}_0^I, \hat{b}_1^I, \ldots, \hat{b}_n^I\right\}; \hat{B}_i^F = \left\{\hat{b}_0^F, \hat{b}_1^F, \ldots, \hat{b}_n^F\right\}$$

where $i = 0,1,\ldots,n$ is NCP. NBC is as shown by $BC(t)$ is a function of the parameter t, with the position vector along the curve, as a result of blending J_i The fuzzy Bézier curve is expressed as by the mixing function.

$$BC(t)^T = \sum_{i=0}^{n} \hat{B}_i^T J_{n,i}(t) \quad 0 \le t \le 1 \tag{9}$$

$$BC(t)^I = \sum_{i=0}^{n} \hat{B}_i^I J_{n,i}(t) \quad 0 \le t \le 1 \tag{10}$$

$$BC(t)^F = \sum_{i=0}^{n} \hat{B}_i^F J_{n,i}(t) \quad 0 \le t \le 1 \tag{11}$$

where the foundation or mixing function is Bézier or Bernstein

$$J_{(n,i)}(t) = \binom{n}{i} t^i (1-t)^{n-i} \qquad (0)^0 \equiv 1 \tag{12}$$

with

$$\binom{n}{i} = \frac{n!}{i!(n-1)!} \qquad (0)^0 \equiv 1 \tag{13}$$

For the cubic case, the degree is $n=3$ and **Eq. 9, 10,** and **11** for NBC approximation can written as follows

$$BC(t)^T = \hat{B}_0^T J_{3,0} + \hat{B}_1^T J_{3,1} + \hat{B}_2^T J_{3,2} + \hat{B}_0^T J_{3,2} \tag{14}$$

$$BC(t)^I = \hat{B}_0^I J_{3,0} + \hat{B}_1^I J_{3,1} + \hat{B}_2^I J_{3,2} + \hat{B}_0^I J_{3,2} \tag{15}$$

$$BC(t)^F = \hat{B}_0^F J_{3,0} + \hat{B}_1^F J_{3,1} + \hat{B}_2^F J_{3,2} + \hat{B}_0^F J_{3,2} \tag{16}$$

Let's consider one of the memberships which is truth membership as unknown points to show the interpolation equation, below are the unknown data points for **Eq. 14**.

$$\begin{aligned}
\hat{T}_0 &= \hat{B}_0 \hat{J}_{3,0}(t_0) + \hat{B}_1 \hat{J}_{3,1}(t_0) + \hat{B}_2 \hat{J}_{3,2}(t_0) + \hat{B}_3 \hat{J}_{3,2}(t_0) \\
\hat{T}_1 &= \hat{B}_0 \hat{J}_{3,0}(t_1) + \hat{B}_1 \hat{J}_{3,1}(t_1) + \hat{B}_2 \hat{J}_{3,2}(t_1) + \hat{B}_3 \hat{J}_{3,2}(t_1) \\
\hat{T}_2 &= \hat{B}_0 \hat{J}_{3,0}(t_2) + \hat{B}_1 \hat{J}_{3,1}(t_2) + \hat{B}_2 \hat{J}_{3,2}(t_2) + \hat{B}_3 \hat{J}_{3,2}(t_2) \\
\hat{T}_3 &= \hat{B}_0 \hat{J}_{3,0}(t_3) + \hat{B}_1 \hat{J}_{3,1}(t_3) + \hat{B}_2 \hat{J}_{3,2}(t_3) + \hat{B}_3 \hat{J}_{3,2}(t_3)
\end{aligned} \tag{17}$$

To obtain the answer for **Eq. 17**, the matrices below have been used to determine $\hat{T}_i$

$$\begin{pmatrix} \hat{T}_0 \\ \hat{T}_1 \\ \hat{T}_2 \\ \hat{T}_3 \end{pmatrix} = \begin{pmatrix} \hat{J}_{3,0}(t_0) & \hat{J}_{3,1}(t_0) & \hat{J}_{3,2}(t_0) & \hat{J}_{3,2}(t_0) \\ \hat{J}_{3,0}(t_1) & \hat{J}_{3,1}(t_1) & \hat{J}_{3,2}(t_1) & \hat{J}_{3,2}(t_1) \\ \hat{J}_{3,0}(t_2) & \hat{J}_{3,1}(t_2) & \hat{J}_{3,2}(t_2) & \hat{J}_{3,2}(t_2) \\ \hat{J}_{3,0}(t_3) & \hat{J}_{3,1}(t_3) & \hat{J}_{3,2}(t_3) & \hat{J}_{3,2}(t_3) \end{pmatrix} \begin{pmatrix} \hat{B}_0 \\ \hat{B}_1 \\ \hat{B}_2 \\ \hat{B}_3 \end{pmatrix} \tag{18}$$

