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On Normality in Soft Topological Spaces

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Abstract: ***The concept Soft Sets was introduced by Molodtsov in the year 1999 to deal with problems of incomplete information. Due to the parameterization tools the used soft sets enhanced applicability of various generalizations of crisp sets. Soft topological space was formulated by Shabir et. al. and Cagman et al. separately in 2011. In this paper we study normality and related problems in soft topological spaces. We prove a form of Urysohn Lemma in this setting.***

Keywords: Soft point, soft neighborhood, soft continuity, soft topology, soft normality

1. Introduction

In 1999, Molodtsov [6] proposed a new concept called soft set theory to model uncertainty, which associates a set with a set of parameters. The soft set theory has been applied to many different fields. In 2010 M. Shabir, Munazza , Naz [4] used soft sets to define a topology namely Soft topology and studied soft neighborhoods of a point, soft separation axioms and their basic properties. The same concept was introduced and studied independently by Cagman et. al. [3] independent ally in 2011. In [1], Aygunoglu- Aygun introduced the soft product topology and defined the version of compactness in soft spaces named soft compactness.

2. Prelimanaries

In this section, we give some basic definitions and results of soft set theory .

In this paper, U refers to an initial universe, E is a set of parameters, *P(U)* is the power set of U, and $A \subseteq E$.

Definition 2.1. A soft set F_A on the universe U is defined by the set of ordered pairs
$F_A = \{(x, f_A(x)) : x \in E, f_A(x) \in P(U)\}$,
where $f_A : E \to P(U)$ such that $f_A(x) = \emptyset \ if \ x \notin A$

Here, f_A is called an approximate function of the soft set F_A. The value of $f_A(x)$ may be arbitrary. Some of them may be empty, some may have nonempty intersection. Note that the set of all soft sets over U will be denoted by *S(U)*.

Example 2.1. Let a soft set F_A describe the attractiveness of the shirts with respect to the parameters, which Mr. A is going to wear. Suppose that there are four shirts in the universe $U = \{x_1, x_2, x_3, x_4\}$ under consideration and $E = \{e_1 = cheap, e_2 = warm,\ e_3 = colorful\}$ is the set of parameters. To define a soft set means to point out cheap shirts, expensive shirts and colorful shirts. Suppose that $f_A(e_1) = \{x_1, x_2\}$, $f_A(e_2) = \{x_3, x_4\}$, $f_A(e_3) = \{x_1, x_3, x_4\}$. Then the family $\{\ A(e_i) : i = 1, 2, 3\}$ of 2^X is a soft set F_A .

For two soft sets F_A and G_B over common universe U, 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 $F_A \subseteq G_B$ and G_B is said to be a *soft superset* of F_A. Two soft sets F_A and G_B over a common universe U are said to be *soft equal* if $F_A \subseteq G_B$ and $G_B \subseteq F_A$

A soft set F_A over U is called a *null soft set*, denoted by Φ_A, if for each $\in A, F\ (e) = \phi$; Similarly, it is called *absolute soft set*, denoted by $\widetilde{U}$, if for each $e \in A, F\ (e) = U$.

The *union* of two soft sets F_A and G_B over the common universe U is the soft set H_C, where $C = A \cup B$ and for each $e \in C$

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

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 U, denoted by $F_A \cap G_B$, is defined as $C = A \cap B$ and $H(e) = F\ (e) \cap G(e)$ for each $e \in C$.

The *difference* H_E of two soft sets F_E and G_E over X, denoted by $F_E \setminus G_E$, is defined as $H(e) = F\ (e) \setminus G(e)$, for each $e \in E$.

Let Y be a nonempty subset of U. Then $\widetilde{Y}$ denote the soft set Y_E over U where $(e) = Y$, for each $e \in E$.
In particular, U_E will be denoted by $\widetilde{U}$.

Let F_E be a soft set over U and $x \in U$. We say that $x \in F_E$, whenever $x \in F\ (e)$, for each $e \in E$.

The relative complement of a soft set F_A is denoted by F_A^c and is defined as a mapping given $F^c : A \longrightarrow \mathbb{P}(U)$ by $F^C(e) = U \setminus F\ (e)$, for each $e \in A$.

