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COMMON FIXED POINT THEOREM IN MENGER SPACE USING $(CLRg)$ PROPERTY

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ABSTRACT. The object of this paper is to establish a common fixed point theorem for semi-compatible pair of self maps by using CLRg Property in menger space.

1. INTRODUCTION

There have been a number of generalizations of metric space. One such generalization is Menger space initiated by Menger [2]. It is a probabilistic generalization in which we assign to any two points x and y, a distribution function $F_{x,y}$. Schweizer and Sklar [6] studied this concept and gave some fundamental results on this space. Sehgal and Bharucha-Reid [7] obtained Banach contraction principal in a complete Menger space, which is a milestone in developing fixed point theory in Menger space. Sessa [8] initiated the tradition of improving comutativity in fixed point theorems by introducing the notion of weakly commuting maps in metric spaces. Jungck [1] soon enlarged this concept to compatible maps. The notion of compatible mapping in a Menger space has been introduced by Mishra [3]. Pant [4] introduced the notion of reciprocal continuity of mappings in metric spaces. Popa [5] proved theorem for weakly compatible non-continuous mapping using implicit relation. Singh and Jain [9] have been introduced semi-compatible , compatible and weak compatible maps in Menger space.

B. Singh et. al. [10] introduced the notion of semi compatible maps in fuzzy metric space. In 2011, Sintunayarat and Kuman [11] introduced the concept of common limit in the range property. Chouhan et. al. [12] utilize the notion of common limit range property to prove fixed point theorems for weakly compatible mapping in fuzzy metric space.

In 2012, Jain et al. [13] extended the concept of CLRg property in the coupled case and also established a common fixed point theorem for weakly compatible

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mappings in fuzzy metric spaces. Most recently, Hierro and Sintunavarat [14] generalized the results in [13] by using the generalized contractive conditions and the CLRg property in fuzzy metric spaces.

2. Preliminaries

Definition 2.1 A mapping $F : R \to R^+$ is called a distribution if it is non-decreasing left continuous with $\inf\{F(t) : t \in R\} = 0$ and $\sup\{F(t) : t \in R\} = 1$. We shall denote by L the set of all distribution functions while H will always denote the specific distribution function defined by

$$H(x) = \begin{cases} 0, & x \leq 0 \\ 1, & x > 0. \end{cases}$$

Definition 2.2 A Probabilistic metric space (PM-space) is an ordered pair (X, F), where X is an abstract set of elements and $F : X \times X \to L$, defined by $(p, q) \to F_{p,q}$, where L is the set of all distribution functions i.e. $L = \big\{F_{p,q/p,q} \in X\big\}$, if the functions $F_{p,q}$ satisfy.
(a) $F_{p,q}(x) = 1$, for all $x > 0$, if and only if $p = q$;
(b) $F_{p,q}(0) = 0$;
(c) $F_{p,q} = F_{q,p}$;
(d) If $F_{p,q}(x) = 1$ and $F_{q,r}(y) = 1$ then $F_{p,r}(x + y) = 1$.

Definition 2.3 A mapping $t : [0, 1] \times [0, 1] \to [0, 1]$ is called a t-norm if
(a) $t(a, 1) = a$;
(b) $t(a, b) = t(b, a)$;
(c) $t(c, d) \geq t(a, b)$ for $c \geq a, d \geq b$;
(d) $t\big(t(a, b), c\big) = t\big(a, t(b, c)\big)$,
for all $a, b, c, d \in [0, 1]$.

Definition 2.4 A Menger space is a triplet (X, F, t) where (X, F) is PM-space and t is a t-norm such that $\forall\, p, q, r \in X$ and $\forall\, x, y \geq 0$

$$F_{p,r}(x + y) \geq t\big(F_{p,q}(x), F_{q,r}(y)\big).$$

Schweizer and Sklar [6] proved that if (X, F, t) is a Menger space with $\sup_{0<x<1} t(x, x) = 1$, then (X, F, t) is a Hausdorff topological space in the topology induced by the family of (ε, λ)-neighborhoods, $\big\{U_p(\varepsilon, \lambda) : p \in X, \varepsilon > 0, \lambda > 0\big\}$, where $U_p(\varepsilon, \lambda) = \big\{x \in X : F_{x,p}(\varepsilon) > 1 - \lambda\big\}$.

