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On the Pasting Lemma on a Fuzzy Soft Topological Space with Mixed Structure

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Abstract
In this paper, we define the notion of a (υ_1, υ_2)-generalized closed fuzzy soft set (shorlty, a (υ_1, υ_2)-g-closed fuzzy soft set) on a fuzzy soft topological space. Using this notion, we investigate some properties of a (υ_1, υ_2)-g-closed fuzzy soft set and prove a new version of the "Pasting Lemma" with a mixed structure.

Keywords: *Pasting lemma; Fuzzy soft topological space; (υ_1, υ_2)-g-closed fuzzy soft set; Mixed structure.*

AMS Subject Classification (2020): *Primary: 54A40 ; Secondary: 06D72; 54C10; 54A05.*

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1. Introduction and Motivation

Soft set theory was introduced as a new approach to the mathematical tool for coping with encountered problems in different sciences [18]. After then, in [17], the notion of a fuzzy soft set was presented combined with the notions of a soft set [18] and a fuzzy set [28] as a generalization of fuzzy set theory. Using this new theory, some topological concepts and their basic properties were studied via different approaches (for example, see [3, 8, 9, 16, 17, 20, 22, 26, 27] and the references therein). On the other hand, some applications of the fuzzy soft set theory were given to other sciences as an another important approach (see [4, 10, 12, 13, 15, 21, 24]).

Recently, some topological notions and properties have been generalized using the mixed structure on various generalized topological spaces such as soft topological space, generalized topological space etc. (see [1, 2, 7, 23]). One of the important topological notions is the pasting lemma for continuous functions. For example, this notion has an important role in algebraic topology. Many researchers have studied on various versions of the pasting lemma with different aspects (see [5, 6, 11, 14, 25] and the references therein for more details).

In this paper, we focus on the pasting lemma on a fuzzy soft topological space for mixed g-fuzzy soft continuous functions. To do this, we define the concept of a (υ_1, υ_2)-g-closed fuzzy soft set with a mixed structure. We investigate some properties of this new notion with some necessary examples. Then using the notion of a (υ_1, υ_2)-g-closed fuzzy soft set, we introduce the mixed g-fuzzy soft continuity on a fuzzy soft topological space. Finally, we prove a new version of the pasting lemma with regard to the mixed g-fuzzy soft continuity.

2. Preliminaries

In this section, we recall some basic concepts related to fuzzy soft set theory. Throughout this paper, we assume that U is an initial universal set, E is a nonempty set of parameters and $A, B \subseteq E$.

Definition 2.1. [28] A fuzzy set F on U is a mapping $F : U \to I$. The value $F(u)$ represents the degree of membership of $u \in U$ in the fuzzy set F for $u \in U$.

Let I^U denotes the family of all fuzzy sets on U. If $F, G \in I^U$ then some basic set operations are given in [28] as follows:

(i) $F \leq G \Leftrightarrow F(u) \leq G(u)$ for all $u \in U$.

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(ii) $F = G \Leftrightarrow F(u) = G(u)$ for all $u \in U$.
(iii) $H = F \vee G \Leftrightarrow H(u) = F(u) \vee G(u)$ for all $u \in U$.
(iv) $K = F \wedge G \Leftrightarrow K(u) = F(u) \wedge G(u)$ for all $u \in U$.
(v) $C = F^c \Leftrightarrow C(u) = 1 - F(u)$ for all $u \in U$.

Definition 2.2. [17] A pair (α, A), denoted by α_A, is called a fuzzy soft set over U, where $\alpha : A \to I^U$ is a function. The family of all fuzzy soft sets over U denoted by $FSS(U)_E$.

