International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2014): 5.611

Solving Hybrid Fuzzy Fractional Differential Equations by Runge Kutta Fehlberg 6th Order Method

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Abstract: ***In this paper we study numerical methods for hybrid fuzzy fractional differential equations and the iteration method is used to solve the hybrid fuzzy fractional differential equations with a fuzzy initial condition. We consider a differential equation of fractional order and we compared the results with their exact solutions in order to demonstrate the validity and applicability of the method. We further give the definition of the Degree of Sub element hood of hybrid fuzzy fractional differential equations with examples.***

Mathematical Subject Classification (MSC) Code: 65L06

1. Introduction

With the rapid development of linear and nonlinear science, many different methods such as the variational iteration method (VIM) [1] were proposed to solve fuzzy differential equations. Fuzzy initial value problems for fractional differential equations have been considered by some authors recently [2, 3]. To study some dynamical processes, it is necessary to take into account imprecision, randomness or uncertainty.

The origins of fractional calculus go back to 1695 when Leibniz considered the derivative of order 1/2. Miller and Ross [4] provide historical details on the fractional calculus. Many applications have been found for fractional calculus. When the continuous time dynamics of a hybrid system comes from fuzzy fractional differential equations the system is called a hybrid fuzzy fractional differential system or a hybrid fuzzy fractional differential equation. This is one of the first papers to study hybrid fractional differential equations. The aim of this paper is to study their numerical solution.

This paper is organized as follows. In Section 2, we provide some background on fuzzy fractional differential equations and hybrid fuzzy fractional differential equations. In Section 3 we discuss the numerical solution of hybrid fuzzy fractional differential equations by Runge Kutta Fehlberg 6th order method. The method given uses piecewise application of a numerical method for fuzzy fractional differential equations. In Section 4, as an example, we numerically solve the Degree of Sub element hood of hybrid fuzzy fractional differential equations. The objective of the present paper is to extend the application of the variational iteration method, to provide approximate solutions for fuzzy initial value problems of differential equations of fractional order, and to make comparison with that obtained by an exact fuzzy solution.

2. Hybrid Fuzzy Fractional Differential Equations

Preliminaries

In this section the most basic notations used in fuzzy calculus are introduced. We start with defining a fuzzy number.

We now recall some definitions needed through the paper. The basic definition of fuzzy numbers is given by R, we denote the set of all real numbers. A fuzzy number is a mapping $u : R \to [0; 1]$ with the following properties:

a) u is upper semi-continuous,
b) u is fuzzy convex, i.e., $u(\lambda x + (1 - \lambda)y) \geq min\{u(x); u(y)\}$ for all $x; y \in R; \lambda \in [0; 1]$,
c) u is normal, i.e., $\exists x_0 \in R$ for which $u(x_0) = 1$,
d) supp $u = \{x \in R \mid u(x) > 0\}$ is the support of the u, and its closure cl(supp u) is compact. Let E be the set of all fuzzy number on R. The r-level set of a fuzzy number

$u \in E$, $0 \leq r \leq 1$, denoted by $[u]_r$, is defined as

$$[u]_r = \begin{cases} \{x \in R \mid u(x) \geq r\} & if\ 0 < r \leq 1 \\ cl\ (supp\ u) & if\ r = 0 \end{cases}$$

It is clear that the r-level set of a fuzzy number is a closed and bounded interval $[\underline{u}(r); \overline{u}(r)]$,

where $\underline{u}(r)$ denotes the left-hand endpoint of $[u]_r$ and $\overline{u}(r)$ denotes the right-hand endpoint of $[u]_r$.

2.1. Definition [6]

A fuzzy number (or an interval) u in parametric form is a pair $(\underline{u}, \overline{u})$ of functions $\underline{u}(r), \overline{u}(r)$, $0 \leq r \leq 1$, which satisfy the following requirements:

1) $\underline{u}(r)$ is a bounded non-decreasing left continuous function in (0, 1] and right continuous at 0.

2) $\overline{u}(r)$ is a bounded non-decreasing left continuous function in (0, 1] and right continuous at 0.
3) $\underline{u}(r) \leq \overline{u}(r)$, $0 \leq r \leq 1$.