Definition 2.5 Let (X, F, t) be a Menger space with $\sup_{0<x<1} t(x, x) = 1$. A sequence $\{p_n\}$ in X is said to converge to a point p in X (written as $p_n \to p$) if for every $\varepsilon > 0$ and $\lambda > 0, \exists$ an integer $M(\varepsilon, \lambda)$ such that $F_{pn,p}(\varepsilon) > 1 - \lambda,\ \forall\, n \geq M(\varepsilon, \lambda)$. Further, the sequence is said to be a cauchy sequence if for each $\varepsilon > 0$ and $\lambda > 0, \exists$, an integer $M(\varepsilon, \lambda)$ such that $F_{pn,pm}(\varepsilon) > 1 - \lambda,\ \forall\, n, m \geq M(\varepsilon, \lambda)$. A Menger space (X, F, t) is said to be complete if every cauchy sequence in it converges to a point of it.
A complete metric space can be treated as a complete menger space in the following way.

Proposition 2.6 If (X,d) is a metric space then the metric d induces a mapping $X \times X \to L$, defined by $F_{p,q}(x) = H\big(x - d(p,q)\big),\ \forall\, p,q \in X$ and $x \in R$. Further, if $t : [0,1] \times [0,1] \to [0,1]$ is defined by $t(a,b) = \min\{a,b\}$, then (X,F,t) is a Menger space. It is complete if (X,d) is complete. Then space (X,F,t) so obtained is called the induced Menger space.

Proposition 2.7 In a Menger space (X,F,t), if $t(x,x) \geq x,\ \forall\, x \in [0,1]$ then $t(a,b) = \min\{a,b\},\ \forall\, a,b \in [0,1]$.

Definition 2.8 Self mappings A and S of a Menger space (X,F,t) are said to be weak compatible if they commute at their coincidence points i.e. $Ax = Sx$ for $x \in X$ implies $ASx = SAx$.

Definition 2.9 Self mappings A and S of a Menger space (X,F,t) are called compatible if $F_{AS_{pn},SA_{pn}}(x) \to 1,\ \forall\, x > 0$, whenever $\{p_n\}$ is a sequence in X such that $A_{pn}, S_{pn} \to u$, for some $u \in X$, as $n \to \infty$.

Definition 2.10 Self mappings A and S of a Manger space (X,F,t) are called semi-compatible if $F_{AS_{pn},Su}(x) \to 1,\ \forall\, x > 0$, whenever $\{p_n\}$ is a sequence in X such that $A_{p_n}, S_{p_n} \to u$, for some $u \in X$, as $n \to \infty$.

Proposition 2.11 If self mappings A and S of a Menger space (X,F,t) are semi-compatible then they are weak compatible.

Proposition 2.12 Let S and T be two self maps on a Menger space (X,F,t) with $t(a,a) \geq a,\ \forall\, a \in [0,1]$ of which T is continuous. Then (S,T) is semi-compatible if and only if (S,T) is compatible.

Lemma 2.13 Let $\{p_n\}$ be a sequence in a Menger space (X,F,t) with continuous t-norm $t(x,x) \geq x,\ \forall\, x \in [0,1]$. If $k \in (0,1)$ such that for all $x > 0$ and $n \in N,\ F_{pn,pn+1}(kx) \geq F_{pn-1,pn}(x)$. Then $\{p_n\}$ is a Cauchy sequence in X.

