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Compact fuzzy soft spaces

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Abstract. In this article, by using basic properties of fuzzy soft topology we define fuzzy soft compactness. We also introduce some basic definitions and theorems of the concept.

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1. Introduction

There are many complicated problems encountered in economics, engineering, and environment which can not be solved by using classical mathematical methods because of uncertainties they involve. Various mathematical set theories such as soft set which was introduced by Molodtsov [10] and fuzzy set which developed by Zadeh [16] have been developed to solve some these problems. Maji et al. [9] also initiated the more generalized concept of fuzzy soft sets which is a combination of fuzzy set and soft set. In [4], Bayramov et al. studied on fuzzy soft modules and some researchers ([5], [7]) worked on intuitionistic fuzzy soft sets. Tanay and Kandemir introduced topological structure of fuzzy soft set in [14] and gave a introductory theoretical base to carry further study on this concept. Following this study, some others ([1],[3],[8],[11],[12],[15]) studied on the concept of fuzzy soft topological spaces. Recently, Simsekler and Yuksel [13] constructed a topology over a fuzzy soft set with fixed parameter set and proposed that their work can be continued by defining certain properties of it. In this paper, we introduce compactness on fuzzy soft topological spaces and give some important definitions and theorems.

2. Preliminaries

Definition 2.1 ([16])**.** A fuzzy set A of a non-empty set X is characterized by a membership function $\mu_A : X \to [0, 1] = I$ whose value $\mu_A(x)$ represents the "grade of membership " of x in A for $x \in X$.

Let I^X denotes the family of all fuzzy sets on X. If $A, B \in I^X$, then some basic set operations for fuzzy sets are given by Zadeh as follows:

(1)**:** $A \leq B \Leftrightarrow \mu_A(x) \leq \mu_B(x)$, for all $x \in X$.
(2)**:** $A = B \Leftrightarrow \mu_A(x) = \mu_B(x)$, for all $x \in X$.
(3)**:** $C = A \vee B \Leftrightarrow \mu_C(x) = \mu_A(x) \vee \mu_B(x)$, for all $x \in X$.
(4)**:** $D = A \wedge B \Leftrightarrow \mu_D(x) = \mu_A(x) \wedge \mu_B(x)$, for all $x \in X$.
(5)**:** $E = A^c \Leftrightarrow \mu_E(x) = 1 - \mu_A(x)$, for all $x \in X$.

Definition 2.2 ([10])**.** Let X be the initial universe set and E be the set of parameters. A pair (F, A) is called a soft set over X where F is a mapping given by $F : A \to P(X)$ and $A \subseteq E$.

In other words, the soft set is a parametrized family of subsets of the set X. Every set $F(e)$, for every $e \in A$, from this family may be considered as the set of e-elements of the soft set (F, A).

Definition 2.3 ([9])**.** Let $A \subseteq E$. A pair (f, A) is called a fuzzy soft set over X , where $f : A \to I^X$ is a function.

That is, for each $a \in A$, $f(a) = f_a : X \to I$ is a fuzzy set on X.

Example 2.4 ([14])**.** Suppose that X is the set of houses under consideration, E is the set of parameters where each parameter is a fuzzy word or sentence involving fuzzy words, $E = \{expensive,\ beautiful,\ wooden,\ cheap,\ in\ green\ surroundings,\ modern,\ in\ good\ repair,\ in\ bad\ repair\}$. In this case, to define soft set and fuzzy soft set means to point expensive houses, beautiful houses, and so on. The soft set (F, A) and the fuzzy soft set (f, A) describes the attractiveness of houses. Suppose that there are six houses in the universe X given by $U = \{h^1, h^2, h^3, h^4, h^5, h^6\}$ and $A = \{e_1, e_2, e_3, e_4, e_5\} \subset E$ where e_1 stands for the parameter '*expensive*', e_2 stands for the parameter '*beautiful*', e_3 stands for the parameter '*wooden*', e_4 stands for the parameter '*cheap*', and e_5 stands for the parameter '*in green surroundings*'.

From Definition 2.2, $(F, A) = \{e_1 = \{h^2, h^4\}, e_2 = \{h^1, h^3\}, e_3 = \{h^3, h^4, h^5\}, e_4 = \{h^1, h^3, h^5\}, e_5 = \{h^1\}\}$ is a soft set over X.

