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Fixed point theorem in intuitionistic fuzzy 3–metric space under strict contractive conditions

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Abstract: The resent paper aims to intoduce the notion of intuitionistic fuzzy 3–metric space and prove some common fixed point theorems under strict contractive conditions.

Keywords: Fixed point, Intuitionistic fuzzy 3–metric space, Weakly compatible.

1 Introduction

In 1965, Zadeh [14] introduced the theory of fuzzy set which is an important and useful branch of mathematics, science and engineering. Kramosil and Michalek [9] introduced the definition of fuzzy metric space. Authors [13,6] investigated fixed point theorems in fuzzy metric space. Park described the concept of intuitionistic fuzzy metric space with the help of continuous t-norm and continuous t-conorm.In this paper [10] the authors studied the common fixed point theorems in intuitionistic fuzzy metric space under strict contractive. Jungck[8] defined the concept of weak commutativity in metric space and compatibility and proved the uniqunees of fixed point theorems. Abu-Donia et al. [2,3] investigated common fixed point theorems in intuitionistic fuzzy metric spaces and intuitionistic (ϕ,ψ)–contractive mappings and fixed point theorem using ψ–contraction and (ϕ,φ)–contraction in probabilistic 2–metric spaces.

Gähler[5] introduced the concept of 2–metric space which was proposed in Euclidean space by the area function. Sharma[12] described the definition of fuzzy 2-metric space which is the generalization of the intuitionistic fuzzy metric space and proved some common fixed point theorems. Mursaleen and Lohani[7] using the idea of intuitionistic fuzzy metric space and defined the concept of intuitionistic fuzzy 2–metric space and proved the common fixed point theorems in intuitionistic fuzzy 2–metric space. Aamri[1] described the notion property (E.A.).Shrivastava et al.[11] presented the definition of the weak compatible mappings in intuitionistic fuzzy 2-metric spaces. Chauhan and Singh[4] proved fixed point theorem in intuitionistic fuzzy-3 metric space.

In this paper we obtain some fixed point theorems in intuitionistic fuzzy 3-metric spaces on two mappings and four using the concept of weakly compatible and the property (E.A.).

2 preliminaries

Definition 21 *A binary operation* $*:[0,1]\times[0,1]\times[0,1]\times[0,1]\longrightarrow[0,1]$ *is continuous t–norm if* $*$ *satisfies the following conditions:*
(i)$*$ *is commutative and associative;*
(ii)$*$ *is continuous;*
(iii)$a*1=a$ *for all* $a\in[0,1]$*;*
(iv)$a_1*b_1*c_1*d_1\leq a_2*b_2*c_2*d_2$ *whenever* $a_1\leq a_2, b_1\leq b_2, c_1\leq c_2, d_1\leq d_2$ *and* $a_1,b_1,c_1,d_1,a_2,b_2,c_2,d_2\in[0,1]$.
For example: $a*b*c*d=\min\{a,b,c,d\}$ *or* $a*b*c*d=a.b.c.d$.

Definition 22 *A binary operation* $\diamondsuit:[0,1]\times[0,1]\times[0,1]\times[0,1]\longrightarrow[0,1]$ *is continuous t–conorm if* $\diamondsuit$ *satisfies the following conditions:*
(i)$\diamondsuit$ *is commutative and associative;*

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(ii)$\diamondsuit$ *is continuous;*
(iii)$a\diamondsuit 0 = a$ *for all* $a \in [0,1]$*;*
(iv)$a_1\diamondsuit b_1\diamondsuit c_1\diamondsuit d_1 \leq a_2\diamondsuit b_2\diamondsuit c_2\diamondsuit d_2$ *whenever* $a_1 \leq a_2, b_1 \leq b_2, c_1 \leq c_2, d_1 \leq d_2$ *and* $a_1,b_1,c_1,d_1,a_2,b_2,c_2,d_2 \in [0,1]$.
For example $a\diamondsuit b\diamondsuit c\diamondsuit d = \max\{a,b,c,d\}$ *or* $a\diamondsuit b\diamondsuit c\diamondsuit d = \min\{a+b+c+d,1\}$.

