Fuzzy Binary Soft Separation Axioms and its Properties

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Abstract: In this paper we introduce fuzzy binary soft separation axioms in fuzzy binary soft topological spaces over the two universal sets $U_1$ and $U_2$. We define fuzzy binary soft $T_i$ axioms ($i = 0, 1, 2$), and study fundamental properties such as fuzzy binary soft hereditary of the above mentioned spaces in detailed.

Keywords: Fuzzy binary soft topological spaces, fuzzy binary soft point, fuzzy binary soft separation axioms.

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1. Introduction
Prof. L. A. Zadeh [10] in 1965, introduced the concept of fuzzy set. Soft set was first introduced by Molodtsov [8]. Majiet. al [7] introduced the concept of fuzzy soft set and some of its properties. In 2014, J.Subhashini and Dr.C.Sekar [9] defined soft pre separation axioms in soft topological space. J.Mahanta and P. K. Das [6] first introduced the concept of fuzzy soft separation axioms. AhuAcikgoz and Nihal Das [1] defined binary soft set theory in two universal sets in 2016. In continuation, Benchalli et al. [2] studied the concept of binary soft topology. Also they introduced binary soft separation axioms. In 2020, We have introduced fuzzy binary soft set over two universal sets and fuzzy binary soft topological space [3-5]. we introduced fuzzy binary soft point over two universal sets and also we discussed some major properties related to this. In this paper, In preliminaries we have added definitions and theorems. In the next section we have defined fuzzy binary soft $T_i$ axioms ($i = 0, 1, 2$). we discussed some of its properties in fuzzy binary soft topological spaces.

2. Preliminaries

Definition 2.1 ([3])

Let $U_1$, $U_2$ be the two initial universal sets and $E$ be a set of parameters. Let $F(U_1)$, $F(U_2)$ denote the set of all fuzzy sets over $U_1$, $U_2$ respectively. Also let $A$, $B \subseteq E$. A pair $(F, A)$ is said to be a fuzzy binary soft set over $U_1$, $U_2$, where $F$ is a mapping given by $F: A \rightarrow F(U_1) \times F(U_2)$.

Example 2.2 ([3])

Consider the following sets:
$U_1 = \{p_1, p_2, p_3, p_4\}$ is the set of phones,
$U_2 = \{l_1, l_2, l_3, l_4\}$ is the set of laptops
$E = \{e_1, e_2, e_3, e_4, e_5\}$. $E$ is the set of parameters where $e_1$: expensive, $e_2$: modern, $e_3$: quality, $e_4$: cheap, $e_5$: storage and $A = \{e_1, e_2, e_4\} \subseteq E$.

Now $(F, A)$ is a fuzzy binary soft set over $U_1$, $U_2$ is defined as follows:
$F(e_1) = F(\text{expensive}) = \left\{ \begin{array}{c}
\left( \frac{p_1}{0.4}, \frac{p_2}{0.2}, \frac{p_3}{0.7}, \frac{p_4}{0.4} \right), \\
\left( \frac{l_1}{0.2}, \frac{l_2}{0.3}, \frac{l_3}{0.5}, \frac{l_4}{0.3} \right) \end{array} \right\}$.
\[ F(e_2) = F(\text{modern}) = ((p_1^{0.7}p_2^{0.3}p_3^{0.5}, l_1^{0.5}l_2^{0.3}l_3^{0.6}l_4^{0.4}), \]
\[ F(e_1) = F(\text{quality}) = ((p_1^{0.4}p_2^{0.4}p_4^{0.6}, l_1^{0.5}l_2^{0.7}l_3^{0.9}l_4^{0.6}), \]
Therefore, \( (F, A) = \{(e_1, ((p_1^{0.4}p_2^{0.4}p_4^{0.6}, l_1^{0.5}l_2^{0.7}l_3^{0.9}l_4^{0.6})), e_2, ((p_1^{0.4}p_2^{0.4}p_4^{0.6}, l_1^{0.5}l_2^{0.7}l_3^{0.9}l_4^{0.6}))) \}\]