Definition 2.3. [3, 17, 27] Let $\alpha_A, \beta_A \in FSS(U)_E$. Then the followings hold:
(i) The fuzzy soft set α_A is called a null fuzzy soft set if $\alpha(e) = 0_U$ for each $e \in A$. It is denoted by $\widetilde{\emptyset}$.
(ii) The fuzzy soft set α_A is called an absolute fuzzy soft set if $\alpha(e) = 1_U$ for each $e \in A$. It is denoted by $\widetilde{U}$.
(iii) α_A is a fuzzy soft subset of β_A if $\alpha(e) \leq \beta(e)$ for each $e \in A$. It is denoted by $\alpha_A \sqsubseteq \beta_A$.
(iv) α_A and β_A are equal if $\alpha_A \sqsubseteq \beta_A$ and $\beta_A \sqsubseteq \alpha_A$. It is denoted by $\alpha_A = \beta_A$.
(v) The complement of a fuzzy soft set α_A is denoted by α_A^c, where $\alpha^c : A \to I^U$ is a mapping defined by

$$\alpha^c(e) = 1_U - \alpha(e),$$

for all $e \in A$. Also, we have $(\alpha_A^c)^c = \alpha_A$.
(vi) The union of α_A and β_A is a fuzzy soft set γ_A defined by

$$\gamma(e) = \alpha(e) \vee \beta(e),$$

for all $e \in A$. It is denoted by $\gamma_A = \alpha_A \sqcup \beta_A$.
(vii) The intersection of α_A and β_A is a fuzzy soft set γ_A defined by

$$\gamma(e) = \alpha(e) \wedge \beta(e),$$

for all $e \in A$. It is denoted by $\gamma_A = \alpha_A \sqcap \beta_A$.

Definition 2.4. [3] Let I be an arbitrary index set and $\{\alpha_{i_A}\}_{i \in I}$ be a family of fuzzy soft sets on U. Then we have
(i) The union of these fuzzy soft sets is the fuzzy soft set γ_A defined by

$$\gamma(e) = \vee_{i \in I} \alpha_i(e),$$

for all $e \in A$. It is denoted by $\gamma_A = \sqcup_{i \in I} \alpha_{i_A}$.
(ii) The intersection of these fuzzy soft sets is the fuzzy soft set γ_A defined by

$$\gamma(e) = \wedge_{i \in I} \alpha_i(e),$$

for all $e \in A$. It is denoted by $\gamma_A = \sqcap_{i \in I} \alpha_{i_A}$.

Definition 2.5. [22] Let υ be the collection of fuzzy soft sets on U. Then υ is called a fuzzy soft topology on U if the following conditions hold:
$(FS - t_1)$ $\widetilde{\emptyset}, \widetilde{U} \in \upsilon$,
$(FS - t_2)$ The union of any number of fuzzy soft sets in υ belongs to υ,
$(FS - t_3)$ The intersection of any two fuzzy soft sets in υ belongs to υ.
The pair (U, υ) is called a fuzzy soft topological space. The members of υ are called fuzzy soft open sets. Also a fuzzy soft set α_A is called a fuzzy soft closed set if $\alpha_A^c \in \upsilon$.

Definition 2.6. [27] Let (U, υ) be a fuzzy soft topological space and $\alpha_A \in FSS(U)_E$. The fuzzy soft closure of α_A, denoted by $\upsilon - Fcl(\alpha_A)$ (or $Fcl(\alpha_A)$, $\overline{\alpha_A}$), is the intersection of all fuzzy soft closed supersets of α_A. We note that $\upsilon - Fcl(\alpha_A)$ is the smallest fuzzy soft closed set over U which contains α_A and $\upsilon - Fcl(\alpha_A)$ is closed.