Definition 2.14 Let (X,F,t) be a menger space with continuous t-norm $t(x,x) \geq x,\ \forall\, x \in [0,1]$. Then two mappings $f,g : X \to X$ are said to have the $CLRg$ property if there exist a sequence $\{x_n\}$ in X and a point z in X such that

$$\lim_{n\to\infty} fx_n = \lim_{n\to\infty} gx_n = gz.$$

Definition 2.15 Two pairs (A,S) and (B,T) of self mappings of a menger space (X,F,t) are said to satisfy the (CLR_{ST}) property if there exist two sequence $\{x_n\}$ and $\{y_n\}$ in X such that

$$\lim_{n\to\infty} Ax_n = \lim_{n\to\infty} Sx_n = \lim_{n\to\infty} By_n = \lim_{n\to\infty} Ty_n = Sz, \text{ for some } z \in S(X) \text{ and } z \in T(X).$$

Definition 2.16 Two pairs (A,S) and (B,T) of self mappings of a menger space (X,F,t) are said to share $CLRg$ of S property if there exist two sequence $\{x_n\}$ and

$\{y_n\}$ in X such that

$$\lim_{n\to\infty} Ax_n = \lim_{n\to\infty} Sx_n = \lim_{n\to\infty} By_n = \lim_{n\to\infty} Ty_n = Sz, \text{ for some } z \in X.$$

Example 2.17 Let $X = [0, \infty)$ be the usual metric space. Define $g, h : X \to X$ by $gx = x+3$ and $gx = 4x$, for all $x \in X$. We consider the sequence $\{x_n\} = \{1+1/n\}$. Since, $\lim_{n\to\infty} gx_n = \lim_{n\to\infty} hx_n = 4 = h(1) \in X$. Therefore g and h satisfy the $(CLRg)$ property.

Definition 2.18 We will apply an implicit relation as, Let Φ be set of all real continuous functions $\phi : (R^+)^4 \to R$, nondecreasing in first argument and satisfying the following conditions:
(i) For $u, v \geq 0, \phi(u, v, v, u) \geq 0$ or $\phi(u, v, u, v) \geq 0$ imply $u \geq v$.
(ii) $\phi(u, u, 1, 1) \geq 0$ implies $u \geq 1$.

Example 2.19 Define $\phi(t_1, t_2, t_3, t_4) = 15t_1 - 13t_2 + 5t_3 - 7t_4$. Then $\phi \in \Phi$.

3. Main Result

In the following theorem we replace the continuity condition by using $(CLRg)$ property.

Theorem 3.1 Let A, B, S and T be self mapping on a complete menger space (X, F, t), satisfying
(a) $A(X) \subseteq T(X),\ B(X) \subseteq S(X)$,
(b) (B, T) is semi compatible,
(c) For some $\phi \in \Phi$, there exists $k \in (0, 1)$ such that for all $x, y \in X$ and $t > 0$,

$$\phi\Big(F_{Ax,By}(kt), F_{Sx,Ty}(t), F_{Ax,Sx}(t), F_{By,Ty}(kt)\Big) \geq 0 \tag{1}$$

$$\phi\Big(F_{Ax,By}(kt), F_{Sx,Ty}(t), F_{Ax,Sx}(kt), F_{By,Ty}(t)\Big) \geq 0 \tag{2}$$

If the pair (A, S) and (B, T) share the common limit in the range of S property, then A, B, S and T have a unique common fixed point.

Proof. Let x_0 be an arbitrary point in X. Since $A(X) \subset T(X)$ and $B(X) \subset S(X)$, there exist $x_1, x_2 \in X$ such that $Ax_0 = Tx_1$ and $Bx_1 = Sx_2$. Inductively, we construct the sequences $\{y_n\}$ and $\{x_n\}$ in X such that

$$y_{2n+1} = Ax_{2n} = Tx_{2n+1}, \qquad y_{2n+2} = Bx_{2n+1} = Sx_{2n+2}$$

for $n = 0, 1, 2, ...$ Now putting in (1) $x = x_{2n}, y = x_{2n+1}$, we obtain

$$\phi\Big(F_{Ax_{2n},Bx_{2n+1}}(kt), F_{Sx_{2n},Tx_{2n+1}}(t), F_{Ax_{2n},Sx_{2n}}(t), F_{Bx_{2n+1},Tx_{2n+1}}(kt)\Big) \geq 0$$

that is

$$\phi\Big(F_{y_{2n+1},y_{2n+2}}(kt), F_{y_{2n},y_{2n+1}}(t), F_{y_{2n+1},y_{2n}}(t), F_{y_{2n+2},y_{2n+1}}(kt)\Big) \geq 0$$