**Definition 2.3** ([3])

Let \((F, A)\) and \((G, B)\) be two fuzzy binary soft sets over the common \(U_1, U_2\); \((F, A)\) is called a fuzzy binary soft subset of \((G, B)\) if

(i) \(A \subseteq B\),

(ii) \(F(e)\) is the fuzzy subset of \(G(e)\) for each \(e \in A\) and is denoted by \((F, A) \subseteq (G, B)\), briefly \((F, A)\) is said to be a fuzzy binary soft superset of \((G, B)\) if \((G, B)\) is a fuzzy binary soft subset of \((F, A)\).

We write \((F, A) \subseteq (G, B)\).

**Definition 2.4** ([3])

The complement of a fuzzy binary soft set \((F, A)\) is denoted by \((F, A)^c\) and is defined by \((F, A)^c = (F^c, \lambda A)\), where \(F^c : A \rightarrow F(U_1) \times F(U_2)\) is a mapping given by \(F^c(e) = (F(\lambda e))^c\) for all \(\lambda e \in A\).

**Definition 2.5** ([3])

A fuzzy binary soft set \((F, A)\) over \(U_1, U_2\) is said to be a fuzzy binary null soft set if for all \(e \in A\), \(F(e)\) is the null fuzzy set over \(U_1, U_2\) and is denoted by \(\bar{A}\).

**Definition 2.6** ([3])

A fuzzy binary soft set \((F, A)\) over \(U_1, U_2\) is said to be a fuzzy binary absolute soft set if for all \(e \in A\), \(F(e)\) is the absolute fuzzy set over \(U_1, U_2\) and is denoted by \(\bar{A}\).

**Definition 2.7** ([3])

Union of two fuzzy binary soft sets \((F, A)\) and \((G, B)\) over the common \(U_1, U_2\) is the fuzzy binary soft set \((H, C)\), where \(C = A \cup B\) and for each \(e \in C\),
\[ H(e) = \begin{cases} F(e), & e \in A - B \\ G(e), & e \in B - A \\ F(e) \cup G(e), & e \in A \cap B \end{cases} \]

We write \((H, C) = (F, A) \bar{U} (G, B)\).

**Definition 2.8** ([3])

Intersection of two fuzzy binary soft sets \((F, A)\) and \((G, B)\) over the common \(U_1, U_2\) is the fuzzy binary soft set \((H, C)\), where \(C = A \cap B\) and \(H(e) = F(e) \cap G(e)\) for each \(e \in C\). We denote it by \((H, C) = (F, A) \bar{\cap} (G, B)\).

**Definition 2.9** ([5])

Let \(\bar{\tau}\) be the collection of fuzzy binary soft sets over \(U_1, U_2\); then \(\bar{\tau}\) is said to be a fuzzy binary soft topology on \(U_1, U_2\) if

(i) \(\bar{\tau}, \bar{A} \in \bar{\tau}\),

(ii) The union of any member of fuzzy binary soft sets in \(\bar{\tau}\) belongs to \(\bar{\tau}\),

(iii) The intersection of any two fuzzy binary soft sets in \(\bar{\tau}\) belongs to \(\bar{\tau}\).

Then \((U_1, U_2, \bar{\tau}, E)\) is called a fuzzy binary soft topological space over \(U_1, U_2\).

**Definition 2.10** ([5])

Let \((U_1, U_2, \bar{\tau}, E)\) be a fuzzy binary soft topological space over \(U_1, U_2\) and \((F, E)\), \((G, E)\) be fuzzy binary soft sets over the universal sets \(U_1, U_2\) such that \((G, E) \subseteq (F, E)\). Then \((G, E)\) is called a fuzzy binary interior set of \((F, E)\) if and only if \((F, E)\) is a neighborhood of \((G, E)\).
The union of all fuzzy binary soft interior sets of \((F, E)\) is called the interior \((F, E)\) and is denoted by \((F, E)^\circ\).