Next, **Eq. 18** is simplified to $\hat{T} = \hat{J}\hat{B}$ and finally the NBC for the interpolation method is described as follows.

$$\hat{B} = \left(\hat{J}\right)^{-1}\hat{T} \tag{19}$$

NUMERICAL EXAMPLE AND VISUALIZATION

Consider the following numerical example to show the Neutrosophic Bézier Curve using the interpolation method. This section will visualize and analyze the Neutrosophic Bézier Curve (NBC). The example will only utilize numerical examples at random and will apply the interpolation approach. A neutrosophic cubic Bézier curve will be demonstrated, which comprises of four neutrosophic control points with polynomial degrees of three. Consider the NCP with its respective degree in **Table 1** as an illustration. Three cubic Bézier curves will be visible.

Table 1. Neutrosophic Control Point (NCP) with its respective degrees

NCP $\hat{B}_i$	**Truth Membership** $\hat{B}_i^T$	**Indeterminacy Membership** $\hat{B}_i^I$	**False Membership** $\hat{B}_i^F$
$\hat{B}_0 = (2,4)$	0.4	0.2	0.7
$\hat{B}_1 = (4,7)$	0.9	0.2	0.2
$\hat{B}_2 = (7,3)$	0.8	0.3	0.2
$\hat{B}_3 = (10,6)$	0.3	0.5	0.5

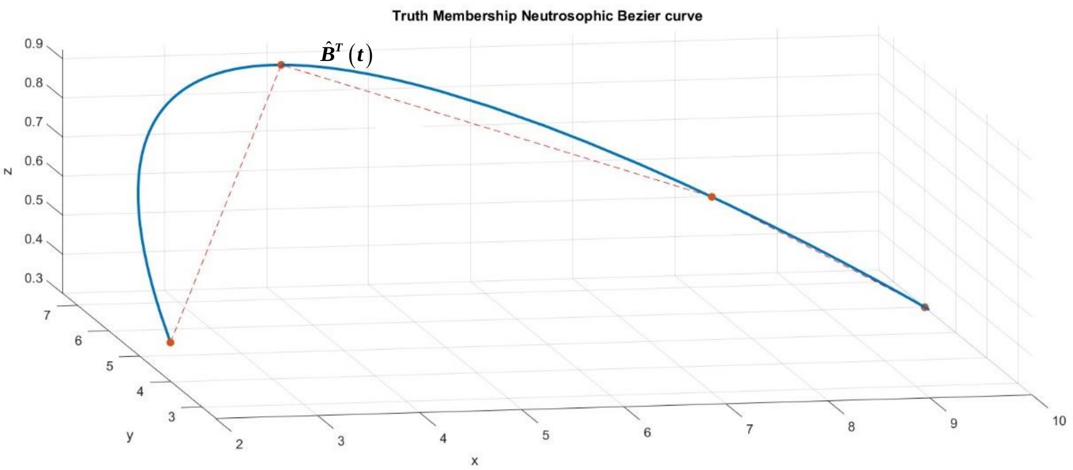


Figure 1 NBC Interpolation (Truth Membership)

Fig. 1-3 shows NBC interpolation, which consists of truth, indeterminacy, and false membership curves obtained from **Eq. (19)** using the interpolation procedure. A control polygon represents the NCP for each curve, as well as its corresponding dash line. Figure 4 shows NBC interpolation of the degree of truth, false, and indeterminacy curves in a single graph to illustrate the curve's behavior.

