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Some Properties of Soft Inverse Semigroups

Anu Joy[1*] and Susha D[2]

[1*] Assistant Professor, Department of Mathematics,
St. Dominics College Kanjirappally, 686512, Kerala, INDIA.
[2] Associate Professor, Department of Mathematics,
Catholicate College, Pathanamthitta, 689645, Kerala, INDIA.
email:anushanpalackal@gmail.com, sushad70@gmail.com

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ABSTRACT

The concept of soft set theory is a general mathematical tool for dealing with uncertainty and vagueness. In this paper, we introduce the concept of soft sets to inverse semigroups and investigate some properties of soft inverse semigroups. We give a relation connecting soft inverse semigroups and soft groups.

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1. INTRODUCTION

Molodtsov[14] introduced the concept of soft sets, which was a new approach for modeling uncertainity. In recent years the algebraic structure of soft set theory has been studied increasingly. Maji *et al*. in[11] gave a theoretical study of soft sets. In[1], Aktas and Cagman defined soft groups. The comparison between soft sets, fuzzy sets and rough sets are also established in[1]. Algebraic structures like fuzzy semigroups introduced by N.Kuroki[9] and rough semigroups introduced by Bagirmaz and Ozcan[4], attracted interest of various researchers. In[8], Feng *et al*. gave a study of soft semirings and several related notions to establish a connection between soft sets and semirings. Feng *et al*.[7], introduced soft relations over semigroups. Shabir *et al*. researched soft ternary semigroups in[15]. T.Changphas and B.Thongkam investigated soft gamma semigroups in[5]. P. Das[6] studied fuzzy regular subsemigroups in regular semigroups, fuzzy inverse subsemigroups in inverse semigroups.

A non empty set *S* together with an associative binary operation is called semigroup. Inverse semigroup is a generalization of a semigroup. In this paper we study another type of algebraic structure namely soft inverse semigroups.

The paper is organized as follows. In section 2 we discuss some basic definitions and results of soft set theory. Section 3 deals with soft inverse semigroup with sufficient examples together with their operations. In section 4 we discuss soft inverse subsemigroups together their properties Section 5 contains connection of soft inverse semigroups to soft groups. The last section devoted to the study of soft homomorphism over inverse semigroups.

2. PRELIMINARIES

Definition 2.1[14] Let U be the initial universe and E be the set of parameters. A pair $(F, A)$is called a soft set over U if $F: A \to P(U)$ where $P(U)$ denotes the power set of U and $A \subseteq E$.In other words, a soft set over U is a parametrized family of subsets of the universe U.

Definition 2.2[11] For two soft sets (F, A) and (G, B) over a common universe U, we say that (F, A) is a soft subset of (G, B) denoted by $(F, A) \subseteq (G, B)$ if

1.$A \subseteq B$

2.$F(a) \subseteq G(a)$, for all $a \in A$

Definition 2.3[8] Let (F, A) be a soft set over U. The set $Supp(F, A) = \{a \in A / F(\alpha) \neq \emptyset\}$ is called support of the soft set (F, A).
A soft set (F, A) is said to be nonnull if $Supp(F, A) \neq \emptyset$.

Definition 2.4[11] Let (F, A) and (G, B) be soft sets over a common universe U. Let $(F, A) OR\ (G, B)$be a soft set over U, denoted by defined by $(F, A) \cup (G, B)$

$$(F, A) \cup (G, B) = (H, A \times B)$$

Where $H(a, b) = F(a) \cup G(b)$ for all $a \in A \times B$.

Definition 2.5[11] Let (F, A) and (G, B) be soft sets over a common universe U. Let $(F, A) AND\ (G, B)$be a soft set over U, denoted by defined by $(F, A) \cup (G, B)$

$$(F, A) \cup (G, B) = (H, A \times B)$$

Where $H(a, b) = F(a) \cap G(b)$ for all $a \in A \times B$.

Definition 2.6[2] Let (F, A) and (G, B) be soft sets over a common universe U.