From Definition 2.3, $(f, A) = \{e_1 = \{h^1_{0.5}, h^2_1, h^3_{0.4}, h^4_1, h^5_{0.3}, h^6_0\}, e_2 = \{h^1_1, h^2_{0.4}, h^3_1, h^4_{0.4}, h^5_{0.6}, h^6_{0.8}\}, e_3 = \{h^1_{0.2}, h^2_{0.3}, h^3_1, h^4_1, h^5_1, h^6_0\}, e_4 = \{h^1_1, h^2_0, h^3_1, h^4_{0.2}, h^5_1, h^6_{0.2}\}, e_5 = \{h^1_1, h^2_{0.1}, h^3_{0.5}, h^4_{0.3}, h^5_{0.2}, h^6_{0.3}\}\}$ is a fuzzy soft set over X.

Definition 2.5 ([15])**.** Fuzzy soft set (f, A) on the universe X is a mapping from the parameter set E to I^X, i.e., $(f, A) : E \to I^X$, where $(f, A)(e) \neq 0_X$ if $e \in A \subseteq E$ and $(f, A)(e) = 0_X$ if $e \notin A$, where 0_X is empty fuzzy set on X.

From now on, we will use $FS(X, E)$ to denote the family of all fuzzy soft sets over X.

Definition 2.6 ([15])**.** Let $(f, A), (g, B) \in FS(X, E)$. The following operations are defined as follows:

Subset: $(f, A)\,\tilde{\subseteq}\,(g, B)$ if $(f, A)(e) \leq (g, B)(e)$, for each $e \in E$.

Equal: $(f, A) = (g, B)$ if $(f, A) \,\tilde{\subseteq}\, (g, B)$ and $(g, B) \,\tilde{\subseteq}\, (f, A)$.
Union: $(h, A \cup B) = (f, A) \,\tilde{\cup}\, (g, B)$ where $(h, A \cup B)(e) = (f, A)(e) \vee (g, B)(e)$, for all $e \in E$.
Intersection: $(h, A \cap B) = (f, A) \,\tilde{\cap}\, (g, B)$ where $(h, A \cap B)(e) = (f, A)(e) \wedge (g, B)(e)$, for all $e \in E$.

Definition 2.7 ([15]). Let $(f, A) \in FS(X, E)$. Then complement of (f, A), denoted by $(f, A)^c$, is the fuzzy soft set defined by $(f, A)^c(e) = 1_X - (f, A)(e)$, for all $e \in E$.
Clearly $((f, A)^c)^c = (f, A)$.

Definition 2.8 ([15]). Let $(f, E) \in FS(X, E)$. The fuzzy soft set (f, E) is called the null fuzzy soft set, denoted by $\tilde{0}_E$, if $(f, E)(e) = 0_X$, for all $e \in E$.

Definition 2.9 ([15]). Let $(f, E) \in FS(X, E)$. The fuzzy soft set (f, E) is called the universal fuzzy soft set, denoted by $\tilde{1}_E$, if $(f, E)(e) = 1_X$, for all $e \in E$.
Clearly $(\tilde{1}_E)^c = \tilde{0}_E$ and $(\tilde{0}_E)^c = \tilde{1}_E$.

Definition 2.10. [2] Let $FS(X, E)$ and $FS(Y, K)$ be the families of all fuzzy soft sets over X and Y, respectively. Let $\varphi : X \to Y$ and $\psi : E \to K$ be two functions. Then the pair (φ, ψ) is called a fuzzy soft mapping from X to Y and denoted by $(\varphi, \psi) : FS(X, E) \to FS(Y, K)$.
If φ and ψ is injective then the fuzzy soft mapping (φ, ψ) is said to be injective. If φ and ψ is surjective then the fuzzy soft mapping (φ, ψ) is said to be surjective.
The fuzzy soft mapping (φ, ψ) is called constant, if φ and ψ are constant.

Definition 2.11. [14] A fuzzy soft topological space is a pair (X, τ) where X is a nonempty set and τ a family of fuzzy soft sets over X satisfying the following properties:
(1) $\tilde{0}_E, \tilde{1}_E \in \tau$,
(2) If $(f, A), (g, B) \in \tau$, then $(f, A) \,\tilde{\cap}\, (g, B) \in \tau$
(3) If $(f_i, A) \in \tau, i \in J$, then $\cup_{i \in I} (f_i, A) \in \tau$
τ is called a topology of fuzzy soft sets on X. Every member of τ is called fuzzy soft open.
(g, B) is called fuzzy soft closed in (X, τ) if $(g, B)^c \in \tau$.