2.2. Analytical solution of Hybrid Fuzzy Fractional Differential Equations:[6]

Let us consider the following fractional differential equation:

$$ {}_cD_a^\beta x(t) = f(t, x(t), \lambda_k(x_k)), \quad t \in [t_k, t_{k+1}] \qquad (1)$$

$$x(t_k) = x_k$$

Where, $0 \leq t_0 \leq t_1 \leq \cdots \leq t_k \to \infty$ $f \in C[R^+ \times E \times E, E]$, $\lambda_k \in C[E, E]$

Here we assume that the existence and uniqueness of solution of the hybrid system hold on each $[t_k, t_{k+1}]$ *to be specific the system would look like:*

$$ {}_cD_a^\beta x(t) = \begin{cases} {}_cD_a^\beta x_0(t) = f(t, x_0(t), \lambda_0(x_0)), x(t_0) = x_0, t \in [t_0, t_1] \\ {}_cD_a^\beta x_1(t) = f(t, x_1(t), \lambda_1(x_1)), x(t_1) = x_1, t \in [t_1, t_2] \\ \cdot \\ \cdot \\ \cdot \\ {}_cD_a^\beta x_k(t) = f(t, x_k(t), \lambda_k(x_k)), x(t_k) = x_k, t \in [t_k, t_{k+1}] \end{cases}$$

By the solution of (1) we mean the following function:

$$x(t) = x(t, t_0, x_0) = \begin{cases} x_0(t), t \in [t_0, t_1] \\ x_1(t), t \in [t_1, t_2] \\ \cdot \\ \cdot \\ x_k(t), t \in [t_k, t_{k+1}] \end{cases}$$

We note that the solutions of (1) are piecewise differentiable in each interval for $t \in [t_k, t_{k+1}]$ for a fixed $x_k \in$ E and k = 0, 1, 2…… We can also represent a fuzzy numbers x ∈ E by a pair of functions

$${}_cD_a^\beta \ x(t) = {}_cD_a^\beta [\underline{x}(t;r), \overline{x}(t;r)]$$

$$= [\, {}_cD_a^\beta \underline{x}(t), {}_cD_a^\beta \overline{x}(t) \,]$$

Using a representation of fuzzy numbers we may represent x ∈ E by a pair of functions $(\underline{x}(r), \overline{x}(r))$, $0 \leq r \leq 1$, such that:

- $\underline{x}(r)$ is bounded, left continuous and non decreasing,
- $\overline{x}(r)$ is bounded, left continuous and non increasing and
- $\underline{x}(r) \leq \overline{x}(r)$, $0 \leq r \leq 1$

Therefore, we may replace (1) by an equivalent system equation (2):

$$\begin{cases} {}_cD_a^\beta \underline{x}(t) = \underline{f}(t, x, \lambda_k(x_k)) \equiv F_k(t, \underline{x}, \overline{x}), \underline{x}(t_k) = \underline{x}_k \\ {}_cD_a^\beta \overline{x}(t) = \overline{f}(t, x, \lambda_k(x_k)) \equiv G_k(t, \underline{x}, \overline{x}), \overline{x}(t_k) = \overline{x}_k \end{cases} \qquad (2)$$

This possesses a unique solution $(\underline{x}, \overline{x})$ *which is a fuzzy function. That is for each t, the pair* $[\underline{x}(t;r), \overline{x}(t;r)]$ *is a fuzzy number, where* $\underline{x}(t;r), \overline{x}(t;r)$ *are respectively the solutions of the parametric form given by Equation (3):*

$$\begin{cases} {}_cD_a^\beta \underline{x}(t) = F_k(t, \underline{x}(t;r), \overline{x}(t;r)), \underline{x}(t_k;r) = \underline{x}_k(r) \\ {}_cD_a^\beta \overline{x}(t) = G_k(t, \underline{x}(t;r), \overline{x}(t;r)), \overline{x}(t_k;r) = \overline{x}_k(r) \end{cases} \qquad \ldots\ldots (3)$$

for $r \in [0, 1]$

3. The Sixth Order Runge Kutta Fehlberg Method with Harmonic Mean

For a hybrid fuzzy fractional differential equation we develop the sixth order Runge Kutta Fehlberg method with harmonic mean when f and λ_k in (1) can be obtained via the Zadeh extension principle from:

f ∈ [R^+ X R X R, R] and $\lambda_k \in$ C [R,R]

