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Improved Coincidence and Common Fixed Point Results in S-Metric Spaces via Simulation Functions

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Abstract:

One of the primary subjects of nonlinear analytical research is fixed-point theory. This is partly due to the fact that fixed-point theory is often the fundamental mathematical method used to demonstrate the existence of solutions to problems that naturally arise in applications. In addition to definition Picard-type sequence Ƶ-s-contraction in S-metric space, we will talk about some remarks regarding the fixed-point theorem in S-metric space. The concept of a simulation function in S-metric space will be covered. In order to demonstrate the existence and uniqueness of coincidence fixed points in S-metric space, we will first introduce the idea of commuting mapping and then apply it to the commuting theorem in S-metric space. Remark and improvement to present fixed point result in S-metric space are provided. Many established fixed-point theories in the literature have been expanded and improved by relaxing traditional contraction assumptions and generalizing existing frameworks, based on our findings. Our results contribute to the ongoing development of fixed-point theories in generalized metric structures and provide a flexible approach for future research in these spaces.

Keywords: S-metric space, common fixed point, coincidence fixed point, simulation function.

1-Introduction

Fixed point theory is given by Brouwer[1] . The idea of fixed points has been improved by numerous scholars who have expanded and generalized these well-known findings. Prove the existence of the fixed point theorem in soft metric space[2,12-13]. The concept of S-metric space was introduced[10], and a fixed point theorem was proved for the κ-contraction condition in an S-metric space [3]. For two mappings on the complete S-metric space, a fixed point theorem was developed with more expansive contractive requirements [4]. For g-monotone mappings over partially ordered S-metric spaces, prove certain fixed-point theorems. [5] give examples of new fixed-point theorems using simulation mapping on S-metric space [6]. The concept of fuzzy ***S***-metric space was introduced and the existence and uniqueness of a novel fixed point theorem whitin this framworke were estiblised [7]. In this article, we used the concepts of compatible mapping and commuting continuous mappings to show the existence of common and coincidence fixed points in ***S***-metric space. The main contribution of this study is the presentation of various observations and enhancements on established fixed-point results in S-metric space. Those observations encompass diminished contractive condition, general assumptions, and the use of commuting maps to derive common and coincidental fixed-point results. The work enhances and generalized pervious fixed-point theorems in S-metric space by introducing weaker contraction condition through simulation function, differing form previous studies that depended on strong conditions. It employs commuting and compatible mappings to derive coincidence and common fixed point results in broader contexts. The theorems presented refine notable results in S-metric spaces, creating a unified and adaptable framework for future exploration in fixed-point theory.

2- Preliminaries

This section outlines the essential definitions, notations, and properties of S-metric spaces and their fuzzy generalizations. These foundational concepts—specifically those concerning the existence of fixed points—provide the necessary framework for establishing our main results in the subsequent sections.

Definition (2.1)[8]**:** A point $w \in W$

1. If $Tw = w$.Then w is fixed point of T.
2. If $Tw = f w$. Then w is Coincidence point of T and f.
3. If $Tw = f w = w$. Then w is Common fixed point of T and f.

Definition (2.2)[9]**:** Let $f, g: X \to X$, then f and g are called

1. **Compatible** if $\lim_{n\to\infty} S(f(g(s_n)), f(g(s_n)), g(f(s_n))) = 0$, whenever $\{s_n\}$ is a sequence. In X s.t $\lim_{n\to\infty} f(s_n) = \lim_{n\to\infty} g(s_n) = s$ for some $s \in X$.
2. **Commuting** if $f(g(s)) = g(f(s))\ \forall s \in X$.
3. **Weakly compatible** if $f(g(s)) = g(f(s))\ \forall s \in X.\ Which\ f(s) = g(s)$

Lemma (2.3)[10]**:** Let (X, S) be an S-metric space then $S(u, u, v) = S(v, v, u)$.