1. The extended union of (F, A) and (G, B), denoted by $(F, A) \cup_E (G, B)$ is the soft set (H, C) where $C = A \cup B$and for $e \in C$
$$H(e) = \begin{cases} F(e) & if\ e \in A - B \\ G(e) & if\ e \in B - A \\ F(e) \cup G(e) & if\ e \in A \cap B \end{cases}$$
2. The restricted union of (F, A) and (G, B), denoted by $(F, A) \cup_R (G, B)$ is the soft set (H, C) where $C = A \cap B$and for $e \in C$,$H(e) = F(e) \cup G(e)$.
3. The extended intersection of (F, A) and (G, B), denoted by $(F, A) \cap_E (G, B)$ is the soft set (H, C) where $C = A \cup B$and for $e \in C$
$$H(e) = \begin{cases} F(e) & if\ e \in A - B \\ G(e) & if\ e \in B - A \\ F(e) \cap G(e) & if\ e \in A \cap B \end{cases}$$

4. The restricted intersecion of (F,A) and (G,B), denoted by $(F,A) \cap_R (G,B)$ is the soft set (H,C) where $C = A \cap B$and for $e \in C$,$H(e) = F(e) \cap G(e)$.

Definition 2.7[16] The restricted product of two soft sets(F,A) and (G,B), over a semigroup S is defined as the the soft set $(F,A)\hat{o}(G,B)$ where $C = A \cap B$ and H is a set valued function from C to *P(S)* defined as $H(e) = F(e)G(e)$ for al $e \in C$.

Definition 2.8[16] The extended product of (F,A) and (G,B) over a semigroup S is defined as the soft set $(H,C) = (F,A) \circ (G,B)$ where $C = A \cup B$and H is asset valued function from C to P(S) defined as

$$H(e) = \begin{cases} F(e) & \text{if } e \in A - B \\ G(e) & \text{if } e \in B - A \\ F(e)G(e) & \text{if } e \in A \cap B \end{cases}$$

Definition 2.9[13] Inverse semigroups are the semigroups S in which for each element $s \in S$ there exist a unique element $s^{-1} \in S$ such that $ss^{-1}s = s$ and $s^{-1}ss^{-1} = s^{-1}$.The element $ss^{-1}s = s$ and $s^{-1}ss^{-1} = s^{-1}$ is called inverse of s in *S*.

Definition 2.10[13] A semigroup *S* is said to be regular semigroup if for every $s \in S$ there is an element s^{-1}, such that $ss^{-1}s = s$ and $s^{-1}ss^{-1} = s^{-1}$.

Remark 2.11 Inverse semigroups are the regular semigroups in which each element has a unique inverse. Every group is an inverse semigroup.

Definition 2.12[13] An inverse subsemigroup of an inverse semigroup is a subsemigroup closed under inverses.

Definition 2.13[3] A non null and non empty soft set (F,A)over a semigroup S is a soft semigroup if and only if $F(a) \neq \emptyset$ is a subsemigroup of *S*.

Definition 2.14[3] A soft semigroup (F,A)over a semigroup *S* is called a soft regular semigroup if for each $a \in A, F(a) \neq \emptyset$ is a regular subsemigroup of *S*.

3. SOFT INVERSE SEMIGROUPS

Let *S* be an inverse semigroup.

Definition 3.1[10] A soft semigroup (F,A)over a semigroup *S* is called a soft inverse semigroup if for each $a \in A, F(a) \neq \emptyset$ is an inverse subsemigroup of *S*.

Example 3.2 Let $S = \{a,b\}$ be an inverse semigroup with the binary operation as shown in the table

.	*a*	*b*
A	*a*	*b*
B	*b*	*b*

Clearly S is an inverse semigroup.
We define $F: A \rightarrow P(S)$ by $F(a) = a, F(b) = b$

It is clear that each $F(x)$is an inverse subsemigroup of S, for all $x \in S$. Hence (F, S) is a soft inverse semigroup over S.

Example 3.3 Let $S = \{e, a, b, c\}$ be a semigroup with the binary operation as shown in the Cayley table.

.	e	a	b	c
e	e	a	b	c
a	a	e	c	b
b	b	c	e	a
c	c	b	a	e

Clearly S is an inverse semigroup.
We define $F: A \rightarrow P(S)$ by $F(e) = \{e\}, F(a) = \{e, a\}, F(b) = \{e, b\}, F(c) = \{e, c\}$
It is clear that each $F(x)$is an inverse subsemigroup of S, for all$x \in S$.Hence (F, S) is a soft inverse semigroup over S.