Using (i), we get

$$F_{y_{2n+2},y_{2n+1}}(kt) \geq F_{y_{2n+1},y_{2n}}(t) \tag{3}$$

Analogously, putting $x = x_{2n+2},\ y = x_{2n+1}$ in (2), we have

$$\phi\Big(F_{Ax_{2n},Bx_{2n+1}}(kt), F_{Sx_{2n+2},Tx_{2n+1}}(t), F_{Ax_{2n+2},Sx_{2n+2}}(kt), F_{Bx_{2n+1},Tx_{2n+1}}(t)\Big) \geq 0$$

$$\phi\Big(F_{y_{2n+3},y_{2n+2}}(kt), F_{y_{2n+2},y_{2n+1}}(t), F_{y_{2n+3},y_{2n+2}}(kt), F_{y_{2n+2},y_{2n+1}}(t)\Big) \geq 0$$

Using (i), we get

$$F_{y_{2n+3},y_{2n+2}}(kt) \geq F_{y_{2n+1},y_{2n+2}}(t) \tag{4}$$

Thus, from (3) and (4), for n and t, we have

$$F_{y_n,y_{n+1}}(kt) \geq F_{y_{n-1},y_n}(t)$$

Hence, by Lemma 2.13, $\{y_n\}$ is a Cauchy sequence in X, which is complete. Therefore, $\{y_n\}$ converges to z in X. That is $\{Ax_{2n}\}, \{Tx_{2n+1}\}, \{Bx_{2n+1}\}$ and $\{Sx_{2n}\}$ also converges to z in X.

Since the pair (A, S) and (B, T) share the common limit in the range of S property, then there exist two sequences $\{x_n\}$ and $\{y_n\}$ in X such that

$$\lim_{n\to\infty} Ax_n = \lim_{n\to\infty} Sx_n = \lim_{n\to\infty} By_n = \lim_{n\to\infty} Ty_n = Sz, \ \text{ for some } \ z \in X$$

First we prove that $Az = Sz$

By (1), putting $x = z$ and $y = y_n$, we get

$$\phi\Big(F_{Az,By_n}(kt), F_{Sz,Ty_n}(t), F_{Az,Sz}(t), F_{By_n,Ty_n}(kt)\Big) \geq 0$$

Taking limit $n \to \infty$, we get

$$\phi\Big(F_{Az,Sz}(kt), F_{Sz,Sz}(t), F_{Az,Sz}(t), F_{Sz,Sz}(kt)\Big) \geq 0$$

As ϕ is non-decreasing in first argument, we have

$$\phi\Big(F_{Az,Sz}(t), 1, F_{Az,Sz}(t), 1\Big) \geq 0$$

using (ii) , we have

$F_{Az,Sz}(t) \geq 1$ for all $t > 0$

$$\text{which gives } F_{Az,Sz}(t) = 1, \text{ that is } Az = Sz \tag{5}$$

$$\text{Since, } A(X) \subseteq T(X), \text{ therefore there exist } u \in X, \text{ such that } Az = Tu \tag{6}$$

