1. Introduction

In 1999, Molodtsov [21] suggested a different approach for dealing with problems of incomplete information under the name of soft set theory. This notion has been utilized in many directions, like: smoothness of function, Riemann integration, theory of measurement, probability theory, game theory and so on. The core concept of the theory of soft set is the nature of sets of parameters that provides a general framework for modeling uncertain data. This essentially contributes to the development of soft set theory during a short period of time. Maji et al. [20] studied a (detailed) theoretical structure of soft set theory. In particular, they established some operators and operations between soft sets. Then, some mathematicians reformulated the operators and operations between soft sets given in Maji et al.’s work as well as proposed different types of them; to see the recent contributions concerning soft operators and operations, we refer the reader to [7].

In 2011, the concept of soft (general) topology was defined by Shabir and Naz [24] and Çağman et al. [10] independently. In 2013, Nazmul and Samanta [22] defined soft continuity of functions. Then various generalizations of soft continuity and soft openness of functions appeared in the literature. For instance, soft $\alpha$-continuous functions [1], soft semicontinuous functions [19], soft $\beta$-continuous functions [26], soft somewhere dense continuous [5], soft $\alpha$-open functions [1], soft semi-open functions [19], soft $\beta$-open functions [26], soft somewhere dense open [5], and so on. Different kinds of belong and nonbelong relations were studied in [24] [13]. These relations led to the variety and abundance of the forms of the concepts and notions on soft topology.

After this brief introduction, we recollect some preliminaries concepts in Section 2. Then, we devote Section 3 to introduce the concept of soft somewhat open sets and study its relationships with some generalizations of soft open sets. The goals of Section
are misleading and ambiguous as reported by Ali et al. [2]. Therefore, we follow the
arbitrary subsets of $E$
Clearly,
Definition 2.1. [21] A pair $(F, E) = \{(e, F(e)) : e \in E\}$ is said to be a soft set over $X$,
where $F : E \to \mathcal{P}(X)$ is a (crisp) map. We write $F_E$ in place of the soft set $(F, E)$.
The class of all soft sets on $X$ is symbolized by $SS_E(X)$ (or simply $SS(X)$). If $A \subseteq E$,
then it will be symbolized by $SS_A(X)$.
Definition 2.2. [22] A soft set $F_E$ over $X$ is called:
(i) a soft element if $F(e) = \{x\}$ for all $e \in E$, where $x \in X$. It is denoted by $\{x\}_E$
(or shortly $x$).
(ii) a soft point if there are $e \in E$ and $x \in X$ such that $F(e) = \{x\}$ and $F(e') = \emptyset$
for each $e' \neq e$. It is denoted by $P^e_x$. An expression $P^e_x \subseteq F_E$ means that $x \in F(e)$.
Definition 2.3. [2] The complement of $F_E$ is a soft set $X_E \setminus F_E$ (or simply $F_E^c$),
where $F^c : E \to \mathcal{P}(X)$ is given by $F^c(e) = X \setminus F(e)$ for all $e \in E$.
Definition 2.4. [21] A soft subset $F_E$ over $X$ is called
(i) null if $F(e) = \emptyset$ for any $e \in E$.
(ii) absolute if $F(e) = X$ for any $e \in E$.
The null and absolute soft sets are respectively symbolized by $\Phi_E$ and $X_E$.
Clearly, $X_E^c = \Phi_E$ and $X_E^c = X_E$.
Definition 2.5. [20] Let $A, B \subseteq E$. It is said that $G_A$ is a soft subset of $H_B$ (written by
$G_A \sqsubseteq H_B$) if $A \subseteq B$ and $F(e) \subseteq G(e)$ for any $e \in A$. We call $G_A$ soft equals to $H_B$
if $G_A \sqsubseteq H_B$ and $H_B \sqsubseteq G_A$.

The definitions of soft union and soft intersection of two soft sets with respect to arbitrary
subsets of $E$ was given by Maji et al. [20]. But it turns out that these definitions are misleading
and ambiguous as reported by Ali et al. [2]. Therefore, we follow the definitions given by Ali et al. [2]
and M. Terepeta [25].
Definition 2.6. Let $\{F^\alpha_E : \alpha \in \Lambda\}$ be a collection of soft sets over $X$, where $\Lambda$
is any indexed set.

1. The intersection of $F^\alpha_E$, for $\alpha \in \Lambda$, is a soft set $G_E$ such that $G(e) = \bigcap_{\alpha \in \Lambda} F^\alpha(e)$
for each $e \in E$ and denoted by $G_E = \prod_{\alpha \in \Lambda} F^\alpha_E$.
2. The union of $F^\alpha_E$, for $\alpha \in \Lambda$, is a soft set $G_E$ such that $G(e) = \bigcup_{\alpha \in \Lambda} F^\alpha(e)$
for each $e \in E$ and denoted by $G_E = \bigcup_{\alpha \in \Lambda} F^\alpha_E$.

Definition 2.7. [24] A subfamily $\mathcal{T}$ of $SS_E(X)$ is called a soft topology on $X$ if

1. $\Phi_E$ and $X_E$ belong to $\mathcal{T}$,
2. finite intersection of sets from $\mathcal{T}$ belongs to $\mathcal{T}$, and
3. any union of sets from $\mathcal{T}$ belongs to $\mathcal{T}$.
Terminologically, we call \((X, \mathcal{T}, E)\) a soft topological space on \(X\). The elements of \(\mathcal{T}\) are called soft open sets, and their complements are called soft closed sets.

Henceforward, \((X, \mathcal{T}, E)\) means a soft topological space.

**Definition 2.8.** \([24]\) Let \(Y_E\) be a non-null soft subset of \((X, \mathcal{T}, E)\). Then \(\mathcal{T}_Y := \{G_E \cap Y_E : G_E \in \mathcal{T}\}\) is called a soft relative topology on \(Y\) and \((Y, \mathcal{T}_Y, E)\) is a soft subspace of \((X, \mathcal{T}, E)\).