We assume that the existence and uniqueness of solutions of (1) hold for each $[t_k, t_{k+1}]$. For a fixed r, to integrate the system in (3) $[t_0,t_1],[t_1,t_2],\ldots[t_k,t_{k+1}]$……we replace each interval by a set of N_{k+1} discrete equally spaced grid points (including the end points) at which the exact solution

x(t; r)=($\underline{x}(t;r), \overline{x}(t;r)$) is approximated by some

($\underline{y}(t;r), \overline{y}(t;r)$).

For the chosen grid points on $[t_k, t_{k+1}]$ at $t_{k,n} = t_k + nh_k$, $h_k = \dfrac{t_{k+1} - t_k}{N_k}$, $0 \leq n \leq N_k$.

Let ($\underline{Y}_k(t;r), \overline{Y}_k(t;r)$) $\equiv$ ($\underline{x}_k(t;r), \overline{x}_k(t;r)$), ($\underline{y}_k(t;r), \overline{y}_k(t;r)$) and ($\underline{y}_k(t;r), \overline{y}_k(t;r)$) may be denoted respectively by ($\underline{Y}_{k,n}(t;r), \overline{Y}_{k,n}(t;r)$) and ($\underline{y}_{k,n}(t;r), \overline{y}_{k,n}(t;r)$).

We allow N_k's to vary over the $[t_k, t_{k+1}]$'s so that the h_k's may be comparable.

The Sixth Order Runge Kutta Fehlberg method for (1) is given by:

($\underline{Y}_k(t;r), \overline{Y}_k(t;r)$) $\equiv$ ($\underline{x}_k(t;r), \overline{x}_k(t;r)$),

($\underline{y}_k(t;r), \overline{y}_k(t;r)$)

Where

$$\underline{k}_1(t_{k,n}; y_{k,n}(r)) = \min\left\{ \begin{array}{l} h_k f(t_{k,n}, u, \lambda_k(u_k)) \\ \backslash u \in [\underline{y}_{k,n}(r), \overline{y}_{k,n}(r)], \\ u_k \in [\underline{y}_{k,n}(r), \overline{y}_{k,n}(r)] \end{array} \right\},$$

$$\overline{k}_1(t_{k,n}; y_{k,n}(r)) = \max\left\{ \begin{array}{l} h_k f(t_{k,n}, u, \lambda_k(u_k)) \\ \backslash u \in [\underline{y}_{k,n}(r), \overline{y}_{k,n}(r)], \\ u_k \in [\underline{y}_{k,n}(r), \overline{y}_{k,n}(r)] \end{array} \right\},$$

$$\underline{k}_2(t_{k,n};y_{k,n}(r))=\min\left\{\begin{array}{l} h_k f(t_{k,n}+(h_k),u,\lambda_k(u_k)) \\ \backslash u\in\begin{bmatrix}\underline{\Phi}_{k_1}(t_{k,n},y_{k,n}) \\ \overline{\Phi}_{k_1}(t_{k,n},y_{k,n})\end{bmatrix} \\ u_k\in[\underline{y}_{k,0}(r),\overline{y}_{k,0}(r)]\end{array}\right\},$$

$$\overline{k}_2(t_{k,n};y_{k,n}(r))=\max\left\{\begin{array}{l} h_k f(t_{k,n}+(h_k),u,\lambda_k(u_k)) \\ \backslash u\in\begin{bmatrix}\underline{\Phi}_{k_1}(t_{k,n},y_{k,n}) \\ \overline{\Phi}_{k_1}(t_{k,n},y_{k,n})\end{bmatrix} \\ u_k\in[\underline{y}_{k,0}(r),\overline{y}_{k,0}(r)]\end{array}\right\},$$