**Definition 2.11** ([5])

Let \((U_1, U_2, \tilde{t}, E)\) be a fuzzy binary soft topological space and \((F, E)\) be the fuzzy binary soft set over the universal sets \(U_1, U_2\). Then the fuzzy binary soft closure of \((F, E)\) denoted by \((\tilde{F}, \tilde{E})\) and is defined as the intersection of all fuzzy binary soft closed sets containing \((F, E)\).

That is \((F, E) = \tilde{F}) \cap (G, E) / (F, E) \subseteq (G, E) \text{ and } (G, E) \text{ is the fuzzy binary soft closed set}.

**Definition 2.12** ([5])

Let \((U_1, U_2, \tilde{t}, E)\) be a fuzzy binary soft topological space over \(U_1, U_2\) and \(V_1, V_2\) be a non-empty subset of \(U_1, U_2\). Then \(\tilde{t}_{1,2} = \{(V_1, V_2) | \tilde{t}(F, E) | (F, E) \in \tilde{t}\}\) is said to be the fuzzy binary soft relative topology over \(V_1, V_2\) and \((V_1, V_2, \tilde{t}_{1,2}, E)\) is called a fuzzy binary soft subspace of \((U_1, U_2, \tilde{t}, E)\). We can easily verify that \(\tilde{t}_{1,2}\) is, in fact, a fuzzy binary soft topology over \(V_1, V_2\).

**Definition 2.13** ([4])

A fuzzy binary soft set \((F, A)\) is said to be a fuzzy binary soft point over \(U_1, U_2\) denoted by \(e_{(F,A)}\) if for the element \(e \in A, F(e) \neq (\tilde{0}, \tilde{0})\) and \(F(e') = (\tilde{0}, \tilde{0})\), for all \(e' \in A - \{e\}\).

**Example 2.14** ([4])

Let \(U_1 = \{a_1, a_2, a_3\}\), \(U_2 = \{b_1, b_2, b_3\}\), \(E = \{e_1, e_2, e_3, e_4\}\) and \(A = \{e_1, e_2\} \subseteq E\), the set of parameters.

Then \(e_{(F,A)} = \{(e_1, (\{a_1, a_2, a_3\}, \{b_1, b_2, b_3\})), (e_2, (\{a_1, a_2, a_3\}, \{b_1, b_2, b_3\}))\}\) is a fuzzy binary soft point.

**Definition 2.15** ([4])

A fuzzy binary soft point \(e_{(F,A)}\) is said to be in a fuzzy binary soft set \((G, A)\) denoted by \(e_{(F,A)} \subseteq (G, A)\) if for the element \(e \in A, F(e) \subseteq G(e)\).

3. Fuzzy binary soft separation axioms and its properties

**Definition 3.1**

A fuzzy binary soft topological space \((U_1, U_2, \tilde{t}, E)\) is said to be a fuzzy binary soft \(T_0\)–space if for every pair of disjoint fuzzy binary soft points \(e_{(F,E)}, e_{(G,E)}\), there exists a fuzzy binary soft open set containing one but not the other.

**Example 3.2**

Let \(U_1 = \{a_1, a_2\}, U_2 = \{b_1, b_2\}, E = \{e_1, e_2\}\) and \(\tilde{t} = \{\tilde{0}, \tilde{1}\}, (F, E), (F_2, E), (F_3, E), (F_4, E), (F_5, E), (F_6, E)\) where

\((F_1, E) = \{(e_1, (\{a_1, a_2\}, \{b_1, b_2\})), (e_2, (\{a_1, a_2\}, \{b_1, b_2\})), (e_3, (\{a_1, a_2\}, \{b_1, b_2\}))\}\)

\((F_2, E) = \{(e_1, (\{a_1, a_2\}, \{b_1, b_2\})), (e_2, (\{a_1, a_2\}, \{b_1, b_2\})), (e_3, (\{a_1, a_2\}, \{b_1, b_2\}))\}\)

\((F_3, E) = \{(e_1, (\{a_1, a_2\}, \{b_1, b_2\})), (e_2, (\{a_1, a_2\}, \{b_1, b_2\})), (e_3, (\{a_1, a_2\}, \{b_1, b_2\}))\}\)