**Definition 2.9.** \([24]\) Let \(F_E\) be a soft subset of \((X, \mathcal{T}, E)\). The soft interior of \(F_E\) is the largest soft open set contained in \(F_E\) and denoted by \(\text{Int}_X(F_E)\) (or simply \(\text{Int}(F_E)\)). The soft closure of \(F_E\) is the smallest soft closed set which contains \(F_E\) and denoted by \(\text{Cl}_X(F_E)\) (or simply \(\text{Cl}(F_E)\)).

**Lemma 2.1.** \([15]\) For a soft subset \(G_E\) of \((X, \mathcal{T}, E)\), \(\text{Int}(G_E^c) = (\text{Cl}(G_E))^c\) and \(\text{Cl}(G_E^c) = (\text{Int}(G_E))^c\).

**Definition 2.10.** A soft subset \(G_E\) of \((X, \mathcal{T}, E)\) is called

(i) soft dense if \(\text{Cl}(G_E) = X_E\),
(ii) soft co-dense if \(\text{Int}(G_E) = \Phi_E\)
(iii) soft semiopen \([11]\) if \(G_E \subseteq \text{Cl}(\text{Int}(G_E))\),
(iv) soft \(\beta\)-open \([26]\) if \(G_E \subseteq \text{Cl}(\text{Int}(\text{Cl}(G_E)))\),
(v) soft somewhere dense \([4]\) if \(\text{Int}(\text{Cl}(G_E)) \neq \Phi_E\) (For a better connection between these soft sets, we force \(\Phi_E\) to be soft somewhere dense).

We call \(F_E\) a countable soft set if \(F(e)\) is countable for each \(e \in E\).

**Definition 2.11.** A soft topological space \((X, \mathcal{T}, E)\) is called

(i) soft separable \([23]\) if it has a countable soft dense subset.
(ii) soft hyperconnected \([10]\) if any pair of non-null soft open subsets intersect.
(iii) soft connected \([18]\) if it cannot be written as a union of two disjoint soft open sets.
(iv) soft compact \([5]\) if every cover of \(X\) by soft open sets has a finite subcover. It is soft locally compact if each soft point has a soft compact neighborhood.
(v) soft metrizable \([12]\) if \(T\) is induced by soft metric space.

**Definition 2.12.** \([24, 9]\) A soft topological space \((X, \mathcal{T}, E)\) is called

(i) soft \(T_0\) if for each \(P^x, P^y \in X\) with \(P^x \neq P^y\), there exist soft open sets \(G_E, H_E\) such that \(P^x \in G_E, P^y \notin G_E\) or \(P^y \in H_E, P^x \notin H_E\).
(ii) soft \(T_1\) if for each \(P^x, P^y \in X\) with \(P^x \neq P^y\), there exist soft open sets \(G_E, H_E\) such that \(P^x \in G_E, P^y \notin G_E\) and \(P^y \in H_E, P^x \notin H_E\).
(iii) soft \(T_2\) (soft Hausdorff) if for each \(P^x, P^y \in X\) with \(P^x \neq P^y\), there exist soft open sets \(G_E, H_E\) containing \(P^x, P^y\) respectively such that \(G_E \cap H_E = \Phi_E\).

**Definition 2.13.** Let \((X, \mathcal{T}, E)\) and \((Y, S, E')\) be soft topological spaces. A soft function \(f : (X, \mathcal{T}, E) \rightarrow (Y, S, E')\) is called

(i) soft continuous \([22]\) (resp., soft semicontinuous \([19]\), soft SD-continuous \([3]\), soft \(\beta\)-continuous \([26]\)) if the inverse image of each soft open subset of \((Y, S, E')\) is a soft open (resp., soft semiopen, soft somewhere dense, \(\beta\)-open) subset of \((X, \mathcal{T}, E)\).
(ii) soft open \([22]\) (resp., soft semiopen \([19]\), soft SD-open \([3]\), soft \(\beta\)-open \([26]\)) if the image of each soft open subset of \((X, \mathcal{T}, E)\) is a soft open (resp., soft semiopen, soft somewhere dense, \(\beta\)-open) subset of \((Y, S, E')\).
(iii) soft homeomorphism \([22]\) if it is one to one soft open and soft continuous from \((X, \mathcal{T}, E)\) onto \((Y, S, E')\).
For the definition of soft functions between collections of all soft sets, we refer the reader to [17]. Henceforward, by the word "function" we mean "soft function".

3. Soft Somewhat Open Sets

In this section, we introduce the concept of soft somewhat open sets and establish main properties. With the help of examples, we show the relationships between soft somewhat open sets and some generalizations of soft open sets such that soft semiopen and soft somewhere dense sets.

Definition 3.1. A subset $G_E$ of a soft topological space $(X, T, E)$ is said to be soft somewhat open (briefly soft $sw$-open) if either $G_E$ is null or $\text{Int}(G_E) \neq \Phi_E$.

The complement of each soft $sw$-open set is called soft $sw$-closed. That is, a set $F_E$ is soft $sw$-closed if $\text{Cl}(F_E) \neq X_E$ or $F_E = X_E$.

Remark 3.1. Let $(X, T, E)$ be a soft topological space.

(a) A non-null set $G_E$ over $X$ is soft $sw$-open iff there is a soft open set $U_E$ such that $\Phi_E \neq U_E \subseteq G_E$.

(b) A proper set $H_E$ over $X$ is soft $sw$-closed iff there is a soft closed set $F_E$ such that $H_E \subseteq F_E \neq X_E$.

Proposition 3.1. (a) Every superset of a soft $sw$-open set is soft $sw$-open.

(b) Every subset of a soft $sw$-closed set is soft $sw$-closed.

Proof. Straightforward.

Proposition 3.2. A non-null soft set is soft $sw$-open iff it is a soft neighbourhood of a soft point.

Proof. Let $G_E$ be a non-null soft $sw$-open set. Then there is a soft open set $U_E$ such that $\Phi_E \neq U_E \subseteq G_E$. Therefore, $G_E$ is a soft neighbourhood of all soft points in $U_E$. Conversely, let $G_E$ be a soft neighbourhood of a soft point $P_E$. Then there is a soft open set $U_E$ such that $P_E \in U_E \subseteq G_E$. Hence, we obtain $\text{Int}(G_E) \neq \Phi_E$, as required.

