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Soft locally closed sets and decompositions of soft continuity

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Abstract. This paper introduces soft locally closed sets in soft topological spaces which are defined over an initial universe with a fixed set of parameters. Some basic properties of them and their relationships with different types of soft open sets are studied. Also, the concept of soft LC-continuous functions is presented. Finally, some decompositions of soft continuity and a decomposition of soft A-continuity are given with the help of soft LC-continuity.

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1. Introduction

It is known that set theory and continuity of functions in topological spaces are important notions for mathematicians. But these notions are also important for quantum physicists [5, 6, 7, 8]. For example, in [6] El Naschie derived quantum gravity from set theory. And also it is used in engineering, medical science, economics, environments, etc. But most of problems in these areas have various uncertainties. To exceed them, some kind of theories were given like theory of fuzzy sets [20], rough sets [15] and soft sets [14] which can be considered as mathematical tools for dealing with uncertainties.

Soft set theory was firstly introduced by Molodtsov [14] in 1999 as a general mathematical tool for dealing with uncertainty. 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. [12, 13] 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.

Shabir and Naz [16] 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. [3], Zorlutuna et al. [21] and Hussain et al. [9] 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 [4] investigated soft semiopen sets in soft topological spaces and studied some properties of them. Later Arockiarani et al. [2] defines soft β-open sets and soft preopen sets in soft topological spaces. Akdag and Ozkan [1] introduced soft α-open sets and soft α-continuous functions in soft topological spaces. Finally, the concepts of soft A-sets and soft A-continuous functions in soft topological spaces were introduced by Yuksel and Tozlu [18].

In the present paper, we introduce soft locally closed sets in soft topological spaces which are defined over an initial universe with a fixed set of parameters. We study some basic properties of them and discuss their relationships with different types of soft open sets in soft topological spaces. We also introduce and study the notion of generalized soft continuity, namely soft LC-continuity. Finally, the decompositions are given.

2. Preliminaries

In this section, we present the basic definitions and results of soft set theory which may be found in earlier studies.

Let X be an initial universe set and E be the set of all possible parameters with respect to X. Parameters are often attributes, characteristics or properties of the objects in X. Let $P(X)$ denote the power set of X. Then a soft set over X is defined as follows.

Definition 2.1 ([14])**.** A pair (F, A) is called a soft set over X where $A \subseteq E$ and $F : A \to P(X)$ is a set valued mapping. In other words, a soft set over X is a parameterized family of subsets of the universe X. For $\forall \varepsilon \in A$, $F(\varepsilon)$ may be considered as the set of $\varepsilon-$approximate elements of the soft set (F, A). It is worth noting that $F(\varepsilon)$ may be arbitrary. Some of them may be empty, and some may have nonempty intersection.

The set of all soft sets over X is denoted by $SS(X)_E$.

Definition 2.2 ([13])**.** A soft set (F, A) over X is said to be null soft set denoted by Φ if for all $e \in A$, $F(e) = \varnothing$. A soft set (F, A) over X is said to be an absolute soft set denoted by $\widetilde{A}$ if for all $e \in A$, $F(e) = X$.

Definition 2.3 ([16])**.** Let Y be a nonempty subset of X, then $\widetilde{Y}$ denotes the soft set (Y, E) over X for which $Y(e) = Y$, for all $e \in E$. In particular, (X, E) will be denoted by $\widetilde{X}$.

Definition 2.4 ([13])**.** For two soft sets (F, A) and (G, B) over X, we say that (F, A) is a soft subset of (G, B) if $A \subseteq B$ and for all $e \in A$, $F(e)$ and $G(e)$ are identical approximations. We write $(F, A) \sqsubset (G, B)$. (F, A) is said to be a soft super set of (G, B), if (G, B) is a soft subset of (F, A). We denote it by $(G, B) \sqsubset (F, A)$. Then (F, A) and (G, B) are said to be soft equal if (F, A) is a soft subset of (G, B) and (G, B) is a soft subset of (F, A).

