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 \((\upsilon_1, \upsilon_2)\)-generalized closed fuzzy soft set (shortly, a \((\upsilon_1, \upsilon_2)\)-g-closed fuzzy soft set) on a fuzzy soft topological space. Using this notion, we investigate some properties of a \((\upsilon_1, \upsilon_2)\)-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; \((\upsilon_1, \upsilon_2)\)-g-closed fuzzy soft set; Mixed structure.

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

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 \((\upsilon_1, \upsilon_2)\)-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 \((\upsilon_1, \upsilon_2)\)-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 \(F: U \rightarrow I\). 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:

\[(i) F \leq G \iff F(u) \leq G(u) \text{ for all } u \in U.\]
Definition 2.1. [17] A pair \((\alpha, A)\), denoted by \(\alpha_A\), is called a fuzzy soft set over \(U\), where \(\alpha : A \rightarrow I^U\) is a function. The family of all fuzzy soft sets over \(U\) denoted by \(FSS(U)_E\).

Definition 2.2. [3, 17, 27] Let \(\alpha, \beta \in FSS(U)_E\). Then the followings hold:

(i) The fuzzy soft set \(\alpha_A\) is a null fuzzy soft set if \(\alpha(e) = 0_U\) for each \(e \in A\). It is denoted by \(\emptyset\).

(ii) The fuzzy soft set \(\alpha_A\) is an absolute fuzzy soft set if \(\alpha(e) = 1_U\) for each \(e \in A\). It is denoted by \(\bar{U}\).

(iii) \(\alpha_A\) is a fuzzy soft subset of \(\beta_A\) if \(\alpha(e) \leq \beta(e)\) for each \(e \in A\). It is denoted by \(\alpha_A \subseteq \beta_A\).

(iv) \(\alpha_A\) and \(\beta_A\) are equal if \(\alpha_A \subseteq \beta_A\) and \(\beta_A \subseteq \alpha_A\). It is denoted by \(\alpha_A = \beta_A\).

(v) The complement of a fuzzy soft set \(\alpha_A\) is denoted by \(\alpha_A^c\), where \(\alpha_e : A \rightarrow I^U\) is a mapping defined by

\[
\alpha_A^c(e) = 1_U - \alpha(e),
\]

for all \(e \in A\). Also, we have \((\alpha_A^c)^c = \alpha_A^c\).

(vi) The union of \(\alpha_A\) and \(\beta_A\) is a fuzzy soft set \(\gamma_A\) defined by

\[
\gamma(e) = \alpha(e) \lor \beta(e),
\]

for all \(e \in A\). It is denoted by \(\gamma_A = \alpha_A \lor \beta_A\).

(vii) The intersection of \(\alpha_A\) and \(\beta_A\) is a fuzzy soft set \(\gamma_A\) defined by

\[
\gamma(e) = \alpha(e) \land \beta(e),
\]

for all \(e \in A\). It is denoted by \(\gamma_A = \alpha_A \land \beta_A\).

Definition 2.4. [3] Let \(I\) be an arbitrary index set and \(\{\alpha_i\}_{i \in I}\) 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 \(\gamma_A\) defined by

\[
\gamma(e) = \lor_{i \in I} \alpha_i(e),
\]

for all \(e \in A\). It is denoted by \(\gamma_A = \sqcup_{i \in I} \alpha_i\).

(ii) The intersection of these fuzzy soft sets is the fuzzy soft set \(\gamma_A\) defined by

\[
\gamma(e) = \land_{i \in I} \alpha_i(e),
\]

for all \(e \in A\). It is denoted by \(\gamma_A = \sqcap_{i \in I} \alpha_i\).

Definition 2.5. [22] Let \(v\) be the collection of fuzzy soft sets on \(U\). Then \(v\) is called a fuzzy soft topology on \(U\) if the following conditions hold:

\(FS - t_1\) \(\emptyset, U \in v,\)

\(FS - t_2\) The union of any number of fuzzy soft sets in \(v\) belongs to \(v,\)

\(FS - t_3\) The intersection of any two fuzzy soft sets in \(v\) belongs to \(v,\)

The pair \((U, v)\) is called a fuzzy soft topological space. The members of \(v\) are called fuzzy soft open sets. Also a fuzzy soft set \(\alpha_A\) is called a fuzzy soft closed set if \(\alpha_A^c \in v\).

