Fixed Point Theorems In Fuzzy Menger Cone Metric Spaces

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Abstract—We define Fuzzy Menger Cone metric space and find some fixed point results for weak contraction condition. In support an example is furnished.

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1. INTRODUCTION

There have been a number of generalizations of metric space. One such generalization is Menger space introduced in 1942 by Menger [3] who used distribution functions instead of nonnegative real numbers as values of the metric, the notion of probabilistic metric space correspond to situations when we do not know exactly the distance between the two points but we know probabilities of possible values of this distance. A probabilistic generalization of metric spaces appears to be interest in the investigation of physical quantities and physiological threshold. It is also a fundamental importance in probabilistic functional analysis. Schweizer and Sklar [5] studied this concept and then the important development of Menger space theory was due to Sehgal and Bharucha-Reid [6]. The development of fixed point theory in PM-spaces was due to Schweizer and Sklar [4, 5].

In [1] Huang and Zhang generalized the concept of metric spaces, replacing the set of real numbers by an ordered Banach space, hence they have defined the cone metric spaces. They also described the convergence of sequences and introduced the notion of completeness in cone metric spaces. They have proved some fixed point theorems of contractive mappings on complete cone metric space with the assumption of normality of a cone. Subsequently, various authors have generalized the results of Huang and Zhang and have studied fixed point theorems for normal and non-normal cones. There exist a lot of works involving fixed points used the Banach contraction principle. This principle has been extended kind of contraction mappings by various authors [2, 8]. Further Rajesh Shrivastav, Vivek Patel and Vanita Ben Dhagat [7] have given the definition of fuzzy probabilistic metric space and proved fixed point theorem for such space.

2. PRELIMINARY

Definition 2.1: Let (E, τ) be a topological vector space and P a subset of E, P is called a cone if

1. P is non-empty and closed, P ≠ (0),
2. For x, y ∈ P and a, b ∈ R ⇒ ax + by ∈ P where a, b ≥ 0
3. If x ∈ P and −x ∈ P ⇒ x = 0

For a given cone P ⊆ E, a partial ordering ≥ with respect to P is defined by x ≥ y if and only if x − y ∈ P,

x > y if x ≥ y and x ≠ y,

while x>>y will stand for x − y ∈ int P, int P denotes the interior of P.

Definition 2.2: A fuzzy probabilistic metric space (FPM space) is an ordered pair (X, Fα) consisting of a nonempty set X and a mapping Fα from XxX into the collections of all fuzzy distribution functions Fα ∈ P(R) for all α ∈ [0,1]. For x, y ∈ X we denote the fuzzy distribution function Fα (x, y) by Fα(x,y) and Fα(x,y) (u) is the value of Fα(x,y) at u in R. The functions Fα(x,y) for all α ∈ [0,1] assumed to satisfy the following conditions:

(a) Fα(x,y)(u) = 1 ∀ u > 0 iff x = y,
(b) Fα(x,y)(0) = 0 ∀ x, y in X,
(c) Fα(x,y) = Fα(y,x) ∀ x, y in X,
(d) If Fα(0,0)(u) = 1 and Fα(0,v) (v) = 1 ⇒ Fα(x,v) (u+v) = 1 ∀ x, y, z ∈ X and u, v > 0.

Definition 2.3: A commutative, associative and non-decreasing mapping t: [0,1] × [0,1] → [0,1] is a t-norm if and only if

t(a,1) = a ∀ a ∈ [0,1], t(0,0) = 0
and t(c,d) ≥ t(a,b) for c ≥ a, d ≥ b.

Definition 2.4: A Fuzzy Menger space is a triplet (X,Fα,t), where (X, Fα) is an FPM-space, t is a t-norm and the generalized triangle inequality Fα(x,y) (u+v) ≥ t (Fα(x,z)(u), Fα(y,z)(v)) holds for all x, y, z in X and u, v > 0 and α ∈ [0,1].