Proposition 3.3. Any union of soft $sw$-open sets is soft $sw$-open.

Proof. Let $\{G_E^\alpha : \alpha \in \Lambda\}$ be any collection of soft $sw$-open subsets of a soft topological space $(X, T, E)$. Now

$$\text{Int}(\bigcup_{\alpha \in \Lambda} G_E^\alpha) \supseteq \bigcup_{\alpha \in \Lambda} \text{Int}(G_E^\alpha) \neq \Phi_E.$$ 

Thus $\bigcup_{\alpha \in \Lambda} G_E^\alpha$ is soft $sw$-open.

Corollary 3.1. Any intersection of soft $sw$-closed sets is soft $sw$-closed.

The intersection of two soft $sw$-open sets need not be soft $sw$-open, as showing in the next example:

Example 3.1. Let $\mathbb{R}$ be the set of real numbers and $E = \{e_1, e_2\}$ be a set of parameters. Let $T$ be the soft topology on $\mathbb{R}$ generated by $\{(e_i, B(e_i)) : B(e_i) = (a_i, b_i) ; a_i, b_i \in \mathbb{R} ; a_i \leq b_i ; i = 1, 2\}$. Take soft $sw$-open sets $G_E = \{(e_1, [0, 1]), (e_2, [0, 1])\}$ and $H_E = \{(e_1, [1, 2]), (e_2, [1, 2])\}$ over $\mathbb{R}$, then $G_E \cap H_E \neq \Phi_E$ but $\text{Int}(G_E \cap H_E) = \Phi_E$.

Remark 3.2. The intersection of a soft $sw$-open set with another soft open, soft closed or soft dense set need not be a soft $sw$-open set, and counterexamples showing this are easy to find.
The result below explains the conditions under which the intersection of soft sw-open and soft open sets is a soft sw-open set.

**Proposition 3.4.** The intersection of two soft sw-open sets in a soft hyperconnected space \((X, \mathcal{T}, E)\) is a soft sw-open set.

**Proof.** If one of the two soft sw-open sets is null, the proof is trivial. Suppose \(G_E \) and \(H_E \) are two soft sw-open sets. Then \(\text{Int}(G_E) = U_E \neq \Phi_E \) and \(\text{Int}(H_E) = V_E \neq \Phi_E \). Now, \(\text{Int}(G_E \cap H_E) = \text{Int}(G_E) \cap \text{Int}(H_E) = U_E \cap V_E \). Since \((X, \mathcal{T}, E)\) is soft hyperconnected, \(U_E \cap V_E \neq \Phi_E \). Thus \(\text{Int}(G_E \cap H_E) \neq \Phi_E \); hence, we obtain the desired result. \(\square\)

**Corollary 3.2.** The intersection of soft sw-open and soft open sets in a soft hyperconnected space \((X, \mathcal{T}, E)\) is a soft sw-open set.

**Example 3.2.** Let \(X = \{w, x, y, z\} \) and \(E = \{e_1, e_2\} \). Set \(\mathcal{T} = \{\Phi_E, E, G_E, H_E, X_E\} \), where

\[
F_E = \{(e_1, \{x, z\}), (e_2, \{w, x\})\}
\]

\[
G_E = \{(e_1, X), (e_2, \{y, z\})\}
\]

\[
H_E = \{(e_1, \{x, z\}), (e_2, \emptyset)\}
\]

Take \(Y = \{x, y\} \), so \(\mathcal{T}_Y = \{\Phi_E, I_E, J_E, K_E, Y_E\} \), where

\[
I_E = \{(e_1, \{x\}), (e_2, \{x\})\}
\]

\[
J_E = \{(e_1, Y), (e_2, \{y\})\}
\]

\[
K_E = \{(e_1, \{x\}), (e_2, \emptyset)\}
\]

\[
Y_E = \{(e_1, \{x, y\}), (e_2, \{x, y\})\}
\]

The set \(I_E \) is soft sw-open over the soft dense set \(Y \) but not soft sw-open over \(X \).

**Lemma 3.3.** Let \(G_E \) be a subset of \((X, \mathcal{T}, E)\). Then \(G_E \) is soft semiopen iff \(\text{Cl}(G_E) = \text{Cl}(\text{Int}(G_E)) \).

**Proof.** If \(G_E \) is soft semiopen, then \(G_E \subseteq \text{Cl}(\text{Int}(G_E)) \) and so \(\text{Cl}(G_E) \subseteq \text{Cl}(\text{Int}(G_E)) \). For other side of inclusion, we always have \(\text{Int}(G_E) \subseteq G_E \). Therefore \(\text{Cl}(\text{Int}(G_E)) \subseteq \text{Cl}(G_E) \). Thus \(\text{Cl}(G_E) = \text{Cl}(\text{Int}(G_E)) \).

Conversely, assume that \(\text{Cl}(G_E) = \text{Cl}(\text{Int}(G_E)) \), but \(G_E \subseteq \text{Cl}(G_E) \) always, so \(G_E \subseteq \text{Cl}(\text{Int}(G_E)) \). Hence \(G_E \) is soft semiopen. \(\square\)
Lemma 3.4. Let $G_E$ be a non-null subset of $(X, T, E)$. If $G_E$ is soft semiopen, then $\text{Int}(G_E) \neq \Phi_E$.

Proof. Suppose otherwise that if $G_E$ is a non-null soft semiopen set such that $\text{Int}(G_E) = \Phi_E$, by Lemma 3.3 $\text{Cl}(G_E) = \Phi_E$ which implies that $G_E = \Phi_E$. Contradiction! □

Remark 3.3. Since $\text{Int}(G_E) \subseteq \text{Int}(\text{Cl}(G_E))$ for each soft set $G_E$ in a soft topological space $(X, T, E)$, so each soft sw-open set is soft somewhere dense.

