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Characterization of Quotient Multi-Fuzzy Subgroup

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Abstract: In this paper we define a new algebraic structure of quotient multi-fuzzy subgroup of a group and some of its properties under homomorphism and anti-homomorphism are investigated. The purpose of this study is to implement the fuzzy set theory and group theory in multi-fuzzy set. Characterization of quotient multi-fuzzy subgroup of a group is given.

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Key Words: Fuzzy set, multi-fuzzy set, fuzzy subgroup, multi-fuzzy subgroup, multi-fuzzy coset

I. INTRODUCTION

L.A.Zadeh [9] introduced the theory of fuzzy set in 1965. Rosenfeld [6] introduced fuzzy subgroups in 1971. P.S.Das[2] studied the inter-relationship between the fuzzy subgroup and its level subgroups in 1981. Mukharjee and Bhattacharya [4] proposed the concept of normal fuzzy subgroups and fuzzy cosets in 1984. S.Sabu and T.V.Ramakrishnan[7, 8] proposed the theory of multi-fuzzy set in terms of multi-dimensional membership functions and investigated some properties of multi-level fuzziness in 2010 and 2011. R.Muthuraj and S.Balamurugan[5] proposed the inter-relationship between the multi-fuzzy subgroup and its level subgroups in 2013. Several researchers N.Ajmal [1], Kumar I.J., Saxena P.K., and Yadav P. [3], etc., are developed the concept of fuzzy normal subgroup and fuzzy quotient group. In this paper we define a new algebraic structure of multi-fuzzy quotient group of a group and also establish some of its related properties.

II. PRELIMINARIES

In this section, we site the fundamental definitions that will be used in the sequel.

A. Definition 2.1

Let X be any non-empty set. A fuzzy subset μ of X is $\mu : X \rightarrow [0,1]$.

B. Definition 2.2

Let X be a non-empty set. A multi-fuzzy set A in X is defined as a set of ordered sequences: $A = \{ (x, \mu_1(x), \mu_2(x), \dots, \mu_k(x), \dots) : x \in X \}$, where $\mu_i : X \rightarrow [0,1]$ for all i .

C. Remark 2.3

- 1) If the sequences of the membership functions have only k -terms (finite number of terms), then k is called the dimension of A
- 2) The multi-fuzzy membership function μ_A is a function from X to $[0, 1]^k$ such that for all x in X , $\mu_A(x) = (\mu_1(x), \mu_2(x), \dots, \mu_k(x))$
- 3) For the sake of simplicity, we denote the multi-fuzzy set $A = \{ (x, \mu_1(x), \mu_2(x), \dots, \mu_k(x)) : x \in X \}$ as $A = (\mu_1, \mu_2, \dots, \mu_k)$.

D. Definition 2.4

Let k be a positive integer and let A and B be two multi-fuzzy subsets of a non-empty set X , where $A = (\mu_1, \mu_2, \dots, \mu_k)$ and $B = (v_1, v_2, \dots, v_k)$, then we have the following relations and operations:

- 1) $A \subseteq B$ if and only if $\mu_i \leq v_i$, for all $i = 1, 2, \dots, k$;
- 2) $A = B$ if and only if $\mu_i = v_i$, for all $i = 1, 2, \dots, k$;
- 3) $A \cup B = (\mu_1 \cup v_1, \dots, \mu_k \cup v_k) = \{ (x, \max(\mu_1(x), v_1(x)), \dots, \max(\mu_k(x), v_k(x))) : x \in X \}$;
- 4) $A \cap B = (\mu_1 \cap v_1, \dots, \mu_k \cap v_k) = \{ (x, \min(\mu_1(x), v_1(x)), \dots, \min(\mu_k(x), v_k(x))) : x \in X \}$;

E. Definition 2.5

Let $A = (\mu_1, \mu_2, \dots, \mu_k)$ be a multi-fuzzy subset of X having dimension k and let μ_i' be the fuzzy complement of the ordinary fuzzy set μ_i for each $i = 1, 2, \dots, k$. The complement of a multi-fuzzy set A is a multi-fuzzy set $A^C = (\mu_1', \mu_2', \dots, \mu_k')$ where each $\mu_i' = 1 - \mu_i$ for $i = 1, 2, \dots, k$. That is, $A^C = \{(x, 1 - \mu_1(x), \dots, 1 - \mu_k(x)) : x \in X\}$.