Remark 3.4 Not every soft set over an inverse semigroup *S* will be a soft inverse semigroup over *S*. It can be shown by an example.

Example 3.5 If $S = \{e, a, b, c\}$is an inverse semigroup with Cayley's table given above and let $G: S \rightarrow P(S)$defined by $G(x) = \{y \in S: y = x\}$.
Then $((G, S)$ is a soft set over *S*, but not a soft inverse semigroup over *S* because $G(a) = a$ is not an inverse subsemigroup of *S*.

Proposition 3.6 Let (F, A) and (G, B) be two soft inverse semigroups over S such that $A \cap B \neq \emptyset$. Then their restricted intersection $(F, A) \cap_R (G, B)$ is a soft inverse semigroup over S.
Proof. By definition$(H, C) = (F, A) \cup_R (G, B)$, where $C = A \cap B \neq \emptyset$ and $H(e) = F(e) \cap G(e)$ for all$e \in C$. As $F(e)$ and $G(e)$ are inverse subsemigroups of S, $H(e)$ is either empty or an inverse subsemigroup of S. Consequently (H, C) is a soft inverse semigroup over S.

Proposition 3.7 Let (F, A) and (G, B) be two soft inverse semigroups over S. Then their extended intersection $(F, A) \cap_E (G, B)$ is a soft inverse semigroup over S.
Proof. By definition $(H, C) = (F, A) \cap_E (G, B)$, where $C = A \cup B$ and

$$H(e) = \begin{cases} F(e) & if\ e \in A - B \\ G(e) & if\ e \in B - A \\ F(e) \cap G(e) & if\ e \in A \cap B \end{cases}$$

For all $e \in C$. As$F(e)$ and $G(e)$ are inverse subsemigroups of S, $H(e)$ is an inverse subsemigroup of S. Consequently (H, C) is a soft inverse semigroup over S.

Proposition 3.8 Let (F, A) and (G, B) be two soft inverse semigroups over S such that $A \cap B = \emptyset$. Then their extended union $(F, A) \cup_E (G, B)$ is a soft inverse semigroup over S.

Proof. By definition$(H,C)=(F,A)\cup_E (G,B)$, where $C=A\cap B\neq\emptyset$. Then for all $e\in C$, either $e\in A-B$ or $e\in B-A$.If $e\in A-B$, $H(e)=F(e)$ and if $e\in B-A$, $H(e)=G(e)$.In both cases $H(e)$ is an inverse subsemigroup of S. Hence(H,C) is a soft inverse semigroup over S.

Proposition 3.9 Let (F,A) and (G,B) be two soft inverse semigroups over S.Then $(F,A)\cap(G,B)$ is a soft inverse semigroup over S.
Proof. By definition $(H,C)=(F,A)\cap(G,B)$ where $C=A\times B$ and $H(a,b)=F(a)\cap G(b)$ for all $(a,b)\in A\times B$. As $F(a)$ and $G(b)$ are inverse subsemigroups of S, $H(a,b)$ is either empty or an inverse subsemigroup of S. Hence(H,C) is a soft inverse semigroup over S.

4. SOFT INVERSE SUBSEMIGROUPS

Definition 4.1 Let $(\mathrm{F},\mathrm{A})$and (G,B)be two soft inverse semigroups over S.Then(G,B) is a soft inverse subsemigroup of (F,A)if

1.$B\subseteq A$ and
2.$G(b)$ is a inverse subsemigroup of $F(b)$for all$b\in B$.