$$\underline{k}_3(t_{k,n};y_{k,n}(r))=\min\left\{\begin{array}{l} h_k f(t_{k,n}+(h_k),u,\lambda_k(u_k)) \\ \backslash u\in\begin{bmatrix}\underline{\Phi}_{k_2}(t_{k,n},y_{k,n}) \\ \overline{\Phi}_{k_2}(t_{k,n},y_{k,n})\end{bmatrix} \\ u_k\in[\underline{y}_{k,0}(r),\overline{y}_{k,0}(r)]\end{array}\right\},$$

$$\overline{k}_3(t_{k,n};y_{k,n}(r))=\max\left\{\begin{array}{l} h_k f(t_{k,n}+(h_k),u,\lambda_k(u_k)) \\ \backslash u\in\begin{bmatrix}\underline{\Phi}_{k_2}(t_{k,n},y_{k,n}) \\ \overline{\Phi}_{k_2}(t_{k,n},y_{k,n})\end{bmatrix} \\ u_k\in[\underline{y}_{k,0}(r),\overline{y}_{k,0}(r)]\end{array}\right\},$$

$$\underline{k}_4(t_{k,n};y_{k,n}(r))=\min\left\{\begin{array}{l} h_k f(t_{k,n}+h_k,u,\lambda_k(u_k)) \\ \backslash u\in\begin{bmatrix}\underline{\Phi}_{k_3}(t_{k,n},y_{k,n}) \\ \overline{\Phi}_{k_3}(t_{k,n},y_{k,n})\end{bmatrix} \\ u_k\in[\underline{y}_{k,0}(r),\overline{y}_{k,0}(r)]\end{array}\right\},$$

$$\overline{k}_4(t_{k,n};y_{k,n}(r))=\max\left\{\begin{array}{l} h_k f(t_{k,n}+h_k,u,\lambda_k(u_k)) \\ \backslash u\in\begin{bmatrix}\underline{\Phi}_{k_3}(t_{k,n},y_{k,n}) \\ \overline{\Phi}_{k_3}(t_{k,n},y_{k,n})\end{bmatrix} \\ u_k\in[\underline{y}_{k,0}(r),\overline{y}_{k,0}(r)]\end{array}\right\}$$

$$\underline{k}_5(t_{k,n};y_{k,n}(r))=\min\left\{\begin{array}{l} h_k f(t_{k,n}+h_k,u,\lambda_k(u_k)) \\ \backslash u\in\begin{bmatrix}\underline{\Phi}_{k_4}(t_{k,n},y_{k,n}) \\ \overline{\Phi}_{k_4}(t_{k,n},y_{k,n})\end{bmatrix} \\ u_k\in[\underline{y}_{k,0}(r),\overline{y}_{k,0}(r)]\end{array}\right\},$$

$$\overline{k}_5(t_{k,n};y_{k,n}(r))=\max\left\{\begin{array}{l} h_k f(t_{k,n}+h_k,u,\lambda_k(u_k)) \\ \backslash u\in\begin{bmatrix}\underline{\Phi}_{k_4}(t_{k,n},y_{k,n}) \\ \overline{\Phi}_{k_4}(t_{k,n},y_{k,n})\end{bmatrix} \\ u_k\in[\underline{y}_{k,0}(r),\overline{y}_{k,0}(r)]\end{array}\right\}$$

$$\underline{k}_6(t_{k,n};y_{k,n}(r))=\min\left\{\begin{array}{l} h_k f(t_{k,n}+h_k,u,\lambda_k(u_k)) \\ \backslash u\in\begin{bmatrix}\underline{\Phi}_{k_5}(t_{k,n},y_{k,n}) \\ \overline{\Phi}_{k_5}(t_{k,n},y_{k,n})\end{bmatrix} \\ u_k\in[\underline{y}_{k,0}(r),\overline{y}_{k,0}(r)]\end{array}\right\},$$

$$\overline{k}_6(t_{k,n};y_{k,n}(r))=\max\left\{\begin{array}{l} h_k f(t_{k,n}+h_k,u,\lambda_k(u_k)) \\ \backslash u\in\begin{bmatrix}\underline{\Phi}_{k_5}(t_{k,n},y_{k,n}) \\ \overline{\Phi}_{k_5}(t_{k,n},y_{k,n})\end{bmatrix} \\ u_k\in[\underline{y}_{k,0}(r),\overline{y}_{k,0}(r)]\end{array}\right\}$$

