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Regular semiopen soft sets and maps in soft topological spaces

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Abstract. This paper introduces regular semiopen (closed) soft sets in soft topological spaces which are defined over a initial universe with a fixed set of parameters. Some basic properties of them and their relationship with different types of soft open sets are discussed. Also, the concept of soft regular semi continuous (open and closed) functions is presented. Finally, soft regular semi homeomorphisms and soft regular semi C-homeomorphisms are given with the help of soft regular semi continuity.

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1. Introduction

In real life, there are many complicated problems in economics, engineering, environmental, social science, medical science etc, that involve uncertainties, vagueness that cannot be solved by classical methods. In order to over come these, Molodtsov [15], in the year 1999, introduced the soft set theory as a new mathematical tool. He has established the fundamental results of this new theory and successfully applied the soft set theory in to several directions, such as smoothness of functions, Operation research, Riemann integration, Game theory, Theory of probability and so on. Soft set theory has a wider application and its progress in very rapid in different fields. There is no need of membership function in soft set theory and hence very convenient and easy to apply practice. As this area is now, interesting has many applications, many researchers started working in this area. Researchers like [2, 5, 6, 8, 11, 17, 18] etc have contributed to the development of soft set theory.

Later Maji et al. [11, 12] 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. Kharal and Ahmad [10] as well as Majumdar and Samanta [13] defined soft mappings. Shabir and Naz [17] 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. [5], Zorlutuna et al. [18] and Hussain et al. [8] continued to study the properties of soft topological spaces. They got many important results in soft topological spaces.

Recently, weak forms of soft open sets were studied. First, Chen [6] investigated soft semiopen sets in soft topological spaces and studied some properties of them. Later Arockiarani et al [4], defined soft β-open sets and soft preopen sets in soft topological space. Akdag and Ozkan [2] introduced soft α-open sets and soft α-continuous functions in soft topological spaces.

In general topology, the concept of regular semiopen set was introduced by Cameron [7] in 1978. In this concept has been generalized to soft setting. Our motivation in this paper is to define regular semiopen(closed) soft sets, regular semi soft interior(closures) and investigate their properties which are important for further research on soft topology.

These researchers not only can form the theoritical basis for further applications of topology on soft sets but also lead to the development of information systems and various fields in engineering. Furthermore, we will study soft regular semi continuous(open and closed) functions, soft regular semi homeomorphisms and obtain some characterizations of such functions.

2. Preliminaries

In this section, we recall some definition and concepts discussed in [8, 14, 17, 18]. Throughout this study X and Y denote universal sets, $E, E^{'}$ denote two sets of parameters, $A, B, C, D, B^{'}, D^{'} \subseteq E$ or $E^{'}$. Let X be an initial universe and E be a set of parameters. Let $\mathbb{P}(X)$ denote the power set of X and A be a nonempty subset set of E. A pair (F, A) is called a soft set over X, where F is a mapping given by $F : A \rightarrow \mathbb{P}(X)$. For two soft sets (F, A) and (G, B) over common universe X, we say that (F, A) is a soft subset (G, B) if $A \subseteq B$ and $F(e) \subseteq G(e)$, for all $e \in A$. In this case, we write $(F, A)\widetilde{\subseteq}(G, B)$ and (G, B) is said to be a soft super set of (F, A). Two soft sets (F, A) and (G, B) over a common universe X are said to be soft equal if $(F, A)\widetilde{\subseteq}(G, B)$ and $(G, B)\widetilde{\subseteq}(F, A)$. A soft set (F, A) over X is called null soft set, denoted by (Φ, A), if for each $e \in A,\ F(e) = \Phi$. Similarly, it is called absolute soft set, denoted by $\widetilde{X}$, if for each $e \in A,\ F(e) = X$.

The union of two soft sets (F, A) and (G, B) over the common universe X is the soft set (H, C), where $C = A \cup B$ and for each $e \in C$,

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

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

The intersection (H, C) of two soft sets (F, A) and (G, B) over a common universe X, denoted by $(F, A) \cap (G, B)$, is defined as

$$C = A \cap B \text{ and } H(e) = F(e) \cap G(e) \text{ for each } e \in C.$$

The difference (H, E) of two soft sets (F, E) and (G, E) over X, denoted by $(F, E) - (G, E)$, is defined as

$$H(e) = F(e) - G(e), \text{ for each } e \in E.$$

Let Y be nonempty subset of X. Then $\widetilde{Y}$ denotes the soft set (Y, E) over X, where $Y(e) = Y$ for each $e \in E$. In particular, (X, E) will be denoted by $\widetilde{X}$. Let (F, E) be a soft set over X and $x \in X$. We say that $x \in (F, E)$, whenever $x \in F(e)$, for each $e \in E$ [16].

The relative complement of a soft set (F, A) is denoted by $(F, A)^{'}$ and is defined by $(F, A)^{'} = (F, A)$ where $F^{'} : A \to \mathbb{P}(X)$ is defined by following

$$F^{'}(e) = X - F(e), \quad \forall e \in A$$

In this paper, for convenience, let $SS(X, E)$ be the family of soft sets over X with set of parameters E.

Let τ be the collection of soft sets over X. Then τ is called a soft topology [17] on X if τ satisfies the following axioms:

(i) (Φ, E) and $\widetilde{X}$ belongs to τ.

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

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

The trible (X, τ, E) is called soft topological space over X. The members of τ are said to be soft open in X, and the soft set (F, E) is called soft closed in X if its relative complement $(F, E)'$ belongs to τ.

The proof of the following proposition is an easy application of De Morgan's laws with the definition of a soft topology on X (see Proposition 3.3 of [18]).

Proposition 2.1. *Let (X, τ, E) be a soft space over X. Then*

(1) (Φ, E) *and* $\widetilde{X}$ *are closed soft 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 2.2. [1] Let $(X,\ \tau,\ E)$ be a soft topological space and $(F, E) \in SS(X, E)$. Then (F, E) is called a

(i) regular closed soft set, if $(F, E) = cl(int(F, E))$.