F. Definition 2.6

Let μ be a fuzzy set on a group G . Then μ is said to be a fuzzy subgroup of G if

- 1) $\mu(xy) \geq \min \{\mu(x), \mu(y)\}$ and
- 2) $\mu(x^{-1}) = \mu(x)$.

G. Definition 2.7

A multi-fuzzy set A of a group G is called a multi-fuzzy subgroup of G iff for all $x, y \in G$,

- 1) $A(xy) \geq \min \{A(x), A(y)\}$ and
- 2) $A(x^{-1}) = A(x)$.

H. Definition 2.8

Let A be a multi-fuzzy subgroup of a group G . For any $a \in G$, define $(aA)(x) = A(a^{-1}x)$ for all $x \in G$ is called a multi-fuzzy coset of a multi-fuzzy subgroup A of the group G determined by the element $a \in G$.

I. Remark 2.9

If $a = e$ in G , then the multi-fuzzy coset $aA = A$, where A is a multi-fuzzy subgroup of group G .

III. PROPERTIES OF MULTI-FUZZY QUOTIENT GROUP \overline{A} OF A GROUP G DETERMINED BY A AND K

In this section, we discuss some of the properties of multi-fuzzy quotient group \overline{A} of a group G determined by A and K .

A. Theorem 3.1

Let A be a normal multi-fuzzy subgroup of a group G with identity e . Let

$$K = \{ x \in G / A(x) = A(e) \}. \text{ Consider}$$

$\overline{A} = (\overline{A}_1, \overline{A}_2, \overline{A}_3, \dots, \overline{A}_k)$ which is defined by

$$\overline{A}(xK) = \sup_{k \in K} A(xk), \text{ for all } x \in G, \text{ where each } \overline{A}_i : G/K \rightarrow [0,1]. \text{ Then}$$

- 1) K is a normal subgroup of G
- 2) The multi-fuzzy set \overline{A} is well-defined
- 3) \overline{A} is a multi-fuzzy subgroup of G/K .
- 4) *Proof:* Given A is a normal multi-fuzzy subgroup of G and
- a) $K = \{ x \in G / A(x) = A(e) \}$. Let $x \in G$ and $y \in K$. Then $A(y) = A(e)$.

Since A is a normal multi-fuzzy subgroup of G , $A(xy^{-1}) = A(y) = A(e)$. Hence, $xy^{-1} \in K$. Hence, $K = \{ x \in G / A(x) = A(e) \}$ is a normal subgroup of G .

- b) Consider $\overline{A} = (\overline{A}_1, \overline{A}_2, \overline{A}_3, \dots, \overline{A}_k)$ which is defined by $\overline{A}(xK) = \sup_{k \in K} A(xk)$, for all $x \in G$, where each $\overline{A}_i : G/K \rightarrow [0,1]$.

Let $xK = yK$ for some $x, y \in G$.

Then $xy^{-1} \in K$.

That is, $A(xy^{-1}) = A(e)$.

That is, $\overline{A}(xK) = \overline{A}(yK)$.

Hence, the map \overline{A} is well-defined.

$$\text{Now, } \overline{A}(xKyK) = \overline{A}(xyK)$$

$$\begin{aligned}
 &= \sup_{k \in K} A(xyk), \text{ for all } x, y \in G. \\
 &\geq \sup_{k_1, k_2 \in K} \{ \min\{A(xk_1), A(yk_2)\} \}. \\
 &\geq \min\{ \sup_{k_1 \in K} A(xk_1), \sup_{k_2 \in K} A(yk_2) \}. \\
 &\geq \min\{ \bar{A}(xK), \bar{A}(yK) \}. \\
 \bar{A}(xKyK) &\geq \min\{ \bar{A}(xK), \bar{A}(yK) \}. \\
 \bar{A}((xK)^{-1}) &= \bar{A}(x^{-1}K) \\
 &= \sup_{k \in K} A(x^{-1}k), \text{ for all } x \in G. \\
 &= \sup_{k \in K} A(xk), \text{ for all } x \in G. \\
 &= \bar{A}(xK). \\
 \bar{A}((xK)^{-1}) &= \bar{A}(xK).
 \end{aligned}$$