Again by inequality (1), putting $x = z$ and $y = u$, we get

$$\phi\Big(F_{Az,Bu}(kt), F_{Sz,Tu}(t), F_{Az,Sz}(t), F_{Bu,Tu}(kt)\Big) \geq 0$$

using (5) and (6), we get

$$\phi\Big(F_{Tu,Bu}(kt), F_{Az,Az}(t), F_{Sz,Sz}(t), F_{Bu,Tu}(kt)\Big) \geq 0$$

$$\phi\Big(F_{Tu,Bu}(kt), 1, 1, F_{Bu,Tu}(kt)\Big) \geq 0$$

using (i) , we have $F_{Tu,Bu}(kt) \geq 1$ for all $t > 0$,

$$\text{which gives } F_{Tu,Bu}(kt) = 1. \text{ Thus } Tu = Bu \tag{7}$$

$$\text{Thus from } (5), (6), (7), \text{ we get } Az = Sz = Tu = Bu \tag{8}$$

Now we will prove that $Az = z$
By inequality (1), putting $x = z$ and $y = x_{2n+1}$,

$$\phi\Big(F_{Az,Bx_{2n+1}}(kt), F_{Sz,Tx_{2n+1}}(t), F_{Az,Sz}(t), F_{Bx_{2n+1},Tx_{2n+1}}(kt)\Big) \geq 0$$

taking limit $n \to \infty$, using (i) we get

$$\phi\Big(F_{Az,z}(kt), F_{Sz,z}(t), F_{Az,Sz}(t), F_{z,z}(kt)\Big) \geq 0$$
$$\phi\Big(F_{Az,z}(kt), F_{Az,z}(t), F_{Az,Az}(t), F_{z,z}(kt)\Big) \geq 0$$
$$\phi\Big(F_{Az,z}(kt), F_{Az,z}(t), 1, 1\Big) \geq 0$$

as ϕ is non-decreasing in first argument, we have

$$\phi\Big(F_{Az,z}(t), F_{Az,z}(t), 1, 1\Big) \geq 0$$

using (ii) , we have $F_{Az,z}(t) \geq 1$ for all $t > 0$, which gives $F_{Az,z}(t) = 1$. Thus $Az = z$.
Therefore from (8), we get $z = Tu = Bu$
Now Semicompatibility of (B, T) gives $BTy_{2n+1} \to Tz$, i. e. $Bz = Tz$ Now putting $x = z$ and $y = z$ in inequality (1), we get

$$\phi\Big(F_{Az,Bz}(kt), F_{Sz,Tz}(t), F_{Az,Sz}(t), F_{Bz,Tz}(kt)\Big) \geq 0$$
$$\phi\Big(F_{Az,Bz}(kt), F_{Az,Bz}(t), F_{Az,Az}(t), F_{Bz,Bz}(kt)\Big) \geq 0$$
$$\phi\Big(F_{Az,Bz}(kt), F_{Az,Bz}(t), 1, 1\Big) \geq 0$$

as ϕ is non-decreasing in first argument, we have

$$\phi\Big(F_{Az,Bz}(t), F_{Az,Bz}(t), 1, 1\Big) \geq 0$$

using (ii), we have $F_{Az,Bz}(t) \geq 1$ for all $t > 0$, which gives $F_{Az,Bz}(t) = 1$. Thus $Az = Bz$ and hence $Az = Bz = z$. combining all results , we get z = Az = Bz = Sz = Tz.
From this we conclude that z is a common fixed point of A, B, S and T.

Uniqueness. Let z_1 be another common fixed point of A, B, S and T. Then $z_1 = Az_1 = Bz_1 = Sz_1 = Tz_1$ and $z = Az = Bz = Sz = Tz$ then by inequality (1), putting $x = z$ and $y = z_1$, we get

$$\phi\Big(F_{Az,Bz_1}(kt), F_{Sz,Tz_1}(t), F_{Az,Sz}(t), F_{Bz_1,Tz_1}(kt)\Big) \geq 0$$
$$\phi\Big(F_{z,z_1}(kt), F_{z,z_1}(t), F_{z,z}(t), F_{z_1,z_1}(kt)\Big) \geq 0$$
$$\phi\Big(F_{z,z_1}(kt), F_{z,z_1}(t), 1, 1\Big) \geq 0$$

as ϕ is non-decreasing in first argument, we have

$$\phi\Big(F_{z,z_1}(t), F_{z,z_1}(t), 1, 1\Big) \geq 0$$

using (ii), we have $F_{z,z_1}(t) \geq 1$ for all $t > 0$, which gives $F_{z,z_1}(t) = 1$. Thus $z = z_1$.
Thus z is the unique common fixed point of A, B, S and T.