Definition 23[7] *Let* $(X,M,N,*,\diamondsuit)$ *be an intuitionistic fuzzy 3–metric space if* X *is an arbitrary set,* $*$ *is a continuous t–norm,* $\diamondsuit$ *is a continuous t–conorm and* M,N *are intuitionistic fuzzy sets on* $X^4 \times [0,\infty) \longrightarrow [0,1]$ *satisfying the following conditions:*

(i) $M(x,y,z,w,t)+N(x,y,z,w,t) \leq 1$,
(ii) $M(x,y,z,w,0) = 0$,
(iii) $M(x,y,z,w,t) = 1$ *for all* $t > 0$.*Only when at least two of the three simplex* (x,y,z,w) *degenerate,*
(iv) $M(x,y,z,w,t) = M(x,w,z,y,t) = M(y,z,w,x,t)$,
(v) $M(x,y,z,w,t_1+t_2+t_3+t_4) \geq M(x,y,z,u,t_1) * M(x,y,u,w,t_2) * M(x,u,z,w,t_3) * M(u,y,z,w,t_4)$,
(vi) $M(x,y,z,w,.) : [0,\infty) \longrightarrow [0,1]$ *is left continuous,*
(vii) $\lim_{t\longrightarrow\infty} M(x,y,z,w,t) = 1$,
(viii)$N(x,y,z,w,0) = 1$,
(ix) $N(x,y,z,w,t) = 0$ *for all* $t > 0$.*Only when at least three simplex* (x,y,z,w) *degenerate,*
(x) $N(x,y,z,w,t) = N(x,w,z,y,t) = N(y,z,w,x,t)$,
(xi) $N(x,y,z,t_1+t_2+t_3+t_4) \leq N(x,y,z,u,t_1)\diamondsuit N(x,y,u,w,t_2)\diamondsuit N(x,u,z,w,t_3)\diamondsuit N(u,y,z,w,t_4)$,
(xii) $N(x,y,z,w,.) : [0,\infty) \longrightarrow [0,1]$ *is right continuous,*
(xiii) $\lim_{t\longrightarrow\infty} N(x,y,z,w,t) = 0$,

for all $x,y,z,w,u \in X$ *and* $t,t_1,t_2,t_3,t_4 > 0$. *The values* $M(x,y,z,w,t)$ *and* $N(x,y,z,w,t)$ *may interpret the degrees of nearness and non-nearness that the volume of the quadrilateral enlarged* (x,y,z,w) *with respect to* t *respectively.*

Definition 24 *Let* $(X,M,N,*,\diamondsuit)$*be an intuitionistic fuzzy 3–metric space. Then a sequence* $\{x_n\}$ *in* X *is said to be convergent to a point* $x \in X$ *for all* $t > 0$,
$\lim_{n\longrightarrow\infty} M(x_n,x,z,w,t) = 1$ *and* $\lim_{n\longrightarrow\infty} N(x_n,x,z,w,t) = 0$.

Definition 25 *Let* $(X,M,N,*,\diamondsuit)$*be an intuitionistic fuzzy 3–metric space.Then a sequence* $\{x_n\}$ *in* X *is said to be Cauchy sequence if, for all* $t > 0$ *and* $p > 0$,
$\lim_{n\longrightarrow\infty} M(x_{n+p},x_n,z,w,t) = 1$ *and* $\lim_{n\longrightarrow\infty} N(x_{n+p},x_n,z,w,t) = 0$.

Definition 26 *An intuitionistic fuzzy 3–metric space* $(X,M,N,*,\diamondsuit)$ *is said to be complete if and only if every Cauchy sequence in* X *is convergent.*

Lemma 2.1 Let $(X,M,N,*,\diamondsuit)$ is an intuitionistic fuzzy 3–metric space, then M and N are continuous function on $X^4 \times (0,\infty)$.

Lemma 2.2 Let $(X,M,N,*,\diamondsuit)$ is an intuitionistic fuzzy 3–metric space,if for all $x,y,z,w \in X$,$t > 0$ and for a number $k \in (0,1)$
$M(x,y,z,w,kt) \geq M(x,y,z,w,t)$ *and* $N(x,y,z,w,kt) \leq N(x,y,z,w,t)$.

Definition 27 *Two self-mappings* A *and* B *of a intuitionistic fuzzy 3–metric* $(X,M,N,*,\diamondsuit)$ *are said to be weakly compatible if* $ABx = BAx$ *when* $Ax = Bx$ *for some* $x \in X$.

