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Soft nearly C-compactness in fuzzy soft topological spaces

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Abstract. In this paper, we introduce fuzzy soft nearly C-compactness in fuzzy soft topological spaces and some properties of this space. Also we introduce soft almost regular, soft mildly normal and discuss some of their properties.

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1. Introduction

There are many theories like theory of probability, theory of fuzzy sets, theory of intuitionistic fuzzy sets, theory of rough sets etc. which can be considered as mathematical tools for dealing with uncertain data, obtained in various fields of engineering, physics, computer science, economics, social science, medical science, and of many other diverse fields. But all these theories have their own difficulties. The most appropriate theory for dealing with uncertainties is the theory of fuzzy sets, introduced by L.A. Zadeh [24] in 1965. This theory brought a paradigmatic change in mathematics. But there exists difficulty, how to set the membership function in each particular case. The theory of intuitionistic fuzzy sets is a more generalized concept than the theory of fuzzy sets, but this theory has the same difficulties. All the above mentioned theories are successful to some extent in dealing with problems arising due to vagueness present in the real world. But there are also cases where these theories failed to give satisfactory results, possibly due to inadequacy of the parameterization tool in them. As a necessary supplement to the existing mathematical tools for handling uncertainty, in 1999, Molodtsov [11] initiated the theory of soft sets as a new mathematical tool to deal with uncertainties while modelling the problems in engineering, physics, computer science, economics, social sciences, and medical sciences. In [12], Molodtsov et al. successfully applied soft sets in directions such

as smoothness of functions, game theory, operations research, Riemann integration, Perron integration, probability, and theory of measurement. Maji et al. [7] gave the first practical application of soft sets in decision-making problems. In 2003, Maji et al. [8] defined and studied several basic notions of the soft set theory. Also Çağman et al. [1] studied several basic notions of the soft set theory. In 2005, Pei and Miao [18] and Chen [4] improved the work of Maji et al. [7, 8]. Some properties of soft topology studied by Hussai and Ahmed [5] and Tanay et al. [22]. In 1968, C. L. Chang [3] introduced fuzzy topological space and in 2011, subsequently Çağman et al. [2] and Shabir et al. [20] introduced fuzzy soft topological spaces and they defined basic notions of soft topological spaces such as soft open and closed sets, soft subspace, soft closure, soft nbd of a point, soft T_i spaces, $i = 1, 2, 3, 4$, soft regular spaces, and soft normal spaces and established their several properties. More details on soft topological spaces we refer to [10, 16, 23]. In 2012, Mahanta et al. [6], Neog et al. [14] and Ray et al. [19] introduced fuzzy soft topological spaces in different direction.
The nearly C-compact spaces introduced by Sharma et al. [21]. In [17] Palanichetty and Balasubramanian introduced fuzzy nearly C-compactness in fuzzy topological spaces. In this paper, we define and study soft nearly C-compactness in fuzzy soft topological spaces. We establish some interesting properties of this notion.

2. Preliminary results

In this section we recall some basic concepts and definitions regarding fuzzy soft sets and fuzzy soft topological space.

Definition 2.1 ([9])**.** Let U be an initial universe and F be a set of parameters. Let $\tilde{P}(U)$ denote the power set of U and A be a non-empty subset of F. A pair (F, A) is called a fuzzy soft set over U where $F : A \to \tilde{P}(U)$ is a mapping from A into $\tilde{P}(U)$.

Definition 2.2 ([11])**.** F_E is called a soft set over U if and only if F is a mapping of E into the set of all subsets of the set U.

In other words, the soft set is a parameterized family of subsets of the set U. Every set $F(\epsilon)$, $\epsilon \tilde{\in} E$, from this family may be considered as the set of ϵ-elements of the soft set F_E, or as the set of ϵ-approximate elements of the soft set.

Definition 2.3 ([19])**.** A fuzzy soft topology τ on (U, E) is a family of fuzzy soft sets over (U, E) satisfying the following properties:

(i) $\tilde{\phi}, \tilde{E} \tilde{\in} \tau$,
(ii) if $F_A, G_B \tilde{\in} \tau$, then $F_A \tilde{\cap} G_B \tilde{\in} \tau$,
(iii) if $F_{A_\alpha} \tilde{\in} \tau$, for all $\alpha \tilde{\in} \Delta$ an index set, then $\bigcup_{\alpha \in \Delta} F_{A_\alpha} \tilde{\in} \tau$.