Example 2.12. [14] Let X be as in Example 2.4. Then the family
$\tau = \{\tilde{0}_E, \tilde{1}_E, \{e_1 = \{h^1_{0.2}, h^2_1, h^3_{0.1}, h^4_{0.2}, h^5_0, h^6_0\}, e_2 = \{h^1_0, h^2_{0.3}, h^3_{0.6}, h^4_0, h^5_{0.1}, h^6_{0.7}\}\},$
$\{e_3 = \{h^1_{0.2}, h^2_{0.3}, h^3_{0.8}, h^4_{0.2}, h^5_{0.5}, h^6_0\}\}, \{e_3 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\}\},$
$\{e_1 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\}, e_2 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\}\},$
$\{e_1 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\}, e_2 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\},$
$e_3 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\}\}, \{e_1 = \{h^1_{0.2}, h^2_1, h^3_{0.1}, h^4_{0.2}, h^5_0, h^6_0\},$
$e_2 = \{h^1_0, h^2_{0.3}, h^3_{0.6}, h^4_0, h^5_{0.1}, h^6_{0.7}\}, e_3 = \{h^1_{0.2}, h^2_{0.3}, h^3_{0.8}, h^4_{0.2}, h^5_{0.5}, h^6_0\}\},$
$\{e_1 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\}, e_2 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\},$
$e_3 = \{h^1_{0.2}, h^2_{0.3}, h^3_{0.8}, h^4_{0.2}, h^5_{0.5}, h^6_0\},$
$e_4 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\}, e_5 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\}\},$
$\{e_1 = \{h^1_{0.2}, h^2_1, h^3_{0.1}, h^4_{0.2}, h^5_0, h^6_0\}, e_2 = \{h^1_0, h^2_{0.3}, h^3_{0.6}, h^4_0, h^5_{0.1}, h^6_{0.7}\},$
$e_3 = \{h^1_{0.2}, h^2_{0.3}, h^3_{0.8}, h^4_{0.2}, h^5_{0.5}, h^6_0\},$
$e_4 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\}, e_5 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\}\},$
$\{e_1 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\}, e_2 = \{h^1_0, h^2_0, h^3_0, h^4_0, h^5_0, h^6_0\},$

$e_3 = \{h^1_{0.2}, h^2_{0.3}, h^3_{0.8}, h^4_{0.2}, h^5_{0.5}, h^6_0\}\}\}$
of fuzzy soft set over X is a fuzzy soft topology on X and (X, τ) is a fuzzy soft topological space.

Definition 2.13. [14] Let (X, τ_1) and (Y, τ_2) be two fuzzy soft topological spaces. If each $(f, A) \in \tau_1$ is in τ_2, then τ_2 is called fuzzy soft finer than τ_1, or (equivalently) τ_1 is fuzzy soft coarser than τ_2.

Definition 2.14 ([15])**.** Let (X, τ_1) and (Y, τ_2) be two fuzzy soft topological spaces.
(1) A fuzzy soft mapping $(\varphi, \psi) : (X, \tau_1) \to (Y, \tau_2)$ is called fuzzy soft continuous if $(\varphi, \psi)^{-1}((g, B)) \in \tau_1$, $\forall (g, B) \in \tau_2$.
(2) A fuzzy soft mapping $(\varphi, \psi) : (X, \tau_1) \to (Y, \tau_2)$ is called fuzzy soft open if $(\varphi, \psi)((f, A)) \in \tau_2$, $\forall (f, A) \in \tau_1$.

3. Compact fuzzy soft spaces

Definition 3.1. A family Ψ of fuzzy soft sets is a cover of a fuzzy soft set (f, A) if $(f, A) \subseteq \cup \{(f_i, A) : (f_i, A) \in \Psi, i \in I\}$.
It is a fuzzy soft open cover if each member of Ψ is a fuzzy soft open set. A subcover of Ψ is a subfamily of Ψ which is also a cover.

Definition 3.2. Let (X, τ) be fuzzy soft topological space and $(f, A) \in FS(X, E)$. Fuzzy soft set (f, A) is called compact if each fuzzy soft open cover of (f, A) has a finite subcover. Also fuzzy soft topological space (X, τ) is called compact if each fuzzy soft open cover of $\tilde{1}_E$ has a finite subcover.

