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A note on soft topological spaces

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ABSTRACT

Shabir and Naz (2011) [12] introduced and studied the notions of soft topological spaces, soft interior, soft closure and soft separation axioms. But we found that some results are incorrect (see their Remark 3.23). So the purpose of this note is, first, to point out some errors in Remark 4 and Example 9 of Shabir and Naz (2011) [12], and second, to investigate properties of soft separation axioms defined in Shabir and Naz (2011) [12]. In particular, we investigate the soft regular spaces and some properties of them. We show that if a soft topological space (X, τ, E) is soft T_1 and soft regular (i.e. a soft T_3-space), then (x, E) is soft closed for each $x \in X$ (their Theorem 3.21).

1. Introduction

Molodtsov [1] introduced the concept of a soft set in order to solve complicated problems in the economics, engineering, and environmental areas because no mathematical tools can successfully deal with the various kinds of uncertainties in these problems. However, there are some theories: the theory of fuzzy sets [2], the theory of vague sets [3], and the theory of rough sets [4], which can be considered as mathematical tools for dealing with uncertainties. Soft set theory is a mathematical tool for dealing with uncertainties which is free from the difficulties of the above theories. In [5], Maji et al. introduced several operators for soft set theory and made a theoretical study of the soft set theory in more detail. Aktas and Cagman [6] introduced a basic version of soft group theory, which extends the notions of a group to include the algebraic structures of soft sets. Pei and Miao [7] showed that soft sets are a class of special information systems. Recently, work on soft set theory and its applications in various fields has been making progress rapidly [8–11]. Shabir and Naz [12] introduced the notion of soft topological spaces which are defined over an initial universe with a fixed set of parameters and showed that a soft topological space gives a parameterized family of topological spaces. They introduced the notions of soft open sets, soft closed sets, soft interior, soft closure and soft separation axioms. Also they obtained some interesting results for soft separation axioms, which are really valuable for research in this field. But we found some incorrect results (see Remark 3.23) and a problem hindering the investigation of general properties for the soft topological space (see Lemma 3.2). So the purpose of this note is, first, to point out some errors which have appeared in Remark 4 and Example 9 of [12], and second, to investigate some properties of soft separation axioms defined in [12]. In particular, we investigate the soft regular spaces and some properties of them. In [12], it was shown that if (x, E) is soft closed for each $x \in X$ in a soft topological space (X, τ, E), then X is a soft T_1-space. In this note, we show that if a soft topological space (X, τ, E) is soft T_1 and soft regular (i.e. a soft T_3-space), then (x, E) is soft closed for each $x \in X$ (Theorem 3.21).

2. Preliminaries

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

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Definition 2.1 (*[1]*). A pair (F, A) is called a *soft set over* U if $A \subset E_U$ and $F : A \to P(U)$, where $P(U)$ is the set of all subsets of U.

Definition 2.2 (*[5]*). Let U be an initial universe set and E_U be a universe set of parameters. Let (F, A) and (G, B) be soft sets over a common universe set U and $A, B \subset E$. Then (F, A) is a *subset* of (G, B), denoted by $(F, A)\widetilde{\subset}(G, B)$, if: (i) $A \subset B$; (ii) for all $e \in A$, $F(e)$ and $G(e)$ are identical approximations.

(F, A) *equals* (G, B), denoted by $(F, A) = (G, B)$, if $(F, A)\widetilde{\subset}(G, B)$ and $(G, B)\widetilde{\subset}(F, A)$.

Definition 2.3 (*[5]*). A soft set (F, A) over U is called a *null soft set*, denoted by Φ, if $\forall e \in A$, $F(e) = \emptyset$.

Definition 2.4 (*[5]*). A soft set (F, A) over U is called an *absolute soft set*, denoted by $\tilde{A}$, if $\forall e \in A$, $F(e) = U$.

Definition 2.5 (*[5]*). The *union* of two soft sets (F, A) and (G, B) over a common universe U is the soft set (H, C), where $C = A \cup B$, and $\forall e \in C$,

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

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

Definition 2.6 (*[13]*). The *intersection* of two soft sets of (F, A) and (G, B) over a common universe U is the soft set (H, C), where $C = A \cap B$, and $\forall e \in C$, $H(e) = F(e) \cap G(e)$. We write $(F, A) \cap (G, B) = (H, C)$.

Definition 2.7 (*[14]*). For a soft set (F, A) over U, *the relative complement* of (F, A) is denoted by $(F, A)^c$ and is defined by $(F, A)^c = (F^c, A)$, where $F^c : A \to P(U)$ is a mapping given by $F^c(\alpha) = U - F(\alpha)$ for all $\alpha \in A$.