Definition 2.5 ([13])**.** The union of two soft sets (F, A) and (G, B) over X is the soft set (H, C), where $C = A \cup B$ and for all $e \in C$, $H(e) = F(e)$ if $e \in A - B$, $H(e) = G(e)$ if $e \in B - A$, $H(e) = F(e) \cup G(e)$ if $e \in A \cap B$. We write $(F, A) \sqcup (G, B) = (H, C)$.

Definition 2.6 ([13])**.** The intersection (H, C) of (F, A) and (G, B) over X, denoted by $(F, A) \sqcap (G, B)$, is defined as $C = A \cap B$, and $H(e) = F(e) \cap G(e)$ for all $e \in C$.

Definition 2.7 ([16])**.** The difference (H, E) of two soft sets (F, E) and (G, E) over X, denoted by $(F, E) \backslash (G, E)$, is defined as $H(e) = F(e) \backslash G(e)$ for all $e \in E$.

Definition 2.8 ([16])**.** The relative complement of a soft set (F, E) is denoted by $(F, E)^c$ and is defined by $(F, E)^c = (F^c, E)$ where $F^c : E \longrightarrow P(X)$ is a mapping given by $F^c(e) = X \backslash F(e)$ for all $e \in E$.

Definition 2.9 ([16])**.** Let τ be the collection of soft sets over X, then τ is said to be a soft topology on X if

(1) Φ, $\widetilde{X} \in \tau$
(2) If (F, E), $(G, E) \in \tau$, then $(F, E) \sqcap (G, E) \in \tau$
(3) If $\{(F_i, E)\}_{i \in I} \in \tau$, $\forall i \in I$, then $\sqcup_{i \in I} (F_i, E) \in \tau$.

The triplet (X, τ, E) is called a soft topological space over X. Every member of τ is called a soft open set in X. A soft set (F, E) over X is called soft closed set in X if its relative complement $(F, E)^c$ belongs to τ. We will denote the family of all soft open sets (resp., soft closed sets) of a soft topological space (X, τ, E) by SOS(X, τ, E) (resp., SCS(X, τ, E)).

Definition 2.10. Let (X, τ, E) be a soft topological space over X and (F, E) be a soft set over X.

(1) [[16]] The soft closure of (F, E) is the soft set $cl(F, E) = \cap\{(G, E) : (G, E)$ is soft closed and $(F, E) \sqsubset (G, E)\}$.

(2) [[21]] The soft interior of (F, E) is the soft set $int(F, E) = \cup\{(H, E) : (H, E)$ is soft open and $(H, E) \sqsubset (F, E)\}$.

Clearly, $cl(F, E)$ is the smallest soft closed set over X which contains (F, E) and $int(F, E)$ is the largest soft open set over X which is contained in (F, E).

Theorem 2.11 ([16])**.** *Let (X, τ, E) be a soft topological space over X and (F, E), (G, E) are soft sets over X. Then*

(1) $cl(\Phi) = \Phi$ *and* $cl(\widetilde{X}) = \widetilde{X}$.
(2) $(F, E) \sqsubset cl(F, E)$.
(3) (F, E) *is a soft closed set if and only if* $(F, E) = cl(F, E)$.
(4) $cl(cl(F, E)) = cl(F, E)$.
(5) $(F, E) \sqsubset (G, E)$ *implies* $cl(F, E) \sqsubset cl(G, E)$.

(6) $cl((F,E) \sqcup (G,E)) = cl(F,E) \sqcup cl(G,E)$.
(7) $cl((F,E) \sqcap (G,E)) \sqsubset cl(F,E) \sqcap cl(G,E)$.

Throughout the paper, the spaces X and Y (or (X,τ,E) and (Y,ν,K)) stand for soft topological spaces assumed unless stated otherwise.

Definition 2.12 ([19])**.** Let (X,τ,E) be a soft topological space over X and (F,E), (G,E) are soft sets over X. (F,E) and (G,E) are said to be soft separated sets if $(F,E) \sqcap (G,E) = \Phi$.

Definition 2.13 ([4])**.** A soft set (F,E) is called soft semiopen set in a soft topological space X if $(F,E) \sqsubset cl(int(F,E))$. The relative complement of a soft semiopen set is called a soft semiclosed set.