(ii) regular open soft set, if $(F, E) = int(cl(F, E))$.

Definition 2.3. [9] In a soft topological space (X, τ, E), a soft set

(i) (G, C) is said to be semiopen soft set, if $\exists$ an open soft set (H, B) such that

$$(H, B) \widetilde{\subseteq} (G, C) \widetilde{\subseteq} cl(H, B).$$

(ii) (L, A) is said to be semiclosed soft set, if $\exists$ an closed soft set (K, D) such that

$$int(K, D) \widetilde{\subseteq} (L, A) \widetilde{\subseteq} (K, D).$$

We shall denote the family of all semiopen soft sets (semiclosed soft sets) of a soft topological space (X, τ, E) by $SOSS(X, E)$ $(SCSS(X, E))$.

Kharal et al. [10] introduced soft functions over classes of soft sets. The authors also defined and studied the properties of soft images and soft inverse images of soft sets, and used the notions to the problem of medical diagnosis in medical expert system.

Definition 2.4. [10] Let X be a universe and E a set of parameters. Then the collection $SS(X, E)$ of all soft sets over X with parameters from E is called a soft class.

Definition 2.5. [10] Let $SS(X, E)$ and $SS(Y, E^{'})$ be two soft classes. Then $u : X \to Y$ and $p : E \to E^{'}$ be two functions. Then a functions $f_{pu} : SS(X, E) \to SS(Y, E^{'})$ and its inverse are defined as:

(i) Let (L, A) be a soft set in $SS(X, E)$, where $A \subseteq E$. The image of (L, A) under f_{pu}, written as $f_{pu}(L, A) = (f_{pu}(L), p(A))$, is a soft set in $SS(Y, E^{'})$ such that

$$f_{pu}(L, A)(e') = \bigcup_{e \in p^{-1}(e) \cap A} u(L(e)) \text{ for } e' \in B = p(A) \subseteq E^{'}.$$

(ii) Let (G, C) be a soft set in $SS(Y, E^{'})$, where $C \subseteq E^{'}$. Then the inverse image of (G, C) under f_{pu}, written as $f_{pu}^{-1}(G, C) = (f_{pu}^{-1}(G), p^{-1}(C))$ is a soft set in $SS(X, E)$ such that

$$f_{pu}^{-1}(G, C)(e) = u^{-1}(G(p(e))) \text{ for } e \in D = p^{-1}(C) \subseteq E.$$

Definition 2.6. [9] Let $(X,\ \tau,\ E)$ and $(Y,\ \tau',\ E^{'})$ be two soft topological spaces. A soft function $f : SS(X, E) \to SS(Y, E^{'})$ is said to be Soft semi continuous if for each open soft set (G, C) of (Y, E'), the inverse image $f^{-1}(G, C)$ is a semiopen soft set of (X, E).

3. Regular semiopen and regular semiclosed soft sets

Various generalization of closed and open sets in topological spaces and fuzzy topological spaces are of recent developments, but for soft topological spaces such generalization have not been studied so far. In this section, we introduce regular semiopen and regular semiclosed soft sets and study various properties and notions related to these structures.

Definition 3.1. In a soft topological space (X, τ, E), a soft set

(i) (G, C) is said to be regular semiopen soft set if $\exists$ an regular open soft set (H, B) such that $(H, B)\widetilde{\subseteq}(G, C)\widetilde{\subseteq}cl(H, B)$.

(ii) (L, A) is said to be regular semiclosed soft set, if $\exists$ an regular closed soft set (K, D) such that $int(K, D)\widetilde{\subseteq}(L, A)\widetilde{\subseteq}(K, D)$.

We shall denote the family of all regular semiopen soft sets (regular semiclosed soft sets) of a soft topological space (X, τ, E) by $RSOSS(X, E)$, $(RSCSS(X, E))$.

Example 3.2. Let $X = \{h_1, h_2, h_3\}$, $E = \{e_1, e_2\}$, and $\tau = \{\Phi, \widetilde{X}, (F_1, E), (F_2, E), (F_3, E)\}$, where (F_1, E), (F_2, E) and (F_3, E) are soft sets over X defined as follows:

$F_1(e_1) = \{h_1\}$, $F_1(e_2) = \{h_1\}$,
$F_2(e_1) = \{h_2\}$, $F_2(e_2) = \{h_2\}$,
$F_3(e_1) = \{h_1, h_2\}$, $F_3(e_2) = \{h_1, h_2\}$.

Clearly τ defines a soft topology on X. The soft set (G, E) which defined as follows:

$$G(e_1) = \{h_1, h_3\}, \quad G(e_2) = \{h_1, h_3\}$$

is regular semiopen soft set of (X, τ, E), since $\exists$ a regular open soft set (F_1, E) such that

$$(F_1, E)\widetilde{\subseteq}(G, E)\widetilde{\subseteq}cl(F_1, E).$$

Also, the soft set (H, E) which defined as follows

$$H(e_1) = \{h_2, h_3\}, \quad H(e_2) = \{h_2, h_3\}$$

is regular semiclosed soft set of (X, τ, E), since $\exists$ a regular closed soft set $(F_1, E)^{'}$ such that

$$int(F_1, E)^{'} \widetilde{\subseteq} (H, E) \widetilde{\subseteq} (F_1, E)^{'}.$$

Example 3.3. In Example 3.2, the soft set (G, E) is a regular semiopen soft set but not a regular open soft.

Example 3.4. In Example 3.2, the soft set (R, E) which defined as follows

$$R(e_1) = X, \qquad R(e_2) = \{h_1, h_2\}$$

is semiopen soft set of (X, τ, E) but not regular semiopen soft set, since $\exists$ a open soft set (F_3, E) such that

$$(F_3, E) \widetilde{\subseteq} (R, E) \widetilde{\subseteq} cl(F_3, E).$$

But $\exists$ a regular open soft set (F_1, E) such that

$$(F_1, E) \widetilde{\subseteq} (R, E) \widetilde{\nsubseteq} cl(F_1, E).$$

Remark 3.5. From definition of regular semiopen(regular semiclosed) soft sets and Examples 3.2, 3.3 and 3.4, it is clear that

(1) every regular open (regular closed) soft set is a regular semiopen (regular semiclosed) soft sets but not conversely.