Definition 28 *Two self-mappings* A *and* B *of a intuitionistic fuzzy 3–metric* $(X,M,N,*,\diamondsuit)$ *are said to be compatible if* $\lim_{n\longrightarrow\infty} M(ABx_n,BAx_n,z,w,t) = 1$, $\lim_{n\longrightarrow\infty} N(ABx_n,BAx_n,z,w,t) = 0$ *forall* $z,w \in X$ *and* $t > 0$ *whenever* $\{x_n\}$ *is a sequence in* X *such that* $\lim_{n\longrightarrow\infty} Ax_n = \lim_{n\longrightarrow\infty} Bx_n = x$ *for some* $x \in X$.

Definition 29 *Let* A *and* B *be two self-mappings of a intuitionistic fuzzy 3–metric* $(X,M,N,*,\diamondsuit)$.*We say that* A *and* B *satisfy the property* $(E.A)$ *if there exists a sequence* $\{x_n\}$ *such that* $\lim_{n\longrightarrow\infty} Ax_n = \lim_{n\longrightarrow\infty} Bx_n = x$ *for some* $x \in X$.

3 Main results

Theorem 1. *Let* $(X,M,N,*,\diamondsuit)$ *be intuitionistic fuzzy 3–metric such that* $a*b = \min\{a,b\}$ *and* $a\diamondsuit b = \max\{a,b\}$ *for* $a,b \in X$ *and let* A *and* B *be two weakly compatible of* X *into itself such that*
(i)$AX \subset BX$,
(ii)A *and* B *satisfy the property* $(E.A)$,
(iii)
$$M(Ax,Ay,z,w,kt) \geq \min\{M(Bx,By,z,w,t),M(Bx,Ax,z,w,t),M(By,Ay,z,w,t), M(By,Ax,z,w,t),M(Bx,Ay,z,w,t)\}$$
$$N(Ax,Ay,z,w,kt) \leq \max\{N(Bx,By,z,w,t),N(Bx,Ax,z,w,t),N(By,Ay,z,w,t), N(By,Ax,z,w,t),N(Bx,Ay,z,w,t)\}$$

If AX *or* BX *is a complete subspace of* X, *then* A *and* B *have a unique common fixed point.*

Proof. *Since* A *and* B *satisfy the property* $(E.A)$, *there exists in* X *a sequence* $\{x_n\}$ *satisfying* $\lim_{n\longrightarrow\infty} Bx_n = \lim_{n\longrightarrow\infty} Ax_n = v$, *for some* $v \in X$.
Suppose that BX *is complete. Then* $\lim_{n\longrightarrow\infty} Bx_n = Bu$ *for some* $u \in X$.*Also* $\lim_{n\longrightarrow\infty} Ax_n = Bu$. *We show that* $Au = Bu$.
Suppose that $Au \neq Bu$.*From (iii) we take* $x = x_n, y = u$

$$M(Ax_n,Au,z,w,kt) \geq \min\{M(Bx_n,Bu,z,w,t),M(Bx_n,Ax_n,z,w,t),M(Bu,Au,z,w,t), M(Bu,Ax_n,z,w,t),M(Bx_n,Au,z,w,t)\}$$

$N(Ax_n,Au,z,w,kt) \leq \max\{N(Bx_n,Bu,z,w,t),N(Bx_n,Ax_n,z,w,t),N(Bu,Au,z,w,t),$

$$N(Bu,Ax_n,z,w,t),N(Bx_n,Au,z,w,t)\}$$

Letting $n \longrightarrow \infty$ *we get*
$M(Bu,Au,z,w,kt) \geq \min\{M(Bu,Bu,z,w,t),M(Bu,Bu,z,w,t),M(Bu,Au,z,w,t),$

$$M(Bu,Bu,z,w,t),M(Bu,Au,z,w,t)\}$$

$N(Bu,Au,z,w,kt) \leq \max\{N(Bu,Bu,z,w,t),N(Bu,Bu,z,w,t),N(Bu,Au,z,w,t),$

$$N(Bu,Bu,z,w,t),N(Bu,Au,z,w,t)\}$$

$M(Bu,Au,z,w,kt) \geq M(Bu,Au,z,w,t)$, $N(Bu,Au,z,w,kt) \leq N(Bu,Au,z,w,t)$, *by using lemma 2.1 we have* $Au = Bu$.
Since A *and* B *are weakly compatible,* $ABu = BAu$ *thus,* $AAu = ABu = BAu = BBu$.
We show that Au *is common fixed point of* A *and* B. *Suppose that* $Au \neq AAu$. *Then, we take* $x = u, y = Au$ *and we have*
$M(Au,AAu,z,w,kt) \geq \min\{M(Bu,BAu,z,w,t),M(Bu,Au,z,w,t),M(BAu,AAu,z,w,t),$