Theorem 2.1. *[27] Let (U, υ) be a fuzzy soft topological space and $\alpha_A, \beta_B \in FSS(U)_E$. Then the followings hold*:
(i) $\upsilon - Fcl(\widetilde{\emptyset}) = \widetilde{\emptyset}$ *and* $\upsilon - Fcl(\widetilde{U}) = \widetilde{U}$.
(ii) $\alpha_A \sqsubseteq \upsilon - Fcl(\alpha_A)$.
(iii) $\upsilon - Fcl\left(\upsilon - Fcl(\alpha_A)\right) = \upsilon - Fcl(\alpha_A)$.
(iv) *If* $\alpha_A \sqsubseteq \beta_B$ *then* $\upsilon - Fcl(\alpha_A) \sqsubseteq \upsilon - Fcl(\beta_B)$.
(v) α_A *is a fuzzy soft closed set if and only if* $\alpha_A = \upsilon - Fcl(\alpha_A)$.
(vi) $\upsilon - Fcl(\alpha_A \sqcup \beta_B) = \upsilon - Fcl(\alpha_A) \sqcup \upsilon - Fcl(\beta_B)$.

Definition 2.7. [22] Let (U, υ) be a fuzzy soft topological space and $V \subseteq U$. Let γ_E^V be a fuzzy soft set over V such that $\gamma_E^V : E \to I^V$ defined as $\gamma_E^V(e) = \mu^e_{\gamma_E^V}$ with

$$\mu^e_{\gamma_E^V}(u) = \begin{cases} 1 & , \quad u \in V \\ 0 & , \quad u \notin V \end{cases} .$$

Let $\upsilon_V = \{\gamma_E^V \sqcap \beta_B : \beta_B \in \upsilon\}$, then the fuzzy soft topology υ_V on V is called fuzzy soft subspace topology for V and (V, υ_V) is called fuzzy soft subspace of (U, υ).

Theorem 2.2. *[16] The fuzzy soft set γ_E is fuzzy soft closed in a subspace $(\beta_E, \upsilon_{\beta_E})$ of (α_E, υ) if and only if $\gamma_E = \eta_E \sqcap \beta_E$ for some fuzzy soft closed set η_E in α_E.*

Theorem 2.3. *[16] The fuzzy soft closure of a fuzzy soft set γ_E in a subspace $(\beta_E, \upsilon_{\beta_E})$ of (α_E, υ) equals $\upsilon - Fcl(\gamma_E) \sqcap \beta_E$.*

Definition 2.8. [27] Let $FSS(U)_E$ and $FSS(V)_{E'}$ be families of fuzzy soft sets over U and V, respectively. Let $u : U \to V$ and $p : E \to E'$ be mappings. Then the map f_{pu} is called a fuzzy soft mapping from U to V and denoted by $f_{pu} : FSS(U)_E \to FSS(V)_{E'}$ such that

(i) If $\alpha_A \in FSS(U)_E$, then the image of α_A under the fuzzy soft mapping f_{pu} is the fuzzy soft set over V defined by $f_{pu}(\alpha_A)$, where

$$f_{pu}(\alpha_A)(e')(v) = \begin{cases} \bigvee_{u(u^*)=v} \left[\bigvee_{p(e)=e'} (\alpha_A(e)) \right](u^*) & \text{if} \quad u^* \in u^{-1}(v) \\ 0 & \text{otherwise} \end{cases} ,$$

for all $e' \in p(E)$ and all $v \in V$.

(ii) If $\beta_B \in FSS(V)_{E'}$, then the pre-image of β_B under the fuzzy soft mapping f_{pu} is the fuzzy soft set over U defined by $f_{pu}^{-1}(\beta_B)$, where

$$f_{pu}^{-1}(\beta_B)(e)(u^*) = \begin{cases} \beta_B(p(e))(u(u^*)) & \text{if} \quad p(e) \in B \\ 0 & \text{otherwise} \end{cases} ,$$

for all $e \in p^{-1}(E')$ and all $u^* \in U$.

3. A new version of the Pasting Lemma

In this section, we present a new version of the pasting lemma on a fuzzy soft topological space using the notion of a (υ_1, υ_2)-g-closed fuzzy soft set. To do this, we begin the following definition.