Next, we put Remark 3.3, Lemma 3.4 and Proposition 2.8 in [4] into the following diagram:

Diagram I: Relationship between some generalizations of soft open sets

In general, none of these implications can be replaced by equivalence as shown below:

Example 3.3. Consider the soft topology defined in Example 3.1. The soft set of rational numbers $\mathbb{Q}_E$ over $\mathbb{R}$ is soft $\beta$-open (consequently, is soft somewhere dense) but not soft sw-open (consequently, is not soft semi-open). On the other hand, the set $\{(e_1, (0, 1)), (e_2, \{2\})\}$ is clearly soft sw-open but not soft semiopen. The soft set $F_E$ given in Example 2.9 in [4] is soft somewhere dense but not soft $\beta$-open.

Lemma 3.5. [4, Lemma 2.24] Let $G_E$ be a subset of $(X, T, E)$. Then $\text{Cl}(G_E) \cap U_E \subseteq \text{Cl}(G_E \cap U_E)$ for each soft open set $U_E$ over $X$.

Lemma 3.6. Let $G_E, H_E$ be subsets of $(X, T, E)$. If $G_E$ is soft open and $H_E$ is soft semiopen, then $G_E \cap H_E$ is soft semiopen over $X$.

Proof. Assume $H_E$ is soft semiopen and $G_E$ is soft open. By Theorem 3.1 in [11], there exists a soft open set $U_E$ over $X$ such that $U_E \subseteq H_E \subseteq \text{Cl}(U_E)$. Now $U_E \cap G_E \subseteq H_E \cap G_E \subseteq \text{Cl}(U_E) \cap G_E$. By Lemma 3.5 $U_E \cap G_E \subseteq H_E \cap G_E \subseteq \text{Cl}(U_E \cap G_E)$ and since $U_E \cap G_E$ is soft open, therefore by Theorem 3.1 in [11], $H_E \cap G_E$ is soft semiopen over $X$. □

Lemma 3.7. Let $G_E, H_E$ be subsets of $(X, T, E)$. If $G_E$ is soft open and $H_E$ is soft semiopen, then $G_E \cap H_E$ is soft semiopen over $G$.

Proof. Apply the same steps in the proof of above lemma and use the statement that $\text{Cl}(U_E) \cap G_E = \text{Cl}_{G_E}(U_E)$. □

Lemma 3.8. A subset $G_E$ of $(X, T, E)$ is soft semiopen iff $G_E \cap U_E$ is soft sw-open for each soft open set $U_E$ over $X$.

Proof. Since each soft semiopen set is soft sw-open and by Lemma 3.6 the intersection of a soft semiopen set with a soft open set is semiopen, so the first part follows.

Conversely, let $P_E^x \in G_E$ and assume that $G_E \cap U_E$ is soft sw-open for each soft open set $U_E$ over $X$. That is $\text{Int}(G_E \cap U_E) \neq \Phi_E$. But $\Phi_E \neq \text{Int}(G_E \cap U_E) = \text{Int}(G_E) \cap \text{Int}(U_E) = \text{Int}(G_E) \cap U_E$, which implies that $P_E^x \in \text{Cl}(\text{Int}(G_E))$ and so $G_E \subseteq \text{Cl}(\text{Int}(G_E))$. This proves that $G_E$ is soft semiopen. □
**Lemma 3.9.** Let $F_E$ be a subset of $(X, T, E)$. If $F_E$ is soft semiclosed and soft somewhere dense, it is soft $sw$-open.

**Proof.** Directly follows from Lemma 3.3 which implies that $F_E$ is semiclosed if $\text{Int}(\text{Cl}(F_E)) = \text{Int}(F_E)$.

4. **Soft Somewhat Continuous Functions**

We devote this section to presenting the concepts of soft somewhat continuous functions (briefly soft $sw$-continuous) and giving several characterizations of it. In addition, we illustrate its relationships with some types of soft continuity. Finally, we derive some results related to soft separable and hyperconnected spaces.

**Definition 4.1.** Let $(X, T, E)$ and $(Y, S, E')$ be soft topological spaces. A function $f : (X, T, E) \to (Y, S, E')$ is said to be soft $sw$-continuous if the inverse image of each soft open set over $Y$ is soft $sw$-open over $X$.

The above definition can be stated as:

**Remark 4.1.** A function $f : (X, T, E) \to (Y, S, E')$ is soft $sw$-continuous if for each $P^x_e \in X$ and each soft open set $V^e_e$ over $Y$ containing $f(P^x_e)$, there exists a soft $sw$-open set $U^e_e$ over $X$ containing $P^x_e$ such that $f(U^e_e) \subseteq V^e_e$.

From Diagram I, we conclude that

```
soft semicontinuous  ---->  soft $\beta$-continuous
                    \downarrow
soft $sw$-continuous  ---->  soft SD-continuous
```

Diagram II: Relationship between some generalizations of soft continuity

None of the implications in the above diagram is reversible.

**Example 4.1.** Let $X = \{x, y, z\}$ and $E = \{e_1, e_2\}$. Put $T = \{\Phi_E, F_E, G_E, X_E\}$, where $F_E = \{(e_1, \{y\}), (e_2, \{y\})\}$, $G_E = \{(e_1, \{x, z\}), (e_2, \{x, z\})\}$ and $S = \{\Phi_E, H_E, X_E\}$, where $H_E = \{(e_1, X), (e_2, \{x, y\})\}$. Let $f : (X, T, E) \to (X, S, E)$ be the soft identity function. Then $f$ is soft $sw$-continuous but not soft semicontinuous.