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

Theorem 2.1. [27] Let \((U, v)\) be a fuzzy soft topological space and \(\alpha_A, \beta_B \in FSS(U)_E\). Then the followings hold:

(i) \(v - Fcl(\emptyset) = \emptyset\) and \(v - Fcl(U) = U\).

(ii) \(\alpha_A \subseteq v - Fcl(\alpha_A)\).

(iii) \(v - Fcl(v - Fcl(\alpha_A)) = v - Fcl(\alpha_A)\).

(iv) If \(\alpha_A \subseteq \beta_B\) then \(v - Fcl(\alpha_A) \subseteq v - Fcl(\beta_B)\).

(v) \(\alpha_A\) is a fuzzy soft closed set if and only if \(\alpha_A^c = v - Fcl(\alpha_A)\).

(vi) \(v - Fcl(\alpha_A \lor \beta_B) = v - Fcl(\alpha_A) \lor v - Fcl(\beta_B)\).
Definition 2.7. [22] Let \((U, v)\) be a fuzzy soft topological space and \(V \subseteq U\). Let \(\gamma^V_E : E \to I^V\) defined as \(\gamma^V_E(e) = \mu^V_{\gamma^V_E}\) with
\[
\mu^V_{\gamma^V_E}(u) = \begin{cases} 
1 & , u \in V \\
0 & , u \notin V 
\end{cases}
\]

Let \(\nu_V = \{\gamma^V \cap \beta_B : \beta_B \in \nu^V\}\), then the fuzzy soft topology \(\nu_V\) on \(V\) is called fuzzy soft subspace topology for \(V\) and \((V, \nu_V)\) is called fuzzy soft subspace of \((U, v)\).

Theorem 2.2. [16] The fuzzy soft set \(\gamma_E\) is fuzzy soft closed in a subspace \((\beta_E, v_{\beta_E})\) of \((\alpha_E, v)\) if and only if \(\gamma_E = \eta_E \cap \beta_E\) for some fuzzy soft closed set \(\eta_E\) in \(\alpha_E\).

Theorem 2.3. [16] The fuzzy soft closure of a fuzzy soft set \(\gamma_E\) in a subspace \((\beta_E, v_{\beta_E})\) of \((\alpha_E, v)\) equals \(v - \text{Fcl}(\gamma_E) \cap \beta_E\).

Definition 2.8. [27] Let \(\text{FSS}(U)_E\) and \(\text{FSS}(V)_{E'}\) 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 \(fp_u\) is called a fuzzy soft mapping from \(U\) to \(V\) and denoted by \(fp_u : \text{FSS}(U)_E \to \text{FSS}(V)_{E'}\) such that

(i) If \(\alpha_A \in \text{FSS}(U)_E\), then the image of \(\alpha_A\) under the fuzzy soft mapping \(fp_u\) is the fuzzy soft set over \(V\) defined by \(fp_u(\alpha_A)\), where
\[
fp_u(\alpha_A)(e')(v) = \bigvee_{u(u^*) = v} \left( \bigvee_{p(e) = e'} (\alpha_A(e)) (u^*) \right) \ 	ext{if} \ u^* \in u^{-1}(v),
\]
for all \(e' \in p(E)\) and all \(v \in V\).

(ii) If \(\beta_B \in \text{FSS}(V)_{E'}\), then the pre-image of \(\beta_B\) under the fuzzy soft mapping \(fp_u\) is the fuzzy soft set over \(U\) defined by \(fp_u^{-1}(\beta_B)\), where
\[
fp_u^{-1}(\beta_B)(e)(u^*) = \left\{ \begin{array}{ll}
\beta_B(p(e))(u(u^*)) & \text{if} \ p(e) \in B \\
0 & \text{otherwise}
\end{array} \right.
\]
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 \((v_1, v_2)\)-\(g\)-closed fuzzy soft set. To do this, we begin the following definition.

Definition 3.1. Let \(v_1, v_2\) be two fuzzy soft topologies on \(U\) and \(\alpha_A \in \text{FSS}(U)_E\). Then \(\alpha_A\) is called a \((v_1, v_2)\)-\(g\)-closed fuzzy soft set if \(v_2 - \text{Fcl}(\alpha_A) \subseteq \beta_A\) whenever \(\alpha_A \subseteq \beta_A\) and \(\beta_A\) is a fuzzy soft open set according to \(v_1\). The complement of a \((v_1, v_2)\)-\(g\)-closed fuzzy soft set is called \((v_1, v_2)\)-\(g\)-open fuzzy soft.