\((F_4, E) = \{(e_1, (\{a_1, a_2\}, \{b_1, b_2\})), (e_2, (\{a_1, a_2\}, \{b_1, b_2\})), (e_3, (\{a_1, a_2\}, \{b_1, b_2\}))\}\)

\((F_5, E) = \{(e_1, (\{a_1, a_2\}, \{b_1, b_2\})), (e_2, (\{a_1, a_2\}, \{b_1, b_2\})), (e_3, (\{a_1, a_2\}, \{b_1, b_2\}))\}\)

\((F_6, E) = \{(e_1, (\{a_1, a_2\}, \{b_1, b_2\})), (e_2, (\{a_1, a_2\}, \{b_1, b_2\})), (e_3, (\{a_1, a_2\}, \{b_1, b_2\}))\}\)

Then clearly \(\tilde{t}\) is a fuzzy binary soft topology over \(U_1, U_2\). Also for every pair of distinct fuzzy binary soft points, there exists fuzzy binary soft open set containing one of the points but not the other. Hence \((U_1, U_2, \tilde{t}, E)\) is a fuzzy binary soft \(T_0\)–space.

**Theorem 3.3**

A fuzzy binary soft subspace of a fuzzy binary soft \(T_0\)–space is fuzzy binary soft \(T_0\)–space. That is, the property of being a \(T_0\)–space of a fuzzy binary soft topological space is hereditary.
Proof: Let $(V_1, V_2, \bar{\tau}_{V_1, V_2}, E)$ be a fuzzy binary soft subspace of a fuzzy binary soft $T_0$ space $(U_1, U_2, \bar{\tau}, E)$ and let $e_{(F,E)}, e_{(G,E)}$ be two distinct fuzzy binary soft points in $\bar{\tau}_{V_1, V_2}$. Then these fuzzy binary soft points are also in $\bar{\tau}$. That implies there exists a fuzzy binary soft open set $(H, E) \in \bar{\tau}$ containing one fuzzy binary soft point but not other. That implies $(V_1, V_2) \bar{\tau} (H, E)$ is a fuzzy binary soft open set in $\bar{\tau}_{V_1, V_2}$ containing one fuzzy binary soft point but not other. Hence proved.

**Definition 3.4**
A fuzzy binary soft topological space $(U_1, U_2, \bar{\tau}, E)$ is said to be a fuzzy binary soft $T_1$ space if for every pair of disjoint fuzzy binary soft points $e_{(F,E)}, e_{(G,E)}$, there exists a fuzzy binary soft open sets $(H, E), (K, E)$ such that $e_{(F,E)} \in (H, E)$, $e_{(G,E)} \in (K, E)$ and $e_{(G,E)} \notin (K, E)$. 

**Example 3.5**
Let $U_1 = \{a_1, a_2\}$, $U_2 = \{b_1, b_2\}$, $E = \{e_1, e_2\}$ and $\bar{\tau} = \{\emptyset, \bar{\tau}, \bar{\tau}_1, \bar{\tau}_2, \bar{\tau}_3\}$, $(F, E), (F_2, E), (F_3, E), (F_4, E), (F_5, E), (F_6, E)$, $(F_7, E), (F_8, E), (F_9, E), (F_{10}, E), (F_{11}, E), (F_{12}, E)$} where