Example 4.2. Let $M(P)$be the set of all partial one-one mappings on the set$P=\{a,b\}$.
Then$M(P)=\{A,B,C,D,E,F,\emptyset\}$ where $A=\{(a,a)\},B=\{(a,b)\},C=\{(b,b)\}$,
$D=\{(b,a)\},E=\{(a,a),(b,b)\},F=\{(a,b),(b,a)\}$ and $\emptyset$ is the empty relation.
Define the binary operation on $M(P)$as the usual composition of binary relations.
Then $M(P)$ is an inverse semigroup with $A^{-1}=A,B^{-1}=D,C^{-1}=C,D^{-1}=B$,
$E^{-1}=E,F^{-1}=F,\emptyset^{-1}=\emptyset$.
Define $F:M(P)\to P(M(P))$ by
$F(A)=\{A\},F(B)=\{B,D\}=F(D),F(C)=\{C,B,D\},F(E)=\{E\},F(\emptyset)=\{\emptyset\}$.
Then $\left(F,M(P)\right)$ is a soft inverse semigroup.
Let $M'(P)=\{A,C,\emptyset\}$. Define $G:M'(P)\to P(M'(P))$ by $G(A)=\{A\},G(C)=\{C\},G(\emptyset)=\{\emptyset\}$
Then $(\mathrm{G},\mathrm{M'}(\mathrm{P}))$ is a soft inverse subsemigroup of $(\mathrm{F},\mathrm{M}(\mathrm{P}))$.

Theorem 4.3 Let (F,A)be a soft inverse semigroup over S and $\{(H_i,A_i):i\in I\}$ be a non empty family of soft inverse subsemigroups of (F,A). Then their extended intersection $\cap_E (H_i,A_i)$ is a soft inverse subsemigroup of (F,A) over *S*.
Proof. Let $\{(\mathrm{H_i},\mathrm{A_i}):\mathrm{i}\in\mathrm{I}\}$ be a non empty family of soft inverse subsemigroups of(F,A) . Then their extended intersection $\cap_E (H_i,A_i)$ is denoted by $\cap_E (H_i,A_i)=(H,C)$ where $C=\cup A_i$ and for all$i\in I$, is defined as $H(e)=\begin{cases} H_i(e) & if\ e\in A_i-A_j\ for\ all\ i,j\in I\\ \cap H_i(e) & if\ e\in\cap A_i\ for\ all\ i,j\in I\end{cases}$
Each $H_i(e)$is an inverse subsemigroup of $F(e)$ for all $e\in A_i-A_j\ for\ all\ i,j\in I\ and\ i\neq j$.Also $\cap H_i(e)$is an inverse subsemigroup of $F(e)$ for all $e\in\cap A_i$.This implies that $H(e)$ is an inverse subsemigroup for all $e\in C$.Thus(H,C) is a soft inverse subsemigroup of (F,A) over S.

Theorem 4.4 Let (F,A)be a soft inverse semigroup over S and $\{(H_i,A_i):i\in I\}$ be a non empty family of soft inverse subsemigroups of (F,A). Then their restricted intersection $\cap_R (H_i,A_i)$ is a soft inverse subsemigroup of (F,A) over *S*.

Proof. Let $\{(H_i, A_i): i \in I\}$ be a non empty family of soft inverse subsemigroups of (F, A) . Then their restricted intersection $\cap_R (H_i, A_i)$ is denoted by $\cap_R (H_i, A_i) = (H, C)$ where $C = \cap A_i$ and for all $i \in I$, is defined as $H(e) = \cap H_i(e) for\ all\ e \in C$.
Each $H_i(e)$ is an inverse subsemigroup of $F(e)$ for all $e \in C$. Also $\cap H_i(e)$ is an inverse subsemigroup of $F(e)$ for all $e \in \cap A_i$. This implies that $H(e)$ is an inverse subsemigroup for all $e \in C$. Thus (H, C) is a soft inverse subsemigroup of (F, A) over S.

Theorem 4.5 Let (F, A) be a soft inverse semigroup over S and $\{(H_i, A_i): i \in I\}$ be a non empty family of soft inverse subsemigroups of (F, A). Then their extended union $\cup_E (H_i, A_i)$ is a soft inverse subsemigroup of (F, A) over *S*.
Proof. Let $\{(H_i, A_i): i \in I\}$ be a non empty family of soft inverse subsemigroups of (F, A) . Then their extended intersection $\cup_E (H_i, A_i)$ is denoted by $\cup_E (H_i, A_i) = (H, C)$ where $C = \cup A_i$ and for all $i \in I$, is defined as $H(e) = H_i(e)\ if\ e \in A_i - A_j\ for\ all\ i, j \in I$
Each $H_i(e)$ is an inverse subsemigroup of $F(e)$ for all $e \in A_i - A_j\ for\ all\ i, j \in I\ and\ i \neq j$. This implies that $H(e)$ is an inverse subsemigroup for all $e \in C$. Thus (H, C) is a soft inverse subsemigroup of (F, A) over S.

