

Soft rg^{**} -closed sets

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Abstract

Soft sets have many real time applications in the field of engineering, social science, medical science etc. Recently, the concept of soft topological space has been developed with the help of soft sets. In the present paper, we investigate the new notion of soft closed sets, namely soft regular generalized star star closed sets in soft topological spaces. Further, we discuss the concept of soft regular generalized star star open sets also.

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1 Introduction

Molodtsov [1] introduced the concept of soft set which overcome from the difficulties of fuzzy sets [2], intuitionistic fuzzy sets [3], vague sets, interval mathematics [4, 5] and rough sets [6]. A soft set over the universe U is a parametrized family of subsets of the

universe U . Application of soft sets in decision making problems has been found by Maji et al. [7, 8] whereas Chen [9] gave a parametrization reduction of soft sets and a comparison of it with attribute reduction in rough set theory. Further, soft sets are a class of special information [10].

Soft topological spaces was introduced by Muhammad Shabir and Munazza Naz. The notions of soft open sets, soft closed sets, soft closure, soft interior points, soft neighborhood of a point and soft separation axioms are also introduced and their basic properties are investigated by them [11]. Meanwhile, generalized closed sets [12, 13] in topological spaces were introduced by Levine in 1970 which is extended to soft topological spaces in the year 2012 [14].

K. Chandrasekhara Rao and N. Palaniappan [15] introduced regular generalized star star regular closed sets and generalized star star regular closed sets in topological spaces and they are extended to the bitopological context by Chandrasekhara Rao and K. Kannan [16, 17]. In the present paper, we introduce the concepts of soft regular generalized star star closed sets and soft regular generalized star star open sets in soft topological spaces and their basic properties have been investigated further.

2 Preliminaries

Let U , E be an initial universe and a set of parameters, respectively. Let $P(U)$, E_1 denote the power set of U and a non-empty subset of E , respectively. A pair (F, E_1) is called a soft set over U , where $F : E_1 \rightarrow P(U)$ is a function. For $\varepsilon \in E_1$, $F(\varepsilon)$ may be considered as the set of ε -approximate elements of the soft set (F, E_1) . For two soft sets (F, E_1) and (G, E_2) over a common universe U , we say that (F, E_1) is a soft subset of (G, E_2) if (1) $E_1 \subseteq E_2$ and (2) for all $e \in E_1$, $F(e)$ and $G(e)$ are identical approximations. We write $(F, E_1) \tilde{\subseteq} (G, E_2)$. (F, E_1) is said to be a soft superset of (G, E_2) , if (G, E_2) is a soft subset of (F, E_1) . We denote it by $(F, E_1) \tilde{\supseteq} (G, E_2)$. Two soft sets (F, E_1) and (G, E_2) over a common universe U are said to be soft equal if (F, E_1) is a soft subset of (G, E_2) and (G, E_2) is a soft subset of (F, E_1) .

The union of two soft sets of (F, E_1) and (G, E_2) over the common universe U is the soft set (H, E_3) , where $E_3 = E_1 \cup E_2$ and for all

$e \in E_3$, $H(e) = F(e)$ if $e \in E_1 - E_2$, $G(e)$ if $e \in E_2 - E_1$ and $F(e) \cup G(e)$ if $e \in E_1 \cap E_2$. We write $(F, E_1) \dot{\cup} (G, E_2) = (H, E_3)$. The intersection (H, E_3) of two soft sets (F, E_1) and (G, E_2) over a common universe U , denoted by $(F, E_1) \tilde{\cap} (G, E_2)$, is defined as $E_3 = E_1 \cap E_2$, and $H(e) = F(e) \cap G(e)$ for all $e \in E_3$. The relative complement of a soft set (F, E_1) is denoted by $(F, E_1)'$ and is defined by $(F, E_1)' = (F', E_1)$ where $F' : E_1 \rightarrow P(U)$ is a mapping given by $F'(e) = U - F(e)$ for all $e \in E_1$.

Let X be an initial universe set, E be the set of parameters. Let τ be the collection of soft sets over X , then is said to be a soft topology on X if (a) $\emptyset, X$ belong to τ , (b) the union of any number of soft sets in τ belongs to τ , (c) the intersection of any two soft sets in τ belongs to τ . The triplet (X, τ, E) is called a soft topological space over X . Let (X, τ, E) be a soft space over X , then the members of τ are said to be soft open sets in 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 .