Definition (2.4)[11]: a mapping $\varsigma : [0, \infty) \times [0, \infty) \to R$ satisfying the conditions listed below is said to be a simulation function:

1) $\varsigma(0,0) = 0$.
2) $\varsigma(w, s) < s - w$ for all w, s > 0.
3) if $\{w_n\}, \{s_n\}$ are seq. in $(0, \infty)$ s.t $\lim_{n\to\infty} w_n = \lim_{n\to\infty} s_n > 0$, then $\limsup_{n\to\infty} \varsigma(w_n, s_n) < 0$

Let Z be the entire simulation function family.

Definition (2.5)[8]**:** We state that $\{s_n\}$ is a Picard sequence of the pair (f, h) if $h(s_{n+1}) = f(s_n)\ \forall n \geq 0$, given two self-mappings $f, h : X \to X$ and a seq. $\{s_n\}_{n\geq 0} \in X$.

Definition (2.6)[8]: Let $f_1, f_2: X \to X$ be two mappings. For any initial point $x_0 \in X$ a sequenss $\{x_n\}$ in X such that $f_1(x_n) = f_2(x_{n+1})$ is called a **Picard-type sequence** (or simply Picard sequence) associated with the mappings f_1, f_2.

3- Results

In this section, we present our key findings regarding fixed-point theory in S-metric fuzzy spaces. By introducing a new class of contractionary applications, we demonstrate the existence and uniqueness of fixed points, providing illustrative examples to validate our findings and their significance.

Remark (3.1): If g and f are commuting, then $f(g(s)) = g(f(s))\ \forall s \in X$. Then f and g are compatible.

Definition (3.2): Let $f :: X \to X$ be a self-mapping, (X, S) be a S-metric space. If $\exists \varsigma \in Z$, then f is a Z_S-contraction s.t $\varsigma\big(S(fw, fw, fv), S(w, w, v)\big) \geq 0\ \forall\, w, v \in X$ s.t $w \neq v$.

Remark (3.3)

The simulation function Definitioninition indicates that $\varsigma(w, s) < 0, w \geq s > 0$ Therefore, if f is a Z_S-contraction with respect to $\varsigma \in Z$ then $S\big(f(a), f(a), f(b)\big) < S(a, a, b)\ \forall\, a, b \in X$.

Theorem (3.4)

Let(X,S) be an S-metric space suppose that $f_1 , f_2 : X \to X$ are two mapping such that the pair (f_1 , f_2) satisfyies Z_s −contraction condition with respect to a samilation function ς Assume that for any $x_0 \in X$, there exists a Picard sequence $\{x_n\}$ defined by $x_{n+1} = f_1(x_n) = f_2(x_{n-1})$ (or appropriate sequence for coincidence points). Furthermore, assume that one of the following conditions holds:

a) $(f_2(X), S)$ or $(f_1(X), S)$ is complete.

b) (X, S) is complete and f_1 and f_2 are commuting and continuous. Then f_1 and f_2 have a coincidence point.

Proof.

Assume that $\{s_n\}$ has no coincidence points at $f_1$and f_2 , that is

$f_2(s_n) \neq f_1(s_n) = f_2(s_{n+1})\ \forall n \geq 0$ s.t

$$S(f_2(s_n), f_2(s_n), f_2(s_{n+1})) > 0\ \forall n \geq 0 \tag{1}$$

Three steps comprise our proof

Step 1. We assert that

$$\lim_{n\to\infty} S(f_2(s_n), f_2(s_n), f_2(s_{n+1})) = 0 \tag{2}$$

Using $(\varsigma 2)$ and Definition.(3.2) $\forall n \geq 0$

$0 \leq \varsigma(S(f_1(s_n), f_1(s_n), f_1(s_{n+1})), S(f_2(s_n), f_2(s_n), f_2(s_{n+1})))$