Definition2.2 : Let $\mathcal{T}$ be the collection of soft sets over U. Then $\mathcal{T}$ is called a soft topology on U if $\mathcal{T}$ satisfies the following axioms:
(i) $\Phi_E, \widetilde{U}$ belong to $\mathcal{T}$.
(ii) The union of any number of soft sets in $\mathcal{T}$ belong to $\mathcal{T}$
(iii) The intersection of any two soft sets in $\mathcal{T}$ belong to $\mathcal{T}$.

The triple $(U ; \mathcal{T} ; E)$ is called a soft topological space over X. The member of $\mathcal{T}$ are said to be soft open in X, and the soft set F_E is called soft closed in X if its relative component ${F_E}^C$ belongs to $\mathcal{T}$.

Let *SS*(*U*)*E* be the collection of all soft sets with set of

parameter E, over U. The Cartesian product of soft sets $F_A \in SS(U)A$ and $G_B \in SS(V)B$ is a soft set $F \times G_{A\times B}$ in $SS(U \times V)A \times B$ where
$F \times G : A \times B \rightarrow P(U) \times P(V)$ is a mapping given by $(F \times G)(a; b) = F(a) \times G(b)$ for each $(a; b) \in A \times B$.

Definition2.3: The soft set $F_A \in SS(U)_A$ is called a soft point in U_A, denoted by e_F , if for the element $e \in A, F(e) \neq \varphi$ and $F(e') = \varphi, for\ all\ e \in A - \{e\}$.

Definition2.4: The soft point e_F is said to be in the soft set G_A, denoted by $e_F \in G_A$, if for the element $e \in A, F(e) \subseteq G(e)$.

Definition2.5: Let $(U; \tau; A)$ be a soft topological space over U and F_A a soft set in $SS(U)_A$. The soft point $e_F \in U_A$ is called a soft interior point of a soft set F_A,if there exists a soft open set H_A such that $e_F \in H_A \subseteq F_A$.
The soft interior of a soft set F_A is denoted by $(F_A)^0$ and is defined as the union of all soft open sets contained in F_A.
Clearly $(F_A)^0$ is the largest soft open set contained in F_A.

Definition2.6: Let $(U; \tau; A)$ be a soft topological space. Then a soft set G_A in $SS(U)_A$ is called a soft neighborhood of the soft point $e_F \in U_A$, if there exists a soft open set H_A such that $e_F \in H_A \subseteq G_A$.
The soft neighborhood system of a soft point e_F , denoted by $N_\tau(e_F)$, is the family of all its soft neighborhoods.

Definition2.7: Let $(U; \tau; A)$ be a soft topological space over U and F_A a soft set over$U$. Then the soft closure of F_A, denoted by $\overline{F_A}$, is the intersection of all soft closed supersets of F_A. Clearly $\overline{F_A}$, is the smallest soft closed set in $(U; \tau; A)$ which contains F_A.

Definition2.8: Let $(U; \tau; A)$ be a soft topological space over U and $Y \subseteq U$. Then $\tau_Y = \{(F_Y ; A) = Y_A \cap F_A | F_A \in \tau\}$is said to be the soft relative topology on Y , where $F_Y(e) = Y \cap F(e)$, for all $e \in A. (Y; \tau_Y ; A)$ is called a soft subspace of $(U; \tau; A)$.

We can easily verify that τ_Y is, in fact, a soft topology on Y .

Theorem2. 1: Let $(Y; \tau_Y ; A)$ be a soft subspace of a soft topological space $(U; \tau; A)$ and F_A a soft set over U. Then
(1) F_A is soft open in $(Y; \tau Y ; A)$ if and only if $F_A = Y_A \cap G_A$, for some soft open set G_A in $(U; \tau; A)$.
(2) F_A is soft closed in $(Y; \tau_Y ; A)$ if and only if $F_A = Y_A \cap G_A$, for some soft closed set G_A in $(U; \tau; A)$.