Let (X, τ, E) be a soft topological space over X and (F, E) be a soft set over X . Then, the soft closure of (F, E) , denoted by $\overline{(F, E)}$ is the intersection of all soft closed supersets of (F, E) . Clearly $\overline{(F, E)}$ is the smallest soft closed set over X which contains (F, E) . The soft interior of (F, E) , denoted by $(F, E)^o$ is the union of all soft open subsets of (F, E) . Clearly $(F, E)^o$ is the largest soft open set over X which is contained in (F, E) . Further, $cl_Y(A, E)$ and $int_Y(A, E)$ are the closure and interior of (A, E) with respect to the subspace Y of X , respectively.

Definition 1. A soft subset (A, E) of a soft topological space (X, τ, E) is called

- (a) soft regular closed [18] if $(A, E) = \overline{(A, E)^o}$
- (b) soft regular open [18] if $(A, E)'$ is soft regular closed.
- (c) soft g -closed [14] if $\overline{(A, E)} \subseteq (U, E)$ whenever $(A, E) \subseteq (U, E)$ and (U, E) is soft open in X .
- (d) soft g -open [14] if $(A, E)'$ is soft g -closed in X .
- (e) soft $g^{**}r$ -closed [19] if $\overline{[(A, E)^o]} \subseteq (U, E)$ whenever $(A, E) \subseteq (U, E)$ and (U, E) is soft open in X .

(f) soft $g^{**}r$ -open [19] if $(A, E)'$ is soft $g^{**}r$ -closed in X .

3 Soft rg^{**} -closed sets

Definition 2. A soft subset (A, E) of a soft topological space (X, τ, E) is called soft regular generalized star star closed (soft rg^{**} -closed) in X if and only if $\overline{[(A, E)^o]} \subseteq (U, E)$ whenever $(A, E) \subseteq (U, E)$ and (U, E) is soft regular open in X .

Example 3. Let $X = \{a, b, c\}$, $E = \{e_1, e_2\}$, $\tau = \{\tilde{\phi}, \tilde{X}, (F_1, E), (F_2, E), (F_3, E), (F_4, E), (F_5, E)\}$ where $(F_1, E), (F_2, E), (F_3, E), (F_4, E), (F_5, E)$ are defined as follows: $F_1(e_1) = \{a\}$, $F_1(e_2) = \phi$, $F_2(e_1) = \{a\}$, $F_2(e_2) = \{b, c\}$, $F_3(e_1) = \{b, c\}$, $F_3(e_2) = \{a, b, c\}$, $F_4(e_1) = \{b, c\}$, $F_4(e_2) = \{a\}$, $F_5(e_1) = \phi$, $F_5(e_2) = \{b, c\}$. Then (F_6, E) is soft rg^{**} -closed where $F_6(e_1) = \phi$, $F_6(e_2) = \{a, c\}$.

Theorem 4. Let (A, E) be a soft subset of a soft topological space (X, τ, E) . If (A, E) is soft rg^{**} -closed then $\overline{[(A, E)^o]} - (A, E)$ does not contain non empty soft regular closed sets.

Proof. Suppose that (A, E) is soft rg^{**} -closed. Let (F, E) be a soft regular closed set such that $(F, E) \subseteq \overline{[(A, E)^o]} - (A, E)$. Then $(F, E) \subseteq \overline{[(A, E)^o]} \cap (A, E)'$. Since $F \subseteq (A, E)'$, we have $(A, E) \subseteq (F, E)'$. Since (F, E) is soft regular closed set, we have $(F, E)'$ is soft regular open. Since (A, E) is soft rg^{**} -closed, we have $\overline{[(A, E)^o]} \subseteq (F, E)'$. Therefore, $(F, E) \subseteq \left[\overline{[(A, E)^o]} \right]'$. Also $(F, E) \subseteq \overline{[(A, E)^o]}$. Hence $(F, E) \subseteq \tilde{\phi}$. Therefore, $(F, E) = \tilde{\phi}$. $\square$

Theorem 5. If (A, E) is soft rg^{**} -closed and (B, E) is soft g -closed, then $(A, E) \tilde{\cup} (B, E)$ is soft rg^{**} -closed.

