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Soft Semiopen Sets via Operations

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Abstract: In this paper, we introduce and study the concept of soft semiopen sets via operations on soft topological space.

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1. Introduction

Soft set theory [9] was firstly introduced by Molodtsov in 1999 as a general mathematical tool for dealing with uncertain, fuzzy, not clearly defined objects. He has shown several applications of this theory in solving many practical problems in Economics, Engineering, Social Science, Medical Science, etc. In recent years the development in the fields of soft set theory and its application has been taking place in a rapid pace. This is because of the general nature of parametrization expressed by a soft set. Later Maji et. al. [10] presented some new definitions on soft sets such as a subset, the complement of a soft set and discussed in detail the application of soft set theory in decision making problems [11]. Chen et. al. [4, 5] and Kong et. al. [7] introduced a new definition of soft set parameterization reduction. Xiao et. al. [16] and Pei and Miao [13] discussed the relationship between soft sets and information systems. Also an attempt was made by Kostek [3] to assess sound quality based on a soft set approach. Mushrif et al. [12] presented a novel method for the classification of natural textures using the notions of soft set theory. The algebraic nature of set theories dealing with uncertainties has been studied by some authors. Chang introduced the notion of fuzzy topology and also studied some of its basic properties. Lashin et. al. [8] generalized rough set theory in the framework of topological spaces. Recently, Shabir and Naz [15] introduced the notion of soft topological spaces which are defined over an initial universe with a fixed set of parameters. They also studied some of basic concepts of soft topological spaces. Later, Aygunoglu et. al. [1], Zorlutuna et. al. [17] and Hussain et. al. [14] continued to study the properties of soft topological spaces. They got many important results in soft topological spaces. In the present study, we introduce some new concepts in soft topological spaces such as γ-soft semiopen sets, γ-soft semiclosed sets, γ-soft semiinterior and γ-soft semiclosure.

2. Preliminaries

Let U be an initial universe set and E_U be a collection of all possible parameters with respect to U, where parameters are the characteristics or properties of objects in U. We will call E_U the universe set of parameters with respect to U.

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Definition 2.1 ([9]). *A pair (F, A) is called a soft set over U if $A \subset E_U$ and $F : A \to P(U)$, where $P(U)$ is the set of all subsets of U.*

Definition 2.2 ([6]). *Let U be an initial universe set and E_U be a universe set of parameters. Let (F, A) and (G, B) be soft sets over a common universe set U and $A, B \subset E$. Then (F, A) is a subset of (G, B), denoted by $(F, A)\widetilde{\subset}(G, B)$, if $A \subset B$ and for all $e \in A, F(e) \subset G(e)$. Also (F, A) equals (G, B), denoted by $(F, A) = (G, B)$, if $(F, A)\widetilde{\subset}(G, B)$ and $(G, B)\widetilde{\subset}(F, A)$.*

Definition 2.3 ([10]). *A soft set (F, A) over U is called a null soft set, denoted by $\emptyset$, if $e \in A$, $F(e) = \emptyset$.*

Definition 2.4 ([10]). *A soft set (F, A) over U is called an absolute soft set, denoted by $\widetilde{A}$, if $e \in A$, $F(e) = U$.*

Definition 2.5 ([10]). *The union of two soft sets (F, A) and (G, B) over a common universe U is the soft set (H, C), where $C = A \cup B$, and for all $e \in C$,*

$$H(e) = \begin{cases} F(e) & \text{if } e \in A \backslash B, \\ G(e) & \text{if } e \in B \backslash A, \\ F(e) \cup G(e) & \text{if } e \in B \cap A. \end{cases}$$

We write $(F, A) \cup (G, B) = (H, C)$.

Definition 2.6 ([6]). *The intersection of two soft sets of (F, A) and (G, B) over a common universe U is the soft set (H, C), where $C = A \cap B$, and for all $e \in C$, $H(e) = F(e) \cap G(e)$. We write $(F, A) \cap (G, B) = (H, C)$.*

Now we recall some definitions and results defined and discussed in [14, 15]. Henceforth, let X be an initial universe set and E be the fixed nonempty set of parameter with respect to X unless otherwise specified.

Definition 2.7. *For a soft set (F, A) over U, the relative complement of (F, A) is denoted by $(F, A)'$ and is defined by $(F, A)' = (F', A)$, where $F' : A \to P(U)$ is a mapping given by $F'(e) = U \backslash F(e)$ for all $e \in A$.*

Definition 2.8. *Let τ be the collection of soft sets over X, then τ is called a soft topology on X if τ satisfies the following axioms.*

(1). $\emptyset$,$\widetilde{X}$ belong to τ.

(2). The union of any number of soft sets in τ belongs to τ.

(3). The intersection of any two soft sets in τ belongs to τ.

The triplet (X, τ, E, γ) is called a soft topological space over X.

Definition 2.9. *Let (X, τ, E, γ) be a soft topological space over X, then the members of τ are said to be soft open sets in X.*

Definition 2.10. *Let (X, τ, E, γ) be a soft topological space over X. A soft set (F, E) over X is said to be a soft closed set in X, if its relative complement $(F, E)'$ belongs to τ.*

Proposition 2.11. *Let (X, τ, E, γ) be a soft topological space over X. Then one has the following*

(1). $\emptyset$, $\widetilde{X}$ are soft closed sets over X.