$(F, E) = \{(e_1, ((a_1, a_2), \{b_1, b_2\})), (e_2, ((a_1, a_2), \{b_1, b_2\}))\}$,
$(F_2, E) = \{(e_1, ((a_1, a_2), \{b_1, b_2\})), (e_2, ((a_1, a_2), \{b_1, b_2\}))\}$,
$(F_3, E) = \{(e_1, ((a_1, a_2), \{b_1, b_2\})), (e_2, ((a_1, a_2), \{b_1, b_2\}))\}$,
$(F_4, E) = \{(e_1, ((a_1, a_2), \{b_1, b_2\})), (e_2, ((a_1, a_2), \{b_1, b_2\}))\}$,
$(F_5, E) = \{(e_1, ((a_1, a_2), \{b_1, b_2\})), (e_2, ((a_1, a_2), \{b_1, b_2\}))\}$,
$(F_6, E) = \{(e_1, ((a_1, a_2), \{b_1, b_2\})), (e_2, ((a_1, a_2), \{b_1, b_2\}))\}$,
$(F_7, E) = \{(e_1, ((a_1, a_2), \{b_1, b_2\})), (e_2, ((a_1, a_2), \{b_1, b_2\}))\}$,
$(F_8, E) = \{(e_1, ((a_1, a_2), \{b_1, b_2\})), (e_2, ((a_1, a_2), \{b_1, b_2\}))\}$,
$(F_9, E) = \{(e_1, ((a_1, a_2), \{b_1, b_2\})), (e_2, ((a_1, a_2), \{b_1, b_2\}))\}$,
$(F_{10}, E) = \{(e_1, ((a_1, a_2), \{b_1, b_2\})), (e_2, ((a_1, a_2), \{b_1, b_2\}))\}$,
$(F_{11}, E) = \{(e_1, ((a_1, a_2), \{b_1, b_2\})), (e_2, ((a_1, a_2), \{b_1, b_2\}))\}$,
$(F_{12}, E) = \{(e_1, ((a_1, a_2), \{b_1, b_2\})), (e_2, ((a_1, a_2), \{b_1, b_2\}))\}$.

Then $(U_1, U_2, \bar{\tau}, E)$ is a fuzzy binary soft $T_1$ space.

**Theorem 3.6**
A fuzzy binary soft subspace $(V_1, V_2, \bar{\tau}_{V_1, V_2}, E)$ of a fuzzy binary soft $T_1$ space $(U_1, U_2, \bar{\tau}, E)$ is fuzzy binary soft $T_1$ space.

Proof: It is similar to the proof of Theorem 3.5.

**Theorem 3.7**
If every fuzzy binary soft point $e_{(F,E)}$ of a fuzzy binary soft topological space $(U_1, U_2, \bar{\tau}, E)$ is fuzzy binary soft closed then $(U_1, U_2, \bar{\tau}, E)$ is fuzzy binary soft $T_1$.

Proof: Let $e_{(F,E)} = \{e_i, ((a_i, b_i), \{\gamma_i\})/i = I, 2, \ldots, n\}$, $e_{(G,E)} = \{e_{m_i}, ((a_{m_i}, b_{m_i}), \gamma_{m_i}))/i = I, 2, \ldots, n\}$, where $e_i$ and $e_m$ are distinct parameters, be distinct fuzzy binary soft points in $(U_1, U_2, \bar{\tau}, E)$. By hypothesis, $e_{(F,E)}$ and $e_{(G,E)}$ are fuzzy binary soft closed sets and $\alpha_i, \beta_i, \gamma_i, \delta_i > 0.5$.

Hence $(e_{(F,E)})$ and $(e_{(G,E)})$ are fuzzy binary soft open sets where $e_{(F,E)} \in (e_{(G,E)})$ and $e_{(G,E)} \notin (e_{(F,E)})$.

Therefore, $(U_1, U_2, \bar{\tau}, E)$ is fuzzy binary soft $T_1$.

**Remark 3.8**
The condition $\alpha > 0.5$ in theorem 3.7, is necessary as shown by the following example:

Example 3.9
Let $U_1 = \{a_1, a_2\}, U_2 = \{b_1, b_2\}, E = \{e_1\}$.

