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Common Fixed Point Theorem In Fuzzy Metric Space With Implicit Relation And Property (E.A.)

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Abstract: *Aim the of present paper is to prove a common fixed point theorem for sixmaps via notion of pairwise commuting maps in fuzzy metric space satisfying contractive type implicit relation.Our result extends the result of Aalam Kumar andPant[1].*
Keywords *:Fuzzy Metric Space, weakly compatible maps ,implicit relation, property (E.A.).*

I. Introduction

Zadeh[21] introduced the concept of fuzzy sets in 1965 and in the next decadeKramosil and Michalek [10] introduced the concept of fuzzy metric spaces (briefly,FM-spaces) in 1975, which opened an avenue for further development of analysis insuch spaces. Consequently in due course of time some metric fixed point results were generalized to FM-spaces by various authors viz George and Veeramani [5], Grabiec
[6] and others.
For the last quarter of the twentieth century, there has been considerable interest to study the common fixed points of commuting maps and its weaker forms. In1994, Mishra et al. [14] extended the notion of compatible maps (introduced byJungck [8] in metric space) under the name of asymptotically commuting maps and Singh and Jain [19] extended the notion of weakly compatible maps (introduced byJungck [9] in metric space) to FM-spaces. In 2007, Pant and Pant [16] extended the study of common fixed points of a pair of non-compatible maps (studied by Pant[15] in metric space) and the property (E.A) to FM-spaces. Note that the study ofproperty (E.A) has been initiated by Aamri and Moutawakil [2] as a generalizationof the concept of non-compatible maps in metric spaces. Employing property (E.A),several results have been obtained in fuzzy metric space (see [1], [3], [11], [13]).
In2009, Imdad et al. [7] introduced the notion of pairwise commuting maps.Implicit relations are used as a tool for finding common fixed point of contractionmaps.
Recently, Aalam, Kumar and Pant [1] proved a common fixed point theoremwithout completeness of space and continuity of involved mappings in FM-space,which generalizes the result of Singh and Jain [19].
In the present paper, we prove a common fixed point theorem for six self-mapsin FM-space satisfying contractive type implicit relations. As an application, weextend our main result to four finite families of self-maps in FM-space.

II. Preliminaries

Definition 2.1 ([21]). Let X be any set. A fuzzy set A in X is a function with domain X and values in [0,1].

Definition 2.2 **([18]**). A binary operation* : [0,1] × [0,1] → [0,1] is called acontinuous t-norm if ([0,1],*) is an abelian topological monoid with the unit 1 such that $a * b \cdot \le c * d$, whenever $a \le c$ and $b \le d$ for all a, b,c,d ∈ [0,1].

Definition 2.3 ([10]). The triplet (X , M , *) is an FM-space if X is an arbitrary set ,* is a continuous t-norm and M is a fuzzy set in $X^2 \times [0;\infty)$ satisfying the followingconditions for all x, y ,z ∈X andt, s >0,
(1) M(x ,y , t) = 1 for all t >0 if and only if x = y;
(2) M(x ,y ,0) = 0;
(3) M(x , y , t) = M(y , x , t);
(4) M(x ,y ,t) * M(y, z,s) ≤ M(x, z, t + s);
(5) M(x , y, .) : [0,∞)→[0,1] is left continuous.

Example 2.4. Let (X; d) be a metric space. Define a * b= ab(or a * b = min{a,b})for all x , y ∈ X and

t>0,
M(x ,y ,t) = t /(t+ d(x, y).
Then (X,M, *) is an FM-space and the fuzzy metric M induced by the metric d is often referred to as the standard fuzzy metric.
Definition 2.5 **([**6]). Let (X,M, *) be an FM-space. Then
(1) a sequence $\{x_n\}$ in X is said to be convergent to a point $x \in X$ (denoted by $\lim_{n\to\infty} x_n = x$) if $\lim_{n\to\infty} M(x_n, x, t) = 1$ for all t >0.
(2) a sequence $\{x_n\}$in X is called a Cauchy sequence if $\lim_{n\to\infty} M(x_{n+p}, x_n, t) = 1$ for all t >0 and p>0.
(3) An FM-space in which every Cauchy sequence is convergent is called complete FM-Space.
Lemma 2.6**([6]).** For all, x; y ∈ X, M(x, y, .)is non-decreasing**.**

Lemma 2.7 **([12]**).Let (X,M, *) be an FM-space. Then M is a continuous functionon $X^2\times(0,\infty)$.