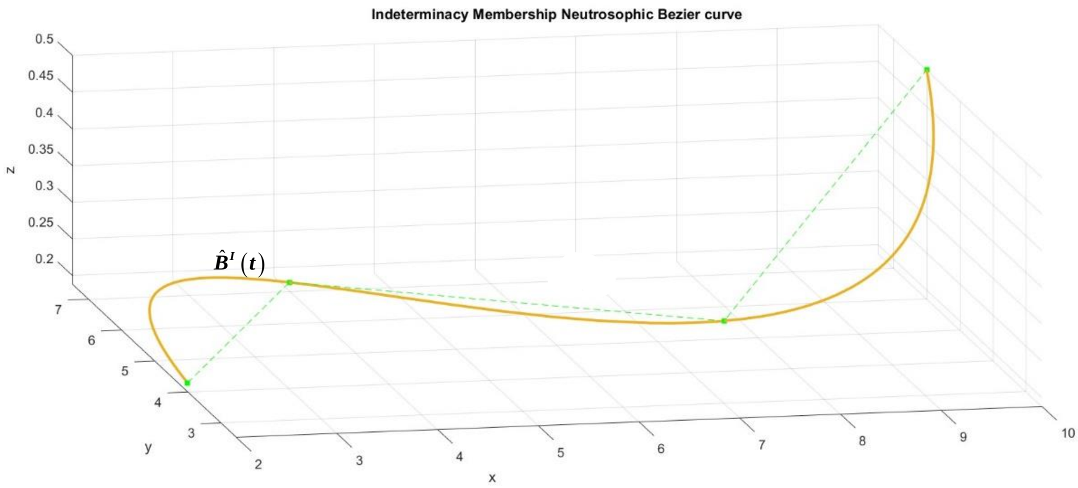


Figure 2 NBC Interpolation (Indeterminacy Membership)

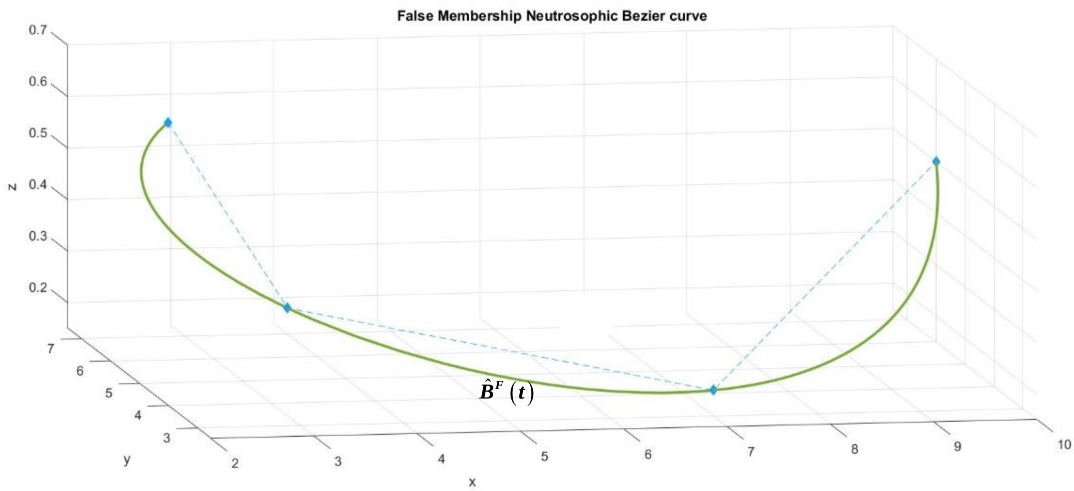


Figure 3 NBC Interpolation (False Membership)