3. The main results

Henceforth, let X be an initial universe set and E be the fixed non-empty set of parameter with respect to X unless otherwise specified.

Definition 3.1 (*[12]*). Let τ be the collection of soft sets over X; then τ is called a *soft topology* on X if τ satisfies the following axioms:

(1) $\Phi, \widetilde{X}$ belong to τ.
(2) The union of any number of soft sets in τ belongs to τ.
(3) The intersection of any two soft sets in τ belongs to τ.

The triplet (X, τ, E) is called a *soft topological space* over X. The members of τ are said to be *soft open* in X. A soft set (F, E) over X is said to be *soft closed* in X if its relative complement $(F, E)^c$ belongs to τ.

Shabir and Naz adopted Definition 2.2 to investigate general properties on the soft topological space. But from the next Lemma 3.2, we can show that the adopting of Definition 2.2 causes a serious problem in treating soft sets over an initial universe with a fixed set of parameters.

Lemma 3.2. *Let (F, E) and (G, E) be soft sets over a common universe set U with a fixed set E of parameters. If $(F, E)\widetilde{\subset}(G, E)$ as in Definition 2.2, then $(F, E) = (G, E)$.*

Proof. If $(F, E)\widetilde{\subset}(G, E)$, then $F(\alpha) = G(\alpha)$ for all $\alpha \in E$. Again, by Definition 2.2, we can say that $(G, E)\widetilde{\subset}(F, E)$. So $(F, E) = (G, E)$. □

From now on, to remove the problem which is pointed out in Lemma 3.2, we will adopt Definition 3.3 instead of Definition 2.2.

Definition 3.3 (*[13]*). Let U be an initial universe set and E_U be an universe set of parameters. Let (F, A) and (G, B) be soft sets over a common universe set U and $A, B \subset E$. Then (F, A) is a *subset* of (G, B), denoted by $(F, A)\widetilde{\subset}(G, B)$, if: (i) $A \subset B$; (ii) for all $e \in A$, $F(e) \subset G(e)$.

(F, A) *equals* (G, B), denoted by $(F, A) = (G, B)$, if $(F, A)\widetilde{\subset}(G, B)$ and $(G, B)\widetilde{\subset}(F, A)$.

Definition 3.4 ([12]). Let (F, E) be a soft set over X and $x \in X$. We say that $x \in (F, E)$ read as x *belongs* to the soft set (F, E), whenever $x \in F(\alpha)$ for all $\alpha \in E$.

Note that for $x \in X$, $x \notin (F, E)$ if $x \notin F(\alpha)$ for some $\alpha \in E$.

Definition 3.5 ([12]). Let $x \in X$; then (x, E) denotes the soft set over X for which $x(\alpha) = \{x\}$, for all $\alpha \in E$.

Lemma 3.6. *Let (F, E) be a soft set over X and $x \in X$. Then:*

(1) *$x \in (F, E)$ iff $(x, E)\tilde{\subset}(F, E)$;*
(2) *if $(x, E) \cap (F, E) = \Phi$, then $x \notin (F, E)$.*

Proof. Obvious. □

In (2) of Lemma 3.6, the converse is not always true, as shown in the next example.

Example 3.7. Let $X = \{h_1, h_2\}$, $E = \{e_1, e_2, e_3\}$, and let (F, E) be a soft set defined as follows: $F(e_1) = \{h_1\}$; $F(e_2) = \{h_1\}$; $F(e_3) = \{h_1, h_2\}$.

Then $h_2 \notin (F, E)$. But $(h_2, E) \cap (F, E) \neq \emptyset$ because of $h_2(e_3) \cap F(e_3) \neq \emptyset$ for $e_3 \in E$.

Definition 3.8 ([12]). Let (X, τ, E) be a soft topological space over X and $x, y \in X$ such that $x \neq y$. If there exist soft open sets (F, E) and (G, E) such that $x \in (F, E)$ and $y \notin (F, E)$; and $y \in (G, E)$ and $x \notin (G, E)$, then (X, τ, E) is called a soft T_1-*space*.

Theorem 3.9. *Let (X, τ, E) be a soft topological space over X and $x \in X$. If X is a soft T_1-space, then for each soft open set (F, E) with $x \in (F, E)$:*

(1) *$(x, E)\tilde{\subset} \cap (F, E)$;*
(2) *for all $z \neq x$, $z \notin \cap(F, E)$.*

Proof. (1) Since $x \in \cap(F, E)$, by Lemma 3.6, it is obvious that $(x, E)\tilde{\subset} \cap (F, E)$.