If we increase the number of self maps from four to six then we have the following.

Corollary 3.2 Let A, B, S, T, I and J be self mappings on a complete menger space (X, F, t), satisfying
(a) $AB(X) \subseteq J(X)$ and $ST(X) \subseteq I(X)$,
(b) (ST, J) is semi compatible,
(c) For some $\phi \in \Phi$, there exists $k \in (0,1)$ such that for all $x, y \in X$ and $t > 0$,

$$\phi\Big(F_{ABx,STy}(kt), F_{Ix,Jy}(t), F_{ABx,Ix}(t), F_{STy,Jy}(kt)\Big) \geq 0 \qquad (1)$$

$$\phi\Big(F_{ABx,STy}(kt), F_{Ix,Jy}(t), F_{ABx,Ix}(kt), F_{STy,Jy}(t)\Big) \geq 0 \qquad (2)$$

If the pair (AB, I) and (ST, J) share the common limit in the range of I property, then AB, ST, I and J have a unique common fixed point. Furthermore, if the pairs $(A, B), (A, I), (B, I), (S, T), (S, J)$ and (T, J) are commuting mapping then A, B, S, T, I and J have a unique common fixed point.

Proof. From theorem 3.1, z is the unique common fixed point of AB, ST, I and J. Finally, we need to show that z is also a common fixed point of A, B, S, T, I, and J. For this, let z be the unique common fixed point of both the pairs (AB, I) and (ST, J). Then, by using commutativity of the pair $(A, B), (A, I)$ and (B, I), we obtain

$$Az = A(ABz) = A(BAz) = AB(Az), \qquad Az = A(Iz) = I(Az),$$

$$Bz = B(ABz) = B\big(A(Bz)\big) = BA(Bz) = AB(Bz), \qquad Bz = B(Iz) = I(Bz), \qquad (3)$$

which shows that Az and Bz are common fixed point of (AB, I), yielding thereby

$$Az = z = Bz = Iz = ABz \qquad (4)$$

in the view of uniqueness of the common fixed point of the pair (AB, I). Similarly, using the commutativity of $(S, T), (S, J), (T, J)$, it can be shown that

$$Sz = Tz = Jz = STz = z. \qquad (5)$$

Now, we need to show that $Az = Sz(Bz = Tz)$ also remains a common fixed point of both the pairs (AB, I) and (ST, I). For this, put $x = z$ and $y = z$ in (1) and using (4) and (5), we get

$$\phi\Big(F_{ABz,STz}(kt), F_{Iz,Jz}(t), F_{ABz,Iz}(t), F_{STz,Jz}(kt)\Big) \geq 0$$

that is,

$$\phi\Big(F_{Az,Sz}(kt), F_{Az,Sz}(t), F_{Az,Az}(t), F_{Sz,Sz}(kt)\Big) \geq 0$$

as ϕ is nondecreasing in first argument, we have

$$\phi\Big(F_{Az,Sz}(t), F_{Az,Sz}(t), F_{Az,Az}(t), F_{Sz,Sz}(kt)\Big) \geq 0$$

$$\phi\Big(F_{Az,Sz}(kt), F_{Az,Sz}(t), 1, 1\Big) \geq 0$$

using (ii), we obtain $F_{Az,Sz}(t) \geq 1$ for all $t > 0$, which gives $F_{Az,Sz}(t) = 1$, that is, $Az = Sz$. Similarly, it can be shown that $Bz = Tz$. Thus, z is the unique common fixed point of A, B, S, T, I, and J.

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