Example 3.3. A fuzzy soft topological space (X, τ) is compact if X is finite.

Example 3.4. Let (X, τ) and (Y, σ) be two fuzzy soft topological spaces and $\tau \subset \sigma$. Then fuzzy soft topological space (X, τ) is compact if (Y, σ) is compact.

Proposition 3.5. *Let (g, B) be a fuzzy soft closed set in fuzzy soft compact space (X, τ). Then (g, B) is also compact.*

Proof. Let (f_i, A) be any open covering of (g, B). Then $\tilde{1}_E \subseteq (\cup_{i \in I} (f_i, A)) \cup (g, B)^c$, that is, (f_i, A) together with fuzzy soft open set $(g_B)^c$ is a open covering of $\tilde{1}_X$. Therefore there exists a finite subcovering $(f_1, A), (f_2, A), ..., (f_n, A), (g, B)^c$. Hence we obtain $\tilde{1}_X \subseteq (f_1, A) \cup (f_2, A) \cup ... \cup (f_n, A) \cup (g, B)^c$. Therefore, we get $(g, B) \subseteq (f_1, A) \cup (f_2, A) \cup ... \cup (f_n, A) \cup (g, B)^c$ which clearly implies $(g, B) \subseteq (f_1, A) \cup (f_2, A) \cup ... \cup (f_n, A)$ since $(g, B) \cap (g, B)^c = \tilde{0}_E$. Hence (g, B) has a finite subcovering and so is compact. □

Definition 3.6 ([8])**.** Let (X, τ) be a fuzzy soft topological space over X and $x, y \in X$ such that $x \neq y$. If there exist fuzzy soft open sets (f, A) and (g, A) such that $x \in (f, A), y \in (g, A)$ and $(f, A) \tilde{\cap} (g, A) = \tilde{0}_E$, then (X, τ) is called a fuzzy soft Hausdorff space.

Proposition 3.7. *Let (g, B) be a fuzzy soft compact set in fuzzy soft Hausdorff space (X, τ). Then (g, B) is closed.*

Proof. Let $x \in (g,B)^c$. For each $y \in (g,B)$, we have $x \neq y$, so there are disjoint fuzzy soft open sets (f_y, A) and (h_y, A) so that $x \in (f_y, A)$ and $y \in (h_y, A)$. Then $\{(h_y, A) : y \in (g,B)\}$ is an fuzzy soft open cover of (g,B). Let $\{(h_{y_1}, A), (h_{y_2}, A), ..., (h_{y_n}, A)\}$ be a finite subcover. Then $\cap_{i=1}^{n} (f_{y_i}, A)$ is an open set containing x and contained in $(g,B)^c$. Thus $(g,B)^c$ is fuzzy soft open and (g,B) is closed. □

Theorem 3.8. *Let (X,τ) and (Y,σ) be fuzzy soft topological spaces and $(\varphi,\psi) : (X,\tau) \to (Y,\sigma)$ continuous and onto fuzzy soft function. If (X,τ) is fuzzy soft compact, then (Y,σ) is fuzzy soft compact.*

Proof. We will use Theorem 3.8 and Theorem 3.10 of [6]. Let (f_i, A) be any open covering of $\tilde{1}_Y$, i.e., $\tilde{1}_Y \subseteq \cup_{i\in I} (f_i, A)$. Then $(\varphi,\psi)^{-1} (\tilde{1}_Y) \subseteq (\varphi,\psi)^{-1} (\cup_{i\in I} (f_i, A))$ and $\tilde{1}_X \subseteq \cup_{i\in I} (\varphi,\psi)^{-1} ((f_i, A))$. So $(\varphi,\psi)^{-1} ((f_i, A))$ is an open covering of $\tilde{1}_X$. As (X,τ) is compact, there are $1, 2, ..., n$ in I such that $\tilde{1}_X \subseteq (\varphi,\psi)^{-1} ((f_1, A)) \cup (\varphi,\psi)^{-1} ((f_2, A)) \cup ... \cup (\varphi,\psi)^{-1} ((f_n, A))$.