Where

$$\underline{\Phi}_{k_1}(t_{k,n},y_{k,n}(r))=\underline{f}(t_{k,n}+1/4*h,\underline{y}_{k,n}(r)+\underline{k}_1(t_{k,n},y_{k,n}(r))*h)$$

$$\overline{\Phi}_{k_1}(t_{k,n},y_{k,n}(r))=\overline{f}(t_{k,n}+1/4*h,\overline{y}_{k,n}(r)+\overline{k}_1(t_{k,n},y_{k,n}(r))*h)$$

$$\underline{\Phi}_{k_2}(t_{k,n},y_{k,n}(r))=\underline{f}(t_{k,n}+3/8*h,\underline{y}_{k,n}(r)+(3/32)*h*(\underline{k}_1(t_{k,n},y_{k,n}(r)+3*\underline{k}_2(t_{k,n},y_{k,n}(r)))$$

$$\overline{\Phi}_{k_2}(t_{k,n},y_{k,n}(r))=\overline{f}(t_{k,n}+3/8*h,\overline{y}_{k,n}(r)+(3/32)*h*(\overline{k}_1(t_{k,n},y_{k,n}(r)+3*\overline{k}_2(t_{k,n},y_{k,n}(r)))$$

$$\underline{\Phi}_{k_3}(t_{k,n},y_{k,n}(r))=\underline{f}(t_{k,n}+(12/13)*h,\underline{y}_{k,n}(r)+(12/2197)*h*(161*\underline{k}_1(t_{k,n},y_{k,n}(r)$$
$$-600*\underline{k}_2(t_{k,n},y_{k,n}(r)+608\underline{k}_3(t_{k,n},y_{k,n}(r)))$$

$$\overline{\Phi}_{k_3}(t_{k,n},y_{k,n}(r))=\overline{f}(t_{k,n}+(12/13)*h,\overline{y}_{k,n}(r)+(12/2197)*h*(161*\overline{k}_1(t_{k,n},y_{k,n}(r)$$
$$-600*\overline{k}_2(t_{k,n},y_{k,n}(r)+608\overline{k}_3(t_{k,n},y_{k,n}(r)))$$

$$\underline{\Phi}_{k_4}(t_{k,n},y_{k,n}(r))=\underline{f}(t_{k,n}+h,\underline{y}_{k,n}(r)+(1/4104)*h*(8341*\underline{k}_1(t_{k,n},y_{k,n}(r)$$
$$-32832*\underline{k}_2(t_{k,n},y_{k,n}(r)+29440*\underline{k}_3(t_{k,n},y_{k,n}(r)-845*\underline{k}_4(t_{k,n},y_{k,n}(r)))$$

$$\overline{\Phi}_{k_4}(t_{k,n}, y_{k,n}(r)) = \overline{f}(t_{k,n} + h, \overline{y}_{k,n}(r) + (1/4104) * h * (8341 * \overline{k}_1(t_{k,n}, y_{k,n}(r)$$
$$- 32832 * \overline{k}_2(t_{k,n}, y_{k,n}(r) + 29440 * \overline{k}_3(t_{k,n}, y_{k,n}(r) - 845 * \overline{k}_4(t_{k,n}, y_{k,n}(r)))$$
$$\underline{\Phi}_{k_5}(t_{k,n}, y_{k,n}(r)) = \underline{f}(t_{k,n} + (0.5)h, \underline{y}_{k,n}(r) + h * (-(8/27) * \underline{k}_1(t_{k,n}, y_{k,n}(r)$$
$$+ 2 * \underline{k}_2(t_{k,n}, y_{k,n}(r) - (3544/2565) * \underline{k}_3(t_{k,n}, y_{k,n}(r) + (1859/4104)$$
$$* \underline{k}_4(t_{k,n}, y_{k,n}(r) - (11/40) * \underline{k}_5(t_{k,n}, y_{k,n}(r)))$$
$$\overline{\Phi}_{k_5}(t_{k,n}, y_{k,n}(r)) = \overline{f}(t_{k,n} + (0.5)h, \overline{y}_{k,n}(r) + h * (-(8/27) * \overline{k}_1(t_{k,n}, y_{k,n}(r)$$
$$+ 2 * \overline{k}_2(t_{k,n}, y_{k,n}(r) - (3544/2565) * \overline{k}_3(t_{k,n}, y_{k,n}(r) + (1859/4104)$$
$$* \overline{k}_4(t_{k,n}, y_{k,n}(r) - (11/40) * \overline{k}_5(t_{k,n}, y_{k,n}(r)))$$