Example 3.1. Let \(U = \{u_1, u_2, u_3\}, E = \{e_1, e_2\}, v_1 = \{\emptyset, \bar{U}, \alpha_E\}\) and \(v_2 = \{\emptyset, \bar{U}\}\) where \(\alpha_E\) is a fuzzy soft set on \(U\) defined as
\[
\alpha_E = \left\{ e_1, \left\{ \begin{array}{ccc}
u_1 & u_2 & u_3 \\
0.4 & 0.2 & 0.3 \\
0 & 0 & 0 \end{array} \right\}, e_2, \left\{ \begin{array}{ccc}
u_1 & u_2 & u_3 \\
0.1 & u_2 & 0.7 \\
0 & 0.3 & 0 \end{array} \right\} \right\}.
\]

Then the fuzzy soft set
\[
\beta_E = \left\{ e_1, \left\{ \begin{array}{ccc}
u_1 & u_2 & u_3 \\
0.4 & 0.2 & 0.3 \\
0 & 0 & 0 \end{array} \right\}, e_2, \left\{ \begin{array}{ccc}
u_1 & u_2 & u_3 \\
0.1 & u_2 & 0.7 \\
0 & 0.3 & 0 \end{array} \right\} \right\}
\]
is a \((v_1, v_2)\)-\(g\)-closed fuzzy soft set.

We investigate some topological properties of a \((v_1, v_2)\)-\(g\)-closed fuzzy soft set as in the following results.

Theorem 3.1. Let \(v_1, v_2\) be two fuzzy soft topologies on \(U\) such that \(v_2 \subset v_1\) and \(\alpha_A, \beta_A \in \text{FSS}(U)_E\). If \(\beta_A \subseteq \alpha_A \subseteq \bar{U}, \beta_A\) is a \((v_1, v_2)\)-\(g\)-closed fuzzy soft set relative to \(\alpha_A\) and \(\alpha_A\) is a \((v_1, v_2)\)-\(g\)-closed fuzzy soft set in \(U\), then \(\beta_A\) is a \((v_1, v_2)\)-\(g\)-closed fuzzy soft set in \(U\).
Proof. Let $\beta_A \subseteq \gamma_A$ and $\gamma_A$ be a fuzzy open soft set according to $v_1$. Then we get

$$\beta_A \subseteq \alpha_A \cap \gamma_A$$

and

$$v_2 \cap \beta = Fcl(\beta_A) \cap \gamma_A,$$

which follows that

$$\alpha_A \cap v_2 - Fcl(\beta_A) \subseteq \alpha_A \cap \gamma_A$$

and

$$\alpha_A \cap \gamma_A \cup [v_2 - Fcl(\beta_A)]^c.$$

Since $\alpha_A$ is a $(v_1, v_2)$-$g$-closed fuzzy soft set and $v_2 \subseteq v_1$, then we obtain

$$v_2 - Fcl(\alpha_A) \subseteq \gamma_A \cup [v_2 - Fcl(\beta_A)]^c.$$

Hence we have

$$v_2 - Fcl(\beta) \subseteq v_2 - Fcl(\alpha_A) \subseteq \gamma_A \cup [v_2 - Fcl(\beta_A)]^c,$$

whence

$$v_2 - Fcl(\beta_A) \subseteq \gamma_A.$$

Consequently, $\beta_A$ is a $(v_1, v_2)$-$g$-closed fuzzy soft set in $U$. \hfill \Box

Now we prove that the union of two $(v_1, v_2)$-$g$-closed fuzzy soft sets is a $(v_1, v_2)$-$g$-closed fuzzy soft set.

Theorem 3.2. Let $v_1, v_2$ be two fuzzy soft topologies on $U$ and $\alpha_A, \beta_A \in FSS(U_E)$. If $\alpha_A$ and $\beta_A$ are two $(v_1, v_2)$-$g$-closed fuzzy soft sets, then $\alpha_A \cup \beta_A$ is $(v_1, v_2)$-$g$-closed fuzzy soft set.

Proof. If $\alpha_A \cup \beta_A \subseteq \gamma_A$ and $\gamma_A$ is a fuzzy open soft set according to $v_1$, then we have

$$v_2 - Fcl(\alpha_A \cup \beta_A) = v_2 - Fcl(\alpha_A) \cup v_2 - Fcl(\beta_A) \subseteq \gamma_A,$$

since $\alpha_A$ and $\beta_A$ are two $(v_1, v_2)$-$g$-closed fuzzy soft sets. Therefore, $\alpha_A \cup \beta_A$ is $(v_1, v_2)$-$g$-closed fuzzy soft set. \hfill \Box

In the following example, we see that the intersection of two $(v_1, v_2)$-$g$-closed fuzzy soft sets is not always a $(v_1, v_2)$-$g$-closed fuzzy soft set.