Definition 2.4 ([22])**.** A fuzzy soft set F_A in a fuzzy soft topological space (U, E, τ) is a neighborhood of a fuzzy soft set G_B if and only if there exists an open fuzzy soft set H_C i.e. $H_C \tilde{\in} \tau$ such that $G_B \tilde{\subseteq} H_C \tilde{\subseteq} F_A$.

Definition 2.5 ([22])**.** Let (U, E, τ_1) and (U, E, τ_2) be two fuzzy soft topological spaces. If each $F_A \tilde{\in} \tau_1$ is in τ_2, then τ_2 is called fuzzy soft finer than τ_1, or τ_1 is fuzzy soft coarser than τ_2.

Definition 2.6 ([14])**.** The fuzzy soft set F_A over (U, E) is called a fuzzy soft point in (U, E) denoted by $e(F_A)$, if for the element $e\tilde{\in}A, F(e) \neq \bar{0}$ and $F(e^{'}) = \bar{0}$ for all $e^{'}\tilde{\in}A - \{e\}$.

Definition 2.7 ([14])**.** Let (U, E, τ) be a fuzzy soft topological space. Let F_A be a fuzzy soft set over (U, E). The fuzzy soft closure of F_A is defined as the intersection of all fuzzy soft closed sets which contained F_A and is denoted by $cl(F_A)$ or $\bar{F_A}$. We write

$$\text{cl}(F_A) = \tilde{\bigcap}\{G_B : G_B \text{ is fuzzy soft closed and } F_A\tilde{\subseteq}G_B\}.$$

Definition 2.8 ([14])**.** Let (U, E, τ) be a fuzzy soft topological space. Let F_A be a fuzzy soft set over (U, E). The fuzzy soft interior of F_A is defined as the union of all fuzzy soft open sets which contained F_A and is denoted by $int(F_A)$ or F_A°. We write

$$\text{int}(F_A) = \tilde{\cup}\{G_B : G_B \text{ is fuzzy soft closed and } G_B\tilde{\subseteq}F_A\}.$$

Definition 2.9 ([14])**.** A fuzzy soft set F_A in a fuzzy soft topological space (U, E, τ) is a fuzzy soft neighborhood of the fuzzy soft point $e(G_B)\tilde{\in}(U, E)$ if there is an open fuzzy soft set H_C such that $e(G_B)\tilde{\in}H_C\tilde{\subseteq}F_A$.

Definition 2.10 ([13])**.** A fuzzy soft set F_A in a fuzzy soft topological space (U, E, τ) is called a fuzzy soft regularly open set if and only if $int(cl(F_A)) = F_A$.

Definition 2.11 ([13])**.** A fuzzy soft set F_A in a fuzzy soft topological space (U, E, τ) is called a fuzzy soft regularly closed set if and only if $cl(int(F_A)) = F_A$.

Definition 2.12 ([15])**.** A family ψ of fuzzy soft sets is a cover of a fuzzy soft set F_A if $F_A\tilde{\subseteq}\bigcup_{i=1}^{n}\{F_{A_i}; F_{A_i}\tilde{\in}\psi\}$. 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 2.13 ([15])**.** A fuzzy soft set F_A in a fuzzy soft topological space (U, E, τ) is called a fuzzy soft compact if each fuzzy soft open cover of F_A has a finite subcover. Also fuzzy soft topological space (U, E, τ) is called soft compact if each fuzzy soft open cover of $\tilde{E}$ has a finite subcover.

3. Fuzzy soft nearly C-compactness in fuzzy soft topological spaces

Definition 3.1. Let (U, E, τ) be fuzzy soft topological space. Then (U, E, τ) is said to be fuzzy soft nearly C-compact if given a fuzzy soft regular closed set F_A on (U, E) and an fuzzy soft open cover ψ of F_A there exists a finite subfamily $\{F_{A_i}; i = 1, 2, 3, ..., n\}$ of ψ such that $F_A\tilde{\subseteq}\bigcup_{i=1}^{n}\text{cl}(F_{A_i})$.

Proposition 3.2. *In a fuzzy soft topological space (U, E, τ) the following are equivalent:*

(1) *U is fuzzy soft nearly C-compact,*

(2) *For each fuzzy soft regularly closed set F_A of (U, E) and each fuzzy soft regular open cover ψ of F_A, there exists a finite subfamily $\{F_{A_i}; i = 1, 2, 3, ..., n\}$ of ψ such that $F_A\tilde{\subseteq}\bigcup_{i=1}^{n} cl(F_{A_i})$.*

(3) *For each fuzzy soft regularly closed set F_A of (U, E) and for each family $\xi = \{G_{A_\alpha}\}_{\alpha\tilde{\in}\Delta}$ of non empty fuzzy soft regularly closed sets such that $\bigcap\xi\bigcap F_A = \tilde{\phi}$, there*

exists a finite subfamily $\{G_{A_i}; i = 1, 2, 3, ..., n\}$ *of* ξ *such that* $\bigcap_{i=1}^{n} int(G_{A_i}) \bigcap F_A = \tilde{\phi}$.