(2). The intersection of any number of soft closed sets is a soft closed set over X.

(3). The union of any two soft closed sets is a soft closed set over X.

Definition 2.12. *Let (X, τ, E, γ) be a soft topological space and (A, E) be a soft set over X.*

(1). The soft interior of (A, E) is the soft set $\mathrm{Cl}(A, E) = \cup\{(O, E) : (O, E)$ is soft open and $(O, E)\widetilde{\subset}(A, E)\}$.

(2). The soft closure of (A, E) is the soft set $\mathrm{Cl}(A, E) = \cap\{(F, E) : (F, E)$ is soft closed and $(A, E)\widetilde{\subset}(F, E)\}$.

Proposition 2.13. *Let (X, τ, E, γ) be a soft topological space and let (F, E) and (G, E) be a soft set over X. Then*

(1). $\mathrm{Cl}(\mathrm{Cl}(F, E)) = \mathrm{Cl}(F, E)$,

(2). $(F, E)\widetilde{\subset}(G, E)$ *implies* $\mathrm{Cl}(F, E)\widetilde{\subset}\,\mathrm{Cl}(G, E)$,

(3). $\mathrm{Cl}(\mathrm{Cl}(F, E)) = \mathrm{Cl}(F, E)$,

(4). $(F, E)\widetilde{\subset}(G, E)$ *implies* $\mathrm{Cl}(F, E)\widetilde{\subset}\,\mathrm{Cl}(G, E)$.

Definition 2.14. *Let (F, E) be a soft set over X and $x \in X$. We say that $x \in (F, E)$ read as x belongs to the soft set (F, E), whenever $x \in F(\alpha)$ for all $\alpha \in E$. Note that for $x \in X$, $x \notin (F, E)$ if $x \notin F(\alpha)$ for $\alpha \in E$.*

Definition 2.15. *Let $x \in X$, then (x, E) denotes the soft set over X for which $x(\alpha) = \{x\}$, for all $\alpha \in E$.*

Definition 2.16 ([2])**.** *An operation on a soft topology τ over X is called a γ-operation if a mapping from τ to the set $P(X)^E$ and defined by $\gamma : \tau \to P(X)^E$ such that for each $(V, E) \in \tau$, $(V, E)\widetilde{\subset}\gamma(V, E)$.*

Definition 2.17 ([2])**.** *A soft set (P, E) is said to be γ-soft open set if for each $x\widetilde{\in}(P, E)$, there exists a soft a γ-soft open set (V, E) such that $x\widetilde{\in}(V, E)\widetilde{\subset}\gamma(V, E)\widetilde{\subset}(P, E)$. The complement of a γ-soft open set is called a γ-soft closed set. The family of all γ-soft open sets of (X, τ, E, γ) is denoted by τ_γ.*

Definition 2.18 ([2])**.** *Let (X, τ, E, γ) be an operation-soft topological space and (A, E) be a soft set over X. Then*

(1). the τ_γ-soft interior of (A, E) is the soft set $\tau_\gamma\text{-}\mathrm{Int}(A, E) = \cup\{(O, E) : (O, E)$ is γ-soft open and $(O, E)\widetilde{\subset}(A, E)\}$.

(2). the τ_γ-soft closure of (A, E) is the soft set $\tau_\gamma\text{-}\mathrm{Cl}(A, E) = \cap\{(F, E) : (F, E)$ is γ-soft closed and $(A, E)\widetilde{\subset}(F, E)\}$.

3. Properties of γ-soft Semiopen Sets

Definition 3.1. *A soft set (A, E) in an operation-soft topological space (X, τ, E, γ) is γ-soft semiopen if $(A, E)\widetilde{\subset}\tau_\gamma\text{-}\mathrm{Cl}(\tau_\gamma\text{-}\mathrm{Int}((A, E)))$. The set of all γ-soft semiopen sets of an operation-soft topological space (X, τ, E, γ) is denoted as $\tau_\gamma\text{-}SSO(X)$.*

Remark 3.2. *Every γ-soft open set in an operation-soft topological space (X, τ, E, γ) is γ-soft semiopen. Now we give an example to show that the converse of this remark does not hold.*

Example 3.3. *Let $X = \{h_1, h_2, h_3\}$, $E = \{e_1, e_2\}$, $\tau = \{\emptyset, \widetilde{X}, (F_1, E), (F_2, E), (F_3, E), ..., (F_7, E)\}$ where $(F_1, E), (F_2, E), (F_3, E), ..., (F_7, E)$ are soft sets over X defined as: $F_1(e_1) = \{h_1, h_2\}$, $F_1(e_2) = \{h_1, h_2\}$, $F_2(e_1) = \{h_2\}$, $F_2(e_2) = \{h_1, h_3\}$, $F_3(e_1) = \{h_2, h_3\}$, $F_3(e_2) = \{h_1\}$, $F_4(e_1) = \{h_2\}$, $F_4(e_2) = \{h_1\}$, $F_5(e_1) = \{h_1, h_2\}$, $F_5(e_2) = X$, $F_6(e_1) = X$, $F_6(e_2) = \{h_1, h_2\}$, $F_7(e_1) = \{h_2, h_3\}$, $F_7(e_2) = \{h_1, h_3\}$ and γ be an identity operation. Then τ defines a soft topology on X and hence (X, τ, E, γ) is an operation-soft topological space over X. A soft set (G, E) in (X, τ, E, γ) is defined as $G_1(e_1) = \{h_2, h_3\}$, $G_1(e_2) = \{h_1, h_2\}$. Then, for the soft set (F_3, E), we have $(F_3, E)\widetilde{\subset}(G, E)$. Because $\tau_\gamma\text{-}\mathrm{Cl}(F_3, E) = \widetilde{X}$, we have $(F_3, E)\widetilde{\subset}(G, E)\widetilde{\subset}\tau_\gamma\text{-}\mathrm{Cl}(F_3, E)$. Then the soft set (G, E) is γ-soft semiopen set in (X, τ, E, γ) but not γ-soft open since $(G, E) \notin \tau$.*