Definition 2.14 ([2])**.** A soft set (F,E) is called soft preopen set in a soft topological space X if $(F,E) \sqsubset int(cl(F,E))$. The relative complement of a soft preopen set is called a soft preclosed set.

Definition 2.15 ([1])**.** A soft set (F,E) is called soft α-open set in a soft topological space X if $(F,E) \sqsubset int(cl(int(F,E)))$. The relative complement of a soft α-open set is called a soft α-closed set.

Remark 2.16 ([1])**.** It is obvious that every soft open (resp., soft closed) set is a soft α-open (resp., soft α-closed) set. Similarly, every soft α-open set is soft preopen and soft semiopen.

Definition 2.17 ([17])**.** A soft set (F,E) is called soft regular open set in X if $(F,E) = int(cl(F,E))$. The relative complement of a soft regular open set is called a soft regular closed set.

Remark 2.18 ([17])**.** Every soft regular open (resp., soft regular closed) set in a soft topological space X is soft open (resp., soft closed).

Definition 2.19 ([18])**.** A soft set (F,E) is called soft A-set in a soft topological space X if $(F,E) = (G,E)\backslash(H,E)$, where (G,E) is a soft open set and (H,E) is a soft regular open set in X.

It is obvious that a soft set (F,E) is a soft A-set if and only if $(F,E) = (G,E) \sqcap (K,E)$, where (G,E) is soft open and (K,E) is soft regular closed.

Remark 2.20 ([18])**.** In a soft topological space X, every soft open set is a soft A-set. Also, every soft A-set is soft semiopen.

We will denote the family of all soft semiopen sets (resp., soft preopen sets, soft α-open sets, soft regular open sets and soft A-sets) of a soft topological space X by SSOS(X) (resp., SPOS(X), SαOS(X), SROS(X) and SAS(X)).

Definition 2.21 ([10])**.** Let $SS(X)_E$ and $SS(Y)_K$ be families of soft sets, $u : X \longrightarrow Y$ and $p : E \longrightarrow K$ be mappings. Then the mapping $f_{pu} : SS(X)_E \longrightarrow SS(Y)_K$ is defined as:

(1) Let $(F,E) \in SS(X)_E$. The image of (F,E) under f_{pu}, written as $f_{pu}(F,E) = (f_{pu}(F), p(E))$, is a soft set in $SS(Y)_K$ such that

$$f_{pu}(F)(y) = \begin{cases} \cup_{x \in p^{-1}(y)\cap A} u(F(x)), & p^{-1}(y) \cap A \neq \varnothing, \\ \varnothing, otherwise \end{cases}$$

for all $y \in K$.

(2) Let $(G,K) \in SS(Y)_K$. The inverse image of (G,K) under f_{pu}, written as $f_{pu}^{-1}(G,K) = (f_{pu}^{-1}(G), p^{-1}(K))$, is a soft set in $SS(X)_E$ such that

$$f_{pu}^{-1}(G)(x) = \begin{cases} u^{-1}(G(p(x))), & p(x) \in K, \\ \varnothing, otherwise \end{cases}$$

for all $x \in E$.

Definition 2.22 ([21]). Let (X,τ,E) and (Y,υ,K) be soft topological spaces and $f_{pu} : SS(X)_E \longrightarrow SS(Y)_K$ be a function. Then f_{pu} is called a soft continuous function if for each $(G,K) \in \upsilon$ we have $f_{pu}^{-1}(G,K) \in \tau$.

Definition 2.23 ([11]). Let (X,τ,E) and (Y,υ,K) be soft topological spaces and $f_{pu} : SS(X)_E \longrightarrow SS(Y)_K$ be a function. Then f_{pu} is called a soft semicontinuous function if for each $(G,K) \in SOS(Y)$ we have $f_{pu}^{-1}(G,K) \in SSOS(X)$.

Definition 2.24 ([1]). Let (X,τ,E) and (Y,υ,K) be soft topological spaces and $f_{pu} : SS(X)_E \longrightarrow SS(Y)_K$ be a function. Then f_{pu} is called a soft α-continuous function if for each $(G,K) \in SOS(Y)$ we have $f_{pu}^{-1}(G,K) \in S\alpha OS(X)$.