(4) *For each fuzzy soft regularly closed set* F_A *of* (U, E) *and for each family* $\xi = \{G_{A_\alpha}\}_{\alpha \tilde{\in} \Delta}$ *of fuzzy soft regularly closed sets, if each finite subfamily* $\{G_{A_i}; i = 1, 2, 3, ..., n\}$ *of* ξ *we have* $\bigcap_{i=1}^{n} int(G_{A_i}) \bigcap F_A \neq \tilde{\phi}$ *then* $\bigcap \xi \bigcap F_A \neq \tilde{\phi}$.

Proof. (1)⇒(2): Obvious.

(2)⇒(1): Suppose (2) holds. Let $\psi = \{F_{A_i}; i = 1, 2, 3, ..., n\}$ be fuzzy soft open cover of F_A. Then $cl(int(F_{A_i}))$ is a fuzzy soft regular open cover of F_A and there exists a finite subfamily $\{cl(int(F_{A_i})); i = 1, 2, 3, ..., n\}$ such that

$$F_A \tilde{\subseteq} \bigcup_{i=1}^{n} \mathrm{cl}(cl(int(F_{A_i}))).$$

Thus for each i, $cl(cl(int(F_{Ai}))) = cl(F_{A_i})$. So $F_A \tilde{\subseteq} cl(F_{A_i})$. Hence U is nearly soft C-compact.

(2)⇒(3): Let $\xi = \{G_{A_\alpha}\}_{\alpha \tilde{\in} \Delta}$ be a family of fuzzy soft regularly closed sets of the soft topological space (U, E, τ) such that $\bigcap \xi \bigcap F_A = \tilde{\phi}$ for each soft regularly closed set F_A of (U, E). Then $\zeta = \{G^c_{A_\alpha}\}_{\alpha \tilde{\in} \Delta}$ is a family of soft closed sets of (U, E) covering the regularly soft closed set F_A. Thus there exists a finite subfamily $\{F_{A_i} = G^c_{A_i}; i = 1, 2..n\}$ of ξ such that

$$F_A \tilde{\subseteq} \bigcup_{i=1}^{n} \mathrm{cl}(F_{A_i}).$$

Now for each i, we have

$$int(G_{A_i}) = int(F^c_{A_i}) = int(\tilde{E} - F_{A_i}) = \tilde{E} - cl(\tilde{E} - (\tilde{E} - F_{A_i})) = \tilde{E} - cl(F_{A_i}).$$

So $\bigcap_{i=1}^{n} \mathrm{int}(G_{A_i}) = \tilde{E} - \bigcup \mathrm{cl} F_{A_i} \tilde{\subseteq} \tilde{E} - F_A$, i.e., $\bigcap_{i=1}^{n} \mathrm{int}(G_{A_i}) \bigcap F_A = \tilde{\phi}$.

(3)⇒(2): Let $\psi = \{F_{A_i}; i = 1, 2, 3, ..., n\}$ be a fuzzy soft regular open cover of the soft regularly closed set F_A of the soft topological space (U, E, τ). Since $F_A \tilde{\subseteq} \bigcup_{i=1}^{n} F_{A_i}$, we will shows that $\bigcap_{i=1}^{n} F^c_{A_i} \bigcap F_A = \tilde{\phi}$.
Since $F^c_{A_i}$ is a family of soft regularly closed sets satiesfying (3), there exists a finite subfamily $F^c_{A_i}$ such that

$$\bigcap_{i=1}^{n} \mathrm{int}(F^c_{A_i}) = \tilde{\phi}.$$

Thus $F_A \tilde{\subseteq} \bigcup_{i=1}^{n} \{\tilde{E} - \mathrm{int}(\tilde{E} - F_{A_i})\}$. Now for each i,

$$int(\tilde{E} - F_{A_i}) = \tilde{E} - cl(\tilde{E} - (\tilde{E} - F_{A_i})) = \tilde{E} - cl(F_{A_i}).$$

So $F_A \tilde{\subseteq} \bigcup_{i=1}^{n} \mathrm{cl}(F_{A_i})$.