**Example 4.2.** Let $X = \mathbb{R}$ be the set of real numbers and $E = \{e\}$ be a set of parameters. Let $T$ be the soft topology on $\mathbb{R}$ generated by $\{(e, B(e)) : B(e) = (a, b); a, b \in \mathbb{R}; a < b\}$. Define a soft function $f : (X, T, E) \to (X, T, E)$ by

$$f(x) = \begin{cases} x, & \text{if } x \notin \{0, 1\}; \\ 0, & \text{if } x = 1; \\ 1, & \text{if } x = 0. \end{cases}$$

One can easily show $f$ is soft $sw$-continuous (consequently, soft SD-continuous) because the inverse image of any soft basic open set always contains some soft basic open, so its soft interior cannot be null. On the other hand $f$ is not soft $\beta$-continuous. Take the soft open set $G_E = \{(e, (-\varepsilon, \varepsilon))\}$, where $\varepsilon < 1$. Therefore

$$f^{-1}(G_E) = \{(e, (-\varepsilon, 0))\} \bigcup \{(e, (0, \varepsilon))\} \bigcup \{(e, \{1\})\}.$$
But $\text{Cl}(\text{Int}(\text{Cl}(f^{-1}(G_E)))) = \{(e, [-\varepsilon, \varepsilon])\}$ and so $f^{-1}(G_E) \not\subseteq \text{Cl}(\text{Int}(\text{Cl}(f^{-1}(G_E))))$. In conclusion, $f$ cannot be soft $\beta$-continuous (consequently, is not soft semicontinuous).

**Example 4.3.** Let $(X, T, E)$ be the soft topological space given in Example 4.2 and let $f : (X, T, E) \to (X, T, E)$ be defined by

$$f(x) = \begin{cases} 0, & x \notin Q_E; \\ 1, & x \in Q_E. \end{cases}$$

Then $f$ is soft $SD$-continuous but not soft sw-continuous. The inverse image of any soft open set containing only 1 is $Q_E$ which is not soft $sw$-open over $X$.

**Definition 4.2.** For a subset $G_E$ of a soft topological space $(X, T, E)$, we introduce the following:

(i) $\text{Cl}_{sw}(G_E) = \bigcap \{F_E : F_E \text{ is soft } sw\text{-closed over } X \text{ and } G_E \subseteq F_E\}$.

(ii) $\text{Int}_{sw}(G_E) = \bigcup \{O_E : O_E \text{ is soft } sw\text{-open over } X \text{ and } O_E \subseteq G_E\}$.

**Proposition 4.1.** Let $(X, T, E)$ and $(Y, S, E')$ be soft topological spaces. For a function $f : (X, T, E) \to (Y, S, E')$, the following are equivalent:

1. $f$ is soft $sw$-continuous,
2. $f^{-1}(F_{E'})$ is soft $sw$-closed set over $X$, for each soft closed set $F_{E'}$ over $Y$,
3. $f(\text{Cl}_{sw}(G_E)) \subseteq \text{Cl}(f(G_E))$, for each set $G_E$ over $X$,
4. $\text{Cl}_{sw}(f^{-1}(H_{E'})) \subseteq f^{-1}(\text{Cl}(H_{E'}))$, for each set $H_{E'}$ over $Y$,
5. $f^{-1}(\text{Int}(H_{E'})) \subseteq \text{Int}_{sw}(f^{-1}(H_{E'}))$, for each set $H_{E'}$ over $Y$.

**Proof.** Follows from the definition of soft $sw$-continuity. $\square$

**Definition 4.3.** [Definition 3.10] Let $(X, E)$ and $(Y, E')$ be soft sets and let $A_E \in (X, E)$. The restriction of $f : (X, E) \to (Y, E')$ is the soft function $f_{A_E} : (X, E) \to (Y, E')$ defined by $f_{A_E}(P^x) = f(P^x)$ for all $P^x \in A_E$. An extension of a soft function $f$ is a soft function $\hat{f}$ such that $\hat{f}$ is a restriction of $f$.

**Theorem 4.1.** Let $(X, T, E)$ and $(Y, S, E')$ be soft topological spaces and let $D_E$ be a soft dense subspace over $X$. If $f : (X, T, E) \to (Y, S, E')$ is soft $sw$-continuous over $X$, then $f|D_E$ is soft $sw$-continuous over $D$.

**Proof.** Standard (by using Lemma 3.1). $\square$

**Theorem 4.2.** Let $(X, T, E)$ and $(Y, S, E')$ be soft topological spaces. Let $f : (X, T, E) \to (Y, S, E')$ be a function and $\{G^\alpha_E : \alpha \in \Lambda\}$ be a soft open cover of $X$. Then $f$ is soft $sw$-continuous, if $f|G^\alpha_E$ is soft $sw$-continuous for each $\alpha \in \Lambda$.

**Proof.** Let $V_{E'}$ be a soft open set over $Y$. By assumption, $(f|G^\alpha_E)^{-1}(V_{E'})$ is soft $sw$-open over $G^\alpha_E$. By Lemma 3.2, $(f|G^\alpha_E)^{-1}(V_{E'})$ is soft $sw$-open over $X$ for each $\alpha \in \Lambda$. But

$$f^{-1}(V_{E'}) = \bigsqcup_{\alpha \in \Lambda} (f|G^\alpha_E)^{-1}(V_{E'}),$$

which a union of soft $sw$-open sets and by Lemma 3.3 $f^{-1}(V_{E'})$ is soft $sw$-open over $X$. Hence $f$ is soft $sw$-continuous. $\square$

**Theorem 4.3.** Let $(X, T, E)$ and $(Y, S, E')$ be soft topological spaces and let $W_E$ be a soft open set over $X$. If $f : (W, T_W, E) \to (Y, S, E')$ is a soft $sw$-continuous function such that $f(W_E)$ is soft dense over $Y$, then each extension function of $f$ over $X$ is soft $sw$-continuous.
Proof. Let $g$ be an extension of $f$ and let $V'_E$ be a (non-null) soft open set over $Y$. If $g^{-1}(V'_E) = \Phi_E$, then $g$ is trivially soft \emph{sw}-continuous. Suppose $g^{-1}(V'_E) \neq \Phi_E$. By density of $f(W_E)$, $f(W_E) \cap V'_E \neq \Phi_E$, which implies that $W_E \cap f^{-1}(V'_E) \neq \Phi_E$. Therefore $f^{-1}(V'_E) \neq \Phi_E$. By assumption, there exists a non-null soft open set $U_E$ over $W$ such that

$$U_E = U_E \cap W_E \subseteq f^{-1}(V'_E) \cap W_E = g^{-1}(V'_E) \cap W_E \subseteq g^{-1}(V'_E).$$

By Lemma 3.2, $U_E$ is a soft open set over $X$ and so $\Phi_E \neq U_E \subseteq g^{-1}(V'_E)$. Thus $g$ is soft \emph{sw}-continuous over $X$. \hfill \Box

**Theorem 4.4.** Let $(X, T, E)$ and $(Y, S, E')$ be soft topological spaces. A function $f : (X, T, E) \to (Y, S, E')$ is soft semicontinuous iff $f|_{U_E}$ is \emph{sw}-continuous for each soft open set $U_E$ over $X$.