Definition 2.25 ([1]). Let (X,τ,E) and (Y,υ,K) be soft topological spaces and $f_{pu} : SS(X)_E \longrightarrow SS(Y)_K$ be a function. Then f_{pu} is called a soft precontinuous function if for each $(G,K) \in SOS(Y)$ we have $f_{pu}^{-1}(G,K) \in SPOS(X)$.

Remark 2.26 ([1]). It is clear that every soft α-continuous function is soft semicontinuous and soft precontinuous. Every soft continuous function is soft α-continuous.

Theorem 2.27 ([1]). *Let (X,τ,E) and (Y,υ,K) be soft topological spaces and $f_{pu} : SS(X)_E \longrightarrow SS(Y)_K$ be a function. If f_{pu} is soft semicontinuous and soft precontinuous, then f_{pu} is soft α-continuous.*

Definition 2.28 ([18]). Let (X,τ,E) and (Y,υ,K) be soft topological spaces and $f_{pu} : SS(X)_E \longrightarrow SS(Y)_K$ be a function. Then f_{pu} is called a soft A-continuous function if for each $(G,K) \in SOS(Y)$, $f_{pu}^{-1}(G,K)$ is a soft A-set in X.

Remark 2.29 ([18]). Every soft continuous function is soft A-continuous and every soft A-continuous function is soft semicontinuous.

3. Soft Locally Closed Sets

Definition 3.1. A soft set (F,E) is called soft locally closed set in a soft topological space X if $(F,E) = (G,E) \sqcap (H,E)$ where (G,E) is soft open and (H,E) is soft closed in X.

We will denote the family of all soft locally closed sets of a soft topological space X by SLCS(X).

Remark 3.2. It is obvious that every soft A-set in a soft topological space X is a soft locally closed set.

Example 3.3. Let $X = \{x_1, x_2, x_3, x_4\}$, $E = \{e_1, e_2\}$ and $\tau = \{\Phi, \widetilde{X}, (F_1, E), (F_2, E), ..., (F_{11}, E)\}$ where $(F_1, E), (F_2, E), ..., (F_{11}, E)$ are soft sets over X, defined as follows:

$$\begin{aligned}
(F_1, E) &= \{(e_1, \{x_1\}),\ (e_2, \{x_1\})\},\\
(F_2, E) &= \{(e_1, \{x_2\}),\ (e_2, \{x_2\})\},\\
(F_3, E) &= \{(e_1, \{x_1, x_2\}),\ (e_2, \{x_1, x_2\})\},\\
(F_4, E) &= \{(e_1, \{x_1, x_2, x_3\}),\ (e_2, \{x_1, x_3\})\},\\
(F_5, E) &= \{(e_1, \{x_1, x_2, x_4\}),\ (e_2, \{x_1, x_2, x_3\})\},\\
(F_6, E) &= \{(e_1, \{x_2\}),\ (e_2, \varnothing)\},\\
(F_7, E) &= \{(e_1, \{x_1, x_2\}),\ (e_2, \{x_1\})\},\\
(F_8, E) &= \{(e_1, \{x_1, x_2, x_3\}),\ (e_2, \{x_1, x_2, x_3\})\},\\
(F_9, E) &= \{(e_1, X),\ (e_2, \{x_1, x_2, x_3\})\},\\
(F_{10}, E) &= \{(e_1, \{x_1, x_2\}),\ (e_2, \{x_1, x_2, x_3\})\},\\
(F_{11}, E) &= \{(e_1, \{x_1, x_2\}),\ (e_2, \{x_1, x_3\})\}.
\end{aligned}$$

Then τ defines a soft topology on X and thus (X, τ, E) is a soft topological space over X [17].

Let (G, E) be a soft set over X such that $(G, E) = \{(e_1, \{x_3, x_4\}), (e_2, \{x_2\})\}$. Since $(G, E) = (F_9, E) \sqcap (H, E)$ where (F_9, E) is soft open and $(H, E) = \{(e_1, \{x_3, x_4\}),\ (e_2, \{x_2, x_4\})\}$ is soft closed in X, (G, E) is a soft locally closed set but not a soft A-set.