Next we define:

$$S_k[t_{k,n}, \underline{y}_{k,n}(r), \overline{y}_{k,n}(r)]$$
$$= \frac{h}{5}\{(16/27)\underline{k}_1(t_{k,n}; y_{k,n}(r)) + (6656/2565)\underline{k}_3(t_{k,n}; y_{k,n}(r))$$
$$+ (28561/11286)\underline{k}_4(t_{k,n}; y_{k,n}(r)) - (9/10)\underline{k}_5(t_{k,n}; y_{k,n}(r) + (12/11)\underline{k}_6(t_{k,n}; y_{k,n}(r))\}$$
$$T_k[t_{k,n}, \underline{y}_{k,n}(r), \overline{y}_{k,n}(r)]$$
$$= \frac{h}{5}\{(16/27)\overline{k}_1(t_{k,n}; y_{k,n}(r)) + (6656/2565)\overline{k}_3(t_{k,n}; y_{k,n}(r))$$
$$+ (28561/11286)\overline{k}_4(t_{k,n}; y_{k,n}(r)) - (9/10)\overline{k}_5(t_{k,n}; y_{k,n}(r) + (12/11)\overline{k}_6(t_{k,n}; y_{k,n}(r))\}$$

The exact solution at $t_{k,n+1}$ is given by:

$$\begin{cases} F_{k,n+1}(r) = \underline{Y}_{k,n}(r) + S_k[t_{k,n}, \underline{y}_{k,n}(r), \overline{y}_{k,n}(r)], \\ G_{k,n+1}(r) = \overline{Y}_{k,n}(r) + T_k[t_{k,n}, \underline{y}_{k,n}(r), \overline{y}_{k,n}(r)]. \end{cases} \quad \ldots\ldots\ldots(4)$$

Degree of Sub Element hood

Let X be a Universal, U be a set of parameters and let ($F_{k,n+1}$) and ($G_{k,n+1}$) are two fuzzy elements of X. Then the degree of sub element hood denoted by $\$(F_{k,n+1}, G_{k,n+1})$ is defined as,

$$\$(F_{k,n+1}, G_{k,n+1}) = \frac{1}{|(F_{k,n+1})|}\{|(F_{k,n+1})| - \sum \max\{0, (F_{k,n+1}) - (G_{k,n+1})\}\}$$

Where $|F_{k,n+1}| = \sum_{e_j \in A} \exp(F_{k,n+1})$

and

$$\$(G_{k,n+1}, F_{k,n+1}) = \frac{1}{|(G_{k,n+1})|}\{|(G_{k,n+1})| - \sum \max\{0, (G_{k,n+1}) - (F_{k,n+1})\}\}.$$

Numerical Example

*In this section, we present the example for solv*ing hybrid fuzzy fractional differential equations. Consider the following linear hybrid fuzzy fractional differential equation:

$${}_cD_a^{\beta}\ X(t) = Y + X^2 + 1 \quad \ldots\ldots (5)$$

X (0) = X_0,

where $\beta \in (0,1]$, t > 0, and X_0 is any triangular fuzzy number.