Since (φ,ψ) is surjective, we have

$$\begin{aligned} \tilde{1}_Y &= (\varphi,\psi) (\tilde{1}_X) \\ &\subseteq (\varphi,\psi) \left((\varphi,\psi)^{-1} ((f_1, A)) \cup ... \cup (\varphi,\psi)^{-1} ((f_n, A)) \right) \\ &= (\varphi,\psi) \left((\varphi,\psi)^{-1} ((f_1, A)) \right) \cup ... \cup (\varphi,\psi) \left((\varphi,\psi)^{-1} ((f_n, A)) \right) \\ &= (f_1, A) \cup (f_2, A) \cup ... \cup (f_n, A). \end{aligned}$$

So we have $\tilde{1}_Y \subseteq (f_1, A) \cup (f_2, A) \cup ... \cup (f_n, A)$, i.e., $\tilde{1}_Y$ is covered by a finite number of (f_i, A).

Hence (Y,σ) is compact. □

Definition 3.9. Let (X,τ) and (Y,σ) be two fuzzy soft topological spaces. A fuzzy soft mapping $(\varphi,\psi) : (X,\tau) \to (Y,\sigma)$ is called fuzzy soft closed if $(\varphi,\psi)((f,A))$ is fuzzy soft closed set in (Y,σ), for all fuzzy soft closed set (f,A) in (X,τ).

Theorem 3.10. *Let (X,τ) be a compact fuzzy soft topological space and (Y,σ) be a fuzzy soft Hausdorff space. Fuzzy soft mapping (φ,ψ) is closed if fuzzy soft mapping $(\varphi,\psi) : (X,\tau) \to (Y,\sigma)$ is continuous.*

Proof. Let (g,B) be any fuzzy soft closed set in (X,τ). By Proposition 3.5 we have (g,B) is compact. Since fuzzy soft mapping (φ,ψ) is continuous, fuzzy soft set $(\varphi,\psi)((g,B))$ is compact in (Y,σ). As (Y,σ) is fuzzy soft Hausdorff space, fuzzy soft set $(\varphi,\psi)((g,B))$ is closed. Then Fuzzy soft mapping (φ,ψ) is closed. □

Definition 3.11. A family Ψ of fuzzy soft sets has the finite intersection property if the intersection of the members of each finite subfamily of Ψ is not the null fuzzy soft set.

Theorem 3.12. *A fuzzy soft topological space is compact if and only if each family of fuzzy soft closed sets with the finite intersection property has a non null intersection.*

Proof. $\Rightarrow$: Let Ψ be an arbitrary family of fuzzy soft closed subsets with finite intersection property. We claim that $\cap_{i\in I}\{(f_i, A) : (f_i, A) \in \Psi\}$ is non null. Consider otherwise, i.e., $\cap_{i\in I}(f_i, A) = \tilde{0}_E$. Then, $(\cap_{i\in I}(f_i, A))^c = \cup_{i\in I}(f_i, A)^c = \tilde{1}_E$. Since each (f_i, A) is closed, then the family $\{(f_i, A)^c : i \in I\}$ is an open cover of the fuzzy soft topological space. By compactness, there is a finite subset $J \subset I$ such that $\cup_{i\in J}(f_i, A)^c = \tilde{1}_E$. However, we have $X = (\cap_{i\in J}(f_i, A))^c$, so $\cap_{i\in J}(f_i, A) = \tilde{0}_E$ which contradicts the finite intersection property of Ψ.

$\Leftarrow$: Suppose we have a fuzzy soft topological space such that each family of fuzzy soft closed sets with the finite intersection property has a non null intersection. To prove that it is compact, let $\{(f_i, A) : i \in I\}$ be a family of fuzzy soft open cover. We claim that this family contains a finite subfamily that also covers the fuzzy soft topological space. Assume that $\tilde{1}_E \neq \cup_{i\in J}(f_i, A)$ for any finite $J \subset I$. Then $\cap_{i\in J}(f_i, A)^c = (\cup_{i\in J}(f_i, A))^c \neq \tilde{0}_E$ since J is finite. Then, the family $\{(f_i, A)^c : i \in I\}$ has finite intersection property. By the hypothesis, $\cap_{i\in I}(f_i, A)^c \neq \tilde{0}_E$ and we have $\cup_{i\in I}(f_i, A) \neq \tilde{1}_E$. This is a contradiction. Thus, the fuzzy soft topological space is compact. □

4. Conclusion

In this work, we introduced fuzzy soft compactness and gave basic definitions and theorems of this concept. Also we introduced fuzzy soft cover, fuzzy soft subcover, fuzzy soft open cover. The results in this work can be extended to the product of fuzzy soft topological spaces and its compactness properties.

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