Proposition 3.4. *Let (X, τ, E, γ) be an operation-soft topological space. A subset (A, E) of X is γ-soft semiopen if, and only if τ_γ-$\mathrm{Cl}((A, E)) = \tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E)))$.*

Proof. Let $(A, E) \in \tau_\gamma$-$SSO(X)$. Then $(A, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E))$. Then τ_γ-$\mathrm{Cl}((A, E))\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E))$ and hence τ_γ-$\mathrm{Cl}((A, E)) = \tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E))$. The converse is obvious. □

Corollary 3.5. *If A is a nonempty γ-soft semiopen set, then τ_γ-$\mathrm{Int}((A, E)) \neq \emptyset$.*

Proof. Since (A, E) is τ_γ-semiopen, by Proposition 3.4, we have τ_γ-$\mathrm{Cl}((A, E)) = \tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E)))$. Suppose τ_γ-$\mathrm{Int}((A, E)) = \emptyset$. Then we have τ_γ-$\mathrm{Cl}((A, E)) = \emptyset$ and hence $(A, E) = \emptyset$. This is contrary to the hypothesis. Therefore, τ_γ-$\mathrm{Int}((A, E)) \neq \emptyset$. □

Proposition 3.6. *Let (X, τ, E, γ) be an operation-soft topological space. Then (A, E) is γ-soft semiopen if, and only if there exists $(U, E) \in \tau_\gamma$ such that $(U, E)\tilde{\subset}(A, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}((U, E))$.*

Proof. Let $(A, E) \in \tau_\gamma$-$SSO(X)$. Then $(A, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E)))$. Take τ_γ-$\mathrm{Int}((A, E)) = (U, E)$. Then $(U, E)\tilde{\subset}(A, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}((U, E))$. Conversely, let (U, E) be a γ-soft open set such that $(U, E)\tilde{\subset}(A, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}((U, E))$. Since $(U, E)\tilde{\subset}(A, E)$, $(U, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Int}((A, E))$ and hence τ_γ-$\mathrm{Cl}((U, E))\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E)))$. Thus, we obtain $(A, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E)))$. □

Proposition 3.7. *If (A, E) is a γ-soft semiopen set in an operation-soft topological space (X, τ, E, γ) and $(A, E)\tilde{\subset}(B, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}((A, E))$, then (B, E) is a γ-soft semiopen set in (X, τ).*

Proof. Since (A, E) is γ-soft semiopen, there exists a γ-soft open set (U, E) such that $(U, E)\tilde{\subset}(A, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}((U, E))$. Then $(U, E)\tilde{\subset}(A, E)\tilde{\subset}(B, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}((A, E))\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Cl}((U, E))) = \tau_\gamma$-$\mathrm{Cl}((U, E))$ and hence $(U, E)\tilde{\subset}(B, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}((U, E))$. By Proposition 3.6, we obtain $(B, E) \in \gamma$-$SO(X)$. □

Theorem 3.8. *A subset (A, E) of an operation-soft topological space (X, τ, E, γ) is γ-soft semiopen if, and only if it is both γ-δ-softopen and γ-soft semipreopen.*

Proof. Let (A, E) be a γ-soft semiopen set. Then $(A, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E)))\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(\tau_\gamma$-$\mathrm{Cl}((A, E))))$. This shows that A is γ-soft semipreopen. Moreover, τ_γ-$\mathrm{Int}(\tau_\gamma$-$\mathrm{Cl}((A, E)))\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}((A, E))\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E)))$. Then (A, E) is γ-δ-soft open. Conversely, let (A, E) be γ-δ-softopen and γ-soft semipreopen set, then τ_γ-$\mathrm{Int}(\tau_\gamma$-$\mathrm{Cl}((A, E)))\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E)))$. Thus τ_γ-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(\tau_\gamma$-$\mathrm{Cl}((A, E))))\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E)))$. Since (A, E) is γ-soft semipreopen, $A\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(\tau_\gamma$-$\mathrm{Cl}((A, E))))\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E)))$ and $(A, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A, E)))$. Hence (A, E) is a γ-soft semiopen set. □

Theorem 3.9. *Let $\{(A_\alpha, E)\}_{\alpha\in\Delta}$ be a collection of γ-soft semiopen sets an operation-soft topological space (X, τ, E, γ). Then $\underset{\alpha\in\Delta}{\cup}(A_\alpha, E)$ is γ-soft semiopen.*