The concept of neighbourhoods in Fuzzy Menger space is introduced as

Definition 2.5: Let (X,Fα,t) be a Fuzzy Menger space. If x ∈ X, ε > 0 and λ ∈ (0,1), then (ε,λ) - neighbourhood of x, called Uε(x,λ), is defined by
Definition 2.6: A sequence \( x_n \) in \((X,F_{a},t)\) is said to be convergent to a point \( x \) in \( X \) if for every \( \varepsilon > 0 \) and \( \lambda > 0 \), there exists an integer \( N = N(\varepsilon,\lambda) \) such that for all \( n > N \), and every \( \alpha \in [0,1] \), \( F_{a}(x_n, x; \varepsilon) < \lambda \).

Definition 2.7: A sequence \( x_n \) in \((X,F_{a},t)\) is said to be Cauchy sequence if for every \( \varepsilon > 0 \) and \( \lambda > 0 \), there exists a number \( N = N(\varepsilon,\lambda) \) such that for all \( \alpha \in [0,1] \), \( F_{a}(x_n, x_k; \varepsilon) < \lambda \) for all \( n, k > N \) and \( \alpha \in [0,1] \).

Definition 2.8: A Fuzzy Menger space \((X,F_{a},t)\) with the continuous t-norm is said to be complete if every Cauchy sequence in \( X \) converges to a point in \( X \) for all \( \alpha \in [0,1] \).

Lemma 2.1: Let \( x_n \) be a sequence in a Fuzzy Menger space \((X,F_{a},t)\) with continuous t-norm \( \ast \) and \( t \ast t \geq t \). If there exists a constant \( k \in (0,1) \) such that for all \( n \), \( F_{a}(x_n, x_{n+1}; t) \leq kF_{a}(x_n, x_{n+1}; t) \), then \( x_n \) is a Cauchy sequence in \( X \).

Lemma 2.2: Let \((X,F_{a},t)\) be a Fuzzy Menger space. If there exists \( \alpha \in (0,1) \) such that for all \( x, y \in X \), \( F_{a}(x, y; \alpha \ast \alpha) \geq F_{a}(x, y; \alpha \ast \alpha) \), then \( x \) is a limit point of \( X \).

Definition 2.9: Let \( M \) be a nonempty set and the mapping \( d: M \rightarrow \mathbb{R} \) be a cone, satisfies the following conditions:

2.9.1) \( F_{a}(x, y; \alpha) \geq 1 \) \( \forall x, y \in X \cap X \Rightarrow x = y \)

2.9.2) \( F_{a}(x, y; \alpha) = F_{a}(y, x; \alpha) \) \( \forall x, y \in X \),

2.9.3) \( F_{a}(x, y; \alpha + \beta) \geq F_{a}(x, y; \alpha) \cdot F_{a}(x, y; \beta) \) \( \forall x, y, \alpha, \beta \in X \).

2.9.4) For any \( x, y \in X \), \( F_{a}(x, y; \alpha) \) is non-increasing and left continuous.

3. MAIN RESULTS

Theorem 3.1: Let \((X, d)\) be a complete Menger Cone Metric space and \( P \) a normal cone with normal constant \( K \). Suppose \( M \) is a nonempty separable closed subset of Menger cone metric space \( X \) and \( T \) and \( S \) be commuting mappings defined on \( M \) satisfying the contraction

\[ ||F_{a}(Tx, Ty) - (u)|| \geq t ||F_{a}(x, y; \alpha)|| \] for all \( x, y \in X \).