Theorem 4.6 Let (F, A) be a soft inverse semigroup over S and $\{(H_i, A_i): i \in I\}$ be a non empty family of soft inverse subsemigroups of (F, A). Then $\times_{i \in I} (H_i, A_i)$ is a soft inverse subsemigroup of (F, A) over *S*.
Proof. Let $\{(H_i, A_i): i \in I\}$ be a non empty family of soft inverse subsemigroups of (F, A) . Then $\times_{i \in I} (H_i, A_i)$ is denoted by $\times_{i \in I} (H_i, A_i) = (H, C)$ where $C = \times_{i \in I} A_i$, is defined as $H(a_1, a_2, \ldots) = \cap H_i(a_i)\ if\ (a_1, a_2, \ldots) \in \times_{i \in I} A_i$, .
Each $H_i(a_i)$ is an inverse subsemigroup of $F(e)$ for all $e \in C$. Also $\cap H_i(a_i)$ is an inverse subsemigroup of $F(e)$. Thus (H, C) is a soft inverse subsemigroup of (F, A) over S.

5. SOFT INVERSE SEMIGROUP AND SOFT GROUP

Here we have the relation connecting soft inverse semigroup and soft group.

Definition 5.1[1] Let (F, A) is a soft set over a group G. Then (F, A) is called a soft group over G if for each $a \in A$, $F(a) \neq \emptyset$ is a subgroup of G.

Proposition 5.2[13] Groups are precisely the inverse semigroups with exactly one idempotent.

Theorem 5.3 Let (F, A) be a soft inverse semigroup over S. Then (F, A) is a soft group if and only if $F(a)$ contains exactly one idempotent, for all $a \in A$.
Proof. Let (F, A) be a soft group. Then $F(a)$ is a subgroup of S for all $a \in A$. Then for all $a \in A$, $F(a)$ has a unique idempotent, which is the identity of $F(a)$.
Conversely suppose (F, A) is a soft inverse semigroup and $F(a)$ contains exactly one idempotent, for all $a \in A$. In particular let $x \in F(a)$. Thus $xx^{-1} = x^{-1}x = e$(say). Then $ex = xx^{-1}x = x$ and $xe = xx^{-1}x = x$. So $F(a)$ is a subgroup with identity e. Hence each $F(a)$ is a subgroup and so (F, A) is a soft group.

Theorem 5.4. Every soft group is a soft inverse semigroup.
Proof. Let(F, A) be a soft group. Then $F(a)$ is a subgroup of S for all $a \in A$.
Since every group is an inverse semigroup the theorem holds.

6. SOFT INVERSE SEMIGROUP HOMOMORPHISM

Definition 6.1 Let $(\mathrm{F}, \mathrm{A})$and (H, B)be two soft inverse semigroups over $\mathrm{S}_1$and S_2respectively. Let $\mathrm{f}: \mathrm{S}_1 \rightarrow \mathrm{S}_2$ and $\mathrm{g}: \mathrm{A} \rightarrow \mathrm{B}$. Then $(\mathrm{f}, \mathrm{g})$is said to be a soft inverse semigroup homomorphism if

1)f is an epimorphism from S_1ontoS_2,
2) g is a surjective mapping from A onto B,
3)$\mathrm{f}(\mathrm{F}(\mathrm{x})) = \mathrm{H}(\mathrm{g}(\mathrm{x}))$for all $\mathrm{x} \in \mathrm{A}$.

Then $(\mathrm{F}, \mathrm{A})$is said to be a soft homomorphic to $(\mathrm{H}, \mathrm{B})$and it is denoted by $(\mathrm{F}, \mathrm{A}) \simeq (\mathrm{H}, \mathrm{B})$
If f is an isomorphism from $\mathrm{S}_1$to S_2 and g is a bijection from A to B, then $(\mathrm{f}, \mathrm{g})$is said to be a soft inverse semigroup isomorphism and we say (F, A) is soft isomorphic to $(\mathrm{H}, \mathrm{B})$and it is denoted by$(\mathrm{F}, \mathrm{A}) \cong (\mathrm{H}, \mathrm{B})$.