Proof. For each $\alpha \in \Delta$, we have a γ-soft open set (O_α, E) such that $(O_\alpha, E)\tilde{\subset}(A_\alpha, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(O_\alpha, E)$. Then $\underset{\alpha\in\Delta}{\cup}(O_\alpha, E)\tilde{\subset}\underset{\alpha\in\Delta}{\cup}(A_\alpha, E)\tilde{\subset}\underset{\alpha\in\Delta}{\cup}\tau_\gamma$-$\mathrm{Cl}(O_\alpha, E)\tilde{\subset}\tau_\gamma$-$\mathrm{Cl}(\underset{\alpha\in\Delta}{\cup}(O_\alpha, E))$. □

Definition 3.10. *A soft set (A, E) of an operation-soft topological space (X, τ, E, γ) is said to be γ-soft semiclosed if $X\backslash A$ is γ-soft semiopen.*

Remark 3.11. *The set of all γ-soft semiclosed sets of an operation-soft topological space (X, τ, E, γ) is denoted as τ_γ-$SSC(X)$.*

Theorem 3.12. *A subset (A,E) of an operation-soft topological space (X,τ,E,γ) is γ-soft semiclosed if, and only if τ_γ-*$\mathrm{Int}(\tau_\gamma\text{-}\mathrm{Cl}((A,E)))\widetilde{\subseteq}(A,E)$.

Proof. Since $(A,E)\in\tau_\gamma\text{-}SSC(X)$, $X\backslash(A,E)\in\tau_\gamma\text{-}SSO(X)$. Hence, $X\backslash(A,E)\widetilde{\subseteq}\tau_\gamma\text{-}\mathrm{Cl}(\tau_\gamma\text{-}\mathrm{Int}(X\backslash A))\widetilde{\subseteq}\tau_\gamma\text{-}\mathrm{Cl}(\tau_\gamma\text{-}\mathrm{Int}(X\backslash(A,E))) = X\backslash(\tau_\gamma\text{-}\mathrm{Int}(\tau_\gamma\text{-}\mathrm{Cl}((A,E))))\widetilde{\subseteq}X\backslash(\tau_\gamma\text{-}\mathrm{Int}(\tau_\gamma\text{-}\mathrm{Cl}((A,E))))$. Hence $\tau_\gamma\text{-}\mathrm{Int}(\tau_\gamma\text{-}\mathrm{Cl}((A,E)))\widetilde{\subseteq}(A,E)$. The converse is clear. □

Theorem 3.13. *A subset (A,E) of an operation-soft topological space (X,τ,E,γ) is γ-soft semiclosed if and only if there exists a γ-soft closed set F such that $\tau_\gamma\text{-}\mathrm{Int}(F)\widetilde{\subseteq}(A,E)\widetilde{\subseteq}(F,E)$.*

Proof. Suppose that (A,E) is γ-soft semiclosed. By Theorem 3.12, $\tau_\gamma\text{-}\mathrm{Int}(\tau_\gamma\text{-}\mathrm{Cl}((A,E)))\widetilde{\subseteq}(A,E)$. Let $(F,E)=\tau_\gamma\text{-}\mathrm{Cl}((A,E))$, then (F,E) is γ-soft closed set such that $\tau_\gamma\text{-}\mathrm{Int}((F,E))\widetilde{\subseteq}(A,E)\widetilde{\subseteq}(F,E)$. Conversely, let (F,E) be a γ-soft closed set such that $\tau_\gamma\text{-}\mathrm{Int}((F,E))\widetilde{\subseteq}(A,E)\widetilde{\subseteq}(F,E)$. But $(F,E)\widetilde{\supseteq}\tau_\gamma\text{-}\mathrm{Cl}((A,E))$, so $\tau_\gamma\text{-}\mathrm{Int}((F,E))\widetilde{\supseteq}\tau_\gamma\text{-}\mathrm{Int}(\tau_\gamma\text{-}\mathrm{Cl}((A,E)))$. Hence $\tau_\gamma\text{-}\mathrm{Int}(\tau_\gamma\text{-}\mathrm{Cl}((A,E)))\widetilde{\subseteq}(A,E)$. Therefore, (A,E) is γ-soft semiclosed. □

Proposition 3.14. *A subset (A,E) of an operation-soft topological space (X,τ,E,γ) is γ-soft semipreclosed and γ-δ-soft open, then it is γ-soft semiclosed.*

Proof. The proof follows from the definitions. □

Theorem 3.15. *Arbitrary intersection of γ-soft semiclosed sets is always γ-soft semiclosed.*

Proof. Follows from Theorems 3.9 and 3.12. □

Definition 3.16. *Let (A,E) be subset of an operation-soft topological space (X,τ,E,γ). Then*

(1). the τ_γ-semiclosure of (A,E) is defined as intersection of all γ-semiclosed sets containing (A,E). That is, τ_γ-$s\,\mathrm{Cl}((A,E)) = \cap\{(F,E) : (F,E)$ is γ-soft semiclosed and $(A,E)\widetilde{\subseteq}(F,E)\}$.

(2). the τ_γ-semiinterior of (A,E) is defined as union of all γ-soft semiopen sets contained in (A,E). That is, τ_γ-$s\,\mathrm{Int}((A,E)) = \cup\{(U,E) : (U,E)$ is γ-soft semiopen and $(U,E)\widetilde{\subseteq}(A,E)\}$.

The proof of the following theorem is obvious and therefore is omitted.