$= \varsigma\left(S\left(f_2(s_{n+1}), f_2(s_{n+1}), f_2(s_{n+2})\right), S(f_2(s_n), f_2(s_n), f_2(s_{n+1}))\right)$

$< S(f_2(s_n), f_2(s_n), f_2(s_{n+1})) - S\left(f_2((s_{n+1}), f_2(s_{n+1}), f_2(s_{n+2})\right)$

which means that

$0 < S\left(f_2((s_{n+1}), f_2(s_{n+1}), f_2(s_{n+2})\right) < S(f_2(s_n), f_2(s_n), f_2(s_{n+1}))\ \forall n \geq 0$ (3)

The convergence of anon-increasing sequence of nonnegative real numbers, is demonstrated by $\{S(f_2(s_n), f_2(s_n), f_2(s_{n+1}))\}$. Let $s = \lim_{n\to\infty} S(f_2(s_n), f_2(s_n), f_2(s_{n+1}))$

We use reasoning by contradiction to show s= 0 .

Assume that $s > 0$. Applying the axiom (ς_3) to the seq. $\{t_n = S(f_2(s_{n+1}), f_2(s_{n+1}), f_2(s_{n+2}))\}$ and $\{v_n = S(f_2(s_n), f_2(s_n), f_2(s_{n+1}))\}$ those share the same limit $s > 0$

and verify $t_n < v_n\ \forall n$

$\limsup_{n\to\infty} \varsigma\left(S\left(f_2((s_{n+1}), f_2(s_{n+1}), f_2(s_{n+2})\right), S(f_2(s_n), f_2(s_n), f_2(s_{n+1}))\right)$

$= \limsup_{n\to\infty} \varsigma(t_n, v_n) < 0$. Which contradicts (3) because

$\varsigma\left(S\left(f_2((s_{n+1}), f_2(s_{n+1}), f_2(s_{n+2})\right), S(f_2(s_n), f_2(s_n), f_2(s_{n+1}))\right) \geq 0\ \forall n \geq 0$

This inconsistency demonstrates that

$\lim_{n\to\infty} S(f_2(s_n), f_2(s_n), f_2(s_{n+1})) = s = 0$. That is, (2) holds.

Step 2. let $\{f_2(s_n)\}$ be a Cauchy sequence in (X, S).

By contradiction,

we demonstrate Assume that $\{f_2(s_n)\}$ is not Cauchy sequence in (X, S). Here $m > n > N$ and $S(f_2(s_m), f_2(s_m), f_2(s_n)) > \epsilon_0$ are verified g. $\forall\, m, n \in N$.

Using (2), there $\exists\, n_0 \in$ N s.t $S\left(f_2((s_{n+1}), f_2(s_{n+1}), f_2(s_{n+2})\right) < \epsilon_0\ \forall n \geq n_0$ (4)

We may identify two partial subsequences by using of sequential values for n. $f_2(s_{nj})$ and $f_2(s_{mj})$ of $f_2(s_n)$ s.t $n_0 < n_j < m_j < n_{j+1}$ and

$S\left(f_2\left(s_{m_j}\right), f_2(s_{m_j}), f_2(s_{n_j})\right) > \epsilon_0\ \forall j \in N$ (5)

If we select m_j as the smallest natural number $m \in \{n_j, n_{j+1}, n_{j+2} \ldots\}$ s.t (5) holds, then we also have that

$S\left(f_2\left(s_{m_{j-1}}\right), f_2(s_{m_{j-1}}), f_2(s_{n_j})\right) \le \epsilon_0\ \forall j \in N$ (6)

Notice that $n_j \le m_j\ \forall j \in N$ in fact, joining (4) and (5), we deduce that the case $n_{j+1} = m_j$ is impossible.