Definition 3.1. Let υ_1, υ_2 be two fuzzy soft topologies on U and $\alpha_A \in FSS(U)_E$. Then α_A is called a (υ_1, υ_2)-g-closed fuzzy soft set if $\upsilon_2 - Fcl(\alpha_A) \sqsubseteq \beta_A$ whenever $\alpha_A \sqsubseteq \beta_A$ and β_A is a fuzzy soft open set according to υ_1. The complement of a (υ_1, υ_2)-g-closed fuzzy soft set is called (υ_1, υ_2)-g-open fuzzy soft.

Example 3.1. Let $U = \{u_1, u_2, u_3\}$, $E = \{e_1, e_2\}$, $\upsilon_1 = \left\{\widetilde{\emptyset}, \widetilde{U}, \alpha_E\right\}$ and $\upsilon_2 = \left\{\widetilde{\emptyset}, \widetilde{U}\right\}$ where α_E is a fuzzy soft set on U defined as

$$\alpha_E = \left\{ \left(e_1, \left\{\frac{u_1}{0.4}, \frac{u_2}{0}, \frac{u_3}{0}\right\}\right), \left(e_2, \left\{\frac{u_1}{0}, \frac{u_2}{0.3}, \frac{u_3}{0}\right\}\right) \right\}.$$

Then the fuzzy soft set

$$\beta_E = \left\{ \left(e_1, \left\{\frac{u_1}{0.4}, \frac{u_2}{0.2}, \frac{u_3}{0}\right\}\right), \left(e_2, \left\{\frac{u_1}{0.1}, \frac{u_2}{0}, \frac{u_3}{0.7}\right\}\right) \right\}$$

is a (υ_1, υ_2)-g-closed fuzzy soft set.

We investigate some topological properties of a (υ_1, υ_2)-g-closed fuzzy soft set as in the following results.

Theorem 3.1. *Let υ_1, υ_2 be two fuzzy soft topologies on U such that $\upsilon_2 \subset \upsilon_1$ and $\alpha_A, \beta_A \in FSS(U)_E$. If $\beta_A \sqsubseteq \alpha_A \sqsubseteq \widetilde{U}$, β_A is a (υ_1, υ_2)-g-closed fuzzy soft set relative to α_A and α_A is a (υ_1, υ_2)-g-closed fuzzy soft set in U, then β_A is a (υ_1, υ_2)-g-closed fuzzy soft set in U.*

Proof. Let $\beta_A \sqsubseteq \gamma_A$ and γ_A be a fuzzy open soft set according to υ_1. Then we get

$$\beta_A \sqsubseteq \alpha_A \sqcap \gamma_A$$

and

$$\upsilon_{2_{\alpha_A}} - Fcl(\beta_A) \sqsubseteq \alpha_A \sqcap \gamma_A,$$

which follows that

$$\alpha_A \sqcap \upsilon_2 - Fcl(\beta_A) \sqsubseteq \alpha_A \sqcap \gamma_A$$

and

$$\alpha_A \sqsubseteq \gamma_A \sqcup [\upsilon_2 - Fcl(\beta_A)]^c .$$

Since α_A is a (υ_1, υ_2)-g-closed fuzzy soft set and $\upsilon_2 \subset \upsilon_1$, then we obtain

$$\upsilon_2 - Fcl(\alpha_A) \sqsubseteq \gamma_A \sqcup [\upsilon_2 - Fcl(\beta_A)]^c .$$

Hence we have

$$\upsilon_2 - Fcl(\beta_A) \sqsubseteq \upsilon_2 - Fcl(\alpha_A) \sqsubseteq \gamma_A \sqcup [\upsilon_2 - Fcl(\beta_A)]^c ,$$

whence

$$\upsilon_2 - Fcl(\beta_A) \sqsubseteq \gamma_A.$$

Consequently, β_A is a (υ_1, υ_2)-g-closed fuzzy soft set in U. □

Now we prove that the union of two (υ_1, υ_2)-g-closed fuzzy soft sets is a (υ_1, υ_2)-g-closed fuzzy soft set.