Theorem 3.17. *Let (A,E) be subset of an operation-soft topological space (X,τ,E,γ). Then*

(1). τ_γ-$s\,\mathrm{Int}((A,E))$ is the largest γ-soft semiopen subset of X contained in (A,E).

(2). (A,E) is γ-soft semiopen if and only if $(A,E)=\tau_\gamma$-$s\,\mathrm{Int}((A,E))$.

(3). τ_γ-$s\,\mathrm{Int}(\tau_\gamma$-$s\,\mathrm{Int}((A,E))) = \tau_\gamma$-$s\,\mathrm{Int}((A,E))$.

(4). If $(A,E)\widetilde{\subseteq}(B,E)$, then τ_γ-$s\,\mathrm{Int}((A,E))\widetilde{\subseteq}\tau_\gamma$-$s\,\mathrm{Int}((B,E))$.

(5). τ_γ-$s\,\mathrm{Int}((A,E)\cap(B,E)) = \tau_\gamma$-$s\,\mathrm{Int}((A,E))\cap\tau_\gamma$-$s\,\mathrm{Int}((B,E))$.

(6). τ_γ-$s\,\mathrm{Int}((A,E)\cup(B,E))\widetilde{\supseteq}\tau_\gamma$-$s\,\mathrm{Int}((A,E))\cup\tau_\gamma$-$s\,\mathrm{Int}((B,E))$.

(7). A point $x\widetilde{\in}\tau_\gamma$-$s\,\mathrm{Cl}((A,E))$ if, and only if $(U,E)\cap(A,E)\neq\emptyset$ for every $(U,E)\in\gamma$-$SO(X,x)$.

(8). τ_γ-$s\,\mathrm{Cl}((A,E))$ is the smallest γ-soft semiclosed subset of $\widetilde{X}$ containing (A,E).

(9). (A,E) is γ-soft semiclosed if, and only if $(A,E)=\tau_\gamma$-$s\,\mathrm{Cl}((A,E))$.

(10). τ_γ-$s\,\mathrm{Cl}(\tau_\gamma$-$s\,\mathrm{Cl}((A,E))) = \tau_\gamma$-$s\,\mathrm{Cl}((A,E))$.

(11). *If* $(A,E)\widetilde{\subset}(B,E)$, *then* τ_γ-$s\,\mathrm{Cl}((A,E))\widetilde{\subset}\tau_\gamma$-$s\,\mathrm{Cl}((B,E))$.

(12). τ_γ-$s\,\mathrm{Cl}((A,E)\cup(B,E)) = \tau_\gamma$-$s\,\mathrm{Cl}((A,E))\cup\tau_\gamma$-$s\,\mathrm{Cl}((B,E))$.

(13). τ_γ-$s\,\mathrm{Cl}((A,E)\cap(B,E))\widetilde{\subset}\tau_\gamma$-$s\,\mathrm{Cl}((A,E))\cap\tau_\gamma$-$s\,\mathrm{Cl}((B,E))$.

(14). τ_γ-$s\,\mathrm{Int}(\widetilde{X}\backslash(A,E)) = \widetilde{X}\backslash\tau_\gamma$-$s\,\mathrm{Cl}((A,E))$.

(15). τ_γ-$s\,\mathrm{Cl}(\widetilde{X}\backslash(A,E)) = \widetilde{X}\backslash\tau_\gamma$-$s\,\mathrm{Int}((A,E))$.

Theorem 3.18. *Let* (A,E) *be subset of an operation-soft topological space* (X,τ,E,γ) *and* γ *be regular operations on* τ. *Then the following hold*

(1). τ_γ-$s\,\mathrm{Cl}((A,E)) = (A,E)\cup\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}((A,E)))$.

(2). τ_γ-$s\,\mathrm{Int}((A,E)) = (A,E)\cap\tau_\gamma$-$\mathrm{Int}(\tau_\gamma$-$\mathrm{Cl}((A,E)))$.

Proof. (1). τ_γ-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(A\cup\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(A)))\subset\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(A)\cup\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Cl}-\mathrm{Int}(A)))\subset\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(A))\cup\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(A))\subset A\cup(\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(A))$. Hence $A\cup\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(A))$ is a γ-soft semiclosed set containing A. Therefore, τ_γ-$sp\,\mathrm{Cl}(A)\subset A\cup\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(A))$. Conversely, τ_γ-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(A))\subset\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(\tau_\gamma$-$sp\,\mathrm{Cl}(A))\subset\tau_\gamma$-$sp\,\mathrm{Cl}(A)$ since τ_γ-$sp\,\mathrm{Cl}(A)$ is a γ-soft semiclosed set. Hence τ_γ-$sp\,\mathrm{Cl}(A) = A\cup\tau_\gamma$-$\mathrm{Cl}(\tau_\gamma$-$\mathrm{Int}(A))$.
(2). Follows from (i) and Lemma **??**(1). □

Theorem 3.19. *For an operation-soft topological space* (X,τ,E,γ), *the following hold:*

(1). $(A,E) = \tau_\gamma$-$s\,\mathrm{Cl}((A,E))$.

(2). τ_γ-$s\,\mathrm{Int}(\tau_\gamma$-$s\,\mathrm{Cl}((A,E)))\widetilde{\subset}(A,E)$.