(2) Every regular semiopen soft set is a semiopen soft set but not conversely.

Remark 3.6. (Φ, E) and $\widetilde{X}$ are always regular semiclosed and regular semiopen soft sets.

The above definition and Examples show that the following implications are true and reverse implications need not be true.

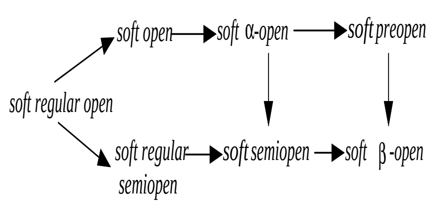

Diagram - I

The other implications are already proved in [3].

Theorem 3.7. *Arbitrary union of regular semiopen soft sets is a regular semiopen soft set.*

Proof. Let $\{(G_i, C) | i \in I\}$ be a collection of regular semiopen soft sets of a soft topological space $(X,\ \tau,\ E)$. Then $\exists$ a regular open soft sets (H_i, B) such that

$$(H_i, B) \widetilde{\subseteq} (G_i, C) \widetilde{\subseteq} cl(H_i, B) \text{ for each } i.$$

Thus $\widetilde{\bigcup}(H_i, B)\widetilde{\subseteq}\widetilde{\bigcup}(G_i, C)\widetilde{\subseteq}\widetilde{\bigcup}cl(H_i, B)$ and $\widetilde{\bigcup}(H_i, B)$ is regular open soft set. So $\widetilde{\bigcup}(G_i, C)$ is a regular semiopen soft set. □

Remark 3.8. Arbitrary intersection of regular semiclosed soft sets is a regular semiclosed soft set.

Theorem 3.9. *If a regular semiopen soft set (G, C) is such that $(G, C)\widetilde{\subseteq}(K, D)\widetilde{\subseteq}cl$ (G, C), then (K, D) is also regular semiopen.*

Proof. As (G, C) is regular semiopen soft set, $\exists$ an regular open soft set (H, B) such that

$$(H, B)\widetilde{\subseteq}(G, C)\widetilde{\subseteq}cl(H, B).$$

Then, by hypothesis, $(H, B)\widetilde{\subseteq}(K, D)$ and $cl(G, C)\widetilde{\subseteq}cl\ (H, B)$. So

$$(K, D)\widetilde{\subseteq}cl(G, C)\widetilde{\subseteq}cl(H, B), \text{ i.e., } (H, B)\widetilde{\subseteq}(K, D)\widetilde{\subseteq}cl(H, B).$$

Hence (K, D) is a regular semiopen soft set. □

Theorem 3.10. *If a regular semiclosed soft set (L, A) is such that $int(L, A)\widetilde{\subseteq}(K, D)$ $\widetilde{\subseteq}(L, A)$, then (K, D) is also regular semiclosed soft set.*

Theorem 3.11. *A soft set $(G, C) \in RSOSS(X, E) \Leftrightarrow$ for every soft point $G(e)\widetilde{\in}$ (G, C), $\exists$ a soft set $(H, B) \in RSOSS(X, E)$ such that $G(e)\widetilde{\in}(H, B)\widetilde{\subseteq}(G, C)$.*

Proof. ($\Rightarrow$): Take $(H, B) = (G, C)$.
($\Leftarrow$): $(G, C) = \widetilde{\bigcup}_{G(e)\widetilde{\in}(G,C)} (G(e))\widetilde{\subseteq} \widetilde{\bigcup}_{G(e)\widetilde{\in}(G,C)} (H, B)\widetilde{\subseteq}(G, C)$. □

Definition 3.12. Let $(X,\ \tau,\ E)$ be a soft topological space and (G, C) be a soft set over X.
(i) The soft regular semiclosure of (G, C) defined by

$$rsscl(G, C) = \widetilde{\bigcap}\{(S, F)|(G, C)\widetilde{\subseteq}(S, F) \text{ and } (S, F) \in RSCSS(X, E)\}$$

is a soft set.
(ii) the soft regular semiinterior of (G, C) defined by

$$rssint(G, C) = \widetilde{\bigcup}\{(S, F)|(S, F)\widetilde{\subseteq}(G, C) \text{ and } (S, F) \in RSOSS(X, E)\}$$

is a soft set.

Clearly, $rsscl(G, C)$ is the smallest regular semiclosed soft set containing (G, C) and $rssint(G, C)$ is the largest regular semiopen soft set contained in (G, C).

Theorem 3.13. *Let $(X,\ \tau,\ E)$ be a soft topological space and (G, C) and (K, D) be two soft sets over X. Then*
(1) $(G, C) \in RSCSS(X, E) \Leftrightarrow (G, C) = rsscl(G, C)$,
(2) $(G, C) \in RSOSS(X, E) \Leftrightarrow (G, C) = rssint(G, C)$,
(3) $(rsscl(G, C))' = rssint(G', C)$,
(4) $(rssint(G, C))' = rsscl(G', C)$,
(5) $(G, C)\widetilde{\subseteq}(K, D) \Rightarrow rssint(G, C)\widetilde{\subseteq}rssint(K, D)$,

(6) $(G,C)\widetilde{\subseteq}(K,D) \Rightarrow rsscl(G,C)\widetilde{\subseteq}rsscl(K,D)$,
(7) $rsscl(\Phi,E)=(\Phi,E)$ *and* $rsscl(X,E)=(X,E)$,
(8) $rssint(\Phi,E)=(\Phi,E)$ *and* $rssint(X,E)=(X,E)$,
(9) $rsscl((G,C)\widetilde{\cup}(K,D))=rsscl(G,C)\widetilde{\cup}rsscl(K,D)$,
(10) $rssint((G,C)\widetilde{\cap}(K,D))=rssint(G,C)\widetilde{\cap}rssint(K,D)$,
(11) $rsscl((G,C)\widetilde{\cap}(K,D))\widetilde{\subset}rsscl(G,C)\widetilde{\cap}rsscl(K,D)$,
(12) $rssint((G,C)\widetilde{\cup}(K,D))\widetilde{\subset}rssint(G,C)\widetilde{\cup}rssint(K,D)$,
(13) $rsscl(rsscl(G,C))=rsscl(G,C)$,
(14) $rssint(rssint(G,C))=rssint(G,C)$.