Theorem 3.2. *Let υ_1, υ_2 be two fuzzy soft topologies on U and $\alpha_A, \beta_A \in FSS(U)_E$. If α_A and β_A are two (υ_1, υ_2)-g-closed fuzzy soft sets, then $\alpha_A \sqcup \beta_A$ is (υ_1, υ_2)-g-closed fuzzy soft.*

Proof. If $\alpha_A \sqcup \beta_A \sqsubseteq \gamma_A$ and γ_A is a fuzzy open soft set according to υ_1, then we have

$$\upsilon_2 - Fcl(\alpha_A \sqcup \beta_A) = \upsilon_2 - Fcl(\alpha_A) \sqcup \upsilon_2 - Fcl(\beta_A) \sqsubseteq \gamma_A,$$

since α_A and β_A are two (υ_1, υ_2)-g-closed fuzzy soft sets. Therefore, $\alpha_A \sqcup \beta_A$ is (υ_1, υ_2)-g-closed fuzzy soft. □

In the following example, we see that the intersection of two (υ_1, υ_2)-g-closed fuzzy soft sets is not always a (υ_1, υ_2)-g-closed fuzzy soft set.

Example 3.2. Let $U = \{u_1, u_2, u_3\}$, $E = \{e_1, e_2\}$, $\upsilon_1 = \left\{\widetilde{\emptyset}, \widetilde{U}, \alpha_E\right\}$ and $\upsilon_2 = \left\{\widetilde{\emptyset}, \widetilde{U}\right\}$ where α_E is a fuzzy soft set on U defined as

$$\alpha_E = \left\{\left(e_1, \left\{\frac{u_1}{0.3}, \frac{u_2}{0}, \frac{u_3}{0}\right\}\right), \left(e_2, \left\{\frac{u_1}{0.3}, \frac{u_2}{0}, \frac{u_3}{0}\right\}\right)\right\}.$$

Then the fuzzy soft sets

$$\beta_E = \left\{\left(e_1, \left\{\frac{u_1}{0.3}, \frac{u_2}{0.4}, \frac{u_3}{0}\right\}\right), \left(e_2, \left\{\frac{u_1}{0.3}, \frac{u_2}{0}, \frac{u_3}{0.5}\right\}\right)\right\}$$

and

$$\gamma_E = \left\{\left(e_1, \left\{\frac{u_1}{0.3}, \frac{u_2}{0}, \frac{u_3}{0.7}\right\}\right), \left(e_2, \left\{\frac{u_1}{0.3}, \frac{u_2}{0.6}, \frac{u_3}{0}\right\}\right)\right\}$$

are two (υ_1, υ_2)-g-closed fuzzy soft sets. Also we obtain

$$\beta_E \sqcap \gamma_E = \left\{\left(e_1, \left\{\frac{u_1}{0.3}, \frac{u_2}{0}, \frac{u_3}{0}\right\}\right), \left(e_2, \left\{\frac{u_1}{0.3}, \frac{u_2}{0}, \frac{u_3}{0}\right\}\right)\right\},$$

which is not a (υ_1, υ_2)-g-closed fuzzy soft set.

Proposition 3.1. *Let υ_1, υ_2 be two fuzzy soft topologies on U such that $\upsilon_2 \subset \upsilon_1$ and $\alpha_A, \beta_A \in FSS(U)_E$. Assume that α_A is a (υ_1, υ_2)-g-closed fuzzy soft set and β_A is a fuzzy soft closed set relative to υ_2. Then $\alpha_A \sqcap \beta_A$ is a (υ_1, υ_2)-g-closed fuzzy soft set.*

Proof. Since β_A is a fuzzy soft closed set relative to υ_2, then $\alpha_A \sqcap \beta_A$ is a fuzzy soft closed set relative to υ_2 in α_A whence it is (υ_1, υ_2)-g-closed fuzzy soft. By Theorem 3.1, $\alpha_A \sqcap \beta_A$ is a (υ_1, υ_2)-g-closed fuzzy soft set in U. □

We introduce the notion of the mixed g-fuzzy soft continuity in the following definition.