(3). $(\tau_\gamma$-$\mathrm{Cl}(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E))))\backslash(\widetilde{X}\backslash(\tau_\gamma$-$s\,\mathrm{Cl}((A,E)))))\widetilde{\supset}(\tau_\gamma$-$\mathrm{Cl}((A,E))\backslash(A,E))$.

Proof. $(1)\Rightarrow(2)$: If $(A,E) = \tau_\gamma$-$s\,\mathrm{Cl}((A,E))$, then τ_γ-$s\,\mathrm{Int}(\tau_\gamma$-$s\,\mathrm{Cl}((A,E))) = \tau_\gamma$-$s\,\mathrm{Int}((A,E))\subset(A,E)$.
$(2)\Rightarrow(3)$: Suppose τ_γ-$s\,\mathrm{Int}(\tau_\gamma$-$s\,\mathrm{Cl}((A,E)))\widetilde{\subset}(A,E)$. Now τ_γ-$s\,\mathrm{Cl}((A,E))$ is a γ-soft semiclosed set, so by Proposition 3.13, there is a γ-soft closed set (F,E) such that τ_γ-$\mathrm{Int}((F,E))\widetilde{\subset}\tau_\gamma$-$s\,\mathrm{Cl}((A,E))\widetilde{\subset}(F,E)$. Since τ_γ-$\mathrm{Int}((F,E))$ is γ-soft semiopen, τ_γ-$s\,\mathrm{Int}(\tau_\gamma$-$\mathrm{Int}((F,E))) = \tau_\gamma$-$\mathrm{Int}((F,E))$. Therefore, τ_γ-$\mathrm{Int}((F,E)) = \tau_\gamma$-$s\,\mathrm{Int}((\tau_\gamma$-$\mathrm{Int}((F,E)))\widetilde{\subset}\tau_\gamma$-$s\,\mathrm{Int}(\tau_\gamma$-$s\,\mathrm{Cl}((A,E)))$ and hence τ_γ-$\mathrm{Int}((F,E))\widetilde{\subset}(A,E)$. But $(A,E)\widetilde{\subset}\tau_\gamma$-$s\,\mathrm{Cl}((A,E))\widetilde{\subset}(F,E)$. Thus, τ_γ-$\mathrm{Int}((F,E))\widetilde{\subset}(A,E)\widetilde{\subset}(F,E)$, where (F,E) is γ-soft closed.
$(3)\Leftrightarrow(1)$: We have $(\tau_\gamma$-$\mathrm{Cl}(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E))))\backslash(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E)))))\widetilde{\supset}(\tau_\gamma$-$\mathrm{Cl}((A,E))\backslash(A,E))\Leftrightarrow\tau_\gamma$-$\mathrm{Cl}((A,E))\backslash(\tau_\gamma$-$\mathrm{Cl}(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E))))\backslash(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E)))))\widetilde{\subset}(A,E)\Leftrightarrow\tau_\gamma$-$\mathrm{Cl}((A,E))\cap(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E))))\backslash(X\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E)))))\widetilde{\subset}(A,E)\Leftrightarrow\tau_\gamma$-$\mathrm{Cl}((A,E))\cap(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E))))\cap(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E))))))\widetilde{\subset}(A,E)\Leftrightarrow\tau_\gamma$-$\mathrm{Cl}((A,E))\cap((\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E)))))\cup(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E)))))))\widetilde{\subset}(A,E)\Leftrightarrow\tau_\gamma$-$\mathrm{Cl}((A,E))\cap((\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E)))))\cup(\tau_\gamma$-$\mathrm{Cl}((A,E))\cap(\widetilde{X}\backslash(\tau_\gamma$-$\mathrm{Cl}((A,E)))))))\widetilde{\subset}(A,E)\Leftrightarrow\tau_\gamma$-$\mathrm{Cl}((A,E))\cap\tau_\gamma$-$\mathrm{Int}(\tau_\gamma$-$\mathrm{Cl}((A,E)))\widetilde{\subset}(A,E)\Leftrightarrow\tau_\gamma$-$\mathrm{Int}(\tau_\gamma$-$\mathrm{Cl}((A,E)))\widetilde{\subset}(A,E)$ (A,E) is γ-soft semiclosed $\Leftrightarrow(A,E) = \tau_\gamma$-$s\,\mathrm{Cl}((A,E))$. □

4. γ-Soft Semineighborhoods

Definition 4.1. *A soft set (F, E) in an operation-soft topological space (X, τ, E, γ) is said to be a γ-soft semineighborhood of the soft point e_F if there is a γ-soft semiopen set (B, E) such that $e_F \widetilde{\in} (B, E) \widetilde{\subseteq} (F, E)$. The γ-soft semineighborhood system of a soft point e_F which is denoted by $\mathcal{U}_{e_F}$ is the set of all its γ-soft semineighborhoods.*

Proposition 4.2. *The γ-soft semineighborhood system $\mathcal{U}_{e_F}$ at a soft point e_F in the operation-soft topological space (X, τ, E, γ) has the following results.*

(1). If $(F, E) \in \mathcal{U}_{e_F}$, then one has $e_F \widetilde{\in} (F, E)$.

(2). If $(F, E) \in \mathcal{U}_{e_F}$ and $(F, E) \widetilde{\subseteq} (B, E)$, then one has $(B, E) \in \mathcal{U}_{e_F}$.