Hence, \bar{A} is a multi-fuzzy subgroup of G/K .

B. Definition 3.2

Let A be a normal multi-fuzzy subgroup of a group G with the identity element 'e'. Let $K = \{ x \in G / A(x) = A(e) \}$. Consider $\bar{A} = (\bar{A}_1, \bar{A}_2, \bar{A}_3, \dots, \bar{A}_k)$ which is defined by $\bar{A}(xK) = \sup_{k \in K} A(xk)$, for all $x \in G$ where each $\bar{A}_i : G/K \rightarrow [0,1]$. Then the multi-fuzzy subgroup \bar{A} of G/K is called a multi-fuzzy quotient group or quotient multi-fuzzy subgroup of A by K .

C. Remarks 3.3

- 1) \bar{A} is not a normal multi-fuzzy quotient group of G/K , Since, $\bar{A}(xKyK) \neq \bar{A}(yKxK)$.
- 2) Consider $\bar{A} = (\bar{A}_1, \bar{A}_2, \bar{A}_3, \dots, \bar{A}_k)$ which is defined by $\bar{A}(xK) = A(x)$, for all $x \in G$, where each $\bar{A}_i : G/K \rightarrow [0,1]$. Then \bar{A} is a normal multi-fuzzy quotient group of G/K .

D. Theorem 3.4

$\bar{A} = (\bar{A}_1, \bar{A}_2, \bar{A}_3, \dots, \bar{A}_k)$ is a multi-fuzzy quotient group of a group G/K iff each $\bar{A}_i, i = 1, 2, \dots, k$, is a fuzzy quotient group of a group G/K .

- 1) *Proof:* Let $\bar{A} = (\bar{A}_1, \bar{A}_2, \bar{A}_3, \dots, \bar{A}_k)$ be a multi-fuzzy quotient group of a group G/K . Then,
 - $\Leftrightarrow \bar{A}(xyK) \geq \min\{ \bar{A}(xK), \bar{A}(yK) \}$ and $\bar{A}(x^{-1}K) = \bar{A}(xK)$.
 - $\Leftrightarrow \bar{A}_i(xyK) \geq \min\{ \bar{A}_i(xK), \bar{A}_i(yK) \}$ and $\bar{A}_i(x^{-1}K) = \bar{A}_i(xK)$, for all $i = 1, 2, \dots, k$.
 - $\Leftrightarrow \bar{A}_i, i = 1, 2, \dots, k$, is a fuzzy quotient group of a group G/K .

E. Remark 3.5

If $\bar{A} = (\bar{A}_1, \bar{A}_2, \bar{A}_3, \dots, \bar{A}_k)$ is not a multi-fuzzy quotient group of a group G/K , then there is atleast one $\bar{A}_i, i=1,2,\dots,k$, is not a fuzzy quotient group of a group G/K .

F. Theorem 3.6

If \bar{A} is a multi-fuzzy quotient group of a group G/K , then $\bar{A}(xK) \leq \bar{A}(eK)$, for all $x \in G$, where e is the identity element of G .

1) *Proof:* Let the element $x \in G$, where e is the identity element of G .

$$\begin{aligned} \text{Now, } \bar{A}(eK) &= \bar{A}(xx^{-1}K) \\ &\geq \min\{ \bar{A}(xK), \bar{A}(x^{-1}K) \} \\ &= \bar{A}(xK). \end{aligned}$$

Therefore, $\bar{A}(eK) \geq \bar{A}(xK)$, for all $x \in G$.