Proof. Let $(A, E) \tilde{\cup} (B, E) \subseteq (U, E)$ and (U, E) is soft regular open in X . Since $(A, E) \subseteq (U, E)$ and (A, E) is soft rg^{**} -closed, we have $\overline{[(A, E)^o]} \subseteq (U, E)$. Since $(B, E) \subseteq (U, E)$ and (B, E) is soft g -closed, we have $\overline{(B, E)} \subseteq (U, E)$. Now, $(A, E) \tilde{\cup} (B, E) \subseteq \overline{[(A, E)^o]} \tilde{\cup} \overline{(B, E)} \subseteq (U, E)$. Therefore, $(A, E) \tilde{\cup} (B, E)$ is soft rg^{**} -closed. $\square$

Theorem 6. If a soft subset (A, E) is soft rg -closed then (A, E) is soft rg^{**} -closed.

Proof. Let $(A, E) \tilde{\subseteq} (U, E)$ and (U, E) is soft regular open. Since (A, E) is soft rg -closed, we have $(A, E) \tilde{\subseteq} (U, E)$. Hence $[(A, E)^o] \tilde{\subseteq} (U, E)$. Therefore, (A, E) is soft rg^{**} -closed. $\square$

Theorem 7. If a soft subset (A, E) is $g^{**}r$ -closed then (A, E) is soft rg^{**} -closed.

Proof. Let $(A, E) \tilde{\subseteq} (U, E)$ and (U, E) is soft regular open. Since (U, E) is soft open and (A, E) is soft $g^{**}r$ -closed, we have $[(A, E)^o] \tilde{\subseteq} (U, E)$. Hence, (A, E) is soft rg^{**} -closed. $\square$

Definition 8. Let $(B, E) \tilde{\subseteq} (Y, E) \tilde{\subseteq} (X, \tau, E)$. A soft subset (B, E) of (Y, τ_Y, E) is said to be soft rg^{**} -closed relative to (Y, τ_Y, E) if (B, E) is soft rg^{**} -closed in the soft subspace (Y, τ_Y, E) .

Lemma 9. If (A, E) is soft open and (U, E) is soft regular open in (X, τ, E) then $(U, E) \tilde{\cap} (A, E)$ is soft regular open in (A, τ_A, E) .

Proof. Let (A, E) be soft open and (U, E) is soft regular open in X . Now, $int_A \{cl_A [(U, E) \tilde{\cap} (A, E)]\} = \{cl_A [(U, E) \tilde{\cap} (A, E)]\}^o \tilde{\cap} (A, E) \tilde{\supseteq} [(U, E)]^o \tilde{\cap} (A, E) \tilde{\cap} (A, E) = (U, E) \tilde{\cap} (A, E)$.

Now, $(U, E) \tilde{\cap} (A, E) = [(U, E)]^o \tilde{\cap} (A, E)^o = [(U, E) \tilde{\cap} (A, E)]^o \tilde{\supseteq} int_A \{cl_A [(U, E) \tilde{\cap} (A, E)]\}$. Therefore, $int_A \{cl_A [(U, E) \tilde{\cap} (A, E)]\} = (U, E) \tilde{\cap} (A, E)$. Hence $(U, E) \tilde{\cap} (A, E)$ is soft regular open in (A, τ_A, E) . $\square$

Theorem 10. Let (Y, τ_Y, E) be a soft subspace of (X, τ, E) . Suppose that a soft subset (B, E) of (Y, τ_Y, E) is soft rg^{**} -closed relative to (Y, τ_Y, E) and (Y, E) is soft open and soft g -closed in (X, τ, E) then (B, E) is soft rg^{**} -closed in (X, τ, E) .

Proof. Let $(B, E) \tilde{\subseteq} (U, E)$ and (U, E) is soft regular open in X . Since (Y, E) is soft open in X , we have $(U, E) \tilde{\cap} (Y, E)$ is soft regular open in Y {by Lemma 9} and $(B, E) \tilde{\subseteq} (U, E) \tilde{\cap} (Y, E)$. Since (B, E) is soft rg^{**} -closed relative to (Y, τ_Y, E) , we have $cl_Y [int_Y (B, E)] \tilde{\subseteq} (U, E) \tilde{\cap} (Y, E)$. Hence $[(B, E)^o] \tilde{\cap} (Y, E) \tilde{\subseteq} (U, E) \tilde{\cap} (Y, E)$. Let $(G, E) = (U, E) \cup \left\{[(B, E)^o]\right\}$. Then (G, E) is soft open and $(Y, E) \tilde{\subseteq} (G, E)$. Since (Y, E) is soft g -closed, we have $(Y, E) \tilde{\subseteq} (G, E)$. Now, $[(B, E)^o] = (Y, E) \tilde{\cap} [(B, E)^o] \tilde{\subseteq}$