(3). If $(F, E) \in \mathcal{U}_{e_F}$, then there exists a soft set $(B, E) \in \mathcal{U}_{e_F}$ such that $(F, E) \in \mathcal{U}_{e'}$ for each $e' \widetilde{\in} (B, E)$.

Proof. (1). If $(F, E) \in \mathcal{U}_{e_F}$, then we have a γ-soft semiopen set (B, E) such that $e_F \widetilde{\in} (B, E) \widetilde{\subseteq} (F, E)$. So we have $e_F \widetilde{\in} (F, E)$.

(2). If $(F, E) \in \mathcal{U}_{e_F}$ and $(F, E) \widetilde{\subseteq} (B, E)$. Because $(F, E) \in \mathcal{U}_{e_F}$, there exists a γ-soft semiopen set (H, E) such that $e_F \widetilde{\in} (H, E) \widetilde{\subseteq} (F, E)$. So we have $e_F \widetilde{\in} (H, E) \widetilde{\subseteq} (F, E) \widetilde{\subseteq} (B, E)$ and we have $(B, E) \in \mathcal{U}_{e_F}$.

(3). If $(F, E) \in \mathcal{U}_{e_F}$, then there is a γ-soft semiopen set (H, E) such that $e_F \widetilde{\in} (H, E) \widetilde{\subseteq} (F, E)$. Let $(B, E) = (H, E)$ and for each $e' \widetilde{\in} (B, E), e' \widetilde{\in} (B, E) \widetilde{\subseteq} (H, E) \widetilde{\subseteq} (F, E)$. This shows $(F, E) \in \mathcal{U}_{e'}$. □

Definition 4.3. *Let (X, τ, E, γ) be an operation-soft topological space and $\mathcal{U}_{e_F}$ be a γ-soft semineighborhood of a soft point e_F. If for every γ-soft semineighborhood (F, E) of e_F, there is a $(H, E) \in \mathcal{V}_{e_F} \subseteq \mathcal{U}_{e_F}$ such that $e_F \widetilde{\in} (H, E) \widetilde{\subseteq} (F, E)$, then $\mathcal{V}_{e_F}$ is said to be a γ-soft semineighborhoods base of $\mathcal{U}_{e_F}$ at e_F.*

Proposition 4.4. *Let (X, τ, E, γ) be an operation-soft topological space and $\mathcal{U}_{e_F}$ be a γ-soft semineighborhood of a soft point e_F. $\mathcal{V}_{e_F}$ is the γ-soft semineighborhoods base of $\mathcal{U}_{e_F}$ at e_F. Then one has the following.*

(1). If $(F, E) \in \mathcal{V}_{e_F}$, then we have $e_F \widetilde{\in} (F, E)$.

(2). If $(F, E) \in \mathcal{V}_{e_F}$ and $(F, E) \widetilde{\subseteq} (B, E)$, then one has $(B, E) \in \mathcal{V}_{e_F}$.

(3). If $(F, E) \in \mathcal{V}_{e_F}$, then there exists a soft set $(B, E) \in \mathcal{V}_{e_F}$ such that $(F, E) \in \mathcal{V}_{e'}$ for each $e' \widetilde{\in} (B, E)$.

Proof. These properties are easily verified by referring to the corresponding properties of γ-soft semineighborhoods in Proposition 4.2. □

Definition 4.5. *Let (X, τ, E, γ) be a soft topological space and e_F be a soft point in (X, τ, E, γ). If e_F has a countable γ-soft semineighborhoods base, then we say that (X, τ, E, γ) is γ-soft semi-first countable at e_F. If each soft point in (X, τ, E, γ) is γ-soft semi-first countable, then we say that (X, τ, E, γ) is a γ-soft semifirst-countable space.*

Proposition 4.6. *Let (X, τ, E, γ) be a soft topological space and e_F be a soft point in (X, τ, E, γ). Then (X, τ, E, γ) is γ-soft semifirst-countable at e_F if and only if there is a countable soft semineighborhoods base $\{(F_n, E), n \in N\}$ at e_F such that $(F_{n+1}, E) \widetilde{\subseteq} (F_n, E)$ for each $n \in N$.*

Proof. Necessity: Obvious.

Sufficiency: Let $\{(U_n, E), n \in N\}$ be a countable γ-soft semineighborhoods base at e_F. For each $n \in N$, put $(F_n, E) = \bigcap_{i=1}^{n} (U_i, E)$. Then it is easy to see that $\{(F_n, E), n \in N\}$ is a γ-soft semineighborhoods base at e_F and $(F_{n+1}, E) \widetilde{\subseteq} (F_n, E)$ for each $n \in N$. □

Definition 4.7. *Let (X, τ, E, γ) be an operation soft topological space, (B, E) be a soft set, and e_F be a soft point in (X, τ, E). Then e_F is said to be a γ-soft semiinterior point of (B, E) if there is a γ-soft semiopen set (H, E) satisfies $e_F \widetilde{\in} (H, E) \widetilde{\subseteq} (B, E)$.*

Proposition 4.8. *Let e_F be a soft point in (X, τ, E) and (B, E) be a γ-soft semiopen set. Then one has the following results.*

(1). Each soft point $e_F \widetilde{\in} (B, E)$ is a γ-soft semiinterior point.