G. Theorem 3.7

\bar{A} is a multi-fuzzy quotient group of a group G/K if and only if

$\bar{A}(xKy^{-1}K) \geq \min\{ \bar{A}(xK), \bar{A}(yK) \}$, for all x and y in G .

1) *Proof:* Assume that \bar{A} is a multi-fuzzy quotient group of a group G/K .

$$\begin{aligned} \text{We have, } \bar{A}(xKy^{-1}K) &\geq \min\{ \bar{A}(xK), \bar{A}(y^{-1}K) \} \\ &\geq \min\{ \bar{A}(xK), \bar{A}(yK) \} \end{aligned}$$

Therefore, $\bar{A}(xKy^{-1}K) \geq \min\{ \bar{A}(xK), \bar{A}(yK) \}$, for all x and y in G .

Conversely, if $\bar{A}(xKy^{-1}K) \geq \min\{ \bar{A}(xK), \bar{A}(yK) \}$, then

$$\begin{aligned} \bar{A}(x^{-1}K) &= \bar{A}(ex^{-1}K) \\ &\geq \min\{ \bar{A}(eK), \bar{A}(xK) \} \\ &= \bar{A}(xK). \end{aligned}$$

Therefore, $\bar{A}(x^{-1}K) \geq \bar{A}(xK)$, for all x in G .

Hence, $\bar{A}((x^{-1})^{-1}K) \geq \bar{A}(x^{-1}K)$ and $\bar{A}(xK) \geq \bar{A}(x^{-1}K)$.

herefore, $\bar{A}(x^{-1}K) = \bar{A}(xK)$, for all x in G .

Now, replace y by y^{-1} , then

$$\begin{aligned} \bar{A}(xyK) &= \bar{A}(x(y^{-1})^{-1}K) \\ &\geq \min\{ \bar{A}(xK), \bar{A}(y^{-1}K) \} \\ \bar{A}(xyK) &\geq \min\{ \bar{A}(xK), \bar{A}(yK) \}, \text{ for all } x \text{ and } y \text{ in } G. \end{aligned}$$

Hence, \bar{A} is a multi-fuzzy quotient group of a group G/K .

H. Theorem 3.8

If \bar{A} and \bar{B} are two multi-fuzzy quotient groups of a group G/K , then $\bar{A} \cap \bar{B}$ is a multi-fuzzy quotient group of G/K .

1) *Proof:* It is trivial.

I. Remark 3.9

The intersection of a family of multi-fuzzy quotient groups of a group G/K , is a multi-fuzzy quotient group of a group

G/K .

IV. PROPERTIES OF MULTI-FUZZY QUOTIENT GROUP \overline{A} DETERMINED BY A AND K UNDER HOMOMORPHISM AND ANTI-HOMOMORPHISM

In this section, we discuss some of the properties of multi-fuzzy quotient group of a group G/K determined by A and K under homomorphism and anti-homomorphism.

A. Theorem 4.1

Let G and G' be any two groups. Let f: G → G' be a homomorphism and onto. Let \overline{A} be a multi-fuzzy quotient group of G/K . Then $f(\overline{A})$ is a multi-fuzzy quotient group of G'/K' , if \overline{A} has sup property and \overline{A} is f-invariant and $f(\overline{A}) = \overline{f(A)}$.

1) *Proof:* Let \overline{A} be a multi-fuzzy quotient group of G/K .

$$\begin{aligned}
 f(\overline{A})(f(x)f(y)K) &= (f(\overline{A}))(f(xy)K) \\
 &= \overline{A}(xyK) \\
 &\geq \min\{\overline{A}(xK), \overline{A}(yK)\} \\
 &= \min\{(f(\overline{A}))(f(x)K), (f(\overline{A}))(f(y)K)\} \\
 f(\overline{A})(f(x)f(y)K) &\geq \min\{(f(\overline{A}))(f(x)K), (f(\overline{A}))(f(y)K)\}. \\
 f(\overline{A})([f(x)]^{-1}K) &= f(\overline{A})[f(x^{-1})K] \\
 &= \overline{A}(x^{-1}K) \\
 &= \overline{A}(xK) \\
 &= f(\overline{A})[f(x)K] \\
 f(\overline{A})([f(x)]^{-1}K) &= f(\overline{A})[f(x)K].
 \end{aligned}$$