Theorem 3.4. *In a soft topological space (X, τ, E), every soft open set is soft locally closed.*

Proof. Let (F, E) be a soft open set in X. Then (F, E) is a soft locally closed set since Φ=$(F, E) \sqcap \Phi$. □

Theorem 3.5. *Let (X, τ, E) be a soft topological space over X. If (F, E) and (G, E) are two soft locally closed sets in X, then $(F, E) \sqcap (G, E)$ is a soft locally closed set.*

Proof. Let $(F, E) = (H_1, E) \sqcap (K_1, E)$ where (H_1, E) is soft open and (K_1, E) is soft closed and $(G, E) = (H_2, E) \sqcap (K_2, E)$ where (H_2, E) is soft open and (K_2, E) is soft closed. Then $(F, E) \sqcap (G, E)$ is a soft locally closed set since $(F, E) \sqcap (G, E) = ((H_1, E) \sqcap (H_2, E)) \sqcap ((K_1, E) \sqcap (K_2, E))$ where $(H_1, E) \sqcap (H_2, E)$ is soft open and $(K_1, E) \sqcap (K_2, E)$ is soft closed. □

Proposition 3.6. *Let (X, τ, E) be a soft topological space over X. Then (F, E) is called soft locally closed if and only if $(F, E) = (G, E) \sqcap cl(F, E)$ for some soft open set (G, E).*

Proof. Let (F, E) be a soft locally closed set in X. Hence $(F, E) = (G, E) \sqcap (H, E)$ where (G, E) is soft open and (H, E) is soft closed in X. Then $cl(F, E) = cl((G, E) \sqcap (H, E)) \sqsubset cl(G, E) \sqcap cl(H, E) = cl(G, E) \sqcap (H, E)$. We have $cl(F, E) \sqsubset (H, E)$ and so $(F, E) \sqsubset (G, E) \sqcap cl(F, E) \sqsubset (G, E) \sqcap (H, E) = (F, E)$. Hence we obtain $(F, E) = (G, E) \sqcap cl(F, E)$.

Conversely, if $(F, E) = (G, E) \sqcap cl(F, E)$ for some soft open set (G, E), (F, E) is a soft locally closed set since $cl(F, E)$ is soft closed in X. □

Theorem 3.7. *Let (X, τ, E) be a soft topological space over X and (F, E), (G, E) be soft locally closed sets in X. If (F, E) and (G, E) are separated, i.e. if $(F, E) \sqcap cl(G, E) = cl(F, E) \sqcap (G, E) = \Phi$, then $(F, E) \sqcup (G, E)$ is a soft locally closed set in X.*

Proof. Suppose that there exist soft open sets (H_1, E) and (H_2, E) such that $(F, E) = (H_1, E) \sqcap cl(F, E)$ and $(G, E) = (H_2, E) \sqcap cl(G, E)$. Since (F, E) and (G, E) are separated we may assume that $(H_1, E) \sqcap cl(G, E) = (H_2, E) \sqcap cl(F, E) = \Phi$. Consequently $(F, E) \sqcup (G, E) = ((H_1, E) \sqcup (H_2, E)) \sqcap cl((F, E) \sqcup (G, E))$. Hence $(F, E) \sqcup (G, E)$ is soft locally closed. □

Remark 3.8. Let (X, τ, E) be a soft topological space over X. Then the relative complement of a soft locally closed set need not be soft locally closed in X.

Example 3.9. Let $X = \{x_1, x_2, x_3, x_4\}$ and $E = \{e_1, e_2\}$. Let us take the soft topology τ on X and the soft set $(G, E) = \{(e_1, \{x_3, x_4\}), (e_2, \{x_2\})\}$ in Example 3.3. Then (G, E) is a soft locally closed set but $(G, E)^c = \{(e_1, \{x_1, x_2\}), (e_2, \{x_1, x_3, x_4\})\}$ is not soft locally closed.

