On $(M, Q, G\zeta^*)$-Open Functions in $\mathcal{M}$-Structures

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Abstract. The purpose of this paper is to give a new type of open function and closed function called $(M, Q, G\zeta^*)$-open function and $(M, Q, G\zeta^*)$-closed function. Also, we obtain its characterizations and its basic properties.

Keywords. $(M, Q, G\zeta^*)$- Open function, $(M, Q, G\zeta^*)$ - Closed function.

I. Introduction

Njastad [11] initiated the concept of nearly open sets in topological spaces. Semi-open sets, pre-open sets, α-open sets, β-open sets and δ-open sets play an important role in the research of generalizations of open functions in topological spaces. By using these sets, several authors introduced and studied various types of modifications of open functions in topological spaces.

In 2000, V.Popa and T.Noiri [16] introduced the notion of minimal structure. Also they introduce the notion of m_X-open sets and m_X-closed sets and characterized those sets using m_X-closure and m_X-interior respectively. Further they introduced m -continuous functions and studied some of its basic properties. V.Popa and T.Noiri [14] obtained the definitions and characterizations of separation axioms by using the concept of minimal structures.They achieved many important results compatible by the general topology case. Some other results about minimal spaces can be found in [1], [2], [3], [9], [10], [12] and [13].

Already we introduce the paper, On Quasi $g\zeta^*$-open functions in topological spaces [5] and also Kokilavani V [6] et all. introduce $\mathcal{M}_X G\zeta^*$- closed set. In this paper we introduced the Minimal structure on Quasi $G\zeta^*$-open functions in topological spaces and also we obtain its characterizations and its basic properties.

II. PRELIMINARIES

In this section, we introduce the minimal quasi function namely $(M, Q, G\zeta^*)$ and define some important subsets associated to the $\mathcal{M}$-structure and the relation between them.

Definition 2.1. [8]

Let X be a nonempty set and let $m_x \subseteq P(X)$, where $P(X)$ denote the power set of X where m_x is an $\mathcal{M}$-structure (or a minimal structure) on X, if φ and X belong to m_x.

The members of the minimal structure m_x are called m_x-open sets, and the pair (X, m_x) is called an m-space. The complement of m_x-open set is said to be m_x-closed.

Definition 2.2. [8]

Let X be a nonempty set and m_x an $\mathcal{M}$-structure on X. For a subset A of X, m_x-closure of A and m_x-interior of A are defined as follows:

$m_x\text{-}cl(A) = \cap\{F : A \subseteq F, X\text{-}F \in m_x\}$

$m_x\text{-}int(A) = \cup\{F : U \subseteq A, U \in m_x\}$

Lemma 2.3.[8]

Let X be a nonempty set and m_x an $\mathcal{M}$-structure on X. For subsets A and B of X, the following properties hold:

(a) $m_x\text{-}cl(X - A) = X - m_x\text{-}int(A)$ and $m_x\text{-}int(X - A) = X - m_x\text{-}cl(A)$.

(b) If $X - A \in m_x$, then $m_x\text{-}cl(A) = A$ and if $A \in m_x$ then $m_x\text{-}int(A) = A$.

(c) $m_x\text{-}cl(\varphi) = \varphi, m_x\text{-}cl(X) = X and\, m_x\text{-}int(\varphi) = \varphi, m_x\text{-}int(X) = X$.

(d) If $A \subset B$ then $m_x\text{-}cl(A) \subseteq m_x\text{-}cl(B)$ and $m_x\text{-}int(A) \subseteq m_x\text{-}int(B)$.

(e) $A \subseteq m_x\text{-}cl(A)$ and $m_x\text{-}int(A) \subseteq A$.

(f) $m_x\text{-}cl(m_x\text{-}cl(A)) = m_x\text{-}cl(A)$ and $m_x\text{-}int(m_x\text{-}int(A)) = m_x\text{-}int(A)$.