Definition 2.8 ([14]). Let A and S be self map from an FM-space (X,M, *) into itself .Then, the maps A and S are said to be compatible (or asymptotically commuting), if for all t
$\lim_{n\to\infty} M(ASx_n, SAx_n, t) = 1$.
whenever$\{x_n\}$ is a sequence in X such that $\lim_{n\to\infty} Ax_n = z = \lim_{n\to\infty} Sx_n$forsome z ∈ X.

Definition 2.9 ([20]). Let A and S be maps from an FM-space (X,M, *) into itself. Then, the mapsA and S aresaid to be weakly compatible if they commute at their coincidence points, that is, Az= Szimplies that ASz= SAz.
Remark 2.10.Every pair of compatible maps is weakly compatible but converse is not always true.

Definition 2.11 ([16]). Let A and S be two self-maps of an FM-space (X , M , *).We say that A and S satisfy the property (E.A) if there exists a sequence $\{x_n\}$ such that $\lim_{n\to\infty} Ax_n = \lim_{n\to\infty} Sx_n = z$ for some z∈ X.
Notice that weakly compatible and property (E.A) are independent to each other (see [17], Example 2.2).
Remark 2.12.From Definition 2.11, it is inferred that two self maps A and S onan FM-space (X , M , *) are non-compatible if and only if there exists at least onesequence $\{x_n\}$ in X such that
$\lim_{n\to\infty} Ax_n = z = \lim_{n\to\infty} Sx_n$for some z ∈ X, butfor some t >0,
either$\lim_{n\to\infty} M(ASx_n, SAx_n, t) \neq 1$ or the limit does not exist.
Therefore, it is easy to see that any two non-compatible self-maps of (X , M , *).satisfythe property E.A) from Definition2.11. But, two maps satisfying the property(E.A) need not be noncompatible (see - [4],Example 1).
Definition 2.13 ([7]). Two families of self-maps $\{ A_i \}$and $\{ B_j\}$are said to bepairwise commuting if:
(1) $A_iA_j = A_jA_i$, i, j ∈{1,2,…,m }
(2) $B_iB_j = B_jB_i$, i, j ∈ {1, 2,…,m }
(3) $A_iB_j = B_jA_i$,i, j ∈ {1, 2,…,m }

III. Implicit Relation

In our results, we deal with implicit relation used in [19]. Let Φ be the set of all real continuous functions,
ϕ: $(R^+)^4 \to R$, non-decreasing in the first argument and satisfying the following conditions:
(ϕ) for u, v ≥ 0, ϕ (u, v, u, v) ≥ 0 or ϕ(u, v, v, u) ≥ 0 implies that u ≥ v.
(ϕ_2) ϕ (u, u, 1, 1) ≥ 0 implies that u ≥ 1.
Example 3.1 Define $\phi(t_1,t_2,t_3,t_4) = at_1 + bt_2 + ct_3 + dt_4$, where a, b ,c, d are real constants. if a> max { b,d}
And a+c =b+d> 0, then $\phi \in \Phi$.

Aalam Kumar S and Pant B.D.Proved following fixed point theorem in fuzzy metric space :
Theorem 3.1 Let A,B,S and T be self maps of a fuzzy metric space (X , M ,*) satisfying following condition :
(i) $A(X) \subset T(X)$, $B(X) \subset S(X)$.
(ii) (A ,S) and (B,T) are weakly compatible pairs.
(iii) (A ,S) or (B ,T) satisfy the property (E.A.).
(iv) For some $\phi \in \Phi$ and for all x , y ∈ X, t > 0.
ϕ(M (Ax, By, kt) , M(Sx , Ty , t) , M (Ax , Sx ,t) M(By , Ty , t)) ≥ 0.
The range of one of the maps A, B ,S and T is a complete subspace of X, than A, B, S and T have a unique common fixed point in X.
In our main result we extends this result and utilize the notion of commuting pairwise due to Imdad et al.[7].

IV. Main Result

Theorem 4.1LetF,G,R,S,H and T be self-maps of a FM-space (X ,M ,*) satisfying

(i) (F,SR) or (G, TH) satisfies the property (E.A);

(ii) $\phi\begin{pmatrix} M(Fx,Gy,t), M(SRx,THy,t), \\ M(Fx,SRx,t), M(Gy,THy,t) \end{pmatrix} \geq 0$ for all t > 0. x , y ∈ X and for some $\phi \in \Phi$.

