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Stronger Forms of Fuzzy Generalized Preregular Continuous Functions in Fuzzy Topological Spaces

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Abstract

In this paper, the stronger forms of fuzzy generalized preregular continuous functions namely, strongly fuzzy $fgpr$-continuous, perfectly $fgpr$-continuous and completely fuzzy $fgpr$-continuous functions have been introduced and studied in fuzzy topological spaces.

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Keywords: Strongly $fgpr$-continuous function, perfectly $fgpr$-continuous function and completely $fgpr$-continuous function.

1. Introduction

The concept of a fuzzy subset which was introduced and studied by L. A. Zadeh [26] in the year 1965. The subsequent research activities in this area and the related areas have found applications in many branches of science and engineering. C. L. Chang [5] introduced and studied fuzzy topological spaces in 1968 as a generalization of topoloical spaces. Many researchers like K.K> Azad [1, 2], M. Ferraro and D. H. Foster [6], A. Haydar Es [7], R. Lowen [8], S. R. Malghan and S. S. Benchalli [9, 10], A. S. Mashhour et. al [11, 12, 13, 14], M. N. Mukherjee and B. Ghosh [15], M. N. Mukherjee and S. P. Sinha [16], P. Sundaram [17, 18], R. H. Warren [21, 22], C. K. Wong [23, 24, 25], and many others have contributed to the development of fuzzy topological spaces.

In this paper, it is proved that every strongly $fgpr$-continuous function is f-continuous function and also every f-strongly continuous function is a strongly $fgpr$-continuous function. Also every perfectly $fgpr$-continuous function is f-continuous function and also every perfectly $fgpr$-continuous function is a f-perfectly continuous function. Further every completely $fgpr$-continuous function is f-continuous function and also every completely $fgpr$-continuous function is a f-completely continuous function. Also the image of regular fts is regular under f-continuous, f-open, $fgpr$-closed maps.

Let X, Y and Z be sets. Throughout the present chapter (X, α), (Y, β) and (Z, γ) (or simply X, Y and Z) mean fuzzy topological spaces on which no separation axioms is assumed unless explicitely stated.

Before entering into our work we recall the following definitions, which are due to various authors.

2. Preliminaries

If A is a subset of X with a topology τ, then the closure of A is denoted by τ-$cl(A)$ or $cl(A)$, the interior of A is denoted by τ-$int(A)$ or $int(A)$ and the complement of A in X is denoted by A^c.

Definition 2.1. A fuzzy set λ in a fts (X, τ) is called

(i) a fuzzy pre-open set [4] if $\lambda \leq cl(int(\lambda))$ and a fuzzy pre-closed set if $cl(int(\lambda)) \leq \lambda$,

(ii) fuzzy regular open set [1] if $int(cl\lambda) = \lambda$ and a fuzzy regular closed set if $cl(int(\lambda)) = \lambda$.

Definition 2.2. A fuzzy set λ in a fts (X, τ) is called

(i) a fuzzy generalized closed set (briefly, fg-closed set)[4] if $cl(\lambda) \leq \mu$ whenever $\lambda \leq \mu$ and μ is fuzzy open in X,

(ii) a fuzzy generalized preregular closed set [19] (briefly $fgpr$-closed fuzzy set) if $pcl(\lambda) \subseteq \mu$ whenever $\lambda \leq \mu$ and μ is fuzzy regular open set in X.

The complement of the above mentioned closed sets are respective open sets.

Definition 2.3. Let X, Y be two fuzzy topolgogical spaces. A function $f : X \to Y$ is called

(i) fuzzy continuous (briefly, f-continuous) [3] if $f^{-1}(\lambda)$ is fuzzy open set in X, for every fuzzy open set λ of Y,

(ii) fuzzy strongly continuous (briefly, fs-continuous) [3] if $f^{-1}(\lambda)$ is fuzzy open and fuzzy closed set in X, for every fuzzy set λ in Y,

(iii) fuzzy perfectly continuous (briefly, fp-continuous) [3] if $f^{-1}(\lambda)$ is fuzzy open and fuzzy closed set in X, for every fuzzy open set λ in Y,

(iv) fuzzy completely continuous (briefly, fc-continuous) [15] if $f^{-1}(\lambda)$ is fuzzy regular open set in X, for every fuzzy open set λ in Y.

(v) fuzzy generalized preregular continuous (briefly, $fgpr$-continuous) [20] if $f^{-1}(\lambda)$ is $fgpr$-open set in X, for every fuzzy open set λ in Y.