Proof. Assume that $f$ is soft semicontinuous and $U_E$ is any soft open over $X$. Let $G_{E'}$ be a soft open set over $Y$. Then $f^{-1}(G_{E'})$ is soft semiopen and so, by Lemma 3.7, $f|_{U_E}^{-1}(G_{E'}) = f^{-1}(G_{E'}) \cap U_E$ is soft semiopen over $U$. Thus $f|_{U_E}$ is soft semicontinuous and hence soft \emph{sw}-continuous.

Conversely, suppose that $f|_{U_E}$ is soft \emph{sw}-continuous for each soft open set $U_E$ over $X$. Let $H_{E'}$ be soft open over $Y$. Then $f^{-1}(H_{E'}) = f^{-1}(H_{E'}) \cap U_E$ is soft \emph{sw}-open over $U$. Since $U_E$ is a soft open set over $X$, by Lemma 3.8, $f^{-1}(H_{E'}) \cap U_E$ is soft \emph{sw}-open over $X$ and so, by Lemma 3.8, $f^{-1}(H_{E'})$ is soft semiopen over $X$. Thus $f$ is soft semicontinuous. \hfill \Box

**Theorem 4.5.** Let $(X, T, E)$ and $(Y, S, E')$ be soft topological spaces. For a function $f : (X, T, E) \to (Y, S, E')$, the following are equivalent:

1. $f$ is soft \emph{sw}-continuous,
2. for each soft open set $V'_E$ over $Y$ with $f^{-1}(V'_E) \neq \Phi_E$, there exists a non-null soft open set $U_E$ over $X$ such that $U_E \subseteq f^{-1}(V'_E)$,
3. for each soft closed set $F'_E$ over $Y$ with $f^{-1}(F'_E) \neq X_E$, there exists a proper soft closed $K_E$ over $X$ such that $f^{-1}(F'_E) \subseteq K_E$,
4. for each soft dense set $D_E$ over $X$, then $f(D_E)$ is soft dense over $f(X)$.

Proof. (1) $\implies$ (2) Remark 3.1 and the definition of \emph{sw}-continuity.

(2) $\implies$ (3) Let $F'_E$ be a soft closed set over $Y$ such that $f^{-1}(F'_E) \neq X_E$. Then $Y_E \setminus F'_E$ is soft open over $Y$ with $f^{-1}(Y_E \setminus F'_E) \neq \Phi_E$. By (2), there exists a soft open set $U_E$ over $X$ such that $\Phi_E \neq U_E \subseteq f^{-1}(Y_E \setminus F'_E) = X_E \setminus f^{-1}(F'_E)$. This implies that $f^{-1}(F'_E) \subseteq X_E \setminus U_E \neq X_E$. If $K_E = X_E \setminus U_E$, then $K_E$ is a proper soft closed set that satisfies the required property.

(3) $\implies$ (4) Let $D_E$ be soft dense over $X$. We need to prove that $f(D_E)$ is soft dense over $f(X)$. Suppose that $f(D_E)$ is not soft dense over $f(X)$. There exists a proper soft closed set $D'_E$ such that $f(D'_E) \subseteq f(E') \cap f(X_E)$. Therefore $D_E \subseteq f^{-1}(D'_E)$. By (3), there exists a soft closed set $K_E$ over $X$ such that $D_E \subseteq f^{-1}(D'_E) \subseteq K_E \neq X_E$. This contradicts that $D_E$ is soft dense over $X$. Thus (4) holds.

(4) $\implies$ (1) Out with loss of generality, let $H_{E'}$ be a soft open set over $Y$ with $f^{-1}(H_{E'}) \neq \Phi_E$, because if $f^{-1}(H_{E'}) = \Phi_E$, then it is trivially soft \emph{sw}-open. Suppose that $f^{-1}(H_{E'})$ is not soft \emph{sw}-open. That is, $\text{Int}(f^{-1}(H_{E'})) = \Phi_E$. Therefore $\text{Cl}(X_E \setminus f^{-1}(H_{E'})) = X_E$. This implies that $X_E \setminus f^{-1}(H_{E'})$ is soft dense over $X$. By (4), $f(X_E \setminus f^{-1}(H_{E'}))$ is soft dense over $f(X)$, i.e., $\text{Cl}(f(X_E \setminus f^{-1}(H_{E'}))) = f(X_E)$. This yields that $\text{Cl}(f(X_E \setminus f^{-1}(H_{E'}))) = f(X_E) \setminus H_{E'} = f(X_E)$ and so $H_{E'} = \Phi_E$. Contradiction to the choice of $H_{E'}$. It follows that $\text{Int}(f^{-1}(H))$ must not be null. Thus $f^{-1}(H_{E'})$ is soft \emph{sw}-open over $X$. \hfill \Box
Corollary 4.1. Let \((X, T, E)\) and \((Y, S, E')\) be soft topological spaces. For a one to one function \(f\) from a space \((X, T, E)\) onto a space \((Y, S, E')\), the following are equivalent:

1. \(f\) is soft \(sw\)-continuous,
2. for each soft co-dense set \(N_E\) over \(X\), \(f(N_E)\) is soft co-dense over \(Y\).

We complete this section by discussing two related results related to soft separable and hyper-connected spaces.

Theorem 4.6. Let \((X, T, E)\) and \((Y, S, E')\) be soft topological spaces, and let \(f\) be a function from \((X, T, E)\) onto \((Y, S, E')\). If \(f\) is soft \(sw\)-continuous and \((X, T, E)\) is soft separable, then \((Y, S, E')\) is soft separable.