(iii) F(X) ⊂ TH(X) and G(X) ⊂ SR(X);

(iv) one of F(X) ,G(X) ,SR(X) AND TH(X) is a complete subspace of X.

Then the pair (F,SR) and (G,TH) have a unique common fixed point provided the pairs (F,SR) and (G,TH) commute pair wise (i.e. FS = SF ,GR=RG ,SR=RS,GT =TG.GH=HG and TH=HT).

Proof :If the pair G, TH) satisfies the property (E.A), then there exists a sequence{ y_n } in X such that $Gy_n \to z$ and $THy_n \to z$, for some z ∈ X as n →∞ .Since G(X) ⊂ SR(X) ,there exists a sequence { x_n }in X such that $Gy_n = SRx_n$. Hence,$SRx_n \to z$ as n →∞.

Now we show that $Fx_n \to z$ as n →∞. By putting $x = x_n$and $y = y_n$in (ii),we have

$$\phi\begin{pmatrix} M(Fx_n,Gy_n,t), M(SRx,THy_n,t), \\ M(Fx_n,SRx_n,t), M(Gy_n,THy_n,t) \end{pmatrix} \geq 0.$$

Let $Fx_n \to l (\neq z)$ for t >0 as n →∞ . Then, passing to limit as n →∞ ,we get

ϕ (M (*l*, z ,t) , M(z , z, t) , M(*l* , z, t) , M(z ,z ,t)) ≥ 0.

Or

ϕ (M(*l* , z, t) , 1,M(*l*, z, t) ,1) ≥ 0.

Using (ϕ_1), we get M (*l*, z ,t) ≥ 1 for all t >0 .Hence M (*l*, z ,t) = 1,i.e. *l* =z.

It follows that $Fy_n \to z$ as n →∞ .Suppose that SR(X) is a complete subspace of X.

Then, z = SRufor some u ∈ X. Putting x = u and $y = y_n$in (2), we have

$$\phi\begin{pmatrix} M(Fu,Gy_n,t), M(SRu,THy_n,t), \\ M(Fu,SRu,t), M(Gy_n,THy_n,t) \end{pmatrix} \geq 0.$$

Letting n→∞ ,

ϕ (M (Fu, z ,t) , M(z , z, t) , M(Fu , z, t) , M(z ,z ,t)) ≥ 0.

Or

ϕ(M(Fu , z, t) , 1, M (Fu, z, t) ,1) ≥ 0.

Using (ϕ_1), we get M(Fu, z, t) ≥ 1 for all t >0. Hence, M(Fu, z, t) = 1 i.e. Fu = z.Thus Fu = SRu= z which shows that the pair (F, S) has a point of coincidence.

On the other hand, since F(X) ⊂ TH(X) and Fu = z, there exists a point v ∈ X such that THv= z. Now we show that THv= Gv. By putting x = u and y = v in(ii) we have

$$\phi\begin{pmatrix} M(Fu,Gv,t), M(SRu,THv,t), \\ M(Fu,SRu,t), M(Gv,THv,t) \end{pmatrix} \geq 0.$$ Or

ϕ(M(z ,Gv , t),1,1, M(Gv ,z ,t)) ≥ 0.

Using (ϕ_1) we get M(z ,Gv , t) ≥ 1 for all t > 0.Hence M(z ,Gv , t) = 1,i.e. Gv = z.

Thus Gv= THv= z which shows that the pair (G, T) has a point of coincidence.

Since the pairs (F, SR) and (G, TH) are commuting pair wise i.e. FS = SF, FR =RF, SR = RS, GT = TG, GH = HG and TH = HT. It implies that both the pairs (F, SR) and (G, TH) are weakly compatible at u and v respectively,

i.e.z= Fu = SRu= Gv= THv, therefore Fz= F(SR)u = (SR)Fu = (SR)z and Gz= G(TH)v = (TH)Gv= THz. Now we assert that z is a fixed point of the self-maps F, S and R. Putting x = Rzand y = z in (ii), we have

$$\phi\begin{pmatrix} M(F(Rz),Gz,t), M(SR(Rz),THz,t), \\ M(F(Rz),SR(Rz),t), M(Gz,THz,t) \end{pmatrix} \geq 0.$$

ϕ (M (Rz, z ,t) , M(Rz , z, t) , M(Rz , Rz , t) , M(z ,z ,t)) ≥ 0.

ϕ (M (Rz, z ,t) , M(Rz , z, t) , 1 ,1) ≥ 0.