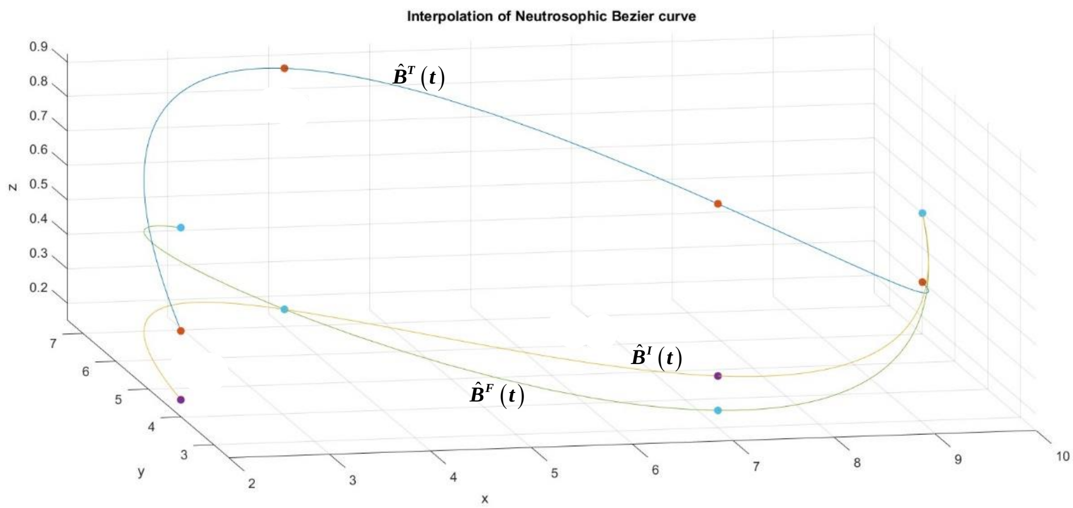
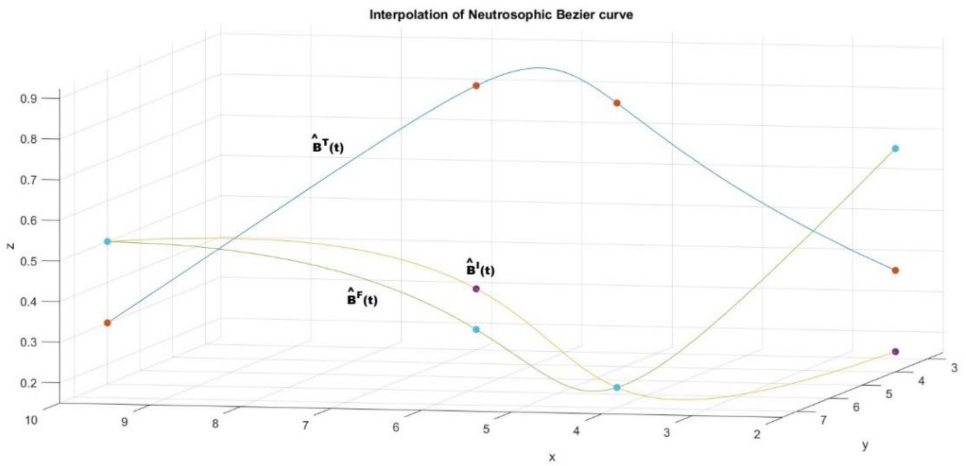
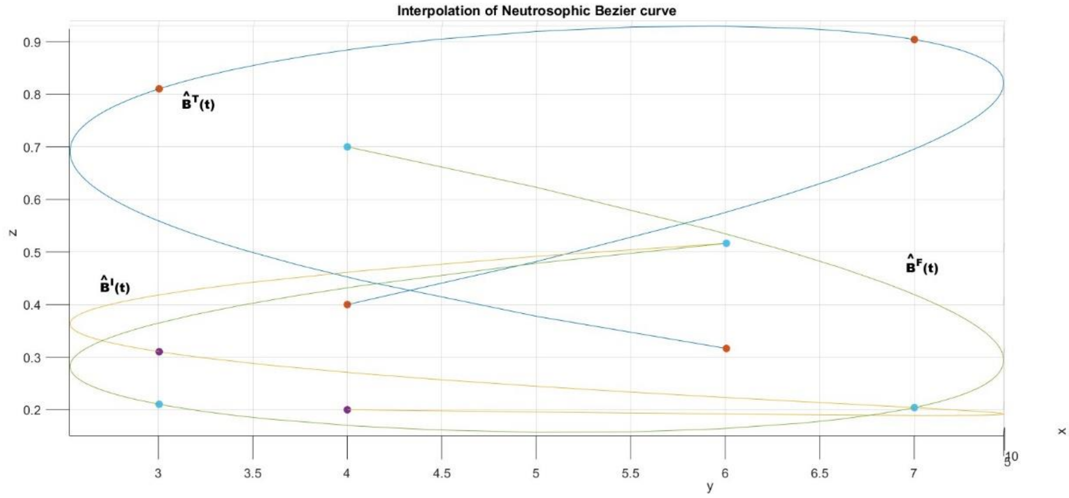