(vi) fuzzy generalized preregular irresolute (briefly, $fgpr$-irresolute) [20] if $f^{-1}(\lambda)$ is $fgpr$-open set in X, for every $fgpr$-open set λ in Y.

3. Stronger forms of fuzzy generalized preregular continuous functions

Now, the stronger forms of $fgpr$-contionuous functions namely strongly fuzzy $fgpr$-contionuous, perfectly $fgpr$-continuous and completely $fgpr$-continuous functions have been introduced and studied.

Now we introduce the following

Definition 3.1. A function $f : X \to Y$ is called strongly fuzzy generalized preregular continuous (briefly strongly $fgpr$-continuous) iff the inverse image of every $fgpr$-open set in Y is fuzzy open set in X.

Theorem 3.2. A function $f : X \to Y$ is strongly $fgpr$-continuous iff the inverse image of every $fgpr$-closed set in Y is fuzzy closed set in X.

Proof. Assume that f is strongly $fgpr$-contionuous. Let λ be $fgpr$-closed set in Y. Then $1 - \lambda$ is $fgpr$-open set in X. Since f is strongly $fgpr$-continuous, $f^{-1}(1 - \lambda)$ if fuzzy open set in X. But $f^{-1}(1 - \lambda) = 1 - f^{-1}(\lambda)$ and so $f^{-1}(\lambda)$ is fuzzy closed set in X.

Conversely, supppose that the inverse image of every $fgpr$-closed set in Y is fuzzy closed set in X. Let μ be $fgpr$-open set in Y, then $1 - \mu$ is $fgpr$-closed set in Y. By hypothesis, $f^{-1}(1 - \mu)$ is fuzzy closed set in X. Now $f^{-1}(1 - \mu) = 1 - f^{-1}(\mu)$ and so $f^{-1}(\mu)$ is fuzzy open set in X. Hence f is strongly $fgpr$-continuous. ■

Theorem 3.3. Every strongly $fgpr$-continuous function is a f-continuous function.

Proof. Let $f : X \to Y$ be strongly $fgpr$-continuous funtion. Let μ be fuzzy open set in Y, and so μ is $fgpr$-open set in Y. Then $f^{-1}(\mu)$ is fuzzy open set in X. Hence f is f-continuous function. ■

The converse of the above theorem need not be true as seen from the following example.

Example 3.4. Let $X = Y = \{a, b, c\}$ and the fuzzy sets λ, μ and γ be defined as follows. $\lambda = \frac{0.4}{a} + \frac{0.5}{b} + \frac{0.7}{c}$, $\mu = \frac{1}{a} + \frac{0.9}{b} + \frac{0.8}{c}$, $\gamma = \frac{1}{a} + \frac{0.8}{b} + \frac{0.8}{c}$. Consider $\tau = \{0, 1, \lambda, \mu\}$ and $\sigma = \{0, 1, \mu\}$. Then (X, τ) and (Y, σ) are fts. Define $f : X \to Y$ by $f(a) = a$, $f(b) = b$ and $f(c) = c$. Then f is f-continuous but not strongly $fgpr$-continuous as the fuzzy set γ is $fgpr$-closed in Y and $f^{-1}(\gamma) = \gamma$ is not fuzzy closed set in X.

Theorem 3.5. Every f-strongly continuous function is a strongly $fgpr$-continuous function.

Proof. Let $f : X \to Y$ be f-strongly continuous function. Let λ be $fgpr$-open set in Y. And then $f{-}1(\lambda)$ is both fuzzy open and fuzzy closed set in X as f is f-strongly continuous function. Hence f is strongly $fgpr$-continuous function.

The converse of the above theorem need not be true as seen from the following example. ■

Example 3.6. Let $X = Y = \{a, b, c\}$ and the fuzzy sets λ and μ be defined as follows. $\lambda = \frac{0.4}{a} + \frac{0.5}{b} + \frac{0.7}{c}$, $\mu = \frac{1}{a} + \frac{0.9}{b} + \frac{0.8}{c}$. Consider $\tau = \{0, 1, \lambda\}$ and $\sigma = \{0, 1, \mu\}$. Then (X, τ) and (Y, σ) are fts. Define $f : X \to Y$ by $f(a) = a$, $f(b) = b$ and $f(c) = c$. Then f is strongly $fgpr$-continuous but not strongly f-continuous as the fuzzy set μ in Y is such that $f^{-1}(\mu) = \mu$ is fuzzy open but not fuzzy closed set in X.

Theorem 3.7. If $f : X \to Y$ be strongly $fgpr$-continuous and $g : Y \to Z$ is strongly $fgpr$ continuous. Then the composition map $g \circ f : X \to Z$ is strongly $fgpr$ continuous function.