(2) Let $x \neq z$ for $x, z \in X$; then there exist soft open sets (H, E) such that $x \in (H, E)$ and $z \notin (H, E)$. So $z \notin H(\alpha)$ for some $\alpha \in E$, and we have $z \notin \cap_{\alpha \in E} F(\alpha)$. Consequently, $z \notin \cap(F, E)$. □

In (1) of Theorem 3.9, the equality may not hold, as shown in the next example.

Example 3.10. Let $X = \{x, z\}$, $E = \{e_1, e_2, e_3, e_4\}$ and $\tau = \{\Phi, \tilde{X}, (F_1, E), (F_2, E), (F_3, E), (F_4, E), (F_5, E)\}$ where

$$F_1(e_1) = \{x, z\}; \quad F_1(e_2) = F_1(e_3) = F_1(e_4) = \{x\}$$
$$F_2(e_1) = F_2(e_2) = \{x, z\}; \quad F_2(e_3) = F_2(e_4) = \{x\}$$
$$F_3(e_1) = F_3(e_2) = F_3(e_3) = \{z\}; \quad F_3(e_4) = \{x, z\}$$
$$F_4(e_1) = \{z\}; \quad F_4(e_2) = F_4(e_3) = \emptyset; \quad F_4(e_4) = \{x\}$$
$$F_5(e_1) = F_5(e_2) = \{z\}; \quad F_5(e_3) = \emptyset; \quad F_5(e_4) = \{x\}.$$

For $x, z \in X$, since $x \neq z$, we can take two soft sets (F_1, E) and (F_3, E) satisfying $x \in (F_1, E)$ and $z \notin (F_1, E)$; and $z \in (F_3, E)$ and $x \notin (F_3, E)$. So the soft topological space (X, τ, E) is a soft T_1-space. But for all soft open sets $x \in (F_1, E)$ and $x \in (F_2, E)$, $(F_1, E) \cap (F_2, E) = (F_1, E) \neq (x, E)$.

Definition 3.11 ([12]). Let (X, τ, E) be a soft topological space over X and $x, y \in X$ such that $x \neq y$. If there exist soft open sets (F, E) and (G, E) such that $x \in (F, E)$, $y \in (G, E)$ and $(F, E) \cap (G, E) = \Phi$, then (X, τ, E) is called a soft T_2-*space*.

Theorem 3.12. *Let (X, τ, E) be a soft topological space over X and $x \in X$. If X is a soft T_2-space, then $(x, E) = \cap(F, E)$ for each soft open set (F, E) with $x \in (F, E)$.*

Proof. Suppose there exists $z \in X$ such that $x \neq z$ and $z \in \cap F(\alpha)$ for some $\alpha \in E$. Since X is soft T_2, there exist soft open sets (H, E) and (G, E) such that $x \in (H, E)$ and $z \in (G, E)$ and $(H, E) \cap (G, E) = \Phi$ and so $(H, E) \cap (z, E) = \Phi$ and $H(\alpha) \cap z(\alpha) = \emptyset$. This contradicts the fact that $z \in \cap F(\alpha)$ for some $\alpha \in E$. This completes the proof. □

Corollary 3.13. *Let (X, τ, E) be a soft topological space over X and $x \in X$. If X and E are finite, and if X is a soft T_2-space, then (x, E) is a soft open set for $x \in X$.*

Definition 3.14 ([12]). Let (X, τ, E) be a soft topological space over X, and let (G, E) be a soft closed set in X and $x \in X$ such that $x \notin (G, E)$. If there exist soft open sets (F_1, E) and (F_2, E) such that $x \in (F_1, E)$, $(G, E)\tilde{\subset}(F_2, E)$ and $(F_1, E) \cap (F_2, E) = \Phi$, then (X, τ, E) is called a *soft regular space*.

Lemma 3.15. *Let (X, τ, E) be a soft topological space over X, and let (G, E) be a soft closed set in X and $x \in X$ such that $x \notin (G, E)$. If (X, τ, E) is a soft regular space, then there exist soft open sets (F, E) such that $x \in (F, E)$ and $(F, E) \cap (G, E) = \Phi$.*

Theorem 3.16. *Let (X, τ, E) be a soft topological space over X and $x \in X$.*
If X is a soft regular space, then:

(1) *For a soft closed set (G, E), $x \notin (G, E)$ iff $(x, E) \cap (G, E) = \Phi$.*
(2) *For a soft open set (F, E), $x \notin (F, E)$ iff $(x, E) \cap (F, E) = \Phi$.*

Proof. (1) Let $x \notin (G, E)$. By Lemma 3.15, there exists a soft open set (F, E) such that $x \in (F, E)$ and $(F, E) \cap (G, E) = \Phi$. Since $(x, E)\tilde{\subset}(F, E)$, we have $(x, E) \cap (G, E) = \Phi$.