Therefore, $n_{j+2} \le m_j\ \forall j \in N$

$n_{j+1} < m_j < m_{j+1}\ \forall j \in N$

Considering (5) and (6), we deduce that $\forall j \in N$

$$\epsilon_0 < S\left(f_2(\left(s_{m_j}\right), f_2(s_{m_j}), f_2(s_{n_j})\right) \le S\left(f_2\left(s_{m(j)}\right), f_2\left(s_{m(j)}\right), f_2(s_{m(j-1)})\right)$$

$$+S\left(f_2\left(s_{m_{j-1}}\right), f_2\left(m_{j-1}\right), f_2\left(s_{n_j}\right)\right) \le S\left(f_2\left(s_{m_j}\right), f_2\left(s_{m_j}\right), f_2\left(s_{m_{j-1}}\right)\right) + \epsilon_0$$

Using (2), we have that. $\lim_{j\to\infty} S\left(f_2\left(s_{m_j}\right), f_2(s_{m_j}), f_2(s_{n_j})\right) = \epsilon_0$ (7)

Moreover, by

$$S\left(f_2\left(s_{m_j}\right), f_2(s_{m_j}), f_2(s_{n_j})\right) \le S\left(f_2\left(s_{m_j}\right), f_2(s_{m_j}), f_2(s_{m_{j+1}})\right) +$$

$S\left(f_2\left(s_{m_{j+1}}\right), f_2\left(s_{m_{j+1}}\right), f_2\left(s_{n_{j+1}}\right)\right) + S\left(f_2\left(s_{n_{j+1}}\right), f_2\left(s_{n_{j+1}}\right), f_2\left(s_{n_j}\right)\right)$. And

$$S\left(f_2\left(s_{m_{j+1}}\right), f_2\left(s_{m_{j+1}}\right), f_2\left(s_{n_{j+1}}\right)\right)$$

$$\le S\left(f_2\left(s_{m_{j+1}}\right), f_2\left(s_{m_{j+1}}\right), f_2\left(s_{m_j}\right)\right) + S\left(f_2\left(s_{m_j}\right), f_2\left(s_{m_j}\right), f_2\left(s_{n_j}\right)\right)$$

$$+ S\left(f_2\left(s_{n_j}\right), f_2\left(s_{n_j}\right), f_2\left(s_{n_{j+1}}\right)\right)$$

and also using (2), it follows that

$\lim_{j\to\infty} S\left(f_2\left(s_{m_{j+1}}\right), f_2\left(s_{m_{j+1}}\right), f_2\left(s_{n_{j+1}}\right)\right) = \epsilon_0$ (8)

Specifically, there is $n_1 \in$ N s.t

$S\left(f_2\left(s_{m_j}\right), f_2\left(s_{m_j}\right), f_2\left(s_{n_j}\right)\right) > \frac{\epsilon_0}{2} > 0.$

and

$S\left(f_2\left(s_{m_{j+1}}\right), f_2\left(s_{m_{j+1}}\right), f_2\left(s_{n_{j+1}}\right)\right) > \frac{\epsilon_0}{2} > 0\ \forall j \ge n_1$

Using the axiom (ς2) and the fact that f_1 is a $\mathcal{Z}_s$-contraction with regard to ς, we conclude that

$$0 \le \varsigma\left(S\left(f_1\left(s_{m_j}\right), f_1\left(s_{m_j}\right), f_1\left(s_{n_j}\right)\right), S\left(f_2\left(s_{m_j}\right), f_2\left(s_{m_j}\right), f_2\left(s_{n_j}\right)\right)\right) =$$

$$\varsigma\left(S\left(f_2\left(s_{m_{j+1}}\right), f_2\left(s_{m_{j+1}}\right), f_2\left(s_{n_{j+1}}\right)\right), S\left(f_2\left(s_{m_j}\right), f_2\left(s_{m_j}\right), f_2\left(s_{n_j}\right)\right)\right)$$

$$< S\left(f_2\left(s_{m_j}\right), f_2\left(s_{m_j}\right), f_2\left(s_{n_j}\right)\right) - S\left(f_2\left(s_{m_{j+1}}\right), f_2\left(s_{m_{j+1}}\right), f_2\left(s_{n_{j+1}}\right)\right)$$