$$M(BAu,Au,z,w,t),M(Bu,AAu,z,w,t)\}$$

$N(Au,AAu,z,w,kt) \leq \max\{N(Bu,BAu,z,w,t),N(Bu,Au,z,w,t),N(BAu,AAu,z,w,t),$

$$N(BAu,Au,z,w,t),N(Bu,AAu,z,w,t)\}$$

$M(Au,AAu,z,w,kt) \geq M(Au,AAu,z,w,t)$, $N(Au,AAu,z,w,kt) \leq N(Au,AAu,z,w,t)$
Hence by lemma 2.1, we have $Au = AAu$ *and* $BAu = AAu = Au$.*The proof is similar when* AX *is assumed to be a complete subspace of* X, *since* $AX \subset BX$.
Then the common fixed point is unique.

Theorem 2.*Let* $(X,M,N,*,\diamondsuit)$ *be an intuitionistic fuzzy 3–metric space such that* $a*b = \min\{a,b\}$, $a\diamondsuit b = \max\{a,b\}$ *and* $t*t \geq t$. *Let* A,B,P *and* Q *be mappings of* X *into itself such that*
(2.1)$AX \subset QX$ *and* $BX \subset PX$;
(2.2)(A,P) *or* (B,Q) *satisfies the property (E.A);*
(2.3)(A,P) *and* (B,Q) *are weakly compatible;*
(2.4)there exists a number $k \in (0,1)$ *such that*
$M(Ax,By,z,w,kt) \geq \min\{M(Px,Qy,z,w,t),M(Px,By,z,w,t),M(Qy,By,z,w,t)\}$
$N(Ax,By,z,w,kt) \leq \max\{N(Px,Qy,z,w,t),N(Px,By,z,w,t),N(Qy,By,z,w,t)\}$
For all $x,y,z,w \in X$
(2.5)One of AX,BX,PX *or* QX *is a complete subspace of* X.
Then A,B,P *and* Q *have a unique common fixed point in* X .

Proof. *Suppose that* (B,Q) *satisfies the property (E.A).Then there exists a sequence* $\{x_n\}$ *in* X *such that* $\lim_{n\longrightarrow\infty} Bx_n = \lim_{n\longrightarrow\infty} Qx_n = u$ *for some* $u \in X$.
Since $BX \subset PX$, *there exists in* X *a sequence* $\{y_n\}$ *such that* $Bx_n = Py_n$. *Hence* $\lim_{n\longrightarrow\infty} Py_n = u$. *Let us show that* $\lim_{n\longrightarrow\infty} Ay_n = u$. *From(2.4) we have*
$M(Ay_n,Bx_n,z,w,kt) \geq \min\{M(Py_n,Qx_n,z,w,t),M(Py_n,Bx_n,z,w,t),M(Qx_n,Bx_n,z,w,t)\}$

$$\geq \min\{M(Py_n,Qx_n,z,w,t),1,M(Qx_n,Px_n,z,w,t)\}$$

$$\geq M(Py_n,Qx_n,z,w,t)$$

$N(Ay_n,Bx_n,z,w,kt) \leq \max\{N(Py_n,Qx_n,z,w,t),N(Py_n,Bx_n,z,w,t),N(Qx_n,Bx_n,z,w,t)\}$