Hence, $f(\overline{A})$ is a multi-fuzzy quotient group of G'/K' .

$$\begin{aligned}
 \text{Also, } \overline{f(A)}(yK) &= \sup_{k \in K} f(A)(yk), \text{ for all } y \in G'. \\
 &= \sup_{k \in K} f(A)(f(x)k), \text{ f is onto and } x \in G. \\
 &= \sup_{k \in K} A(xk), \text{ for all } x \in G \\
 &= \overline{A}(xK) \\
 &= f(\overline{A})(f(x)K) \\
 &= f(\overline{A})(yK).
 \end{aligned}$$

$$\text{Hence, } \overline{f(A)}(yK) = f(\overline{A})(yK).$$

B. Theorem 4.2

Let G and G' be any two groups. Let f: G → G' be a homomorphism. Let \overline{B} be a multi-fuzzy quotient group of G'/K' . Then $f^{-1}(\overline{B})$ is a multi-fuzzy quotient group of G/K and $f^{-1}(\overline{B}) = \overline{f^{-1}(B)}$.

1) *Proof:* Let \overline{B} be a multi-fuzzy quotient group of G'/K' . For all x, y in G,

$$f^{-1}(\overline{B})(xyK) = \overline{B}(f(xy)K)$$

$$\begin{aligned}
 &= \overline{B}(f(x)f(y)K) \\
 &\geq \min\{\overline{B}(f(x)K), \overline{B}(f(y)K)\} \\
 &\geq \min\{f^{-1}(\overline{B})(xK), f^{-1}(\overline{B})(yK)\}. \\
 &\geq \min\{f^{-1}(\overline{B})(xK), f^{-1}(\overline{B})(yK)\}. \\
 &= \overline{B}(f(x^{-1})K) \\
 &= \overline{B}((f(x))^{-1}K) \\
 &= \overline{B}(f(x)K) \\
 &= f^{-1}(\overline{B})(xK).
 \end{aligned}$$

That is, $f^{-1}(\overline{B})(xyK)$

$$f^{-1}(\overline{B})(x^{-1}K)$$

That is, $f^{-1}(\overline{B})(x^{-1}K)$

Hence, $f^{-1}(\overline{B})$ is a multi-fuzzy quotient group of G/K .

$$\begin{aligned}
 \text{Also, } \overline{f^{-1}(B)}(xK) &= \sup_{k \in K} f^{-1}(B)(xk), \text{ for all } x \in G. \\
 &= \sup_{k \in K} B(f(x)k), \text{ for all } x \in G. \\
 &= \overline{B}(f(x)K) \\
 &= f^{-1}(\overline{B})(xK).
 \end{aligned}$$

$$\text{Hence, } \overline{f^{-1}(B)}(xK) = f^{-1}(\overline{B})(xK).$$

C. Theorem 4.3

Let G and G' be any two groups. Let $f: G \rightarrow G'$ be an anti-homomorphism and onto. Let \overline{A} be a multi-fuzzy quotient group of G/K . Then $f(\overline{A})$ is a multi-fuzzy quotient group of G'/K' , if \overline{A} has sup property and \overline{A} is f -invariant and $f(\overline{A}) = \overline{f(A)}$.