Therefore sequences \( y_n = (Tx_n) = (Sx_n) \) is Cauchy and \( X \) in complete therefore there exist a \( p \) in \( X \) such that

\[ \lim_{n \to \infty} Tx_n = \lim_{n \to \infty} Sx_n = p \]

Now \( S \) is continuous and \( T \) are commuting mappings, we get

\[ sp = S \lim_{n \to \infty} Sx_n = \lim_{n \to \infty} S^2x_n \]

\[ Sp = S \lim_{n \to \infty} Tx_n = \lim_{n \to \infty} TSx_n \]

Now from (3.1.1) we have

\[ ||F_{a}(TSx_n, Sp)(u)|| \geq t||F_{a}(S^2x_n, Sp)(u)|| \]

On taking \( n \to \infty \), we get

\[ ||F_{a}(Sp, Tp)(u)|| \geq t||F_{a}(Sp, Tp)(u)|| \]

Since \( 0 < q < 1 \),

\[ ||F_{a}(Sp, Tp)(u)|| = 0 \Rightarrow Sp = Tp \]

Again from (3.1.1) we have

\[ ||F_{a}(x, Tp)(u)|| \geq t||F_{a}(x, Sp)(u)|| \]

\[ ||F_{a}(p, Tp)(u)|| \geq t||F_{a}(p, Sp)(u)|| = ||F_{a}(p, Sp)(u)|| \]

\[ Tp = p \]

\[ Sp = Tp = p \]

For uniqueness let there exists another fixed point \( q \) in \( X \) such that from (3.1.1)

\[ ||F_{a}(q)(u)|| = ||F_{a}(Tp, Tq)(u)|| \geq t||F_{a}(Sp, Sq)(u)|| = ||F_{a}(p, q)(u)|| \]

Hence for all \( 0 < q < 1 \) we have \( p = q \).

Theorem 3.2: Let \((X, d)\) be a complete Fuzzy Menger Cone metric space and \( P \) a normal cone with normal constant \( K \). Suppose \( M \) is a nonempty separable closed subset of cone metric space \( X \) and \( T \) and \( S \) be commuting operators defined on \( M \) satisfying contraction
\[ |F(a(Tx,Ty))(u)| \geq t(|F(a(Sx, Sy))(u)|) \]
\[ \forall x, y \in X \quad \text{and} \quad t \geq q < 1/2 \quad \text{............ (3.2.1)} \]

\[ |F(a(Tx,Ty))(u)| \geq t(|F(a(Sx, Sy))(u)|) \]
\[ \forall x, y \in X \quad \text{and} \quad t \geq q < 1/2 \quad \text{............ (3.2.2)} \]

\[ |F(a(Tx,Ty))(u)| \geq t(|F(a(Sx, Sy))(u)|) \]
\[ \forall x, y \in X \quad \text{and} \quad t \geq q < 1/2 \quad \text{............ (3.2.3)} \]

and range of S contains range of T and if SX is continuous, then T and S have unique point of coincidence. If T and S weakly compatible, S and T have unique common fixed point in X.

**Proof:** For each \( x_0 \in X \) and \( x_1 \in X \) considered such that \( y_0 = T x_0 = S x_1 \). Therefore in general, \( y_n = T x_n = S x_{n+1} \).

As per theorem 3.1 and for all the cases (3.2.1), (3.2.2), (3.2.3) we have

\[ |F(a(y_{n-1}, y_{n-2}))(u)| \geq t(|F(a(y_{n-1}, y_{n-2}))(u)|) \quad \text{...... (3.2.4)} \]

Indeed by (3.2.1) it follows that

\[ |F(a(y_{n-1}, y_{n-2}))(u)| = |F(a(x_{n-1}, x_{n-2}))(u)| \]
\[ = |F(a(Tx_{n-1}, Tx_{n-2}))(u)| \]
\[ \geq t(|F(a(Sx_{n-1}, Sx_{n-2}))(u)|) \]
\[ = t(|F(a(y_{n-1}, y_{n-2}))(u)|) \]

Indeed by (3.2.2) it follows that

\[ |F(a(y_{n-1}, y_{n-2}))(u)| = |F(a(x_{n-1}, x_{n-2}))(u)| \]
\[ = |F(a(Tx_{n-1}, Tx_{n-2}))(u)| \]
\[ \geq t(|F(a(Sx_{n-1}, Sx_{n-2}))(u)|) \]
\[ = t(|F(a(y_{n-1}, y_{n-2}))(u)|) \]