This problem is a generalization of the following hybrid fuzzy fractional differential equation:

$${}_cD_a^{\beta}\ x(t) = y + x^2 + 1 = [\underline{y}(t;r), \overline{y}(t;r)] + [\underline{x}(t;r), \overline{x}(t;r)]^2 + 1 \quad \ldots.. (6)$$

x (t) = x_0,

Where $\beta \in (0,1]$, t > 0,

α is the step size and x_0 is a real number.

We can find the solution of the hybrid fractional fuzzy differential equation, by the method of Runge kutta Fehlberg 6th order Method. We compared & generalized the hybrid fractional fuzzy differential equation solution with the exact solution in the following table; also we illustrated the figure for this generalization by using Matlab.

Table: Numerical Solution of the Example

α	Exact	$F_{k,n+1}$	$G_{k,n+1}$
0.1	0.682075947	0.576948837	0.787203057
0.2	0.768615305	0.658098213	0.879132397
0.3	0.860103273	0.743919849	0.976286698
0.4	0.957049929	0.834909653	1.079190205
0.5	1.059991499	0.931588958	1.188394042
0.6	1.169491707	1.034505826	1.304477588
0.7	1.286143174	1.14423642	1.428049929
0.8	1.410568911	1.261386441	1.559751381
0.9	1.543423867	1.386592649	1.700255086
1.0	1.685396573	1.520524447	1.850268701

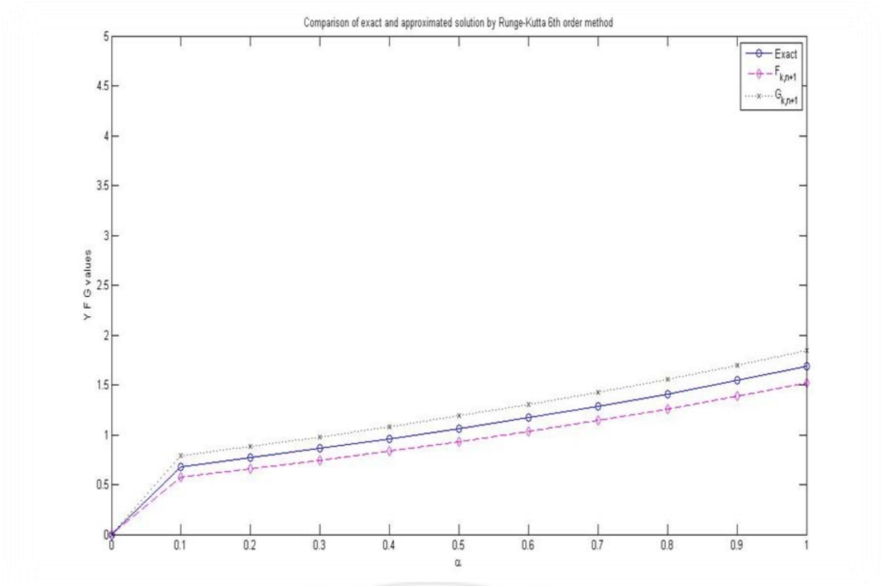

Figure 1: Comparison of exact and approximated solution of Example

$| F_{k,n+1} |$ = 10.09271

$| G_{k,n+1} |$ = 12.75301

$$\$(F_{k,n+1}, G_{k,n+1}) = \frac{1}{|(F_{k,n+1})|}\left\{\left|(F_{k,n+1})\right| - \sum \max\{0, \left(F_{k,n+1}\right) - \left(G_{k,n+1}\right)\}\right\} \cong 1$$

$$\$(G_{k,n+1}, F_{k,n+1}) = \frac{1}{|(G_{k,n+1})|}\left\{\left|(G_{k,n+1})\right| - \sum \max\{0, \left(G_{k,n+1}\right) - (F_{k,n+1})\}\right\}. = 0.7913984 \cong 0.8$$

Conclusion

In this paper, we have studied a hybrid fuzzy fractional differential equation. Final results showed that the solution of hybrid fuzzy fractional differential equations approaches the solution of hybrid fuzzy differential equations as the fractional order approaches the integer order. The results of the study reveal that the proposed method with fuzzy fractional derivatives is efficient, accurate, and convenient for solving the hybrid fuzzy fractional differential equations.

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