Figure 4 NBC Interpolation (Truth, Indeterminacy, and False Membership)

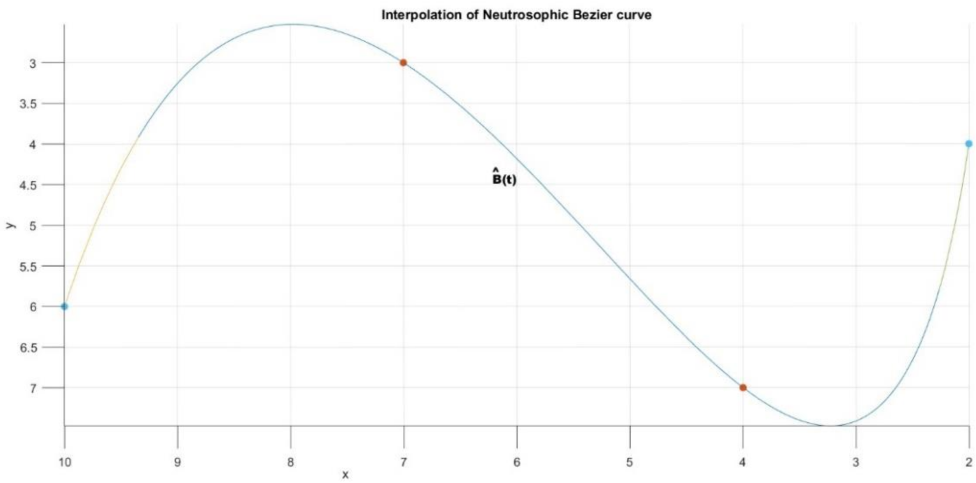
Fig. 5 depicts NBC interpolation from several perspectives. The produced NBC interpolation follows the criteria $0 \le T_{\hat{A}}(x) + I_{\hat{A}}(x) + F_{\hat{A}}(x) \le 3$ where $T_{\hat{A}}(x), I_{\hat{A}}(x), F_{\hat{A}}(x) \in [0,1]$.



(a)



(b)



(c)

Figure 5 (a) NBC Interpolation in a different perspective, **(b)** Y-Z axes, **(c)** X-Y axes.

Since it has truth membership, indeterminacy membership, and false membership, NBC interpolation is an appropriate technique for modeling data using a neutrosophic approach. These routines will handle all data.

The problem of neutrosophic complex data is solved and shown using NS and Bézier curve interpolation (**Fig. 1–5**). The following part will bring this investigation to a close.

The algorithm for constructing and illustrating NBC Interpolation is as follows:
Step 1: Define the NCP using **Definition 1** and **4**.
Step 2: Determine the degree of polynomials, using the number of NCP from **Step 1**.
Step 3: Calculate the Bernstein basis function by using the interpolation method based on **Definition 5** by using **Eq. 9-19**.
Step 4: For truth membership, indeterminacy membership, and false membership, repeat **Steps 1** through **4**.
Step 5: NBC will be visualized using the interpolation method for all three memberships.

CONCLUSION

This paper introduced NBC interpolation by introducing the NCP. The neutrosophic Bézier model, as shown in **Fig 1-5**, can be used to solve the neutrosophic data issue. This model has the benefit of simplicity and is straightforward, including being capable of transforming a neutrosophic complex data issue into a neutrosophic Bézier model. Economic analysis, actual monitoring, equity markets, data gathering, database systems, wireless sensors, business, dynamical systems, routing, and remote sensing are all examples of applications that use the NBC Interpolation model.

Bathymetry data is one example of how this study's implications apply to real-world problems. Bathymetry is the measuring of the depth of the seafloor. Thus, it is one of the complex data aspects, which are large amounts of data with some uncertainty. As a result, the bathymetry data can be shown using this NBC model, which treats truth measurements as truth membership functions, false measurements as falsity membership functions, and uncertainty data as indeterminacy membership functions. With its logic, the feature of neutrosophic data that represents the control point in conjunction with visualization using Bézier curve interpolation plays an important role in analyzing and communicating the nature of difficulties or situations. The method and model that arise from it will be valuable in the field of fuzzy modeling techniques. This method may also be used to the surface to solve neutrosophic complex data issues.

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