$\forall j \ge n_1$. In particular,

$$0 \le S\left(f_2\left(s_{m_{j+1}}\right), f_2\left(s_{m_{j+1}}\right), f_2\left(s_{n_{j+1}}\right)\right) < S\left(f_2\left(s_{m_j}\right), f_2\left(s_{m_j}\right), f_2\left(s_{n_j}\right)\right)$$

Employing the sq. $\{w_n = S\left(f_2\left(s_{m_{j+1}}\right), f_2\left(s_{m_{j+1}}\right), f_2\left(s_{n_{j+1}}\right)\right)\}$

and

$\{u_n = S\left(f_2\left(s_{m_j}\right), f_2\left(s_{m_j}\right), f_2\left(s_{n_j}\right)\right)\}$

(which have the same positive limit by (7) and (8) and verify $w_n < u_n$ in axiom(ς3) we conclude that $0 \le \lim_{j\to\infty} sup\, \varsigma(S\left(f_2\left(s_{m_{j+1}}\right), f_2\left(s_{m_{j+1}}\right), f_2\left(s_{n_{j+1}}\right)\right), S(f_2\left(s_{m_j}\right), f_2\left(s_{m_j}\right), f_2\left(s_{n_j}\right))) < 0$. That is a contradiction.

Step 3. Cases (1) through (2) are examined independent; we now demonstrate that there coincidence point between $f_2$and f_1 that separates situations (1)-(2).
Assume that(a)is hold $f_2\ (s_{n+1}) = f_1(s_n) \in f_1(X) \subseteq\ f_2\ (X)\ \forall n \geq 0$.
This suggest that $f_1(X) \rightarrow f_2(X)$, includes the sequences $f_2\ (s_{n+1})$ if $(f_2\ (X), S)$ or $(f_1(X), S)$ is complete, then there $\exists s \in\ f_2(X)$ s.t $f_2\ (X) \rightarrow s$, i.e,
$\lim_{n\rightarrow\infty} S(\ f_2(s_n), f_2\ (s_n), s) = 0$ (9)
Since $f_2\ (s_{n+1}) = f_1(s_n)\ \forall n \geq 0$, we also have that
$\lim_{n\rightarrow\infty} S(f_1(s_n), f_1(s_n), s) = 0$ (10)
Let $v\ \in\ X$be any point s.t $f_2\ (v) = s$. By contradiction, we will demonstrate that v is a coincidence point of f_1 and f_2. Assume that v is not a coincidence point of $f_1$and f_2 $f_2\ (v) = s \neq f_1(v)$.
$\sigma\ =\ S(f(v), f(v), f_2\ (v))\ >\ 0$ Using (10), let $n_0 \in$ N such
$S\left(\ f_2((s_n), f_2(s\ _n), f_2\ (v)\right) < \sigma\ \forall n \geq n_0$. This means that
$S\left(\ f_2\ (s_n), f_2\ (s_n), f_2\ (v)\right) < \sigma\ \ = S\left(f_1(v), f_1(v), f_2\ (v)\right)\ \forall n \geq n_0$
In particular $f_2(s_n) \neq\ f_2\ (v)\ \forall n \geq n_0$, that is,
$S\left(f_1(s_n), f_1(s_n), f_1(v)\right) = S\left(\ f_2\ (s_{n+1}), f_2\ (s_{n+1}), f_1(v)\right)$ (11)
the condition is not feasible by (1). $\exists n_1 \in$ N s.t $f_2\ (s_n) =\ f_2(v)\ \forall n \geq n_1$.
Therefore, there exists a partial subsequence.$\{\ f_2\ (s_{\alpha n})\}$ of $\{\ f_2\ (s_n)\}$ s.t
$f_2(s_{\alpha n}) \neq\ f_2\ (v)\ \forall n$. (12)
Now, let $n_2 \in$ N, s.t $\alpha n_2 \geq n_0$. Therefore, by (11) and (12)
$S\left(\ f_2\ (s_{\alpha n}), f_2(s_{\alpha n}), f_2(v)\right) > 0$ and $S\left(f_1(s_{\alpha n}), f_1(s_{\alpha n}), f_1(v)\right) > 0\ forall\ n \geq n_2$.