Proposition2.1: Soft set F_A over U is soft open $\Leftrightarrow$ F_A is a soft nbd of each of its soft elements

Proposition2.2: Let $F_A, G_A \in SS(U)_A$. Then following are true
(1) If $F_A \cap G_A = \emptyset_A$ then $F_A \nsubseteq (G_A)^c$
(2) $F_A \subseteq G_A \Leftrightarrow (G_A)^c \subseteq (F_A)^c$

Theorem2.2 : Let (U, A, τ) be a soft space over U. Let F_A and G_A are soft sets over U. Then
(1) $F_A \subseteq \overline{F_A}$
(2) F_A is a soft closed set $\Leftrightarrow F_A = \overline{F_A}$
(3) $F_A \subset G_A \Longrightarrow \overline{F_A} \subset \overline{G_A}$

Definition2.9: Let (U, A, τ) and (V, A, τ') be two soft topological spaces. f :(U, A, τ) → (V, A, τ') be a mapping. For each soft neighborhood H_A of $f(e_X)_A$, if there exists a soft neighborhood F_A of $(e_X)_A$ such that $f(F_A) \subset H_A$. Then f is said to be soft continuous mapping at $(e_X)_A$. If f is soft continuous mapping for all $(e_X)_A$ then f is called *soft continuous mapping*.

Theorem 2.3*:* Let (U, A, τ) and (V, A, τ') be two soft topological spaces.
$f: (U, A, \tau) \rightarrow (V, A, \tau')$ be a mapping. Then following conditions are equivalent:
(1) $f : (U, A, \tau) \rightarrow (V, A, \tau')$ is a soft continuous mapping
(2) For each soft open set G_A over V, $f^{-1}(G_A)$ is a soft open set over U.

Proposition2.3*:* Let U, V be two non-empty sets and f: U⟶V be a mapping.
If $F_A \in S(U)$ then
(i) $F_A \subseteq f^{-1} f(F_A)$
(ii) $f^{-1} f(F_A) = F_A$ if f is injective.

Proposition 2.4*:* Let U, V be two non-empty subsets and f: U ⟶V be a mapping. If $G_{1_A}, G_{2_A} \in S(V)$ then
(i) $G_{1_A} \subseteq G_{2_A} \Longrightarrow f^{-1}(G_{1_A}) \subseteq f^{-1}(G_{2_A})$
(ii) $f^{-1}[G_{1_A} \cup G_{2_A}] = f^{-1}(G_{1_A}) \cup f^{-1}(G_{2_A})$
(iii) $f^{-1}[(G_{1_A}) \cap (G_{2_A})] = f^{-1}(G_{1_A}) \cap f(G_{2_A})$

3. Soft Normal Spaces

In this section we define soft regular spaces, soft normal spaces and discuss their properties and relationship with other Ti spaces.

Definition3.1: Two soft sets G_A, H_A in $SS(U)_A$ are said to be soft disjoint, written $G_A \cap H_A = \Phi_A$, if $G(e) \cap H(e) = \varphi, for\ all\ e \in A$

Definition3.2: Two soft points e_G, e_H in U_A are distinct, written $e_G \neq e_H$, if there corresponding soft sets G_A and H_A are disjoint.

Definition3.3: Let $(U; \tau; A)$ be a soft topological space over U and $e_G; e_H \in U_A$ such that $e_G \neq e_H$. If there exist at least one soft open set $F1_A$ or $F2_A$ such that $e_G \in F1_A$,$e_H \notin F1_A$ or $e_H \in F2_A$, $e_H \notin F2_A$, then $(U; \tau; A)$ is called a soft T_0-space.

Definition3.4: Let $(U; \tau; A)$ be a soft topological space over U and $e_G; e_H \in U_A$such that $e_G \neq e_H$. If there exist soft open sets $F1_A$ and $F2_A$ such that $e_G \in F1_A, e_H \notin F1_A$ and $e_H \in F2_A$, $e_G \notin F2_A$, then $(U; \tau; A)$ is called a soft T_1space.