Using (ϕ_2),we get M(Rz, z, t) ≥ 1 for all t > 0.Hence M(Rz, z, t)= 1.

Thus Rz= z. Hence S(z) = S(Rz) = z. Therefore, z = Fz= Sz= Rz. On using (ii) with x = z, y = Hz, we have

$$\phi\begin{pmatrix} M(Fz,G(Hz),t), M(SRz,TH(Hz),t), \\ M(Fz,SRz,t), M(G(Hz),TH(Hz),t) \end{pmatrix} \geq 0.$$ And so

ϕ(M(z , Hz , t), M(z, Hz ,t) , M(z , z, t) ,M(Hz ,Hz ,t)) ≥ 0 or

ϕ(M(z , Hz , t), M(z, Hz ,t) , M(z , z, t) , 1 ,1) ≥ 0 or

Using (ϕ_2) we get M(z , Hz , t) ≥ 1for all t > 0.Hence M(z , Hz , t)=1.Thus
conclude that z is a common fixed point of self-maps F, G, R,S, H and T .Let w be another common fixed point of self-maps F, G, R,S, H and T then on using (ii)with x = z, y = w, we have
ϕ(M(Fz ,Bw, t),M(Sz, Tw ,t) ,M(FzSz , t) , M(Gw, Tw, t)) ≥ 0 or
ϕ(M (z ,w, t),M (z, w ,t) ,M (z, z , t) , M(w, w, t)) ≥ 0
ϕ(M (z ,w, t),M (z, w ,t) , 1 ,1) ≥ 0
Using (ϕ_2), we get M(z ,w, t) ≥ 1 for all t >0. Hence, M (z ,w, t) = 1. Therefore,z = w and the common fixed point is unique.
We can also prove the same result if the pair (F, S) satisfies the property (E.A). The proof is similar when TH(X) is assumed to be a complete subspace of X. The remaining two cases pertain essentially to the previous cases. If we assume that F(X) is a complete subspace of X, then z ∈ F(X) ⊂ TH(X) or G (X) is a complete subspace of X, then z ∈ G(X) ⊂ SR(X).
Thus we can establish that both the pairs (F,SR) and (G, TH) have a point of coincidence each.
This completes our proof.

On taking R = H = IX (the identity maps on X) in Theorem 4.2 we get the result of Aalam et.al.[1].
Corollary 4.2([1] Theorem 4.1) Let A,B,S and T be self maps of an FM-Space(X , M ,*) satisfying
(i) (A,S) or (B,T) satisfies the property (E.A.)
(ii) ϕ(M (Ax, By, kt) , M(Sx , Ty , t) , M (Ax , Sx ,t) M(By , Ty , t)) ≥ 0,
for all t >0 and x ,y ∈ X and some $\phi \in \Phi$.
(iii) A(X) ⊂ T(X), B(X) ⊂ S(X)
(iv) One of A(X) ,B(X), S(X) and T(X) is a complete subspace of X.
Then the pairs (A; S) and (B; T) have a point of coincidence each. Moreover, A , B,Sand T have a unique common fixed point provided both the pairs (A,S) and (B, T)are weakly compatible.
Now we give an example which illustrates **Corollary 4.2**.

Example 4.3 Let X = [2,20) and d be the usual metric on X. For each t ∈[0,∞) define

$$M(x,y,t) = \begin{cases} \dfrac{t}{t+|x-y|} & if\ t > 0 \\ 0 & \text{if } t = 0 \end{cases}$$

For all x, y ∈ X.clearly (X , M ,*) is an FM-Space, where * is defined as a*b = ab.
Let$\Phi : (R^+)^4 \to R$,be defined as in example 3.1 and define the self maps A, B ,S and T by

$$A(x) = \{\ 2\ ,\ \text{if } x \geq 2.\} \quad S(x) = \begin{cases} 2, if\ x = 2 \\ 6, if\ x > 2 \end{cases}$$

$$B(x) = \begin{cases} 2, if\ x = 2 \text{ or } x > 5 \\ 6, \text{ if } 2 < x \leq 5 \end{cases} \qquad T(x) = \begin{cases} 2, \text{ if } x=2 \\ 12, \text{ if } 2 < x \leq 5 \\ (x+1)/3, \text{ if } x > 5 \end{cases}$$