Example 3.2. Let $U = \{u_1, u_2, u_3\}$, $E = \{e_1, e_2\}$, $v_1 = \emptyset$, $\alpha_E \subseteq U$ and $v_2 = \emptyset$, $\beta_E \subseteq U$ where $\alpha_E$ is a fuzzy soft set on $U$ defined as

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

Then the fuzzy soft sets

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

and

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

are two $(v_1, v_2)$-$g$-closed fuzzy soft sets. Also we obtain

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

which is not a $(v_1, v_2)$-$g$-closed fuzzy soft set.

Proposition 3.1. Let $v_1, v_2$ be two fuzzy soft topologies on $U$ such that $v_2 \subseteq v_1$ and $\alpha_A, \beta_A \in FSS(U_E)$. Assume that $\alpha_A$ is a $(v_1, v_2)$-$g$-closed fuzzy soft set and $\beta_A$ is a fuzzy soft closed set relative to $v_2$. Then $\alpha_A \cap \beta_A$ is a $(v_1, v_2)$-$g$-closed fuzzy soft set.

Proof. Since $\beta_A$ is a fuzzy soft closed set relative to $v_2$, then $\alpha_A \cap \beta_A$ is a fuzzy soft closed set relative to $v_2$ in $\alpha_A$ whence it is $(v_1, v_2)$-$g$-closed fuzzy soft. By Theorem 3.1, $\alpha_A \cap \beta_A$ is a $(v_1, v_2)$-$g$-closed fuzzy soft set in $U$. \hfill \Box
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, $v_1$, $v_2$ two fuzzy soft topologies on $U_1$ and $v$ a fuzzy soft topology on $U_2$. Suppose that $u : U_1 \rightarrow U_2$, $p : A \rightarrow B$ are two mappings and $f_{pu} : FSS(U_1)_A \rightarrow FSS(U_2)_B$ is a function. Then $f_{pu}$ is said to be mixed $g$-fuzzy soft continuous if $f_{pu}^{-1}(\beta_A)$ is a $(v_1, v_2)$-$g$-closed fuzzy soft set for every fuzzy soft closed set $\beta_A$ 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 $U = U_1 \cup U_2$ be a fuzzy soft topological space with two fuzzy soft topologies $v_1$, $v_2$ and $U_3$ a fuzzy soft topological space with a fuzzy soft topology $v$. Let $f_{p_1u_1} : FSS(U_1)_A \rightarrow FSS(U_3)_B$ and $f_{p_2u_2} : FSS(U_2)_A \rightarrow FSS(U_3)_B$ be two mixed $g$-fuzzy soft continuous mappings where $p_1 = p_2 : A \rightarrow B$, $u_1 : U_1 \rightarrow U_3$ and $u_2 : U_2 \rightarrow U_3$ are functions. Suppose that $U_1$, $U_2$ are two $(v_1, v_2)$-$g$-closed fuzzy soft sets and $v_2 \subset v_1$. 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 $f_{pu} : FSS(U)_A \rightarrow FSS(U_3)_B$ 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 $\beta_A$ be a fuzzy soft closed set in $U_3$. Then we have

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

By the mixed $g$-fuzzy continuity of $f_{p_1u_1}$, we obtain that $f_{p_1u_1}^{-1}(\beta_A)$ is a $(v_1, v_2)$-$g$-closed fuzzy soft set in $U_1$. By Theorem 3.1, $f_{p_2u_2}^{-1}(\beta_A)$ is a $(v_1, v_2)$-$g$-closed fuzzy soft set in $U$ since $U_1$ is $(v_1, v_2)$-$g$-closed fuzzy soft. Using the similar approach, we can easily see that $f_{p_1u_1}^{-1}(\beta_A)$ is a $(v_1, v_2)$-$g$-closed fuzzy soft set in $U$. By Theorem 3.2, $f_{pu}^{-1}(\beta_A)$ is a $(v_1, v_2)$-$g$-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.

**Acknowledgements.** The author would like to thank the anonymous referee for his/her comments that helped us improve this article.

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