Proof. Let (G,C) and (K,D) be two soft sets over X.

(1) Let (G,C) be a regular semiclosed soft set. Then it is the smallest regular semiclosed set containing itself. Thus $(G,C)=rsscl(G,C)$.

On the other hand, let $(G,C)=rsscl(G,C)$ and $rsscl(G,C)\in RSCSS(X,E)$. Then $(G,C)\in RSCSS(X,E)$.

(2) Similar to (1).

(3)
$$\begin{aligned}(rsscl(G,C))' &= (\widetilde{\bigcap}\{(S,F)|(G,C)\widetilde{\subseteq}(S,F) \text{ and } (S,F)\in RSCSS(X,E)\})'\\ &= \widetilde{\bigcup}\{(S,F)'|(G,C)\widetilde{\subseteq}(S,F) \text{ and } (S,F)\in RSCSS(X,E)\}\\ &= \widetilde{\bigcup}\{(S,F)'|(S,F)'\widetilde{\subseteq}(G,C)' \text{ and } (S,F)'\in RSOSS(X,E)\}\\ &= rssint(G,C)'.\end{aligned}$$

(4) Similar to (2).

(5) Follows from definitions.

(6) Follows from definitions.

(7) Since (Φ,E) and (X,E) are regular semiclosed soft sets, $rsscl(\Phi,E)=(\Phi,E)$ and $rsscl(X,E)=(X,E)$.

(8) Since (Φ,E) and (X,E) are regular semiopen soft sets, $rssint(\Phi,E)=(\Phi,E)$ and $rssint(X,E)=(X,E)$.

(9) We have $(G,C)\widetilde{\subseteq}(G,C)\widetilde{\bigcup}(K,D)$ and $(K,D)\widetilde{\subseteq}(G,C)\widetilde{\bigcup}(K,D)$. Then by (6),
$$rsscl(G,C)\widetilde{\subseteq}rsscl((G,C)\ \widetilde{\bigcup}\ (K,D))$$
and
$$rsscl(K,D)\widetilde{\subseteq}rsscl((G,C)\ \widetilde{\bigcup}(K,D)).$$
Thus
$$rsscl(K,D)\widetilde{\bigcup}rsscl(G,C)\widetilde{\subseteq}rsscl((G,C)\widetilde{\bigcup}(K,D)).$$
Since $rsscl(G,C),\ rsscl(K,D)\in RSCSS(X,E)$,
$$rsscl(K,D)\ \widetilde{\bigcup}\ rsscl(G,C)\in RSCSS(X,E).$$
Then $(G,C)\widetilde{\subseteq}\ rsscl(G,C)$ and $(K,D)\widetilde{\subseteq}rsscl(K,D)$ imply that
$$(G,C)\widetilde{\bigcup}(K,D)\widetilde{\subseteq}rsscl(G,C)\widetilde{\bigcup}rsscl(K,D).$$
Thus, $rsscl(G,C)\widetilde{\bigcup}rsscl(K,D)$ is regular semiclosed soft set containing $(G,C)\widetilde{\bigcup}(K,D)$. But $rsscl((G,C)\widetilde{\bigcup}(K,D))$ is the smallest regular semiclosed soft set containing

$(G,C)\widetilde{\bigcup}(K,D)$. So $rsscl((G,C)\widetilde{\bigcup}(K,D))\widetilde{\subseteq}rsscl(G,C)\widetilde{\bigcup}rsscl(K,D)$.
Hence $rsscl(\ (G,C)\widetilde{\bigcup}(K,D)) = rsscl(G,C)\widetilde{\bigcup}rsscl(K,D)$.

(10) Similar to (9).

(11) We have $(G,C)\widetilde{\bigcap}(K,D)\widetilde{\subseteq}(G,C)$ and $(G,C)\widetilde{\bigcap}(K,D)\widetilde{\subseteq}(K,D)$. Then

$$rsscl((G,C)\widetilde{\bigcap}(K,D))\widetilde{\subseteq}rsscl(G,C)$$

and

$$rsscl((G,C)\widetilde{\bigcap}(K,D))\widetilde{\subseteq}rsscl(K,D).$$

Thus

$$rsscl((G,C)\widetilde{\bigcap}(K,D))\widetilde{\subseteq}rsscl(G,C)\widetilde{\bigcap}rsscl(K,D).$$

(12) Similar to (11).

(13) Since $rsscl(G,C) \in RSCSS(X,E)$, by (1),

$$rsscl(rsscl(G,C)) = rsscl(\ (G,C)).$$

(14) Since $rssint(G,C) \in RSOSS(X,E)$, by (2),

$$rssint(rssint(G,C)) = rssint((G,C)).$$

□

Definition 3.14. In a soft topological space $(X,\ \tau,\ E)$, a soft set (G,C) is said to be soft semi-regular if it is both semiopen soft set and semiclosed soft set. Equivalently, a soft set (G,C) is said to be semi regular open if $(G,C) = ssint(sscl(G,C))$.

The family of all semi-regular soft set of a soft topological space (X,τ,E) is denoted by $SRSS(X,E)$.

Theorem 3.15. *If (G,C) is any soft set in a soft topological space $(X,\ \tau,\ E)$ then following are equivalent:*

(1) $(G,C) \in SRSS(X,E)$.

(2) $(G,C) = ssint(sscl(G,C))$.

(3) *there exists a regular open soft set* (K,D) *such that* $(K,D)\widetilde{\subseteq}(G,C)\widetilde{\subseteq}cl(K,D)$.