1) Proof: Let \overline{A} be a multi-fuzzy quotient group of G/K .

$$\begin{aligned}
 \text{if } \overline{A}(f(x)f(y)K) &= (f(\overline{A}))(f(yx)K) \\
 &= \overline{A}(yxK) \\
 &\geq \min\{\overline{A}(yK), \overline{A}(xK)\} \\
 &\geq \min\{\overline{A}(xK), \overline{A}(yK)\} \\
 &= \min\{(f(\overline{A}))(f(x)K), (f(\overline{A}))(f(y)K)\} \\
 f(\overline{A})(f(x)f(y)K) &\geq \min\{(f(\overline{A}))(f(x)K), (f(\overline{A}))(f(y)K)\}. \\
 f(\overline{A})([f(x)]^{-1}K) &= f(\overline{A})([f(x^{-1})]K) \\
 &= \overline{A}(x^{-1}K) \\
 &= \overline{A}(xK) \\
 &= f(\overline{A})(f(x)K). \\
 f(\overline{A})([f(x)]^{-1}K) &= f(\overline{A})(f(x)K).
 \end{aligned}$$

Hence, $f(\overline{A})$ is a multi-fuzzy quotient group of G'/K' .

$$\text{Also, } \overline{f(A)}(yK) = \sup_{k \in K} f(A)(yk), \text{ for all } y \in G'.$$

$$\begin{aligned}
 &= \sup_{k \in K} \overline{f(A)(f(x)k)}, f \text{ is onto and } x \in G. \\
 &= \sup_{k \in K} \overline{f(A)(xk)}, \text{ for all } x \in G. \\
 &= \overline{A}(xK) \\
 &= f(\overline{A})(f(x)K) \\
 &= f(\overline{A})(yK). \\
 \text{Hence, } \overline{f(A)}(yK) &= f(\overline{A})(yK).
 \end{aligned}$$

D. Theorem 4.4

Let G and G' be any two groups. Let $f: G \rightarrow G'$ be an anti-homomorphism. Let \overline{B} be a multi-fuzzy quotient group of G'/K' .

Then $f^{-1}(\overline{B})$ is a multi-fuzzy quotient group of G/K and $f^{-1}(\overline{B}) = \overline{f^{-1}(B)}$.

Let \overline{B} be a multi-fuzzy quotient group of G'/K' .

$$\begin{aligned}
 f^{-1}(\overline{B})(xyK) &= \overline{B}(f(xy)K) \\
 &= \overline{B}(f(y)f(x)K) \\
 &\geq \min\{\overline{B}(f(y)K), \overline{B}(f(x)K)\} \\
 &\geq \min\{\overline{B}(f(x)K), \overline{B}(f(y)K)\} \\
 &\geq \min\{f^{-1}(\overline{B})(xK), f^{-1}(\overline{B})(yK)\}. \\
 f^{-1}(\overline{B})(xyK) &\geq \min\{f^{-1}(\overline{B})(xK), f^{-1}(\overline{B})(yK)\}. \\
 f^{-1}(\overline{B})(x^{-1}K) &= \overline{B}(f(x^{-1})K) \\
 &= \overline{B}((f(x))^{-1}K) \\
 &= \overline{B}(f(x)K) \\
 &= f^{-1}(\overline{B})(xK). \\
 f^{-1}(\overline{B})(x^{-1}K) &= f^{-1}(\overline{B})(xK).
 \end{aligned}$$

Hence, $f^{-1}(\overline{B})$ is a multi-fuzzy quotient subgroup of G/K .

$$\begin{aligned}
 \text{Also, } \overline{f^{-1}(B)}(xK) &= f^{-1}(B)(xk), \text{ for all } x \in G. \\
 &= \sup_{k \in K} \overline{f^{-1}(B)(f(x)k)}, \text{ for all } x \in G. \\
 &= \overline{B}(f(x)K) \\
 &= f^{-1}(\overline{B})(xK). \\
 \text{Hence, } \overline{f^{-1}(B)}(xK) &= f^{-1}(\overline{B})(xK).
 \end{aligned}$$

V. CONCLUSION

In this paper we define a new algebraic structure of multi-fuzzy quotient group of a group and discussed some of its related properties under homomorphism and anti-homomorphism. These are very helpful to the development of the theory of multi-fuzzy set. The purpose of this study is to implement the fuzzy set theory and the group theory in multi-fuzzy set. Characterization of multi-fuzzy quotient group of a group are given.

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