(3)⇔(4): It is Obvious. □

Proposition 3.3. *Every soft regularly closed subset of a nearly* C*-compact soft space* (U, E, τ) *is nearly* C*-compact.*

Proof. Obvious □

Proposition 3.4. *For any fuzzy soft topological space (U, E, τ) the following are equivalent:*

(1) *U is fuzzy soft nearly C-compact,*

(2) *if F_A is a proper fuzzy soft regular closed set and φ is a family of fuzzy soft regular closed sets of (U, E) such that $F_A \tilde{\subseteq} (\tilde{E} - \bigcap_{i=1}^{n} F_{A_i})$ then there exists a finite number of elements φ say $F_{A_1}, F_{A_2}, ..., F_{A_n}$ such that $F_A \tilde{\subseteq} (\tilde{E} - \bigcap_{i=1}^{n} int(F_{A_i}))$.*

Proof. (1)⇒(2): Let U be fuzzy soft nearly C-compact and let F_A be a proper fuzzy soft regular closed set. Let φ be a family of fuzzy soft regular closed sets of (U, E) such that $F_A \tilde{\subseteq} (\tilde{E} - \bigcap_{i=1}^{n} F_{A_i}) = \bigcup_{i=1}^{n} F^c_{A_i}$. Then clearly $\zeta = \{F^c_{A_\alpha}\}_{\alpha \tilde{\in} \Delta}$ is a fuzzy soft regular open cover of F_A. Thus from (1), there exists a finite number of elements (say) $F_{A_1}, F_{A_2}, ..., F_{A_n}$ such that $F_A \tilde{\subseteq} \bigcup_{i=1}^{n} \text{cl}(F_{A_i}))$. So $\bigcap_{i=1}^{n} \text{int}(F_{A_i})) = (\tilde{E} - \bigcup_{i=1}^{n} \text{cl}(F_{A_i})) \tilde{\subseteq} (\tilde{E} - F_A)$. Hence $F_A \tilde{\subseteq} (\tilde{E} - \bigcap_{i=1}^{n} \text{int}(F_{A_i}))$.

(2)⇒(1) Let φ be a family of fuzzy soft regular open sets of (U, E) such that $F_A \tilde{\subseteq} \bigcap_{i=1}^{n} (F_{A_i})$. Then $\zeta = \{F^C_{A_i}; i = 1, 2, 3, ..., n\}$ is a family of fuzzy soft regular closed sets of (U, E) such that

$$F_A \tilde{\subseteq} \bigcup_{i=1}^{n} (F_{A_i}) = \bigcup_{i=1}^{n} [\tilde{E} - F^c_{A_i}] = \tilde{E} - \bigcap_{i=1}^{n} F^c_{A_i}.$$

Thus by (2), there exists a finite number of elements, say $F^c_{A_1}, F^c_{A_2}, ..., F^c_{A_n}$ such that

$$F_A \tilde{\subseteq} (\tilde{E} - \bigcap_{i=1}^{n} \text{int}(F^c_{A_i})) = \bigcup_{i=1}^{n} [\tilde{E} - \text{int}(F^c_{A_i}))] = \bigcup_{i=1}^{n} \text{cl}(F_{A_i})).$$

This completes the proof of the result. □

Definition 3.5. Let (U, E, τ) be a fuzzy soft topological space. This soft space is said to be a soft almost regular if for every soft regularly closed set F_A and a soft point $e(X) \notin F_A$ there exist soft open sets L_A and M_A such that $F_A \tilde{\subseteq} L_A$, $e(X) \tilde{\in} M_A$ and $L_A \tilde{\cap} M_A = \tilde{\phi}$. or equivalently, for every soft regularly closed set F_A and each soft point $e(X) \tilde{\notin} F_A$, there exist soft open sets L_A and M_A such that $F_A \tilde{\subseteq} M_A$, $e(X) \tilde{\in} L_A$ and $cl(L_A) \tilde{\cap} cl(M_A) = \tilde{\phi}$.

Definition 3.6. Let (U, E, τ) be a fuzzy soft topological space. This soft space is said to be a soft mildly normal if for every pair oif disjoint soft regularly closed sets P_A and Q_A of (U, E, τ) there exist disjoint soft open sets L_A and M_A such that $P_A \tilde{\subseteq} L_A, Q_A \tilde{\subseteq} M_A$.