Proof. Let \(D_E\) be a countable soft dense set over \(X\). Clearly \(f(D_E)\) is countable. By Theorem 4.5 (4), \(f(D_E)\) is soft dense over \(f(X) = Y\). Therefore \((Y, S, E')\) is soft separable.

\(\square\)

Theorem 4.7. Let \((X, T, E)\) and \((Y, S, E')\) be soft topological spaces. If \(f\) is a soft \(sw\)-continuous from \((X, T, E)\) onto \((Y, S, E')\) and \((X, T, E)\) is soft hyperconnected, then \((Y, S, E')\) is soft hyperconnected.

Proof. Let \(G_{E'}, H_{E'}\) be any two soft open sets over \(Y\) with \(G_{E'} \neq \Phi_{E'} \neq H_{E'}\). Since \(f\) is soft \(sw\)-continuous, then \(Int(f^{-1}(G_{E'})) \neq \Phi_E \neq Int(f^{-1}(H_{E'}))\). But \((X, T, E)\) is soft hyperconnected, so

\[\text{Int}(f^{-1}(G_{E'})) \bigcap \text{Int}(f^{-1}(H_{E'})) \neq \Phi_E.\]

If \(x \in \text{Int}(f^{-1}(G_{E'})) \bigcap \text{Int}(f^{-1}(H_{E'})) \subseteq f^{-1}(G_{E'}) \bigcap f^{-1}(H_{E'}),\)

then \(f(x) \in G_{E'} \bigcap H_{E'}\). Thus \((Y, S, E')\) is soft hyperconnected.

\(\square\)

5. Soft Somewhat Open Functions

In this section, we formulate the concepts of soft somewhat open functions (briefly soft \(sw\)-open) and study its main properties. We characterized it using soft closed and soft dense sets.

Definition 5.1. Let \((X, T, E)\) and \((Y, S, E')\) be soft topological spaces. A function \(f : (X, T, E) \rightarrow (Y, S, E')\) is soft \(sw\)-open if for each soft open set \(U_E\) over \(X\), \(f(U_E)\) is soft \(sw\)-open over \(Y\).

Remark 5.1. Let \((X, T, E)\) and \((Y, S, E')\) be soft topological spaces. A function \(f : (X, T, E) \rightarrow (Y, S, E')\) is soft \(sw\)-open iff for each non-null soft open set \(U_E\) over \(X\), there exists a non-null soft \(sw\)-open set \(V_{E'}\) over \(Y\) such that \(V_{E'} \subseteq f(U_E)\).

For a single soft point, we have

Proposition 5.1. Let \((X, T, E)\) and \((Y, S, E')\) be soft topological spaces. A function \(f : (X, T, E) \rightarrow (Y, S, E')\) is soft \(sw\)-open at \(P_E' \in X_E\) if for each soft open set \(U_E\) over \(X\) containing \(P_E'\), there exists a soft \(sw\)-open set \(V_{E'}\) over \(Y\) such that \(f(P_E') \in V_{E'} \subseteq f(U_E)\).

From [5] Proposition 4.7], Lemma 5.4 and Remark 5.3 one can obtain the following for functions:
Diagram III: Relationship between some generalizations of soft openness

None of the implications in the above diagram is reversible and counterexamples are not difficult to obtain.

**Proposition 5.2.** Let \((X, T, E)\) and \((Y, S, E')\) be soft topological spaces. For a function \(f : (X, T, E) \to (Y, S, E')\), the following are equivalent:

1. \(f\) is soft sw-open,
2. \(f(\text{Int}(G_E)) \subseteq \text{Int}_{sw}(f(G_E))\), for each set \(G_E\) over \(X\),
3. \(f^{-1}(\text{Cl}_{sw}(H_{E'})) \subseteq \text{Cl}(f^{-1}(H_{E'}))\), for each set \(H_{E'}\) over \(Y\).

**Proof.** Standard. \(\square\)

**Theorem 5.1.** Let \((X, T, E)\) and \((Y, S, E')\) be soft topological spaces and let \(G_E\) be a soft open subspace over \(X\). If \(f : (X, T, E) \to (Y, S, E')\) is soft sw-open over \(X\), then \(f|_{G_E}\) is sw-open over \(G\).

**Proof.** If \(U_E\) is any soft open over \(G_E\), then \(U_E\) is also soft open over \(X\) because \(G_E\) is soft open. By assumption, \(f(U_E)\) is soft sw-open and hence the result. \(\square\)

**Theorem 5.2.** Let \((X, T, E)\) and \((Y, S, E')\) be soft topological spaces and let \(D_E\) be a soft dense subspace over \(X\). If \(f : (D, T_D, E) \to (Y, S, E')\) is a soft sw-open function, then each extension of \(f\) is soft sw-open over \(X\).

**Proof.** Let \(g\) be any extension of \(f\) and let \(U_E\) be a soft open set over \(X\). Since \(D_E\) is soft dense over \(X\), so \(U_E \cap D_E\) is a non-null soft open set over \(D_E\). By assumption, there exists a non-null soft sw-open set \(V_{E'}\) over \(Y\) such that \(V_{E'} \subseteq f(U_E \cap D_E) = g(U_E \cap D_E) \subseteq g(U_E)\). Thus \(g\) is soft sw-open over \(X\). \(\square\)

**Theorem 5.3.** Let \((X, T, E)\) and \((Y, S, E')\) be soft topological spaces. Let \(f : (X, T, E) \to (Y, S, E')\) be a function and \(\{G^\alpha_E : \alpha \in \Lambda\}\) be any soft cover over \(X\). Then \(f\) is soft sw-open, if \(f|_{G^\alpha_E}\) is soft sw-open for each \(\alpha \in \Lambda\).