$(G, E) \tilde{\cap} [\overline{(B, E)^o}] = (U, E) \tilde{\cap} [\overline{(B, E)^o}] \tilde{\cup} \tilde{\phi} \tilde{\subseteq} (U, E)$. Therefore, (B, E) is soft rg^{**} -closed in (X, τ, E) . $\square$

Lemma 11. Let (A, E) be a soft open set in (X, τ, E) and let (U, E) be soft regular open in (A, τ_A, E) . Then $(U, E) = (A, E) \tilde{\cap} (W, E)$ for some soft regular open set (W, E) in X .

Proof. Let (A, E) be a soft open set in (X, τ, E) and let (U, E) be soft regular open in (A, τ_A, E) . Since (U, E) is soft regular open in (A, E) , we have $(U, E) = \text{int}_A[\text{cl}_A(U, E)] = \text{int}_A[(A, E) \tilde{\cap} \overline{(U, E)}] = (A, E) \tilde{\cap} [(A, E) \tilde{\cap} \overline{(U, E)}]^o = (A, E) \tilde{\cap} \left\{ (A, E)^o \tilde{\cap} [\overline{(U, E)}]^o \right\} = (A, E) \tilde{\cap} [\overline{(U, E)}]^o$ {since (A, E) is soft open}. Therefore, $(U, E) = (A, E) \tilde{\cap} (W, E)$ for some soft regular open set $(W, E) = [\overline{(U, E)}]^o$ in X . $\square$

Theorem 12. Suppose that a soft subset (B, E) of (Y, τ_Y, E) is soft rg^{**} -closed in (X, τ, E) and (Y, E) is soft open in (X, τ, E) then (B, E) is soft rg^{**} -closed relative to (Y, τ_Y, E) .

Proof. Let $(B, E) \tilde{\subseteq} (U, E)$ and (U, E) is soft regular open in (Y, τ_Y, E) . Since (Y, E) is soft open, we have $(U, E) = (Y, E) \tilde{\cap} (W, E)$ for some soft regular open set (W, E) in (X, τ, E) {by Lemma 11}. Since $(B, E) \tilde{\subseteq} (Y, E) \tilde{\cap} (W, E) \tilde{\subseteq} (W, E)$ and (B, E) is soft rg^{**} -closed in (X, τ, E) , we have $[(B, E)^o] \tilde{\subseteq} (W, E)$. Therefore, $\text{cl}_Y[\text{int}_Y(B, E)] = [(B, E)^o] \tilde{\cap} (Y, E) \tilde{\subseteq} (W, E) \tilde{\cap} (Y, E) = (U, E)$. Hence (B, E) is soft rg^{**} -closed relative to Y . $\square$

Theorem 13. Let (A, E) and (B, E) are soft subsets such that $(A, E) \tilde{\subseteq} (B, E) \tilde{\subseteq} [(A, E)^o]$. If (A, E) is soft rg^{**} -closed, then (B, E) is soft rg^{**} -closed

Proof. Let $(B, E) \tilde{\subseteq} (U, E)$ and (U, E) is soft regular open in X . Since $(A, E) \tilde{\subseteq} (B, E)$, we have $(A, E) \tilde{\subseteq} (U, E)$. Since (A, E) is soft rg^{**} -closed, we have $[(A, E)^o] \tilde{\subseteq} (U, E)$. Since $(B, E) \tilde{\subseteq} [(A, E)^o]$, we have $[(B, E)^o] \tilde{\subseteq} [(A, E)^o] \tilde{\subseteq} (U, E)$. Therefore, (B, E) is soft rg^{**} -closed. $\square$

Theorem 14. Suppose that soft $R.O(X, \tau, E) \tilde{\subseteq}$ soft $C(X, \tau, E)$. Then every soft subset of X is soft rg^{**} -closed.

Proof. Let (A, E) be a soft subset of X . Let $(A, E) \tilde{\subseteq} (U, E)$ and (U, E) is soft regular open in X . Since soft $RO(X, \tau, E) \tilde{\subseteq}$ soft $C(X, \tau, E)$, we have (U, E) is soft closed in X . Since $(A, E) \tilde{\subseteq} (U, E)$, we have $\overline{(A, E)} \tilde{\subseteq} \overline{(U, E)} = (U, E)$. Therefore, $\overline{[(A, E)^o]} \tilde{\subseteq} \overline{(A, E)} \tilde{\subseteq} (U, E)$. Hence (A, E) is soft rg^{**} -closed. $\square$

4 Soft rg^{**} -open sets

Definition 15. A soft subset (A, E) of a soft topological space (X, τ, E) is called soft regular generalized star open (soft rg^{**} -open) in X if and only if its complement is soft regular generalized star closed (soft rg^{**} -closed) in X .