(g) $m_x\text{-}int(A \cap B) = (m_x\text{-}int(A)) \cap (m_x\text{-}int(B))$ and

$(m_x\text{-}int(A)) \cup (m_x\text{-}int(B)) \subseteq m_x\text{-}int(A \cup B)$.

(h) $m_x\text{-}cl(A \cup B) \subseteq (m_x\text{-}cl(A)) \cup (m_x\text{-}cl(B))$ and

$m_x\text{-}cl(A \cap B) \subseteq (m_x\text{-}cl(A)) \cap (m_x\text{-}cl(B))$.

Lemma 2.4.[10]

Let (X, m_x) be an m-space and A be a subset of X. Then $x \in m_x\text{-}cl(A)$ if and only if $U \cap A \neq \varphi$ for every $U \in m_x$ containing x.

Definition 2.5. [16]

A minimal structure m_X on a nonempty set X is said to have the property $\mathcal{B}$ if the union of any family of subsets belonging to m_X belongs to m_X.

Remark 2.6. A minimal structure m_X with the property $\mathcal{B}$ coincides with a generalized topology on the sense of Lugojan.

Lemma 2.7. [2]

Let X be a nonempty set and m_X an $\mathcal{M}$-structure on X satisfying the property $\mathcal{B}$. For a subset A of X, the following property hold:

(a) $A \in m_X$ iff $m_X - int(A) = A$.

(b) $A \in m_X$ iff $m_X - cl(A) = A$.

(c) m_X-$int(A) \in m_X$ and m_X-$cl(A) \in m_X$.

Definition 2.8.[7]

Let X be a nonempty set and m_X an $\mathcal{M}$-structure on X. For a subset A of X, $\mathcal{M}_X G\zeta^*$-closure of A and $\mathcal{M}_X G\zeta^*$-interior of A are defined as follows:

$\mathcal{M}_X Cl_{G\zeta^*}(A) = \cap\{F : A \subseteq F, F is \mathcal{M}_X G\zeta^*\text{-}closed in X\}$

$\mathcal{M}_X Int_{G\zeta^*}(A) = \cup\{F : U \subseteq A, U is \mathcal{M}_X G\zeta^*\text{-}open in X\}$

Definition 2.9.

A subset A of an m-space (X, m_X) is called as

(i) mg-closed set [17] if m_X-$cl(A) \subset G$ whenever $A \subset G$ and G is m_X-open.

(ii) $m_X g^{\#}\alpha$-closed set [6] if $\alpha mcl(A) \subseteq U$ whenever $A \subset U$ and U is mg-open in X.

(iii) $m_X^{\#} g\alpha$-closed set [6] if $\alpha mcl(A) \subseteq U$ whenever $A \subset U$ and U is $m_X g^{\#}\alpha$-open in X.

(iv) $\mathcal{M}_X G\zeta^*$-closed set [6] if $\alpha mcl(A) \subseteq U$ whenever $A \subset U$ and U is $m_X^{\#} g\alpha$-open in X.

The complement of $\mathcal{M}_X G\zeta^*$-closed set is called as $\mathcal{M}_X G\zeta^*$-open set.

Definition 2.10.

A function $f:(X, m_X) \to (Y, m_Y)$ is called as

(i) $\mathcal{M}_X G\zeta^*$-continuous [6] if $f^{-1}(V)$ is a $\mathcal{M}_X G\zeta^*$-closed set in (X, m_X) for every m_Y-closed set V of (Y, m_Y).

(ii) $\mathcal{M}_X G\zeta^*$-irresolute [6] if $f^{-1}(V)$ is a $\mathcal{M}_X G\zeta^*$-closed set in (X, m_X) for every $\mathcal{M}_X G\zeta^*$-closed set V of (Y, m_Y).

III. $(M,Q,G\zeta^*)$-OPEN FUNCTIONS AND $(M,Q,G\zeta^*)$-CLOSED FUNCTIONS

We have introduce the following definition:

Definition 3.1.