Proof. (1)⇒(2): If $(G,C) \in SRSS(X)$, then $ssint(sscl(G,C)) = ssint(G,C) = (G,C)$.

(2)⇒(3): Suppose $(G,C) = ssint(sscl(G,C))$. Since $int(cl(G,C))\ \widetilde{\subseteq}sscl(G,C)$ for any soft set (G,C) of (X,E), $int(cl(G,C))\ \widetilde{\subseteq}ssint(sscl(G,C)) = (G,C)$. Since $(G,C) \in SOSS(X,E)$ we have $(G,C)\widetilde{\subseteq}cl(sint(G,C))$. Then, we obtain

$$int(cl\ (G,C))\widetilde{\subseteq}(G,C)\widetilde{\subseteq}\ cl(int(G,C))\widetilde{\subseteq}cl(int(cl(G,C))).$$

Since $int(cl(int(cl(G,C)))) = int(cl(G,C))$, $int(cl(G,C))$ is regular open soft set.

(3)⇒(1): It is obvious that $(G,C) \in SOSS(X,E)$. We have

$$int(cl(G,C)) = int(cl(K,D)) = (K,D)\widetilde{\subseteq}(G,C).$$

Then (G,C) is soft semiclosed. Thus, we obtain $(G,C) \in SOSS(X,E)$. □

Proposition 3.16. *If $(G,C) \in SOSS(X,E)$, then $sscl(G,C) \in SRSS(X,E)$.*

Proof. Since $sscl(G,C)$ is semiclosed soft set, we show that $sscl(G,C) \in SOSS(XE)$. Since $(G,C) \in SOSS(X,E)$, $(K,D)\widetilde{\subseteq}(G,C)\widetilde{\subseteq}cl(K,D)$ for open soft set (K,D) of (X,E). Then, we have

$$(K,D)\widetilde{\subseteq}sscl(K,D)\widetilde{\subseteq}sscl(G,C)\widetilde{\subseteq}cl(K,D).$$

Thus $sscl(G,C) \in SRSS(X,E)$. □

Proposition 3.17. *If (G,C) is regular semiopen soft set in $(X,\ \tau,\ E)$, then $(G,C)'$ is also regular semiopen soft set.*

Proof. Follows from the Definition 3.1. □

Proposition 3.18. *In a soft topological space $(X,\ \tau,\ E)$, the regular closed soft sets, regular open soft sets and regular clopen soft sets are regular semiopen soft sets.*

Definition 3.19. A soft set (G,C) in a soft topological space (X,τ,E) is called a regular semi soft neighborhood (briefly, rssnbd) of the soft point $F(e)\widetilde{\in}(X,E)$ if there exists a regular semiopen soft set (H,D) such that $F(e)\widetilde{\in}(H,D)\widetilde{\subseteq}(G,C)$.

The regular semi neighborhood system of a soft point $F(e)$, denoted by $RSN_\tau(F(e))$, is the family of all its regular semi soft neighborhoods

Definition 3.20. A soft set (G,C) in a soft topological space (X,τ,E) is called a regular semi soft neighborhood (briefly, rssnbd) of the soft set (H,D) if there exists a regular semiopen soft set (F,A) such that $(H,D)\widetilde{\subseteq}(F,A)\widetilde{\subseteq}(G,C)$.

Theorem 3.21. *The regular semi neighborhood system $RSN_\tau(F(e))$ at $F(e)$ in a soft topological space (X,τ,E) has the following properties:*
(1) *If $(G,C) \in RSN_\tau(F(e))$, then $F(e)\widetilde{\in}(G,C)$.*
(2) *$(G,C) \in RSN_\tau(F(e))$ and $(G,C)\widetilde{\subseteq}(H,D)$, then $(H,D) \in RSN_\tau(F(e))$.*
(3) *(G,C), $(H,D) \in RSN_\tau(F(e))$, then $(G,C)\widetilde{\cap}(H,D) \in RSN_\tau(F(e))$.*
(4) *$(G,C) \in RSN_\tau(F(e))$, then there is a $(H,D) \in RSN_\tau(F(e))$ such that $(G,C) \in RSN_\tau(H(e'))$ for each $H(e')\widetilde{\in}(H,D)$.*

Proof. (1) If $(G,C) \in RSN_\tau(F(e))$, then there is a $(H,D) \in RSOSS(X,E)$ such that $F(e)\widetilde{\in}(H,D)\widetilde{\subseteq}(G,C)$. Then, we have $F(e)\widetilde{\in}(G,c)$.

(2) Let $(G,C) \in RSN_\tau(F(e))$ and $(G,C)\widetilde{\subseteq}(H,D)$. Since $(G,C) \in RSN_\tau(F(e))$, then there is a $(F,A) \in RSOSS(X,E)$ such that $F(e) \in (F,A)\widetilde{\subseteq}(G,C)$. Then, we have $F(e)\widetilde{\in}(F,A)\widetilde{\subseteq}(G,C)\widetilde{\subseteq}(H,D)$. Thus $(H,D) \in RSN_\tau(F(e))$.

(3) If (G,C), $(H,D) \in RSN_\tau(F(e))$, then there exists (F,A), $(E,B) \in RSOSS$ (X,E) such that $F(e)\widetilde{\in}(F,A)\widetilde{\subseteq}(G,C)$ and $F(e)\widetilde{\in}(E,B)\widetilde{\subseteq}(H,D)$. Thus

$$F(e)\widetilde{\in}(F,A)\ \widetilde{\cap}(E,B)\widetilde{\subseteq}(G,C)\widetilde{\cap}(H,D).$$

Since $(F,A)\widetilde{\cap}(E,B) \in \tau$, we have $(G,C)\widetilde{\cap}(H,D) \in RSN_\tau\ (F(e))$.