Proof. Let μ be $fgpr$-open set in Z. Then $g^{-1}(\mu)$ is fuzzy open set in Y, since g is strongly $fgpr$-continuous. And therefore $g^{-1}(\mu)$ is $fgpr$-open set in Y. Also since f is strongly $fgpr$-continuous, $f^{-1}(g^{-1}(\mu) = (g \circ f)^{-1}(\mu)$ is fuzzy open set in X. Henece $g \circ f$ is strongly $fgpr$-continuous function. ■

Theorem 3.8. Let $f : X \to Y$, $g : Y \to Z$ be maps such that f is strongly $fgpr$-continuous and g is $fgpr$-continuous then $g \circ f : X \to Z$ is f-continuous.

Proof. Let λ be a fuzzy closed set in Z. Then $g^{-1}(\lambda)$ is $fgpr$-closed set in Y. Since g is $fgpr$-continuous. And since f is strongly $fgpr$-contionuous, $f^{-1}(g^{-1}(\lambda)) = (g \circ f)^{-1}(\lambda)$ is fuzzy closed set in X. Hence $g \circ f$ is f continuous. ■

Theorem 3.9. If $f : X \to Y$ be strongly $fgpr$-continuous and $g : Y \to Z$ is $fgpr$-irresolute, then the composition map $g \circ f : X \to Z$ is strongly $fgpr$-continuous.

Proof. Let λ be $fgpr$-open set in Z. Then $g^{-1}(\lambda)$ is $fgpr$-open set in Y since g is

$fgpr$-irresolute. And then $f^{-1}(g^{-1}(\lambda)) = (g \circ f)^{-1}(\lambda)$ is fuzzy open set in X. Also since f is strongly $fgpr$-continuous. Hence $g \circ f$ is strongly $fgpr$-continuous. ■

Definition 3.10. A functions $f : X \to Y$ is called perfectly $fgpr$-continuous (briefly perfectly $fgpr$-continuous) if the inverse image of every $fgpr$-open set in Y is both fuzzy open and fuzzy closed set in X.

Theorem 3.11. A map $f : X \to Y$ is perfectly $fgpr$-continuous iff the inverse image of every $fgpr$-closed set in Y is both fuzzy open and fuzzy closed set in X.

Proof. Assume that f is perfectly $fgpr$-continuous. Let λ be $fgpr$-closed set in Y. Then $1 - \lambda$ is $fgpr$-open set. And therefore $f^{-1}(1 - \lambda)$ is both fuzzy open and fuzzy closed set in X. But $f^{-1}(1 - \lambda) = 1 - f^{-1}(\lambda)$ and so $f^{-1}(\lambda)$ is both fuzzy open and fuzzy closed set in X.

Conversely, suppose that the inverse image of every $fgpr$-closed set in Y is both fuzzy open and fuzzy closed set in X. Let λ be $fgpr$-open set in Y. Then $1 - \lambda$ is $fgpr$-closed set in Y. By hypothesis, $f^{-1}(1 - \lambda)$ is both fuzzy open and fuzzy closed set in X. But $f^{-1}(1-\lambda) = 1 - f^{-1}(\lambda)$. Therefore $f^{-1}(\lambda)$ is both fuzzy open and fuzzy closed set in X. Hence f is perfectly $fgpr$-continuous. ■

Theorem 3.12. Every perfectly $fgpr$-continuous function is a f-continuous function.

Proof. Let $f : X \to Y$ be perfectly $fgpr$-continuous. Let λ be a fuzzy open set in Y, and so λ is $fgpr$-open set in Y. Since f is perfectly $fgpr$-continuous, then $f^{-1}(\lambda)$ is both fuzzy open and fuzzy closed set in X. That is $f^{-1}(\lambda)$ is fuzzy open set in X. Hence f is f-continuous function. ■

The converse of the above theorem need not be true as seen from the following example.

Example 3.13. In the Example 3.4, the function f is f-continuous but not perfectly $fgpr$-continuous as the fuzzy set $1 - \gamma = \frac{0}{a} + \frac{0.2}{b} + \frac{0.2}{c}$ is $fgpr$-open set in Y and $f^{-1}(1 - \gamma) = 1 - \gamma$ which is not both fuzzy open and fuzzy closed set in X.

Theorem 3.14. Every perfectly $fgpr$-continuous function is a f-perfectly continuous function.