The converse is obtained by Lemma 3.6(2).

(2) Let $x \notin (F, E)$. Then there are two cases: (i) $x \notin F(\alpha)$ for all $\alpha \in E$ and (ii) $x \notin F(\alpha)$ and $x \in F(\beta)$ for some $\alpha, \beta \in E$. In case (i) it is obvious that $(x, E) \cap (F, E) = \Phi$. In the other case, $x \in F^c(\alpha)$ and $x \notin F^c(\beta)$ for some $\alpha, \beta \in E$ and so $(F, E)^c$ is a soft closed set such that $x \notin (F, E)^c$, by (1), $(x, E) \cap (F, E)^c = \Phi$. So $(x, E)\tilde{\subset}(F, E)$ but this contradicts $x \notin F(\alpha)$ for some $\alpha \in E$. Consequently, we have $(x, E) \cap (F, E) = \Phi$.

The converse is obvious. □

Theorem 3.17. *Let (X, τ, E) be a soft topological space over X and $x \in X$. Then the following are equivalent:*

(1) *(X, τ, E) is a soft regular space.*
(2) *For each soft closed set (G, E) such that $(x, E) \cap (G, E) = \Phi$, there exist soft open sets (F_1, E) and (F_2, E) such that $(x, E)\tilde{\subset}(F_1, E)$, $(G, E)\tilde{\subset}(F_2, E)$ and $(F_1, E) \cap (F_2, E) = \Phi$.*

Proof. The proof is obvious, obtained by Theorem 3.16(1) and Lemma 3.6(1). □

Theorem 3.18. *Let (X, τ, E) be a soft topological space over X and $x \in X$.*
If X is a soft regular space, then:

(1) *For a soft open set (F, E), $x \in (F, E)$ iff $x \in F(\alpha)$ for some $\alpha \in E$.*
(2) *For a soft open set (F, E), $(F, E) = \cup\{(x, E) : x \in F(\alpha)$ for some $\alpha \in E\}$.*
(3) *For each $\alpha, \beta \in E$, $\tau_\alpha = \tau_\beta$.*

Proof. (1) Assume that for some $\alpha \in E$, $x \in F(\alpha)$ and $x \notin (F, E)$. Then by Theorem 3.16(2), $(x, E) \cap (F, E) = \Phi$. By the assumption, this is a contradiction and so $x \in (F, E)$.

The converse is obvious.

(2) It follows from (1) and $x \in (F, E)$ iff $(x, E)\tilde{\subset}(F, E)$.

(3) It is obtained from (2). □

Theorem 3.19. *Let (X, τ, E) be a soft topological space over X. If (X, τ, E) is a soft regular space, then the following are equivalent:*

(1) *(X, τ, E) is a soft T_1-space.*
(2) *For $x, y \in X$ with $x \neq y$, there exist soft open sets (F, E) and (G, E) such that $(x, E)\tilde{\subset}(F, E)$ and $(y, E) \cap (F, E) = \Phi$, and $(y, E)\tilde{\subset}(G, E)$ and $(x, E) \cap (G, E) = \Phi$.*

Proof. It is obvious that $x \in (F, E)$ iff $(x, E)\tilde{\subset}(F, E)$, and by Theorem 3.16, $x \notin (F, E)$ iff $(x, E) \cap (F, E) = \Phi$. Hence we have that the above statements are equivalent. □

Definition 3.20 (*[12]*). Let (X, τ, E) be a soft topological space over X. Then (X, τ, E) is said to be a *soft T_3-space* if it is a soft regular and soft T_1-space.

Theorem 3.21. *Let (X, τ, E) be a soft topological space over X. If (X, τ, E) is a soft T_3-space, then for each $x \in X$, (x, E) is soft closed.*