Definition3.5: Let $(U; \tau; A)$ be a soft topological space over U and $e_G; e_H \in U_A$ such that $e_G \neq e_H$. If there exist soft open sets $F1_A$ and $F2_A$ such that $e_G \in F1_A$,$e_H \in F2_A$ and $F1_A \cap F2_A = \Phi_A$, then $(U; \tau; A)$ is called a soft T_2 -space.

Now we define soft regular space as:

Definition3.6: Let $(U;\ \tau;\ A)$ be a soft topological space over X, G_A a soft closed set in $(U;\ \tau;\ A)$ and $e_F \in X_A$ such that $e_F \notin G_A$. If there exist soft open sets $F1_A$ and $F2_A$ such that $e_F \in F1_A, G_A \subseteq F2_A$ and $F1_A \cap F2_A = \Phi_A$, then $(U;\ \tau;\ A)$ is called a soft regular space.

Theorem3.1: Let $(U;\ \tau;\ A)$ be a soft topological space over U. Then the following statements are equivalent:
(1) $(U;\ \tau;\ A)$ is soft regular.
(2) For any soft open set F_A in $(U;\ \tau;\ A)$ and $e_G \in F_A$, there is a soft open set G_A containing e_G such that $e_G \in \overline{G_A} \subseteq F_A$
(3) Each soft point in $(U;\ \tau;\ A)$ has a soft nbd base consisting of soft closed sets.

Proof: ((1) ⇒ (2)) Let F_A be a soft open set in $(U;\ \tau;\ A)$ and $e_G \in F_A$. Then $(F_A)^c$ is a soft closed set such that $e_G \notin (F_A)^c$ By the soft regularity of $(U;\ \tau;\ A)$, there are soft open sets $F1_A, F2_A$ such that $e_G \in F1_A, (F_A)^c \subseteq F2_A$ and $F1_A \cap F2_A = \Phi_A$. Clearly $(F2_A)^c$ is a soft closed set contained in F_A. Thus $F1_A \subseteq (F2_A)^c \subseteq F_A$. This gives $\overline{F1_A} \subseteq (F2_A)^c \subseteq F_A$. Put $F1_A = G_A$. Consequently, $e_G \in G_A$ and $G_A \subseteq F_A$.

((2) ⇒ (3)) Let $e_G \in U_A$. For soft open set F_A in $(U;\ \tau;\ A)$, there is a soft open set G_A containing e_G such that $e_G \in G_A, \overline{G_A} \subseteq F_A$. Thus for each $e_G \in X_A$, the sets G_A form a soft nbd base consisting of soft closed sets of $(U;\ \tau;\ A)$.

((3) ⇒ (1)) Let F_A be a soft closed set such that $e_G \notin F_A$. Then $(F_A)^c$ is a softo open nbd of e_G. By (3), there is a soft closed set $F1_A$ which contains e_G and is a soft nbd of e_G with $1_A \subseteq (F_A)^c$. Then $e_G \notin (F1_A)^c, F_A \subseteq (F1_A)^c = F2_A$ and $F1_A \cap F2_A = \Phi_A$. Therefore $(X;\ \tau;\ A)$ is soft regular.

Theorem3.2: Let $(U;\ \tau;\ A)$ be a soft regular space over U. Then every soft subspace of $(U;\ \tau;\ A)$ is soft regular.

Proof . Let $(Y;\ \tau_Y;\ A)$be a soft subspace of a soft regular space $(U;\tau;\ A)$. Suppose H_A is a soft closed set in $(Y;\ \tau_Y;\ A)$ and $e_F \in Y_A$ such that $e_F \notin H_A$. Then $H_A = G_A \cap Y_A$, where G_A is soft closed in $(U;\ \tau;\ A)$. Then $e_F \notin G_A$. Since $(U;\ \tau;\ A)$ is soft regular, there exist soft disjoint soft open sets $F1_A , F2_A$ in $(U;\ \tau;\ A)$ such that $e_F \in F1_A, G_A \subseteq F2_A$. Clearly $e_F \in F1_A \cap Y_A = F1Y_A$ and $H_A \subseteq F2_A \cap Y_A = F2Y_A$ such that $F1Y_A \cap F2Y_A = \Phi_A$. This proves that $(Y;\ \tau_Y;\ A)$ is a soft regular subspace of $(U;\ \tau;\ A)$.