Proposition 3.7. *In a fuzzy soft topological (U, E, τ), every soft almost regular, soft nearly C-copmpact space is mildly normal.*

Proof. Let (U, E, τ) be a fuzzy soft topological space. Let F_A and G_A be disjoint soft regularly closed subsets of a soft almost regular and soft nearly C-compact space of (U, E, τ). Since (U, E, τ) is soft almost regular therefore for each $e(X) \tilde{\in} F_A$ there exist soft open sets L_A and M_A such that $e(X) \tilde{\in} L^*_A$, $G_A \tilde{\subseteq} M^*_A$ and $cl(L^*_A) \tilde{\cap} cl(M^*_A) = \tilde{\phi}$. Thus the family $\{L^*_A : e(X) \tilde{\in} F_A\}$ is an open covering of the soft regularly closed set F_A. Since (U, E, τ) is soft nearly C-compact then there exists a finite soft subfamily $\{L_{A_i}; i = 1, 2, 3, ..., n\}$ such that $F_A \tilde{\subseteq} \bigcup_{i=1}^{n} \text{cl}(L_{A_i}))$.

Suppose $M = \bigcap_{i=1}^{n} M_{A_i}$ and $N = (\tilde{E} - \bigcap_{i=1}^{n} \mathrm{cl}(M_{A_i}))$. Then $F_A \tilde{\subseteq} \bigcup_{i=1}^{n} \mathrm{cl}(L_{A_i})) \tilde{\subseteq} (\tilde{E} - \bigcap_{i=1}^{n} \mathrm{cl}(M_{A_i})) = N$. Thus $G_A \tilde{\subseteq} M$ and $M \tilde{\cap} N = \tilde{\phi}$. So (U, E, τ) is soft mildly normal. □

Proposition 3.8. *Let (U, E, τ) be fuzzy soft topological space. If F_A is a soft regularly closed subset of a soft almost regular, soft nearly C-compact spaces of (U, E, τ) and G_A is a soft regularly open set containing F_A. Then there exists a soft regular open set L_A such that $F_A \tilde{\subseteq} L_A \tilde{\subseteq} cl(L_A) \tilde{\subseteq} G_A$.*

Proof. Since G_A is a soft regularly open set, G_A^c is soft regularly closed set and $F_A \tilde{\cap} G_A^c = \tilde{\phi}$. Then by Proposition 3.7, there exist soft open sets P_A and Q_A such that $F_A \tilde{\subseteq} P_A, G_A^c \tilde{\subseteq} Q_A$ and $P_A \tilde{\cap} Q_A = \tilde{\phi}$. Also $cl(P_A) \tilde{\cap} Q_A = \tilde{\phi}$. Thus $cl(P_A) \tilde{\subseteq} Q_A^c \tilde{\subseteq} G_A$. So $F_A \tilde{\subseteq} P_A \tilde{\subseteq} cl(P_A) \tilde{\subseteq} G_A$. Hence $F_A \tilde{\subseteq} P_A \tilde{\subseteq} cl(int(P_A)) \tilde{\subseteq} cl(P_A) \tilde{\subseteq} G_A$.

Suppose $cl(int(P_A)) = L_A$. Then L_A is soft regularly open and $cl(cl(int(P_A))) = cl(P_A) = cl(L_A)$. Thus $F_A \tilde{\subseteq} L_A \tilde{\subseteq} cl(L_A) \tilde{\subseteq} G_A$. □

Proposition 3.9. *Let (U, E, τ) be fuzzy soft topological space. Let F_A and G_A be two disjoint soft regularly closed subsets of a soft almost regular, soft nearly C-compact space (U, E, τ). Then there exist soft open sets L_A and M_A such that $F_A \tilde{\subseteq} L_A, G_A \tilde{\subseteq} M_A$ and $cl(L_A) \tilde{\cap} cl(M_A) = \tilde{\phi}$.*

Proof. Here G_A^c is a soft regularly open set containing the soft regularly closed set F_A. Then by proposition 3.8, there exists a soft regularly open set P_A such that $F_A \tilde{\subseteq} P_A \tilde{\subseteq} cl(P_A) \tilde{\subseteq} G_A^c$. Since P_A is a soft regularly open set containing the soft regularly closed set F_A, there exists a soft regularly open set Q_A such that

$$F_A \tilde{\subseteq} Q_A \tilde{\subseteq} cl(Q_A) \tilde{\subseteq} P_A.$$

If $Q_A = L_A$ and $(Cl(P_A))^c = M_A$, then clearly $F_A \tilde{\subseteq} L_A, G_A \tilde{\subseteq} M_A$
and $cl(L_A) \tilde{\cap} cl(M_A) = \tilde{\phi}$. □

4. Competing interests

The authors declare that they have no competing interests.

5. Authors contributions

Each of the authors contributed to each part of this work equally and read and approved the final version of the manuscript.

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