$$\leq \max\{N(Py_n,Qx_n,z,w,t),0,N(Qx_n,Px_n,z,w,t)\}$$

$$\leq N(Py_n,Qx_n,z,w,t)$$

Letting $n \longrightarrow \infty$, *we get* $\lim_{n\longrightarrow\infty} M(Ay_n,Bx_n,z,w,kt) = 1$, $\lim_{n\longrightarrow\infty} N(Ay_n,Bx_n,z,w,kt) = 0$. *Hence we deduce that* $\lim_{n\longrightarrow\infty} Ay_n = u$. *Suppose* PX *is a complete subspace of* X. *Then,* $Pv = u$ *for some* $v \in X$. *Subsequently, we have* $\lim_{n\longrightarrow\infty} Ay_n = \lim_{n\longrightarrow\infty} Bx_n = \lim_{n\longrightarrow\infty} Qx_n = \lim_{n\longrightarrow\infty} Py_n = Pv$.
From (2.4) we have
$M(Av,Bx_n,z,w,kt) \geq \min\{M(Pv,Qx_n,z,w,t),M(Pv,Bx_n,z,w,t),M(Qx_n,Bx_n,z,w,t)\}$
$N(Av,Bx_n,z,w,kt) \leq \max\{N(Pv,Qx_n,z,w,t),N(Pv,Bx_n,z,w,t),N(Qx_n,Bx_n,z,w,t)\}$
Letting $n \longrightarrow \infty$ *we have* $\lim_{n\longrightarrow\infty} M(Av,pv,z,w,kt) = 1$, $\lim_{n\longrightarrow\infty} N(Av,pv,z,w,kt) = 0$.
Hence, we deduce that $Av = Pv$. *Since* A *and* P *are weakly compatible,*$APv = PAv$ *and then* $AAv = APv = PAv = PPv$.
On the other hand, since $AX \subset QX$, *there exists a point* $s \in X$ *such that* $Av = Qs$. *We show that* $Qs = Bs$. *Using (2.4) we have*
$M(Av,Bs,z,w,kt) \geq \min\{M(Pv,Qs,z,w,t),M(Pv,Bs,z,w,t),M(Qs,Bs,z,w,t)\}$

$$\geq M(Av,Bs,z,w,t)$$

$N(Av,Bs,z,w,kt) \leq \max\{N(Pv,Qs,z,w,t),N(Pv,Bs,z,w,t),N(Qs,Bs,z,w,t)\}$

$$\leq N(Av,Bs,z,w,t)$$

By Lemma 2.1 we have $Av = Bs$, *therefore* $Av = Pv = Qs = Bs$. *Since* B *and* Q *are weakly compatible implies that* $BQs = QBs$ *and* $QQs = QBs = BQs = BBs$. *we show that* Av *common fixed point of* A,B,P*and* Q. *Using(2.4) we have*
$M(Av,AAv,z,w,kt) = M(AAv,Bs,z,w,kt) \geq \min\{M(PAv,Qs,z,w,t),M(PAv,Bs,z,w,t)$
,

$$,M(Qs,BAv,z,w,t)\}$$

$\geq M(AAv, Av, z, w, t)\}$

$N(Av, AAv, z, w, kt) = N(AAv, Bs, z, w, kt) \leq \max\{N(PAv, Qs, z, w, t), N(PAv, Bs, z, w, t)$

,

$, N(Qs, BAv, z, w, t)\}$

$\leq N(AAv, Av, z, w, t)\}$

Therefore by Lemma 2.1, we have $Av = AAv = PAAv$ and Av is common fixed point of A and P.
Similarly, we show that Bs is common fixed point of B and Q. Since $Av = Bs$,we conclude that Au is common fixed point of A, B, P and Q.
The proof is similar when QX is assumed to be complete subspace of X. The cases in which AX OR BX is complete subspace of X are similar to the cases in which PX or QX, respectively, is complete since $AX \subset QX$ and $BX \subset PX$.
If $Av = Bv = Pv = Qv = v$ and $As = Bs = Ps = Qs = s$, using (2.4), we have
$M(v, s, z, w, kt) = M(Av, Bs, z, w, kt) \geq \min\{M(Pv, Qs, z, w, t), M(Pv, Bs, z, w, t)$

$, M(Qs, Bs, z, w, t)\}$

$\geq M(v, s, z, w, t)\}$

$N(v, s, z, w, kt) = N(Av, Bs, z, w, kt) \leq \max\{N(Pv, Qs, z, w, t), N(Pv, Bs, z, w, t)$

$, N(Qs, Bs, z, w, t)\}$

$\leq N(v, s, z, w, t)\}$

By Lemma 2.1, we obtain $v = s$. Then, the common fixed point is unique.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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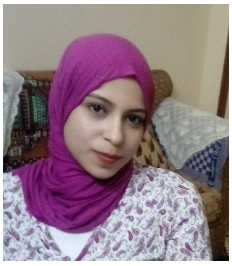

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