Example 16. In Example 3, the soft set (F_7, E) is soft rg^{**} -open in X where (F_7, E) is defined as follows: $F_7(e_1) = \{a\}$, $F_7(e_2) = \{b\}$.

A necessary and sufficient condition for a soft set (A, E) to be a soft rg^{**} -open set is obtained in the next theorem.

Theorem 17. A soft subset (A, E) of a soft topological space (X, τ, E) is soft rg^{**} -open if and only if $(F, E) \tilde{\subseteq} \left[\overline{(A, E)} \right]^o$ whenever $(F, E) \tilde{\subseteq} (A, E)$ and (F, E) is soft regular closed in X .

Proof. Necessity: Let $(F, E) \tilde{\subseteq} (A, E)$ and (F, E) is soft regular closed in X . Then $(A, E)' \tilde{\subseteq} (F, E)'$ and $(F, E)'$ is soft regular open in X . Since (A, E) is soft rg^{**} -open, we have $(A, E)'$ is soft rg^{**} -closed. Hence, $\overline{[(A, E)']^o} \tilde{\subseteq} (F, E)'$. Consequently, $\left\{ \left[\overline{(A, E)} \right]^o \right\}' \tilde{\subseteq} (F, E)'$. Therefore, $(F, E) \tilde{\subseteq} \left[\overline{(A, E)} \right]^o$.

Sufficiency: Let $(A, E)' \tilde{\subseteq} (U, E)$ and (U, E) is soft regular open in X . Then $(U, E)' \tilde{\subseteq} (A, E)$ and $(U, E)'$ is soft regular closed in X . By our assumption, we have $(U, E)' \tilde{\subseteq} \left[\overline{(A, E)} \right]^o$. Hence $\left\{ \left[\overline{(A, E)} \right]^o \right\}' \tilde{\subseteq} (U, E)$. Therefore, $\overline{[(A, E)']^o} \tilde{\subseteq} (U, E)$. Consequently $(A, E)'$ is soft rg^{**} -closed. Hence (A, E) is soft rg^{**} -open. $\square$

Theorem 18. Let (A, E) and (B, E) be soft subsets such that $\left[\overline{(A, E)} \right]^o \tilde{\subseteq} (B, E) \tilde{\subseteq} (A, E)$. If (A, E) is soft rg^{**} -open, then (B, E)

is soft rg^{**} -open.

Proof. Let $(F, E) \tilde{\subseteq} (B, E)$ and (F, E) is soft regular closed in X . Since $(B, E) \tilde{\subseteq} (A, E)$, we have $(F, E) \tilde{\subseteq} (A, E)$. Since (A, E) is soft rg^{**} -open, we have, $(F, E) \tilde{\subseteq} \left[\overline{(A, E)} \right]^o$ {by Theorem 17}. Since $\left[\overline{(A, E)} \right]^o \tilde{\subseteq} (B, E)$, we have $\left\{ \left[\overline{(A, E)} \right]^o \right\} \tilde{\subseteq} (B, E) \tilde{\subseteq} \left[\overline{(B, E)} \right]^o$. Hence $(F, E) \tilde{\subseteq} \left[\overline{(A, E)} \right]^o \tilde{\subseteq} \left[\overline{(B, E)} \right]^o$. Therefore, (B, E) is soft rg^{**} -open. $\square$

Theorem 19. If a soft subset (A, E) is soft rg^{**} -closed, then $\left[\overline{(A, E)^o} \right] - (A, E)$ is soft rg^{**} -open.

Proof. Let $(F, E) \tilde{\subseteq} \left[\overline{(A, E)^o} \right] - (A, E)$ and (F, E) is soft regular closed. Since (A, E) is soft rg^{**} -closed, we have $\left[\overline{(A, E)^o} \right] - (A, E)$ does not contain nonempty soft regular closed {by Theorem 4}. Therefore, $(F, E) = \tilde{\phi}$. Hence $\left[\overline{(A, E)^o} \right] - (A, E)$ is soft rg^{**} -open. $\square$

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