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UPPER AND LOWER SLIGHT (τ_1, τ_2)-CONTINUITY

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Abstract. Our main purpose is to introduce the concepts of upper and lower slightly (τ_1, τ_2)-continuous multifunctions. Moreover, several characterizations of upper and lower slightly (τ_1, τ_2)-continuous multifunctions are investigated.

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1. Introduction

Stronger and weaker forms of open sets play an important role in topological spaces. By utilizing these sets several authors introduced and studied various types of generalizations of continuity. Viriyapong and Boonpok [58] studied some characterizations of (Λ, sp)-continuous functions by utilizing the notions of (Λ, sp)-open sets and (Λ, sp)-closed sets due to Boonpok and Khampakdee [18]. Dungthaisong et al. [31] introduced and studied the concept of $g_{(m,n)}$-continuous functions. Duangphui et al. [30] introduced and investigated the notion of $(\mu, \mu')^{(m,n)}$-continuous functions. Furthermore, some characterizations of almost (Λ, p)-continuous functions, strongly $\theta(\Lambda, p)$-continuous functions, almost strongly $\theta(\Lambda, p)$-continuous functions, $\theta(\Lambda, p)$-continuous functions, weakly (Λ, b)-continuous functions, $\theta(\star)$-precontinuous functions, $\star$-continuous functions, θ-$\mathscr{I}$-continuous functions, almost (g, m)-continuous functions, pairwise M-continuous functions, (τ_1, τ_2)-continuous functions, almost (τ_1, τ_2)-continuous functions, weakly (τ_1, τ_2)-continuous functions, almost quasi (τ_1, τ_2)-continuous functions and weakly quasi (τ_1, τ_2)-continuous functions were presented in [50], [52], [2], [48], [13],

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[14], [8], [22], [27], [28], [3], [4], [5], [39] and [29], respectively. Jain [34] introduced the notion of slightly continuous functions. Nour [43] defined slightly semi-continuous functions as a weak form of slight continuity and investigated some characterizations of slightly semi-continuous functions. Noiri [42] introduced and studied the concept of slightly β-continuous functions. Sangviset et al. [49] introduced the notion of slightly (m, μ)-continuous functions as functions from an m-space into a generalized topological space and investigated some characterizations of slightly (m, μ)-continuous functions. Ekici and Caldas [33] introduced the notion of slightly γ-continuouds functions and investigated the relationships between slight γ-continuity and the other types of continuity.

In 2005, Ekici [32] extended the notion of slightly β-continuous functions to the setting of multifunctions. Noiri and Popa [41] introduced a new class of multifunctions called slightly m-continuous multifunctions as a generalization of m-continuous multifunctions [44]. Popa and Noiri [45] introduced and studied the notion of θ-quasi continuous multifunctions. Laprom et al. [40] introduced and investigated the concept of $\beta(\tau_1, \tau_2)$-continuous multifunctions. Viriyapong and Boonpok [60] introduced and studied the notion of $(\tau_1, \tau_2)\alpha$-continuous multifunctions. Moreover, several characterizations of $(\tau_1, \tau_2)\delta$-semicontinuous multifunctions, almost weakly (τ_1, τ_2)-continuous multifunctions, $\star$-continuous multifunctions, $\beta(\star)$-continuous multifunctions, weakly quasi (Λ, sp)-continuous multifunctions, α-$\star$-continuous multifunctions, almost α-$\star$-continuous multifunctions, almost quasi $\star$-continuous multifunctions, weakly α-$\star$-continuous multifunctions, $s\beta(\star)$-continuous multifunctions, weakly $s\beta(\star)$-continuous multifunctions, $\theta(\star)$-quasi continuous multifunctions, almost $\imath^\star$-continuous multifunctions, weakly (Λ, sp)-continuous multifunctions, $\alpha(\Lambda, sp)$-continuous multifunctions, almost $\alpha(\Lambda, sp)$-continuous multifunctions, almost $\beta(\Lambda, sp)$-continuous multifunctions, slightly (Λ, sp)-continuous multifunctions, (τ_1, τ_2)-continuous multifunctions, almost (τ_1, τ_2)-continuous multifunctions, weakly (τ_1, τ_2)-continuous multifunctions, weakly quasi (τ_1, τ_2)-continuous multifunctions, s-$(\tau_1, \tau_2)p$-continuous multifunctions and c-(τ_1, τ_2)-continuous multifunctions were established in [23], [19], [25], [20], [59], [6], [7], [24], [9], [11], [10], [15], [21], [12], [37], [16], [53], [17], [46], [38], [51], [47], [55] and [36], respectively. Viriyapong et al. [56] introduced and studied the concept of slightly $(\tau_1, \tau_2)\beta$-continuous multifunctions. Khampakdee et al. [35] introduced and investigated the notion of slightly $(\tau_1, \tau_2)s$-continuous multifunctions. Viriyapong et al. [54] introduced and studied the concept of slightly $\alpha(\tau_1, \tau_2)$-continuous multifunctions. In this paper, we introduce the concepts of upper and lower slightly (τ_1, τ_2)-continuous multifunctions. We also investigate several characterizations of upper and lower slightly (τ_1, τ_2)-continuous multifunctions.