Consider the collection $\tau$ of fuzzy binary soft sets over $U_1, U_2$, $\tau = \{\tilde{\emptyset}, \tilde{\emptyset}, (F_1, E), (F_2, E), (F_3, E)\}$ where $(F_1, E), (F_2, E)$ and $(F_3, E)$ are as follows:

$(F_1, E) = \{(e_1, ([a_1 \cdot a_2], \{b_1 \cdot b_2\})), (F_2, E) = \{(e_1, ([a_2 \cdot a_2], \{b_1 \cdot b_2\})), (F_3, E) = \{(e_1, ([a_1 \cdot a_2], \{b_1 \cdot b_2\})).$}

Then $(U_1, U_2, \tau, E)$ is fuzzy binary soft topology over $U_1, U_2$ and $e_{(G, E)}$, $e_{(H, E)}$ where

$e_{(G, E)} = \{(e_1, ([a_1 \cdot a_2], \{b_1 \cdot b_2\})])$ and $e_{(H, E)} = \{(e_1, ([a_1 \cdot a_2], \{b_1 \cdot b_2\})]$ are two distinct fuzzy binary soft points in $(U_1, U_2, \tau, E)$ such that for any fuzzy binary soft open set containing $e_{(G, E)}$ also containing $e_{(H, E)}$. Hence, $(U_1, U_2, \tau, E)$ is not fuzzy binary soft $T_1$.

Definition 3.10
A fuzzy binary soft topological space $(U_1, U_2, \tau, E)$ is said to be a fuzzy binary soft $T_2$ – space if for every pair of disjoint fuzzy binary soft points $e_{(F, E)}$, $e_{(G, E)}$, there exists disjoint fuzzy binary soft open sets $(H, E), (K, E)$ such that $e_{(F, E)} \notin (H, E)$ and $e_{(G, E)} \notin (K, E)$.

Example 3.11
The discrete fuzzy binary soft topological space is a fuzzy binary soft $T_2$ – space, but the indiscrete fuzzy binary soft topological space is not fuzzy binary soft $T_2$ – space.

Remark: 3.12
From the definition we get the following result:

i) Fuzzy binary soft $T_2$ space is fuzzy binary soft $T_1$ space.

ii) Fuzzy binary soft $T_1$ space is fuzzy binary soft $T_0$ space.

But the converse need not be true as shown in the following examples.

Example 3.13
In example 3.2, $(U_1, U_2, \tau, E)$ is a fuzzy binary soft $T_0$ – space but not fuzzy binary soft $T_1$ space.

Since $e_{(G, E)} = \{(e_1, ([a_1 \cdot a_2], \{b_1 \cdot b_2\}))$, $e_{(H, E)} = \{(e_2, ([a_2 \cdot a_2], \{b_1 \cdot b_2\}))$ are distinct fuzzy binary soft points and the only fuzzy binary soft open set containing $e_{(G, E)}$ is $\tilde{\emptyset}$ also containing $e_{(H, E)}$. Hence $(U_1, U_2, \tau, E)$ is not fuzzy binary soft $T_1$ space.

In example 3.7, $(U_1, U_2, \tau, E)$ is a fuzzy binary soft $T_0$ – space but not fuzzy binary soft $T_2$ space.

Since $e_{(G, E)} = \{(e_1, ([a_1 \cdot a_2], \{b_1 \cdot b_2\}))$, $e_{(H, E)} = \{(e_2, ([a_2 \cdot a_2], \{b_1 \cdot b_2\}))$ are distinct fuzzy binary soft points and the only fuzzy binary soft open set containing $e_{(G, E)}$ are $(F_1, E), (F_2, E)$ but they are not disjoint. Hence $(U_1, U_2, \tau, E)$ is not fuzzy binary soft $T_2$ space.

4. Conclusion
In this paper we introduced fuzzy binary soft separation axioms in fuzzy binary soft topological spaces over the two universal sets $U_1$ and $U_2$. We defined fuzzy binary soft $T_i$ axioms ($i = 0, 1, 2$), fuzzy binary soft regular, fuzzy binary soft normal using fuzzy binary soft point and also we studied fundamentals properties such as fuzzy binary soft hereditary. Further we discussed the result that fuzzy binary soft $T_2$ space is fuzzy binary soft $T_1$ space and fuzzy binary soft $T_2$ space is fuzzy binary soft $T_0$ space, but the converse need not be true by giving the suitable examples. It will be very useful for further research work in fuzzy binary soft topological spaces.

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