Proof. Let $f : X \to Y$ be perfectly $fgpr$-continuous. Let λ be fuzzy open set in Y, then λ be $fgpr$-open set in Y. Since f is perfectly $fgpr$-continuous. Then $f^{-1}(\lambda)$ is both fuzzy open and fuzzy closed set in X. And hence f is f-perfectly continuous function. ■

The converse of the above theorem need not true as seen from the following example.

Example 3.15. Let $X = Y = \{a, b, c\}$ and the fuzzy sets λ, μ, γ and δ be defined as follows. $\lambda = \frac{0.4}{a} + \frac{0.5}{b} + \frac{0.7}{c}$, $\mu = \frac{1}{a} + \frac{0.9}{b} + \frac{0.8}{c}$, $\gamma = \frac{0}{a} + \frac{0.1}{b} + \frac{0.2}{c}$ and $\delta = \frac{1}{a} + \frac{0.8}{b} + \frac{0.8}{c}$. Consider $\tau = \{0, 1, \lambda, \mu, \gamma\}$ and $\sigma = \{0, 1, \mu\}$. Then (X, τ) and (Y, σ) are fts. Define $f : X \to Y$ by $f(a) = a$, $f(b) = b$ and $f(c) = c$. Then f is perfectly f-continuous function. As the fuzzy set μ is fuzzy open set in Y and its inverse image $f^{-1}(\mu) = \mu$ is both fuzzy open and fuzzy closed set in X. But f is not perfectly $fgpr$-continuous. As the fuzzy set δ is $fgpr$-open set in Y and $f^{-1}(\delta) = \delta$ is not both fuzzy open and fuzzy closed set in X.

Theorem 3.16. Every perfectly $fgpr$-continuous function is strongly $fgpr$-continuous function.

Proof. Let $f : X \to Y$ be perfectly $fgpr$-continuous. Let λ be $fgpr$-open set in Y. Then $f^{-1}(\lambda)$ is both fuzzy open and fuzzy closed set in X. Therefore $f^{-1}(\lambda)$ is fuzzy open set in X. Hence f is strongly $fgpr$-continuous function. ■

The converse of the above theorem need not be true as seen from the following example.

Example 3.17. In the Example 3.6, the function f is strongly $fgpr$-continuous but not perfectly $fgpr$-continuous as the fuzzy set μ is $fgpr$-open set in Y and $f^{-1}(\mu) = \mu$ is fuzzy open but not fuzzy closed set in X.

Theorem 3.18. Let $f : X \to Y$, $g : Y \to Z$ be two perfectly $fgpr$-continuous function then $g \circ f : X \to Z$ is perfectly $fgpr$-continuous function.

Proof. Let λ be $fgpr$-open fuzzy in Z. Then $g^{-1}(\lambda)$ is both fuzzy open and fuzzy closed set in Y, since g is perfectly $fgpr$-continuous. Therefore $g^{-1}(\lambda)$ is $fgpr$-open set in Y. Also since f is perfectly $fgpr$-continuous, $f^{-1}(g^{-1}(\lambda)) = (g \circ f)^{-1}(\lambda)$ is both fuzzy open and fuzzy closed set in X. Hence $g \circ f$ is perfectly $fgpr$-continuous function. ■

Theorem 3.19. Let $f : X \to Y$ be perfectly $fgpr$-continuous and $g : Y \to Z$ be $fgpr$-irresolute functions then $g \circ f : X \to Z$ is perfectly $fgpr$-continuous functions.

Proof. Let λ be $fgpr$ open set in Z. Then $g^{-1}(\lambda)$ is $fgpr$-open set in Y, since g is $fgpr$-irresolute functions. Also since f is perfectly $fgpr$-continuous, $f^{-1}(g^{-1}(\lambda)) = (g \circ f)^{-1}(\lambda)$ is both fuzzy open and fuzzy closed set in X. Hence $g \circ f$ is perfectly $fgpr$-continuous functions. ■

Definition 3.20. A map $f : X \to Y$ is said to be completely fuzzy generalized preregular continuous (briefly completely $fgpr$-continuous) if the inverse image of every $fgpr$-open set in Y is fuzzy regular open set in X.

Theorem 3.21. A map $f : X \to Y$ is completely $fgpr$-continuous iff the inverse image of every $fgpr$-closed set in Y is fuzzy regular closed set in X.

Proof. Suppose f is completely $fgpr$-continuous. Let λ be $fgpr$-closed set in Y. Then $1-\lambda$ is $fgpr$-open set in Y. Therefore $f^{-1}(1-\lambda)$ is fuzzy regular open set in X. Now $f^{-1}(1-\lambda) = 1 - f^{-1}(\lambda)$. Therefore $f^{-1}(\lambda)$ is fuzzy regular closed set in X.