Then A,B,Sand T satisfy all the conditions of Corollary 4.2 and have a unique common fixed point x = 2. Clearly, the pairs (A,S) and (B, T) are noncompatibleif we assume that { x_n }is a sequence defined as
$x_n = 5 + 1/n$, n ≥ 1. Also, the pairs(A, S) and (B, T) are weakly compatible since they commute at their coincidencepoints. It can also be seen that B and T satisfy the property (E.A) and all the mapsA,B,Sand T are discontinuous at the common fixed point.
On taking A = B and S = T in Corollary 4.2, we get the following result:

Corollary 4.4.Let A and S be self-maps of an FM-space (X , M ,*)satisfying
(1) (A, S) satisfies the property (E.A);
(2)ϕ (M(Ax, Ay, t), M(Sx, Sy, t),M(Ax, Sx, t),M(Ay, Sy, t)) ≥0, for all t > 0 ;
x, y ∈X and for some $\phi \in \Phi$;
(3) A(X) ⊂ S(X);
(4) One of A(X) and S(X) is a complete subspace of X.
Then the pair (A, S) has a point of coincidence. Moreover, A and S have a unique common fixed point provided the pair (A,S) is weakly compatible.
As an application of Corollary 4.2, we extend the related result to four finitefamilies of self-maps on FM-spaces.

Theorem 4.5.Let{ $A_1,A_2,\ldots,A_m$}, { $B_1,B_2,\ldots,B_p$}, { $S_1,S_2,\ldots,S_n$} and { $T_1,T_2,\ldots,T_q$} be four finite families of self-maps of an FM-space (X, M ,*) such that A= $A_1A_2\ldots A_m$, B=$B_1B_2\ldots B_p$, S= $S_1S_2\ldots S_n$
T=$T_1T_2\ldots T_q$ which satisfy conditions (i)- (iv) of corollary 4.2 Then the pairs (A, S) and (B,T) have a point of coincidence each. Moreover, if the family { A_i} (i= 1,2,…,m)commute pairwise with the family {S_j}(j = 1,2,…,n)whereas the family {B_r} (r= 1,2,…,p)commute pairwise with the family { T_k}(k = 1,2,…,q) then (for all i ∈ { i= 1,2,…,m }, { j = 1,2,…,n },{ r= 1,2,…,p } ,{ k = 1,2,…,q })A_i,B_j, $S_r$and T_k have a common fixed point.

Proof.Using the terminology of Theorem 4.1, the proof of this theorem is similarto that of Theorem 3.1 contained in [7], hence it is omitted.

Remark 4.6. Theorem 4.5 improves and extends the results of Singh and Jain [19] and Aalam et al. [1] to four finite families of self-maps.

By setting $A_1 = A_2 = \ldots = A_m = A$, $B_1 = B_2 = \ldots = B_p = B$, $S_1 = S_2 = \ldots = S_n = S$ and $T_1 = T_2 = \ldots = T_q = T$ in Theorem 4.5, we deduce the following:

Corollary 4.7.Let A,B, S and T be self-maps of an FM-space (X ,M ,*) satisfying
(1) (A^m ,S^n) or (B^p , T^q) satisfies the property (E.A);

$$(2)\phi\begin{pmatrix} M\left(A^m x,\ B^p y\ ,t\ \right), M\left(S^n x\ ,T^q y\ ,t\right) \\ M\left(A^m x,\ S^n x\ ,t\right),\ M\left(B^p y, T^q y, t\right) \end{pmatrix} \geq 0.$$

for all t >0, x, y ∈ X, forsome ϕ ∈ Φ and m, n, p and q are fixed positive integers;
(3) $A^m(X) \subset T^q(X)$, $B^p(X) \subset S^n(X)$;
(4) One of $A^m(X)$, $B^p(X)$, $S^n(X)$ and $T^q(X)$ is a complete subspace of X.
Then the pairs (A^m ,Sn) and (B^p ,T^q) have a point of coincidence each. Moreover A , B, S and T have a unique common fixed point provided both the pairs (A^m , S^n)and (B^p , T^q) commute.

Remark 4.8. From the results, it is asserted that property (E.A) buys containment of ranges without any continuity requirements, besides minimize the commutativity conditions of the maps to the commutativity at their points of coincidence. More-over, property (E.A) allows replacing the completeness requirement of the whole space with a more natural condition of completeness of the range space.

V. Conclusion

We established a common fixed point theorem in fuzzy metric space along with property (E.A.)and implicit relation. In this theorem we have used the mappings which are pairwise commutative. The result has a number of applications in various branch of Mathematics and Mathematical Sciences.

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