(4) If $(G,C) \in RSN_\tau(F(e))$, then there is a $(E,B) \in RSOSS(X,E)$ such that $F(e)\widetilde{\in}(E,B)\widetilde{\subseteq}(G,C)$. Put $(F,A) = (E,B)$. Then for every $H(e')\widetilde{\in}(F,A)$, $H(e')\widetilde{\in}(F,A)\widetilde{\subseteq}(E,B)\widetilde{\subseteq}(G,C)$. This implies $(G,C) \in RSN_\tau(H(e'))$. □

4. Soft regular semi continuous, open and closed functions

Using regular semiopen and regular semiclosed soft sets, now we introduce different generalizations of soft functions in soft topological spaces and investigate the properties.

Definition 4.1. Let $(X,\ \tau,\ E)$ and $(Y,\ \tau',\ E^{'})$ be two soft topological spaces. A soft function $f : SS(X,E) \to SS(Y,E^{'})$ is said to be:

(i) Soft regular continuous, if for each open soft set (G,C) of $(Y,E^{'})$, the inverse image $f^{-1}(G,C)$ is a regular open soft set of (X,E).

(ii) Soft regular semi continuous, if for each open soft set (G,C) of $(Y,E^{'})$, the inverse image $f^{-1}(G,C)$ is a regular semiopen soft set of (X,E).

(iii) Soft regular semi irresolute, if for each regular semiopen soft set (G,C) of $(Y,E^{'})$, the inverse image $f^{-1}(G,C)$ is a regular semiopen soft set of (X,E).

(iv) Soft regular semiopen function, if for each soft open set (L,A) of (X,E), the image $f(L,A)$ is a regular semiopen soft set of $(Y,E^{'})$.

Soft regular semiclosed function, if for each soft closed set (K,D) of (X,E), the image $f(K,D)$ is a regular semiclosed soft set of $(Y,E^{'})$.

Example 4.2. Let $X = \{x_1,x_2,x_3\}$, $E = \{e_1,e_2\}$, and $\tau = \{\Phi,\widetilde{X},(F_1,E),(F_2,E),(F_3,E)\}$, $Y = \{y_1,y_2,y_3\}$ and $\tau' = \{\Phi,\widetilde{Y},(G,E)\}$, where (F_1,E), (F_2,E) and (F_3,E) are soft sets over X and (G,E) is soft set over Y, defined as follows:

$F_1(e_1) = \{x_1\},\ \ F_1(e_2) = \{x_1\},$
$F_2(e_1) = \{x_2\},\ \ F_2(e_2) = \{x_2\},$
$F_3(e_1) = \{x_1,x_2\},\ \ F_3(e_2) = \{x_1,x_2\},$
$G(e_1) = \{y_1,y_3\},\ \ G(e_2) = \{y_1,y_3\}.$

Then τ and τ' defines a soft topology on X and Y. If we define the function $f : SS(X,E) \to SS(Y,E)$ as $f(x_1) = y_1$, $f(x_2) = y_2$ and $f(x_3) = y_3$, then f is soft regular semi continuous but not soft regular continuous function. Since $f^{-1}(G,E) = \{(\{x_1,x_3\},e_1),(\{x_1,x_3\},e_2,)\}$ is regular semi open soft set, $\exists$ a regular open soft set (F_1,E) such that

$$(F_1,E)\widetilde{\subseteq}f^{-1}(G,E)\widetilde{\subseteq}cl(F_1,E) = (F_2,E)'$$

but not regular open soft set.

Example 4.3. Let $X = \{x_1,x_2,x_3\}$, $E = \{e_1,e_2\}$, and $\tau = \{\Phi,\widetilde{X},(F_1,E),(F_2,E),(F_3,E)\}$, $Y = \{y_1,y_2,y_3\}$, and $\tau' = \{\Phi,\widetilde{Y},(G,E)\}$, where (F_1,E), (F_2,E) and (F_3,E) are soft sets over X and (G,E) is soft set over Y, defined as follows:

$F_1(e_1) = \{x_1\},\ \ F_1(e_2) = \{x_1\},$
$F_2(e_1) = \{x_2\},\ \ F_2(e_2) = \{x_2\},$
$F_3(e_1) = \{x_1,x_2\},\ \ F_3(e_2) = \{x_1,x_2\},$
$G(e_1) = X,\qquad G(e_2) = \{y_1,y_2\}.$

Then τ and τ' defines a soft topology on X and Y. If we define the function $f : SS(X,E) \to SS(Y,E)$ as $f(x_1) = y_1$, $f(x_2) = y_2$ and $f(x_3) = y_3$, then f is soft semi continuous but not soft regular semi continuous function. Since $f^{-1}(G,E) = \{(X,\ e_1),(\{x_1,x_2\},e_2)\}$ is semiopen soft set but not regular semiopen soft set, $\exists$ a open soft set (F_3,E) such that

$$(F_3,E)\widetilde{\subseteq}f^{-1}(G,E)\widetilde{\subseteq}cl(F_3,E)$$

but $\exists$ a regular open soft set (F_1, E) such that

$$(F_1, E)\widetilde{\subseteq} f^{-1}(G, E)\widetilde{\nsubseteq} cl(F_1, E).$$

The above definition and Examples show that the following implications are true and reverse implications need not be true.

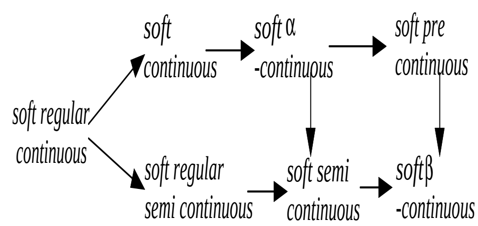

Diagram - II

The other implications are already proved in [3].

Remark 4.4. A soft function $f : SS(X, E) \to SS(Y, E^{'})$ is soft regular semi continuous if for each closed soft set (K, D) of $(Y, E^{'})$, the inverse image $f^{-1}((K, D))$ is a regular semiclosed soft set of (X, E).