Definition3.7: Let $(U;\ \tau;\ A)$be a soft topological space over U, F_A and $G_A$soft closed sets over U such that $F_A \cap G_A = \phi_A$. If there exist soft open sets $F1_A$ and $F2_A$ such that $F_A \subset F1_A, G_A \subset F2_A$ and $F1_A \cap F2_A = \phi_A$, then $(U;\ \tau;\ A)$is called a soft normal space.

Theorem3.3 : A soft topological space $(U;\ \tau;\ A)$ is soft normal if and only if for any soft closed set F_A and soft open set G_A such that $F_A \subset G_A$, there exists at least one soft open set $H_A$containing F_A such that $F_A \subset H_A \subset \overline{H_A} \subset G_A$.

Proof. Suppose that $(U;\ \tau;\ A)$is a soft normal space and F_A is any soft closed subset of $(U;\ \tau;\ A)$ and G_Aa soft open set such that $F_A \subset G_A$. Then $(G_A)^c$ is soft closed, $F_A \cap (G_A)^c = \phi_A$ By supposition, there are soft open sets $H_A$and K_A such that $F_A \subset H_A$, $(G_A)^c \subset K_A$ and $H_A \cap K_A = \phi_A$. Since $H_A \cap K_A = \phi_A$, $H_A \subset (K_A)^c$. But $(K_A)^c$ is soft closed, so that $F_A \subset H_A \subset \overline{H_A} \subset (K_A)^c \subset G_A$. Hence $F_A \subset H_A \subset \overline{H_A} \subset G_A$. .
Conversely, suppose that for every soft closed set F_A and a soft open set $G_A$such that $F_A \subset G_A$, there is a soft open set H_A such that $F_A \subset H_A \subset \overline{H_A} \subset G_A$.Let $F1_A$, $F2_A$ be any two soft disjoint soft closed sets. Then $F1_A \subset (F2_A)^c$,where $(F2_A)^c$ is soft open. Hence there is a soft open set H_A such that $F1_A \subset H_A \subset \overline{H_A} \subset (F2_A)^c$.But then $F2_A \subset (H_A)^c$ and $(H_A) \cap (H_A)^c = \phi$.
So, $F1_A \subset H_A, F2_A \subset (H_A)^c$ with $H_A \cap (H_A)^c = \phi_A$.
Hence $(U;\ \tau;\ A)$ is soft normal.

Proposition3.1: Let $(Y; \tau_Y ; A)$ be a soft subspace of a soft topological space $(U;\ \tau;\ A)$and F_A be a soft open (closed) in $(Y; \tau_Y ; A)$. If Y_A is soft open(closed) in $(U;\ \tau;\ A)$,then F_A is soft open(closed) in $(U\ \tau;\ A)$.

Theorem3.4: A soft closed subspace of a soft normal space is soft normal

Proof. Let $(Y; \tau_Y ; A)$ be soft subspace of soft normal space $(U;\ \tau;\ A)$such that $Y_A \in \tau^c$.
Let $F1_A$, $F2_A$ be two disjoint soft closed subsets of $(Y; \tau_Y ; A)$. Then there exists soft closed sets F_A, $G_A$in $(X;\ \tau;\ A)$such that $F1_A = Y_A \cap F_A$ and $F2_A = Y_A \cap G_A$. Since Y_A is soft closed in $(U;\ \tau;\ A)$, therefore $F1_A, F2_A$ are soft disjoint soft closed in$(U;\ \tau;\ A)$. Then $(U;\ \tau;\ A)$is soft normal implies that there exist soft open sets $F3_A, F4_A$ in $(U; \tau; A)$ such that $F1_A \subset F3_A, F2_A \subset F4_A$ and $F3_A \cap F4_A = \phi_A$. But then $F1_A \subset Y_A \cap F3_A, F2_A \subset Y_A \cap F4_A$, where $Y_A \cap F3_A, Y_A \cap F4_A$ are soft disjoint soft open subsets of $(Y; \tau_Y ; A)$.
This proves that $(Y; \tau_Y ; A)$ is soft normal.