Proof. We show that $(x, E)^c$ is soft open. For each $y \in U - \{x\}$, since (X, τ, E) is a soft regular and T_1-space, by Theorem 3.19, there exists a soft open set (F_y, E) such that $(y, E)\tilde{\subset}(F_y, E)$ and $(x, E) \cap (F_y, E) = \Phi$. So $\cup_{y \in U-\{x\}}(F_y, E)\tilde{\subset}(x, E)^c$. For the other inclusion, let $\cup_{y \in U-\{x\}}(F_y, E) = (H, E)$ where $H(\alpha) = \cup_{y \in U-\{x\}} F_y(\alpha)$ for all $\alpha \in E$. Moreover, from the definition of the relative complement and Definition 3.5, we know that $(x, E)^c = (x^c, E)$, where $x^c(\alpha) = U - \{x\}$ for each $\alpha \in E$. Now, for each $y \in U - \{x\}$ and for each $\alpha \in E$, $x^c(\alpha) = U - \{x\} = \cup_{y \in U-\{x\}}\{y\} = \cup_{y \in U-\{x\}} y(\alpha) \subset \cup_{y \in U-\{x\}} F_y(\alpha) = H(\alpha)$. By Definition 3.3, this implies that $(x, E)^c\tilde{\subset} \cup_{y \in U-\{x\}}(F_y, E)$, and so $(x, E)^c = \cup_{y \in U-\{x\}}(F_y, E)$. Since (F_y, E) is soft open for each $y \in U - \{x\}$, consequently, (x, E) is soft closed. □

Theorem 3.22. *A soft T_3-space is soft T_2.*

Proof. Let (X, τ, E) be any soft T_3-space. For $x, y \in X$ with $x \neq y$, by the above Theorem 3.21, (y, E) is soft closed and $x \notin (y, E)$. From the soft regularity, there exist soft open sets (F_1, E) and (F_2, E) such that $x \in (F_1, E)$, $y \in (y, E)\tilde{\subset}(F_2, E)$ and $(F_1, E) \cap (F_2, E) = \Phi$. Hence (X, τ, E) is soft T_2. □

Remark 3.23. In [12, Remark 4]:

(1) A soft T_3-space may not be a soft T_2-space.

(2) If (X, τ, E) is a soft T_3-space, then (X, τ_α) may not be a T_3-space for each parameter $\alpha \in E$.

I. By Theorem 3.22, we can see that the statement (1) in [12, Remark 4] is incorrect.

II. By Theorem 3.18(3) and Theorem 3.22, we can say that the statement (2) in [12, Remark 4] is incorrect. In particular, from Theorem 3.18(3), we have the corrected statement:

(2)′ If (X, τ, E) is a soft T_3-space, then (X, τ_α) is a T_3-space for each parameter $\alpha \in E$.

III. In Example 9 of [12], if $X = \{h_1, h_2, h_3\}$, $E = \{e_1, e_2\}$ and $\tau = \{\Phi, \widetilde{X}, (F_1, E), (F_2, E), (F_3, E), \ldots, (F_{30}, E)\}$, then Shabir and Naz asserted that the soft topological space (X, τ, E) is a soft T_3-space but this is wrong. For example, let us consider a soft open set $(F_2, E) \in \tau$; then $F_2(e_1) = \{h_1\}$; $F_2(e_2) = \emptyset$, $F_2^c(e_1) = \{h_2, h_3\}$; $F_2^c(e_2) = X$, and $h_1 \notin (F_2, E)^c$. Note that $(F_2, E)^c$ is a soft closed and $h_1 \notin (F_2, E)^c$. For any soft open set $(F_i, E) \ni h_1$ and for any soft open set (K, E) including $(F_2, E)^c$, it is impossible that $(F_i, E) \cap (K, E) = \Phi$ because $F_2^c(e_2) = X$, where $i = 1, \ldots, 30$. In other words, there exist no soft open sets (H, E) and (K, E) such that $h_1 \in (H, E)$, $(F_2, E)^c \widetilde{\subset} (K, E)$ and $(H, E) \cap (K, E) = \Phi$. Consequently, the soft topological space (X, τ, E) is not soft regular, and so it is not soft T_3.

Definition 3.24 (*[12]*)**.** Let (X, τ, E) be a soft topological space over X, (F, E) and (G, E) soft closed sets such that $(F, E) \cap (G, E) = \Phi$. If there exist soft open sets (F_1, E) and (F_2, E) such that $(F, E) \widetilde{\subset} (F_1, E)$, $(G, E) \widetilde{\subset} (F_2, E)$ and $(F_1, E) \cap (F_2, E) = \Phi$, then (X, τ, E) is called a *soft normal space.*

Theorem 3.25. *Let (X, τ, E) be a soft topological space over X. If (X, τ, E) is a soft normal space and if (x, E) is a soft closed set for each $x \in X$, then (X, τ, E) is a soft T_3 space.*

Proof. Since (x, E) is a soft closed set for each $x \in X$, by Theorem 3 of [12], X is soft T_1. It is also soft regular by Theorem 3.17 and Definition 3.24. Hence (X, τ, E) is a soft T_3 space. □

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