Theorem 4.5. *A soft function $f : SS(X, E) \to SS(Y, E^{'})$ is soft regular semi continuous iff $f(rsscl(L, A))\widetilde{\subseteq} cl(f(L, A))$ for every soft set (L, A) of (X, E).*

Proof. Let $f : SS(X, E) \to SS(Y, E^{'})$ is soft regular semi continuous function. Now $cl(f(L, A))$ is a closed soft set of $(Y, E^{'})$. By soft regular semi continuity of f, $f^{-1}(cl(f(L, A)))$ is regular semiclosed soft set and $(L, A)\widetilde{\subseteq} f^{-1}(cl(f(L, A)))$. But $rsscl((L, A))$ is the smallest regular semiclosed soft set containing (L, A). Then $rsscl(L, A)\widetilde{\subseteq} f^{-1}(cl(f(L, A)))$. Thus $f(rsscl(L, A))\widetilde{\subseteq} cl(f(L, A))$.

Conversely, let (G, C) be any closed soft set of $(Y, E^{'})$. Then

$f^{-1}(G, C) \in (X, E)$

$\Rightarrow f(rsscl(f^{-1}(G, C)))\widetilde{\subseteq} cl(f(f^{-1}(G, C)))$

$\Rightarrow f(rsscl(f^{-1}(G, C)))\widetilde{\subseteq} cl(G, C) = (G, C)$

$\Rightarrow rsscl(f^{-1}(G, C)) = f^{-1}(G, C)$.

Thus $f^{-1}(G, C)$ is regular semiclosed soft set. $\square$

Theorem 4.6. *A soft function $f : SS(X, E) \to SS(Y, E^{'})$ is soft regular semi continuous iff $f^{-1}(int(G, C))\widetilde{\subseteq} rssint(f^{-1}(G, C))$ for every soft set (G, C) of $(Y, E^{'})$.*

Proof. Let $f : SS(X, E) \to SS(Y, E^{'})$ is soft regular semi continuous. Now $int(f(G, C))$ is a open soft set of $(Y, E^{'})$. By soft regular semi continuity of f, $f^{-1}(int(f(G, C)))$ is regular semiopen soft set and $f^{-1}(int(f(G, C)))\widetilde{\subseteq}(G, C)$. As $rssint(G, C)$ is the largest regular semiopen soft set containing (G, C), $f^{-1}(int(f(G, C)))\widetilde{\subseteq} rssint(G, C)$.

Conversely, Take a open soft set $(G, C) = f^{-1}(int(G, C))\widetilde{\subseteq} rssint(f^{-1}(G, C))$. Then $f^{-1}(G, C)\widetilde{\subseteq} rssint(f^{-1}(G, C))$. Thus $f^{-1}(G, C)$ is regular semiopen soft set. $\square$

Theorem 4.7. *A soft function $f : SS(X,E) \to SS(Y,E^{'})$ is soft regular semiopen iff $f(int(L,A))\widetilde{\subseteq}rssint(f(L,A))$ for every soft set (L,A) of (X,E).*

Proof. If $f : SS(X,E) \to SS(Y,E^{'})$ is soft regular semiopen function, then

$$f(int\ (L,A)) = rssint(f(int(L,A)))\widetilde{\subseteq}rssint(f(L,A)).$$

On the other hand, take a open soft set (L,A) of (X,E). Then by hypothesis,

$$f(L,A) = f(int(L,A))\widetilde{\subseteq}rssint(f(L,A)).$$

Thus $f(L,A)$ is regular semiopen soft set in $(Y,E^{'})$. □

Theorem 4.8. *Let $f : SS(X,E) \to SS(Y,E^{'})$ be soft regular semiopen. If (K,B) is a soft set in $(Y,E^{'})$ and (G,C) is regular closed soft set containing $f^{-1}(K,B)$ then $\exists$ a regular semiclosed soft set (H,D) such that $(K,B)\widetilde{\subseteq}(H,D)$ and $f^{-1}(H,D)\widetilde{\subseteq}(G,C)$.*

Proof. Take $(H,D) = (f(G,C)')'$. Then $f^{-1}(K,B)\widetilde{\subseteq}(G,C)$. Thus $f((G,C)')\widetilde{\subseteq}(K,B)'$. So $(G,C)'$ is regular open soft set. Hence $f((G,C)')$ is soft regular semiopen. Therefore (H,D) is soft regular semiclosed and $(K,B)\widetilde{\subseteq}(H,D)$ and $f^{-1}(H,D)\widetilde{\subseteq}(G,C)$. □

Theorem 4.9. *A soft function $f : SS(X,E) \to SS(Y,E^{'})$ is soft regular semiclosed iff $rsscl(f(L,A))\widetilde{\subseteq}f(cl(L,A))$ for every soft set (L,A) of (X,E).*

5. Soft regular semi homeomorphisms

Definition 5.1. A bijection $f : (X,\tau,E) \to (Y,\tau',E)$ is called soft regular semi homeomorphism, if f is both soft regular semi continuous and soft regular semi open functions.

Definition 5.2. A bijection $f : (X,\tau,E) \to (Y,\tau',E)$ is called soft regular semi C-homeomorphism, if f is both soft regular semi irresolute and f^{-1} is soft regular semi irresolute.

Proposition 5.3. *For any bijection $f : (X,\tau,E) \to (Y,\tau',E)$, the following statements are equivalent:*
(1) *$f^{-1} : (Y,\tau',E) \to (X,\tau,E)$ is soft regular semi continuous.*
(2) *f is soft regular semi open functions.*
(3) *f is soft regular semi closed functions.*

Proof. (1)⇒(2): Let (G,C) be a open soft set in X. Then $X - (G,C)$ is closed soft set in X. Since f^{-1} is soft regular semi continuous,

$$(f^{-1})^{-1}(X - (G,C)) = f(X - (G,C)) = Y - f(G,C)$$

is regular semiclosed soft set in Y. Then $f(G,C)$ is soft regular semi open in Y. Thus f is a soft regular semi open function.

(2)⇒(3): Let f be a soft regular semi open function. Let (G,C) be a closed soft set in X. Then $X - (G,C)$ open soft set in X. Since f is soft regular semi open function, $f(X - (G,C)) = Y - f(G,C)$ is regular semiopen soft set in Y. Thus $f(G,C)$ is regular semiclosed soft set in Y. So f is soft regular semi closed function.