Conversely, assume that the inverse image of every $fgpr$-closed set in Y is fuzzy regular closed set in X. Let λ be $fgpr$-open set in Y. Then $1-\lambda$ is $fgpr$-closed set in Y. By hypothesis, $f^{-1}(1-\lambda)$ is fuzzy regular closed set in X. Now $f^{-1}(1-\lambda) = 1-f^{-1}(\lambda)$. And therefore $f^{-1}(\lambda)$ is fuzzy regular open set in X. Hence f is completely $fgpr$-continuous function. ■

Theorem 3.22. Every completely $fgpr$-continuous function is a f-continuous funtion.

Proof. Let $f : X \to Y$ be a completely $fgpr$-continuous function. Let λ be fuzzy open set in Y. Then λ is $fgpr$-open set in Y. And then $f^{-1}(\lambda)$ is both fuzzy regular open set in X, and therefore $f^{-1}(\lambda)$ is fuzzy open set in X. Hence f is f-continuous function. ■

The converse of the above theorem need not not be true as seen from the following example.

Example 3.23. In the Example 3.4, the function f is f-continuous but not completely $fgpr$-continuous as the fuzzy set $1-\gamma = \frac{0}{a} + \frac{0.2}{b} + \frac{0.2}{c}$ is $fgpr$-open set in Y and $f^{-1}(1-\gamma) = 1-\gamma$ which is not both fuzzy regular open set in X.

Theorem 3.24. Every completely $fgpr$-continuous function is a f-completely continuous function.

Proof. Let $f : X \to Y$ be completely $fgpr$-continuous. Let λ be fuzzy open set in Y. Then λ be $fgpr$-open set in Y. Then $f^{-1}(\lambda)$ is fuzzy regular open set in X. Hence f is f-completely continuous function. ■

The converse of the above theorem need not not be true as seen from the following example.

Example 3.25. In the Example 3.15, the function f is completely f-continuous function, as the fuzzy set μ is fuzzy open set in Y and its inverse image $f^{-1}(\mu) = \mu$ is fuzzy regular open set in X. But f is not completely $fgpr$-continuous as the fuzzy set $1-\gamma = \frac{0}{a} + \frac{0.2}{b} + \frac{0.2}{c}$ is $fgpr$-open set in Y and $f^{-1}(1-\gamma) = 1-\gamma$ which is not fuzzy regular open set in X.

Theorem 3.26. Every completely $fgpr$-continuous function is strongly $fgpr$-continuous function.

Proof. Let $f : X \to Y$ be completely $fgpr$-continuous. Let λ be $fgpr$-open set in Y. Then $f^{-1}(\lambda)$ is fuzzy regular open set in X. Therefore $f^{-1}(\lambda)$ is fuzzy open set in X. Hence f is strongly $fgpr$-continuous function. ■

The converse of the above theorem need not be true as seen from the following example.

Example 3.27. In the Example 3.6, the function f is strongly $fgpr$-continuous but not completely $fgpr$-continuous as the fuzzy set μ^c is $fgpr$-closed set in Y and its inverse image $f^{-1}(\mu) = \mu$ is not fuzzy regular closed set in X.

Theorem 3.28. If $f : X \to Y$ is completely $fgpr$-continuous and $g : Y \to Z$ is $fgpr$-irresolute functions then $g \circ f : X \to Z$ is completely $fgpr$-continuous funtions.

Proof. Let λ be $fgpr$-open set in Z. Then $g^{-1}(\lambda)$ is $fgpr$-open set in Y, since g is $fgpr$-irresolute function. Also since f is completely $fgpr$-continuous. $f^{-1}(g^{-1}(\lambda)) = (g \circ f)^{-1}(\lambda)$ is fuzzy regular open set in X. Hence $g \circ f$ is completely $fgpr$-continuous functions. ■

Theorem 3.29. If $f : X \to Y$ and $g : Y \to Z$ be two completely $fgpr$-continuous functions then $g \circ f : X \to Z$ is completely $fgpr$-continuous functions.

Proof. Let λ be $fgpr$-open set in Z. Then $g^{-1}(\lambda)$ is fuzzy regular open set in Y. Since g is completely $fgpr$-continuous, $g^{-1}(\lambda)$ is fuzzy open set and then $fgpr$-open set in Y. Also since f is completely $fgpr$-continuous function, $f^{-1}(g^{-1}(\lambda)) = (g \circ f)^{-1}(\lambda)$ is fuzzy regular open set in X. Hence $g \circ f$ is completely $fgpr$-continuous functions. ■

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