Definition 3.2. Let U_1, U_2 be two initial universe sets, $A, B \subseteq E$ two sets of parameters, υ_1, υ_2 two fuzzy soft topologies on U_1 and υ a fuzzy soft topology on U_2. Suppose that $u : U_1 \to U_2$, $p : A \to B$ are two mappings and $f_{pu} : FSS(U_1)_A \to FSS(U_2)_B$ is a function. Then f_{pu} is said to be mixed g-fuzzy soft continuous if $f_{pu}^{-1}(\beta_A)$ is a (υ_1, υ_2)-g-closed fuzzy soft set for every fuzzy soft closed set β_A in U_2.

Finally, we prove a new version of the "Pasting Lemma" on a fuzzy soft topological space.

Theorem 3.3. (*Pasting Lemma*) *Let $\widetilde{U} = \widetilde{U_1} \sqcup \widetilde{U_2}$ be a fuzzy soft topological space with two fuzzy soft topologies υ_1, υ_2 and U_3 a fuzzy soft topological space with a fuzzy soft topology υ. Let $f_{p_1u_1} : FSS(U_1)_A \to FSS(U_3)_B$ and $f_{p_2u_2} : FSS(U_2)_A \to FSS(U_3)_B$ be two mixed g-fuzzy soft continuous mappings where $p_1 = p_2 : A \to B$, $u_1 : U_1 \to U_3$ and $u_2 : U_2 \to U_3$ are functions. Suppose that $\widetilde{U_1}$, $\widetilde{U_2}$ are two (υ_1, υ_2)-g-closed fuzzy soft sets and $\upsilon_2 \subset \upsilon_1$. If $u_1(u^*) = u_2(u^*)$ for every $u^* \in U_1 \cap U_2$, then $f_{p_1u_1}$ and $f_{p_2u_2}$ combine to give a mixed g-fuzzy soft continuous mapping $f_{pu} : FSS(U)_A \to FSS(U_3)_B$ defined by the functions $p = p_1 = p_2$, $u(u^*) = u_1(u^*)$ if $u^* \in U_1$ and $u(u^*) = u_2(u^*)$ if $u^* \in U_2$.*

Proof. Let β_A be a fuzzy soft closed set in U_3. Then we have

$$f_{pu}^{-1}(\beta_A) = f_{p_1u_1}^{-1}(\beta_A) \sqcup f_{p_2u_2}^{-1}(\beta_A).$$

By the mixed g-fuzzy continuity of $f_{p_1u_1}$, we obtain that $f_{p_1u_1}^{-1}(\beta_A)$ is a (υ_1, υ_2)-g-closed fuzzy soft set in U_1. By Theorem 3.1, $f_{p_1u_1}^{-1}(\beta_A)$ is a (υ_1, υ_2)-g-closed fuzzy soft set in U since $\widetilde{U_1}$ is (υ_1, υ_2)-g-closed fuzzy soft. Using the similar approach, we can easily see that $f_{p_2u_2}^{-1}(\beta_A)$ is a (υ_1, υ_2)-g-closed fuzzy soft set in U. By Theorem 3.2, $f_{pu}^{-1}(\beta_A)$ is a (υ_1, υ_2)-g-closed fuzzy soft set in U. Consequently, f_{pu} is a mixed g-fuzzy soft continuous mapping. □

4. Conclusion and Future Work

In this paper, a new version of the pasting lemma are presented on a fuzzy soft topological space. To do this, we have used two fuzzy soft topological spaces. Similarly, the notion of a fuzzy soft Bitopological space was introduced with two fuzzy soft topological spaces [19]. Therefore, this problem can be considered on fuzzy soft Bitopological spaces using the concepts given in [19]. On the other hand, some applications of the pasting lemma can be investigated to analytic continuation on the complex plane as a future work.

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