2. Preliminaries

Throughout the present paper, spaces (X, τ_1, τ_2) and (Y, σ_1, σ_2) (or simply X and Y) always mean bitopological spaces on which no separation axioms are assumed unless explicitly stated. Let A be a subset of a bitopological space (X, τ_1, τ_2). The closure of A and the interior of A with respect to τ_i are denoted by τ_i-Cl(A) and τ_i-Int(A), respectively, for $i = 1, 2$. A subset A of a bitopological space (X, τ_1, τ_2) is called $\tau_1\tau_2$-*closed* [26] if $A = \tau_1\text{-Cl}(\tau_2\text{-Cl}(A))$. The complement of a $\tau_1\tau_2$-closed set is called $\tau_1\tau_2$-*open*. Let A be a subset of a bitopological space (X, τ_1, τ_2). The intersection of all $\tau_1\tau_2$-closed sets of X containing A is called the $\tau_1\tau_2$-*closure* [26] of A and is denoted by $\tau_1\tau_2$-Cl(A). The union of all $\tau_1\tau_2$-open sets of X contained in A is called the $\tau_1\tau_2$-*interior* [26] of A and is denoted by $\tau_1\tau_2$-Int(A). A subset A of a bitopological space (X, τ_1, τ_2) is said to be $\tau_1\tau_2$-*clopen* [26] if A is both $\tau_1\tau_2$-open and $\tau_1\tau_2$-closed.

By a multifunction $F : X \to Y$, we mean a point-to-set correspondence from X into Y, and we always assume that $F(x) \neq \emptyset$ for all $x \in X$. For a multifunction $F : X \to Y$, following [1] we shall denote the upper and lower inverse of a set B of Y by $F^+(B)$ and $F^-(B)$, respectively, that is, $F^+(B) = \{x \in X \mid F(x) \subseteq B\}$ and

$$F^-(B) = \{x \in X \mid F(x) \cap B \neq \emptyset\}.$$

In particular, $F^-(y) = \{x \in X \mid y \in F(x)\}$ for each point $y \in Y$. For each $A \subseteq X$, $F(A) = \cup_{x \in A} F(x)$.

3. Upper and lower slightly (τ_1, τ_2)-continuous multifunctions

In this section, we introduce the notions of upper and lower slightly (τ_1, τ_2)-continuous multifunctions. Moreover, we investigate some characterizations of upper and lower slightly (τ_1, τ_2)-continuous multifunctions.

Definition 1. *A multifunction $F : (X, \tau_1, \tau_2) \to (Y, \sigma_1, \sigma_2)$ is said to be upper slightly (τ_1, τ_2)-continuous if for each point $x \in X$ and each $\sigma_1\sigma_2$-clopen set V of Y containing $F(x)$, there exists a $\tau_1\tau_2$-open set U of X containing x such that $F(U) \subseteq V$.*

Theorem 1. *For a multifunction $F : (X, \tau_1, \tau_2) \to (Y, \sigma_1, \sigma_2)$, the following properties are equivalent:*

(1) *F is upper slightly (τ_1, τ_2)-continuous;*
(2) *$F^+(V)$ is $\tau_1\tau_2$-open in X for every $\sigma_1\sigma_2$-clopen set V of Y;*
(3) *$F^-(V)$ is $\tau_1\tau_2$-closed in X for every $\sigma_1\sigma_2$-clopen set V of Y.*

Proof. (1) $\Rightarrow$ (2): Let V be any $\sigma_1\sigma_2$-clopen set of Y and $x \in F^+(V)$. Then, $F(x) \subseteq V$. By (1), there exists a $\tau_1\tau_2$-open set U of X containing x such that $F(U) \subseteq V$. Thus, $x \in U \subseteq F^+(V)$ and hence $x \in \tau_1\tau_2\text{-Int}(F^+(V))$. Therefore, $F^+(V) \subseteq \tau_1\tau_2\text{-Int}(F^+(V))$. This shows that $F^+(V)$ is $\tau_1\tau_2$-open in X.

(2) $\Leftrightarrow$ (3): This follows from the fact that $F^-(Y - B) = X - F^+(B)$ for every subset B of Y.