Theorem 3.10. *Let (X, τ, E) be a soft topological space over X. A soft set (F, E) over X is soft A-set if and only if it is both soft semiopen and soft locally closed in X.*

Proof. Let (F, E) be a soft A-set in X, so $(F, E) = (G, E) \sqcap (H, E)$ where (G, E) is soft open and (H, E) is soft regular closed. Clearly (F, E) is soft locally closed. Now $int(F, E) = (G, E) \sqcap int(H, E)$, so that $(F, E) = (G, E) \sqcap cl(int(H, E)) \sqsubset cl((G, E) \sqcap int(H, E)) = cl(int(F, E))$. Hence (F, E) is a soft semiopen set in X.

Conversely, let (F, E) be soft semiopen and soft locally closed, so that $(F, E) \sqsubset cl(int(F, E))$ and $(F, E) = (G, E) \sqcap cl(F, E)$ where (G, E) is soft open. Then $cl(F, E) = cl(int(F, E))$ and so (F, E) is soft regular closed. Hence (F, E) is a soft A-set in X. □

Theorem 3.11. *Let (X, τ, E) be a soft topological space over X. For a soft set (F, E) over X, the following are equivalent:*

(1) (F, E) is soft open in X.
(2) (F, E) is soft α-open and soft locally closed in X.
(3) (F, E) is soft preopen and soft locally closed in X.

Proof. (1) implies (2) and (2) implies (3) are obvious.

(3) implies (1): Let (F, E) be soft preopen and soft locally closed in X, so that $(F, E) \sqsubset int(cl(F, E))$ and $(F, E) = (G, E) \sqcap cl(F, E)$ where (G, E) is soft open. Then $(F, E) \sqsubset (G, E) \sqcap int(cl(F, E)) = int((G, E) \sqcap cl(F, E)) = int(F, E)$. Hence we obtain (F, E) is soft open in X. □

Remark 3.12. Theorem 3.10 and 3.11 show that in any soft topological space (X, τ, E) we have the following fundamental relationships between the classes of soft sets over X:

(i) SAS(X) =SSOS$(X)\cap$SLCS(X)
(ii) SOS(X) =SαOS$(X)\cap$SLCS(X)

(iii) SOS(X) =SPOS(X)∩SLCS(X)

We have implications for a soft topological space (X, τ, E). These implications are not reversible.

$$\begin{tikzcd}
\text{soft open set} \arrow[rr] \arrow[d] & & \text{soft } \alpha\text{-open set} \arrow[dl] \arrow[dr] & \\
\text{soft A-set} \arrow[r] \arrow[d] & \text{soft semiopen set} & & \text{soft preopen set} \\
\text{soft locally closed set} & & &
\end{tikzcd}$$

4. Soft LC-Continuity

Definition 4.1. Let (X, τ, E) and (Y, υ, K) be soft topological spaces and $f_{pu} : SS(X)_E \longrightarrow SS(Y)_K$ be a function. Then f_{pu} is called a soft LC-continuous function if for each $(G, K) \in SOS(Y)$, $f_{pu}^{-1}(G, K)$ is a soft locally closed set in X.

Remark 4.2. It is clear that soft A-continuity implies soft LC-continuity.

The relationships in Remark 3.12 provide immediate proofs for the following decompositions.

Theorem 4.3. *Let* (X, τ, E) *and* (Y, υ, K) *be soft topological spaces and* $f_{pu} : SS(X)_E \longrightarrow SS(Y)_K$ *be a function. Then*

(i) f_{pu} is soft A-continuous if and only if f_{pu} is soft semicontinuous and soft LC-continuous.

(ii) f_{pu} is soft continuous if and only if f_{pu} is soft α-continuous and soft LC-continuous.

(iii) f_{pu} is soft continuous if and only if f_{pu} is soft precontinuous and soft LC-continuous.

For a soft topological space (X, τ, E) we have the following implications.

$$\begin{tikzcd}
\text{soft continuity} \arrow[rr] \arrow[d] & & \text{soft } \alpha\text{-continuity} \arrow[dl] \arrow[dr] & \\
\text{soft A-continuity} \arrow[r] \arrow[d] & \text{soft semicontinuity} & & \text{soft precontinuity} \\
\text{soft LC-continuity} & & &
\end{tikzcd}$$

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