4. The Urysohn Lemma

In general topology Urysohn lemma states that in every normal topological space two disjoint closed subsets may be separated by a real-valued function. Here we prove this lemma is true in soft topological spaces.

Theorem4.1 (Urysohn's lemma): Let $(U;\ \tau;\ A)$be a soft normal space; let $F_A$and $G_A$be disjoint soft closed subsets of $(U;\ \tau;\ A)$. Then there exists a soft continuous map $f: (U;\ \tau;\ A) \longrightarrow [0, 1]$ such that: $f(e_x) = 0$ for every $x \in F_A$ and $f(e_x) = 1$ for every $x \in G_A$.

Proof: Let Q be the set of rational numbers in [0, 1]. Clearly the set Q is countable. Define, for each $p \in Q$ a soft open set Up_A of the soft normal space$(U;\ \tau;\ A)$. such that
if p, q∈Q with p< q then $\overline{Up_A} \subseteq Uq_A$.---------------------(1)

Construct a sequence of soft open sets in $(U;\ \tau;\ A)$as follows.

First define $U1_A = (U;\ \tau;\ A) - G_A$. Here F_A is a soft closed set contained in the soft open set $U1_A$. Using soft normality of $(U;\ \tau;\ A)$ and by theorem there must exist a soft open set which contains the soft closed set F_A and its closure is contained in $U1_A$. Let this soft open set be $U0_A$. In general let Qn denote the set consisting of the first n rational numbers in the sequence. Define Ur_A where r is the next rational number in the sequence.

Consider the set $Q_{n+1} = Q_n \cup \{r\}$. It is a finite subset of the interval [0, 1]. In a finite simply ordered set every element has an immediate predecessor and an immediate successor. Let the immediate predecessor of r be p and immediate successor of r be q. The sets Up_A and Uq_A are already defined and by induction hypothesis $\overline{Up_A} \subseteq Uq_A$

Here Uq_A is a soft open set containing a soft closed set $(\overline{Up_A})$. Using theorem there must exist a soft open set containing ($\overline{Up_A}$) and its closure is contained in (Up_A).

Let this soft open set be (Ur_A).
$\therefore (\overline{Up_A}) \subseteq Ur_A \subseteq \overline{Ur_A} \subseteq Uq_A$ It can be concluded that (1) holds for every pair of elements Q_{n+1}. If both the elements lie in Q_n then (1) holds by induction hypothesis.

Let r, s be such a pair from Qn. Then either s ⩽ p or s ⩾ q. So it will lead to
$(\overline{Us_A}) \subseteq \overline{Up_A} \subseteq Ur_A$ and $(\overline{Ur_A}) \subseteq Uq_A \subseteq Us_A$ respectively.

Thus for every pair of elements of Q_{n+1}, relation (1) holds By mathematical induction Xp_A is defined for every p∈Q. Extend this definition to all rational numbers p∈R by definition $Up_A = \emptyset_A \ if \ p < 0$
$= U_A \ if \ p > 0$ ------------(2)

The relation (1) is still true for any pair of rational numbers with p < q.
Let $e_x \in (U; \tau; A)$. Define $L(e_x) = \{p | e_x \in Up_A\}$.
From (2), $L(e_x) = \emptyset \, ; p < 0 \ and \ = Z_+ - \{1\}; p > 1$
So, $L(e_x)$ is bounded below and its g.l.b. is a point in [0, 1] say $f(e_x)$. We consider two cases

Case (i): $e_x \in F_A$ then $e_x \in Up_A$ for every $p \geq 0 \implies L(e_x) = \{p | p \in Z_+ \cup \{0\}\} \implies f(e_x) = 0$.
Case (ii): $e_x \in G_B$ then $e_x \notin Up_A, p \leq 1; \implies e_x \notin U_A, p > 1 \implies L(e_x) = \{p/p \in Z_+ - \{1\}\} \implies f(e_x) = 1$.

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