(2) $\Rightarrow$ (1): Let $x \in X$ and V be any $\sigma_1\sigma_2$-clopen set of Y containing $F(x)$. By (2), we have $x \in F^+(V) = \tau_1\tau_2\text{-Int}(F^+(V))$. There exists a $\tau_1\tau_2$-open set U of X containing x such that $U \subseteq F^+(V)$; hence $F(U) \subseteq V$. This shows that F is upper slightly (τ_1, τ_2)-continuous. □

Definition 2. *A multifunction $F : (X, \tau_1, \tau_2) \to (Y, \sigma_1, \sigma_2)$ is said to be lower slightly (τ_1, τ_2)-continuous if for each point $x \in X$ and each $\sigma_1\sigma_2$-clopen set V of Y such that $F(x) \cap V \neq \emptyset$, there exists a $\tau_1\tau_2$-open set U of X containing x such that $F(z) \cap V \neq \emptyset$ for each $z \in U$.*

Theorem 2. *For a multifunction $F : (X, \tau_1, \tau_2) \to (Y, \sigma_1, \sigma_2)$, the following properties are equivalent:*

(1) *F is lower slightly (τ_1, τ_2)-continuous;*
(2) *$F^-(V)$ is $\tau_1\tau_2$-open in X for every $\sigma_1\sigma_2$-clopen set V of Y;*
(3) *$F^+(V)$ is $\tau_1\tau_2$-closed in X for every $\sigma_1\sigma_2$-clopen set V of Y.*

Proof. The proof is similar to that of Theorem 1. □

Recall that a bitopological space (X, τ_1, τ_2) is said to be (τ_1, τ_2)-*extremally disconnected* [57] if the $\tau_1\tau_2$-closure of every $\tau_1\tau_2$-open set U of X is $\tau_1\tau_2$-open.

Theorem 3. *Let (Y, σ_1, σ_2) be a (σ_1, σ_2)-extremally disconnected space. For a multifunction $F : (X, \tau_1, \tau_2) \to (Y, \sigma_1, \sigma_2)$, the following properties are equivalent:*

(1) *F is upper slightly (τ_1, τ_2)-continuous;*
(2) *$\tau_1\tau_2$-Cl$(F^-(V)) \subseteq F^-(\sigma_1\sigma_2$-Cl$(V))$ for every $\sigma_1\sigma_2$-open set V of Y;*
(3) *$F^+(\sigma_1\sigma_2$-Int$(K)) \subseteq \tau_1\tau_2$-Int$(F^+(K))$ for every $\sigma_1\sigma_2$-closed set K of Y.*

Proof. (1) $\Rightarrow$ (2): Let V be any $\sigma_1\sigma_2$-open set of Y. Then, $\sigma_1\sigma_1$-Cl(V) is a $\sigma_1\sigma_2$-clopen set of Y. By Theorem 1, $F^-(\sigma_1\sigma_1\text{-Cl}(V))$ is $\tau_1\tau_2$-closed in X. Thus,

$$\tau_1\tau_2\text{-Cl}(F^-(V)) \subseteq \tau_1\tau_2\text{-Cl}(F^-(\sigma_1\sigma_2\text{-Cl}(V))) = F^-(\sigma_1\sigma_2\text{-Cl}(V)).$$

(2) $\Rightarrow$ (3): Let K be any $\sigma_1\sigma_2$-closed set of Y. Then, $Y - K$ is $\sigma_1\sigma_2$-open in Y. By (2), we have

$$\begin{aligned} X - \tau_1\tau_2\text{-Int}(F^+(K) &= \tau_1\tau_2\text{-Cl}(F^-(Y-K)) \\ &\subseteq F^-(\sigma_1\sigma_2\text{-Cl}(Y-K)) \\ &= X - F^+(\sigma_1\sigma_2\text{-Int}(K)) \end{aligned}$$

and hence $F^+(\sigma_1\sigma_2\text{-Int}(K)) \subseteq \tau_1\tau_2\text{-Int}(F^+(K))$.

(3) $\Rightarrow$ (1): Let $x \in X$ and V be any $\sigma_1\sigma_2$-clopen set of Y containing $F(x)$. Then by (3), $x \in F^+(V) = F^+(\sigma_1\sigma_2\text{-Int}(V)) \subseteq \tau_1\tau_2\text{-Int}(F^+(V))$. There exists a $\tau_1\tau_2$-open set U of X such that $x \in U \subseteq F^+(V)$. Thus, $F(U) \subseteq V$ and hence F is upper slightly (τ_1, τ_2)-continuous. □

Theorem 4. *Let (Y, σ_1, σ_2) be a (σ_1, σ_2)-extremally disconnected space. For a multifunction $F : (X, \tau_1, \tau_2) \to (Y, \sigma_1, \sigma_2)$, the following properties are equivalent:*

(1) *F is lower slightly (τ_1, τ_2)-continuous;*
(2) *$\tau_1\tau_2$-Cl$(F^+(V)) \subseteq F^+(\sigma_1\sigma_2$-Cl$(V))$ for every $\sigma_1\sigma_2$-open set V of Y;*

(3) $F^{-}(\sigma_1\sigma_2\text{-}Int(K)) \subseteq \tau_1\tau_2\text{-}Int(F^{-}(K))$ *for every* $\sigma_1\sigma_2$*-closed set* K *of* Y.

Proof. The proof is similar to that of Theorem 3. □

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Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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