**Proof.** Let \(U_E\) be a (non-null) soft open set over \(X\). Then \(U_E \cap G^\alpha_E\) is a non-null soft open set in \(G^\alpha_E\) for each \(\alpha\). By assumption, \(f(U_E \cap G^\alpha_E)\) is a soft sw-open set over \(Y\). But

\[
    f(U_E) = \bigsqcup f\left(U_E \cap G^\alpha_E\right),
\]

which a union of soft sw-open sets and by Lemma 3.3, \(f(U_E)\) is a soft sw-open set over \(Y\). Hence \(f\) is soft sw-open. \(\square\)

**Theorem 5.4.** Let \((X, T, E)\) and \((Y, S, E')\) be soft topological spaces. For a one to one function \(f\) from \((X, T, E)\) onto \((Y, S, E')\), the following are equivalent:

1. \(f\) is soft sw-open,
2. for each soft closed set \(F_E\) over \(X\) with \(f(F_E) \neq Y_{E'}\), there exists a proper soft closed \(K_{E'}\) over \(Y\) such that \(f(F_E) \subseteq K_{E'}\).
Proposed to handle uncertainty is the soft set theory. Typologists applied soft sets to logical properties which do not keep by soft

\[ f \text{ is soft } \Leftrightarrow \text{soft open}, \]

(2) for each soft dense set \( D \) over \( Y \), then \( f^{-1}(D) \) is soft dense over \( X \).

\[ \text{Proof.} \quad (1) \Rightarrow (2) \text{ Let } D \text{ be a soft dense set over } Y. \text{ Suppose otherwise that } f^{-1}(D) \text{ is not soft dense over } X. \text{ Then there is a soft closed } K \text{ over } X \text{ such that } f^{-1}(D) \cap K \neq X. \text{ But } X \setminus K \text{ is soft open over } X \text{ so, by (1), there exists a soft open set } V \text{ over } Y \text{ such that } f(V) \cap K \neq X. \text{ Assume } V \coloneqq f^{-1}(D) \cap K \neq X. \text{ Then } V \setminus f(V) \text{ is soft closed over } Y \text{ and hence } f^{-1}(D) \text{ must be soft dense over } X. \]

\[ \text{(2) } (1) \Rightarrow \text{ w.l.o.g., let } U \text{ be a non-null soft open set over } X. \text{ We need to prove that } \text{Int}(f(U)) \neq f(U). \text{ Assume } \text{Int}(f(U)) = f(U). \text{ Then } \text{Cl}_Y(Y \setminus f(U)) = Y. \text{ By (2), } \text{Cl}_X(f^{-1}(Y \setminus f(U))) = X. \text{ But } f^{-1}(Y \setminus f(U)) \subseteq X \setminus U \text{ and } X \setminus U \text{ is soft closed over } X. \text{ Therefore } X = \text{Cl}_X(f^{-1}(Y \setminus f(U))) \subseteq X \setminus U. \text{ This means that } U = f(U), \text{ which is contradiction. Thus } \text{Int}(f(U)) \neq f(U) \text{ and hence } f \text{ is soft sw-open.} \]

In the rest of this section, we define an sw-homeomorphism and show some soft topological properties which do not keep by soft sw-homeomorphisms.

A soft one to one function \( f \) from \( (X, \mathcal{T}, E) \) onto \( (Y, S, E') \) is called sw-homeomorphism if it is soft sw-continuous and soft sw-open. One can easily conclude that each homeomorphism is sw-homeomorphism but not the converse. Evidently, if \( f \) is soft sw-homeomorphism from \( (X, \mathcal{T}, E) \) onto \( (Y, S, E') \), \( f^{-1} \) is sw-open.

It is worth stating that soft sw-homeomorphism does not preserve interesting soft topological properties, as showing in the following examples.

**Example 5.1.** Let \( X = Y = \mathbb{R} \) be the set of real numbers and let \( E = \{ e \} \) be a set of parameters. If \( \mathcal{T} \) is the soft topology on \( X \) generated by \( \{ (e, B(e)) : B(e) = [a, b); a, b \in \mathbb{R}; a < b \} \) and \( S \) is the soft topology on \( Y \) generated by \( \{ (e, B(e)) : B(e) = [a, b); a, b \in \mathbb{R}; a < b \} \) (called soft Sorgenfrey line), then the identity function \( i : (X, \mathcal{T}, E) \to (Y, S, E) \) is soft sw-homeomorphism and \( (X, \mathcal{T}, E) \) is soft metrizable, soft locally compact and soft connected, while \( (Y, S, E) \) does not have any of these properties.

If we take \( A = [0, 1] \), then \( i|_A \) is soft sw-homeomorphism and \( (A, \mathcal{T}_A, E) \) is soft compact, but \( (A, S_A, E) \) is not.

**Example 5.2.** Consider \( X, E \) and \( \mathcal{T} \) given in Example 5.1. Let \( \sigma = \{ \Phi_{E}, X_{E}, \mathcal{T} \setminus \{ G_{E} : G_{E} \in \mathcal{T}_{E}, (e, 0) \in G_{E} \} \} \) be another soft topology over \( X \). The identity function \( i : (X, \mathcal{T}, E) \to (X, \sigma, E) \) is soft sw-homeomorphism and \( (X, \mathcal{T}, E) \) is soft Hausdorff but \( (X, \sigma, E) \) is not soft \( T_0 \) (consequently, not soft \( T_1 \)).
initiate a new mathematical structure called soft topology which is the framework of this study.

In this article, we have introduced the concept of soft somewhat open sets as a new generalization of soft open sets. We have shown that the family of soft somewhat open sets lies between the families of soft semiopen sets and soft somewhere dense sets on one hand. On the other hand, the families of soft somewhat open sets and soft \( \beta \)-open sets are independent of each other. These relationships have been illustrated and main properties have been established with the aid of examples. Then, we have employed soft somewhat open sets to define soft somewhat continuous, and soft somewhat open functions. We have characterized these two functions and investigated the main features. Some nice connections under certain soft topological space are studied in [6]. The reason for defining these concepts was to discuss the differences between soft homeomorphism and soft somewhat homeomorphism regarding the preservation of certain soft topological properties.

In the upcoming work, we plan to study some topological concepts using soft somewhat open sets such as soft compactness, soft Lindelöfness, and soft connectedness. The investigation of some applications soft somewhat homeomorphisms is also planned. Furthermore, we explore soft somewhat open sets in the content of supra soft topology.

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