Theorem 6.2. Let (F, A) and(G, B) be two soft inverse semigroups over S and (G, B)a soft inverse subsemigroup of (F, A) . Define $\mathrm{f}(\mathrm{F})(\mathrm{a}) = \mathrm{f}(\mathrm{F}(\mathrm{a}))$ for all $a \in A$. If f is a homomorphism from semigroup S to a semigroup T, then $(f(\mathrm{F}), \mathrm{A})$ and $(f(\mathrm{G}), \mathrm{B})$ are both soft inverse semigroups over T and $(f(\mathrm{G}), \mathrm{B})$ is a soft inverse subsemigroup of $(f(\mathrm{F}), \mathrm{A})$.
Proof. Since f is a homomorphism from S to T, $f(F(a))$ and $f(G(b))$ are inverse subsemigroups of T. Hence $(f(\mathrm{F}), \mathrm{A})$ and $(f(\mathrm{G}), \mathrm{B})$ are both soft inverse semigroups over T. Now as $G(b)$ is an inverse subsemigroup of $F(b)$, $f(G(b))$ is an inverse subsemigroup of $f(F(b))$. Therefore by definition $(f(\mathrm{G}), \mathrm{B})$ is a soft inverse subsemigroup of $(f(\mathrm{F}), \mathrm{A})$

Theorem 6.3. Let (F, A) and(G, B) be two soft inverse semigroups over T and(G, B) a soft inverse subsemigroup of (F, A) . Define $f^{-1}(F)(a) = f^{-1}(F(a))$ for all $a \in A$. If f is a homomorphism from semigroup S to a semigroup T, then $(f^{-1}(F), A)$ and $(f^{-1}(G), B)$ are both soft inverse semigroups over S and $(f^{-1}(G), B)$ is a soft inverse subsemigroup of $(f^{-1}(F), A)$.
Proof. Since f is a homomorphism from S to T, $f^{-1}(F(a))$ and $f^{-1}(G(b))$ are inverse subsemigroups of S. Hence $(f^{-1}(F), A)$ and $(f^{-1}(G), B)$ are both soft inverse semigroups over S. Now as $G(b)$ is an inverse subsemigroup of $F(b)$, $f^{-1}(G(b))$ is an inverse subsemigroup of $f^{-1}(F(b))$.Therefore by definition $(f^{-1}(G), B)$ is a soft inverse subsemigroup of $(f^{-1}(F), A)$.

Theorem 6.4. Let (F, A) and (H, B)be soft inverse semigroups over inverse semigroups S and T respectively, and (f, g)be a soft inverse semigroup homomorphism from (F, A) onto $H, B)$. Then $(f, g)(F, A)$ is a soft inverse semigroup over T.
Proof. Since (F, A) is a soft inverse semigroup over S, the nonempty set $F(a)$ is an inverse subsemigroup of S for all $a \in A$. Also f is a homomorphism from S to T. Therefore $f(F(a))$ is an inverse subsemigroup over T. Hence by definition $(f(F), B)$is a soft inverse semigroup over T.

Theorem 6.5. Let (F, A) and (H, B)be soft inverse semigroups over inverse semigroups S and T respectively, and(f, g) be a soft inverse semigroup homomorphism from (F, A) onto (H, B). Then$(f, g)^{-1}(H, B)$ is a soft inverse semigroup over S.

Proof. Since$(H, B$ is a soft inverse semigroup over T, the nonempty set $H(b)$ is an inverse subsemigroup of T for all $b \in B$. Also f is a homomorphism from S to T. Therefore $f^{-1}(H(b))$ is an inverse subsemigroup over S. Hence by definition $(f, g)^{-1}(H, B)$ is a soft inverse semigroup over S.

CONCLUSION

Soft set theory, proposed by Molodtsov, has been regarded as an effective mathematical tool to deal with uncertainty. We applied the algebraic properties of soft sets in inverse semigroups. We discussed the notions of soft inverse semigroups, soft inverse subsemigroup and soft homomorphism over inverse semigroups. By using soft set theory, we can consider further algebraic structures of soft inverse semigroups. The theory of soft algebraic structure has applications in soft computing and information science.

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