(2). For each $e \in E$, one can define $(B, \{e\})$ as follows:

$$B(e') = \begin{cases} B(e) & \text{if } e' = e, \\ \emptyset & \text{if } e' \neq e, \end{cases}$$

Then $(B, \{e\})$ is a γ-soft semiinterior point of (B, E) and $(B, \{e\}) = \cup e_F$ for each γ-soft semiinterior point e_F of (B, E).

(3). $\bigcup_{e \in E} (B, \{e\}) = (B, E)$.

Proof. (1), (3) are obvious by definitions.

(2). For (B, E) is a γ-soft semiopen set, the γ-soft semiinterior point $(B, \{e\})$ is the largest γ-soft semiinterior point of (B, E) by $e \in E$ and we have $(B, \{e\}) = \cup e_F$ for every γ-soft semiinterior point e_F of (B, E). □

Proposition 4.9. *Let (X, τ, E) be an operation soft topological space, (B, E) be a soft set. Then $s\,\mathrm{Int}(B, E) = \bigcup_{e \in E} \{e_F : e_F$ is any γ-soft semiinterior point of $(B, E)\}$.*

Proof. By the definition of γ-soft semiinterior and Proposition 4.8. □

Definition 4.10. *A soft set (F, E) in an operation soft topological space (X, τ, E, γ) is called a γ-soft semineighborhood of the soft set (G, E) if there is a γ-soft semiopen set (B, E) such that $(G, E) \widetilde{\subseteq} (B, E) \widetilde{\subseteq} (F, E)$.*

Proposition 4.11. *Let (X, τ, E, γ) be a soft topological space, (B, E) be a soft set. Then (B, E) is γ-soft semiopen if, and only if for each soft set (F, E) contained in (B, E), (B, E) is a γ-soft semineighborhood of (F, E).*

Proof. Necessity: Obvious.

Sufficiency: Because $(B, E) \widetilde{\subseteq} (B, E)$, then we have a γ-soft semiopen set (H, E) such that $(B, E) \widetilde{\subseteq} (H, E) \widetilde{\subseteq} (B, E)$. So we have $(B, E) = (H, E)$ and (B, E) is γ-soft semiopen. □

Definition 4.12. *Let the sequence $\{(F_n, E), n \in N\}$ be a soft sequence in an operation soft topological space (X, τ, E, γ). Then $\{(F_n, E), n \in N\}$ is eventually contained in a soft set (B, E) if and only if there is an integer m such that, if $n \geq m$, then $(F_n, E) \widetilde{\subseteq} (B, E)$. The sequence is frequently contained in (B, E) if and only if for each integer m, there is an integer n such that $n \geq m$ and $(F_n, E) \widetilde{\subseteq} (B, E)$.*

Definition 4.13. *Let the sequence $\{(F_n, E), n \in N\}$ be a soft sequence in an operation soft topological space (X, τ, E, γ), then one says $\{(F_n, E), n \in N\}$ γ-soft semiconverges to a soft point e_F if it is eventually contained in each γ-soft semineighborhood of e_F. And the soft point e_F is said to be a γ-soft semicluster soft point of $\{(F_n, E), n \in N\}$ if the sequence is frequently contained in every γ-soft semineighborhood of e_F.*

Proposition 4.14. *Let (X, τ, E) be γ-soft semi-first countable, then one has the following.*

(1). (B, E) is γ-soft semiopen if and only if for every soft sequence $\{(F_n, E), n \in N\}$ which γ-soft semiconverges to e_F in (B, E) is eventually contained in (B, E).

(2). If e_F is a γ-soft semicluster soft point of the soft sequence $\{(F_n, E), n \in N\}$, then one has a subsequence of $\{(F_n, E), n \in N\}$ which γ-soft semiconverges to e_F.

Proof. (1). If (B, E) is γ-soft semiopen, then (B, E) is a γ-soft semineighborhood of e_F, and $\{(F_n, E), n \in N\}$ γ-soft semiconverges to e_F.Then we have $\{(F_n, E), n \in N\}$ is eventually contained in (B, E). Conversely, for each e_F contained in (B, E), let $\{(F_n, E), n \in N\}$ be the γ-soft semineighborhood systems such that $(F_{n+1}, E)\widetilde{\subseteq}(F_n, E)$ for each $n \in N$ by Proposition 4.6. Then $\{(F_n, E), n \in N\}$ is eventually contained in each γ-soft semineighborhood of e_F that is, $\{(F_n, E), n \in N\}$ γ-soft semiconverges to e_F. So we have an integer m such that, if $n \geq m$, $(F_n, E)\widetilde{\subseteq}(B, E)$. Then (B, E) is a γ-soft semineighborhood of e_F, and by Proposition 4.11, (B, E) is γ-soft semiopen.
(2). Let $\{(F_n, E)\}$, $n \in N$ be the γ-soft semineighborhoods such that $(F_{n+1}, E)\widetilde{\subseteq}(F_n, E)$ for each $n \in N$ by Proposition 4.6. For every nonnegative integer i, find $f(i)$ satisfies $f(i) \geq i$ and $(F_{f(i)}, E)\widetilde{\subseteq}(F_i, E)$. Then $\{F_{f(i)}, E), i \in N\}$ is a subsequence of the sequence $\{(F_n, E), n \in N\}$. Obviously this subsequence γ-soft semiconverges to e_F. $\square$

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