Indeed by (3.2.3) it follows that

\[ |F(a(y_{n-1}, y_{n-2}))(u)| = |F(a(x_{n-1}, x_{n-2}))(u)| \]
\[ \geq t(|F(a(Sx_{n-1}, Sx_{n-2}))(u)|) \]
\[ = t(|F(a(y_{n-1}, y_{n-2}))(u)|) \]

Now, by (3.2.4) for all cases we get

\[ |F(a(y_{n-1}, y_{n-2}))(u)| \geq t(|F(a(y_{n-1}, y_{n-2}))(u)|) \]
\[ \geq t(|F(a(y_{n-1}, y_{n-2}))(u)|) \]

Therefore sequences \( y_n = \{T x_n\} = \{S x_{n+1}\} \) is Cauchy sequence and S(X) is complete therefore there exist p in X such that \( S p = z \). Now we will show that for all cases T(p) = z.

**From 3.2.1**

\[ |F(a(Sx_{n-1}, Tp))(u)| = |F(a(Tx_{n-1}, Tp))(u)| \]
\[ \geq t(|F(a(Sx_{n-1}, Sp))(u)|) \]

By taking \( n \to \infty \), we get

\[ \Rightarrow |F(a(Sp, Sp))(u)| \geq t(|F(a(Sp, Sp))(u)|) \]
\[ \Rightarrow |F(a(Sp, Sp))(u)| = 0. \]

Hence \( Sp \neq Sp = Tp \).

**For unique coincidence let us consider another point of coincidence \( p_1 \) in X such that \( Tp_1 = Sp_1 = z_1 \). Now**

\[ |F(a(Sp_1, Sp_1))(u)| = |F(a(Tp_1, Tp_1))(u)| \]
\[ \geq t(|F(a(Sp_1, Sp_1))(u)|) \]
\[ \Rightarrow |F(a(Sp_1, Sp_1))(u)| = 0. \]

Hence \( Sp_1 = Sp = Tp = Tp_1 \).

Again from (3.2.3)

\[ |F(a(Tx_n, Tu))(u)| = |F(a(Sx_n, Su))(u)| \]
\[ \geq t(|F(a(Sx_n, Su))(u)|) \]
\[ \Rightarrow |F(a(Sp_1, Sp_1))(u)| \geq t(|F(a(Sp_1, Sp_1))(u)|) \]

Taking \( n \to \infty \), we get

\[ |F(a(Sp_1, Sp_1))(u)| = 0. \]

Hence \( Sp_1 = Sp = Tp = Tp_1 \).

For uniqueness let us consider another point of coincidence \( p_1 \) in X such that \( Tp_1 = Sp_1 = z_1 \). Now

\[ |F(a(Sp_1, Sp_1))(u)| = |F(a(Tp_1, Tp_1))(u)| \]
\[ \geq t(|F(a(Sp_1, Sp_1))(u)|) \]
\[ \Rightarrow |F(a(Sp_1, Sp_1))(u)| = 0. \]

Since \( 0 < q < 1/2 \) therefore \( |F(a(Sp_1, Sp_1))(u)| = 0 \). Hence \( Sp_1 = Sp = Tp = Tp_1 \).

Now for weak compatibility of F and S and for \( \alpha \in [0,1] \) in all above cases we can find that p is unique common fixed point of T and S.

**4. Example**

Let \( M = R \) and \( P = \{x \in M : x \geq 0\} \). Let \( X = [0, \infty) \) and define mapping as \( d(x,x) \to M \) by \( F(a(x,x)) = a(x) \). Then \( (X,f,1) \) is a fuzzy Menger cone metric space. Define operator T from X to X as \( T(x) = x/2 \). Therefore sequence of mapping \( x_n : X \to X \) is defined by

\[ x_n = \{1+1/n\} \quad \text{for every} \quad n \in N. \]

T Satisfies all condition of the theorem 3.1 and hence 1 is fixed point of the space.
5. REFERENCES