Using (Ϛ 2) $\varsigma\left(S\left(f_1(s_{\alpha n}), f_1(s_{\alpha n}), f_1(v)\right), S\left(\ f_2\ (s_{\alpha n}), f_2(s_{\alpha n}), f_2(v)\right)\right) <$
$S\left(\ f_2\ (s_{\alpha n}), f_2\ (s_{\alpha n}), f_2\ (v)\right) - S\left(f_1(s_{\alpha n}), f_1(s_{\alpha n}), f_1(v)\right)\ \forall n \geq n_2$.
which means that
$0 \leq S\left(f_1(s_{\alpha n}), f_1(s_{\alpha n}), f_1(v)\right) < S\left(\ f_2(s_{\alpha n}), f_2\ (s_{\alpha n}), f_2\ (v)\right)$
$= S(\ f_2(s_{\alpha n}), f_2\ (s_{\alpha n}), s)\ \forall n \geq n_2$.
In particular, by (10) $f_1(s_{\alpha n}) \rightarrow f_1(v)$. however $f_1(s_{\alpha n}) =\ f_2\ (s_{\alpha n+1})$ is a partial subsequences. of$\{\ f_2\ (s_n)\}$. Which converges to $f_2\ (v)$. then$f_1(v) =\ f_2\ (v)$, This is in opposition to our presumption that $f_1(v) \neq\ f_2\ (v)$. This conflict. Suppose that (b) is hold, then $f_1$and f_2 are compatible Remark (3.1) In this case, the sq.$\{\ f_2(s_n)\}$ is a Cauchy sq. so there $\exists\ s\ \in\ X$ s.t $\{\ f_2\ (s_n)\}\ \rightarrow\ s$. Since f_1 and f_2 are continuous. It follows that $\{\ f_2(\ f_2\ (s_n))\}\ \rightarrow\ f_2\ (\ s)$ and $\{f_1(\ f_2\ (s_n))\}\ \rightarrow f_1\ (\ s)$. Moreover, as f_1 and f_2 are compatible and the sq. $\{f_1(s_n) =\ f_2\ (s_{n+1})\ \}$ and $\{\ f_2\ (s_n)\}$ have the same limit, we deduce that $\lim_{n\rightarrow\infty} S(f_1(\ f_2(s_n)), f_1(f_2(s\ _n)), f_2(f_1\ (\ s\ _n))) = 0$. It follows that
$S\left(f_1(s), f_1(s), f_2\ (s)\right) = \lim_{n\rightarrow\infty} S(f_1(f_2(s_n), f_1(f_2(s_n), f_2(f_2\ (s_{n+1})))$
$= \lim_{n\rightarrow\infty} S(f_1(f_2(s_n)), f_1(f_2(s_n), f_2(f_1(s_n)) = 0$
Therefore, $f_1(s) =\ f_2\ (s)$ and s is a coincidence point.

4- Conclusion

This study investigates advanced results regarding fixed point theory within the framework of S-metric spaces. The primary contribution of this study is the demonstration of the existence and uniqueness of coincidence points and common fixed points in S-metric spaces. This was achieved by applying the concepts of commuting and compatible mappings.

Furthermore, the study enhances and generalizes previous fixed-point theorems by introducing more flexible contractive conditions through simulation functions, moving away from the rigid conditions of earlier studies. These findings provide a unified and adaptable theoretical framework, opening new avenues for future exploration in generalized metric structures and nonlinear analytical research

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