(3)⇒(1): Let (G, C) be closed soft set in X. Then $f(G, C)$ is regular semiclosed soft set in Y. Thus $(f^{-1})^{-1}(G, C)$ is regular semiclosed soft set in Y. So f^{-1} is soft regular semi continuous. □

Proposition 5.4. *Let $f : (X, \tau, E) \to (Y, \tau', E)$ be a bijective and soft regular semi continuous function. Then the following statements are equivalent:*
(1) *f is a soft regular semi open function.*
(2) *f is a soft regular semi-homeomorphism.*
(3) *f is a soft regular semi closed function.*

Proof. (1)⇒(2): Follows from the definition.
(2)⇒(3): Let (G, C) be a closed soft set in X. Then $X - (G, C)$ is open soft in X. Since f is a soft regular semi-homeomorphism, $f(X - (G, C)) = Y - f((G, C))$ is regular semiopen soft set in Y. Then $f((G, C))$ is regular semiclosed soft set in Y. Thus f is a soft regular semiclosed function.
(3)⇒(1): Let (G, C) be a open soft set in X. Then $X - (G, C)$ is closed soft in X. Since f is a soft regular semi closed function, $f(X - (G, C)) = Y - f((G, C))$ is regular semiclosed soft set in Y. Thus $f((G, C))$ is regular semiopen soft set in Y. So f is a soft regular semi open function. □

Proposition 5.5. *If $f : (X, \tau, E) \to (Y, \tau', E)$ and $g : (Y, \tau', E) \to (Z, \tau'', E)$ are soft regular semi C-homeomorphisms, then $g \circ f : (X, \tau, E) \to (Z, \tau'', E)$ is also a soft regular semi C-homeomorphism.*

Proof. Let (G, E) be a regular semiopen soft set in (Z, τ'', E). Then

$$(g \circ f)^{-1}((G, E)) = f^{-1}(g^{-1}((G, E))) = f^{-1}((G, E)),$$

where $(G, E) = g^{-1}((G, E))$. By hypothesis, (G, E) is regular semiopen soft set in (Y, τ', E) and again by hypothesis, $f^{-1}((G, E))$ is regular semiopen soft set in (X, τ, E). Thus, $(g \circ f)$ is soft regular semi irresolute. Also for a regular semiopen soft set (H, E) in (X, τ, E), we have

$$(g \circ f)((H, E)) = g(f((H, E))) = g((L, E)),$$

where $(L, E) = f(H, E)$. By hypothesis, $f((H, E))$ is regular semiopen soft set in (Y, τ', E) and again by hypothesis, $g(L, E)$ is regular semiopen soft set in (Z, τ'', E). So, $(g \circ f)^{-1}$ is soft regular semi irresolute. Hence $g \circ f$ is soft regular semi C-homeomorphism. □

Proposition 5.6. *For a soft topological space (X, τ, E), the collection $srsCh(X, \tau, E)$ forms a group under the composition of functions.*

Proof. Define $\Psi : srsCh(X, \tau, E) \times srsCh(X, \tau, E) \to srsCh(X, \tau, E)$ by $\Psi(f, g) = (g \circ f)$ for every $f,\ g \in srsCh(X, \tau, E)$. Then by Proposition 5.5, $(g \circ f) \in srsCh(X, \tau, E)$. Thus $srsCh(X, \tau, E)$ is soft regular semi closed. We know that the composition of maps is associative. The identity map $i : (X, \tau, E) \to (X, \tau, E)$ is a $srsC$-homeomorphism and $i \in srsCh(X, \tau, E)$. Also $i \circ f = f \circ i = f$ for every $f \in srsCh(X, \tau, E)$. For any $f \in srsCh(X, \tau, E)$, $f \circ f^{-1} = f^{-1} \circ f = i$. So inverse exists for each element of $srsCh(X, \tau_1, \tau_2)$. Hence $srsCh(X, \tau, E)$ is a group under composition of functions. □

Proposition 5.7. *Every soft regular semi-homeomorphism from a rss-space into another rss-space is a soft homeomorphism.*

Proof. Let $f : (X, \tau, E) \to (Y, \tau', E)$, be a soft regular semi-homeomorphism. Then f is bijective, soft regular semi continuous and soft regular semi open. Let (G, E) be an open soft set in (X, τ, E). Since f is soft regular semi open and since (Y, τ', E) is rss-space, $f((G, E))$ is open soft in (Y, τ', E). This implies f is soft open function. Let (G, E) be closed soft in (Y, τ', E). Since f is soft regular semi continuous and since (X, τ, E) is rss-space, $f^{-1}((G, E))$ is soft closed in (X, τ, E). Thus, f is soft continuous. So f is a soft homeomorphism. □

Proposition 5.8. *Every soft regular semi-homeomorphism from a rss-space into another rss-space is a soft regular semi C- homeomorphism.*

Proof. Let $f : (X, \tau, E) \to (Y, \tau', E)$ be a soft regular semi-homeomorphism. Then f is bijective, soft regular semi continuous and soft regular semi open. Let (G, E) be an regular semiclosed soft set in (Y, τ', E). Then (G, E) is soft closed in (Y, τ', E). Since f is soft regular semi continuous $f^{-1}((G, E))$ is regular semiclosed soft set in (X, τ, E). Thus f is a soft regular semi irresolute map. Let (H, E) be regular semiopen soft set in (X, τ, E). Then (H, E) is soft open in (X, τ, E). Since f is soft regular semi open, $f((H, E))$ is regular semiopen soft set in (Y, τ', E). That is, $(f^{-1})^{-1}((H, E))$ is regular semi open soft set in (Y, τ', E) and thus f^{-1} is soft regular semi irresolute. So f is soft regular semi C-homeomorphism. □

6. Conclusion

We hope that the findings in this paper are just the beginning of a new structure and not only will form the theoretical basis for further applications of soft topology on soft sets but also will lead to the development of information system and various fields in engineering.

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