A function $f:(X,m_X) \to (Y,m_Y)$ is said to be $(M,Q,G\zeta^*)$-open if the image of every $\mathcal{M}_X G\zeta^*$-open set in X is m_X-open in Y.

Example 3.2.

Let $X = Y = \{a,b,c\}$ with $m_X = \{X,\varphi,\{a\}\}$ and $m_Y = \{X,\varphi,\{a\},\{a,b\},\{a,c\},\{b,c\}\}$ be the

m-space on (X,m_X) and (Y,m_Y) respectively. Here $\mathcal{M}_X g\zeta^*$-open set in (X,m_X) is $\{X,\varphi,\{a\},\{a,c\},\{a,b\}\}$ and m_X-open set in (Y,m_Y) is $\{Y,\varphi,\{a\},\{a,c\},\{a,b\},\{b,c\}\}$. Define a function $f:(X,m_X) \to (Y,m_Y)$ by $f(a) = a, f(b) = b$ and $f(c) = c$, then f is $(M,Q,G\zeta^*)$-open function. Since the image of each $(M,Q,G\zeta^*)$-open set in (X,m_X) is m_X-open set in (Y,m_Y).

Definition 3.3.

A function $f:(X,m_X) \to (Y,m_Y)$ is said to be $\mathcal{M}_X G\zeta^*$-open if the image of every m_X-open set in X is $\mathcal{M}_X G\zeta^*$-open in Y.

Theorem 3.4.

A function $f:(X,m_X) \to (Y,m_Y)$ is said to be $(M,Q,G\zeta^*)$-open if and only if for every subset U of X, $f(\mathcal{M}_X Int_{G\zeta^*}(U)) \subset m_X$-$int(f(U))$

Proof:

Let f be a $(M,Q,G\zeta^*)$-open function. Now, we have m_X-$int(U) \subset U$ and $\mathcal{M}_X Int_{G\zeta^*}(U)$ is a $\mathcal{M}_X G\zeta^*$-open set. Hence, we obtain that $f(\mathcal{M}_X Int_{G\zeta^*}(U)) \subset f(U)$. As $f(\mathcal{M}_X Int_{G\zeta^*}(U))$ is open, $f(\mathcal{M}_X Int_{G\zeta^*}(U)) \subset m_X$-$int(f(U))$.

Conversely, assume that U is a $\mathcal{M}_X G\zeta^*$-open set in X. Then $f(U) = f(\mathcal{M}_X Int_{G\zeta^*}(U)) \subset m_X$-$int(f(U))$ but m_X-$int(f(U)) \subset f(U)$. Consequently $f(U) = m_X$-$int(f(U))$ and hence f is $(M,Q,G\zeta^*)$-open.

Lemma 3.5.

If a function $f:(X,m_X) \to (Y,m_Y)$ is $(M,Q,G\zeta^*)$-open, then $(\mathcal{M}_X Int_{G\zeta^*}(f^{-1}(G)) \subset f^{-1}(m_X$-$int(G)$ for every subset G of Y.

Proof:

Let G be any arbitrary subset of Y. Then, $(\mathcal{M}_X Int_{G\zeta^*}(f^{-1}(G))$ is a $\mathcal{M}_X G\zeta^*$-open set in X and f is $(M,Q,G\zeta^*)$-open, then $f(\mathcal{M}_X Int_{G\zeta^*}(f^{-1}(G))) \subset m_X int(f(f^{-1}(G))) \subset m_X int(G)$ Thus $(\mathcal{M}_X Int_{G\zeta^*}(f^{-1}(G)) \subset f^{-1}(m_X int(G))$.

Definition 3.6.

A subset S is said to be an $\mathcal{M}_X G\zeta^*$-neighbourhood of a point x of X if there exists a $\mathcal{M}_X G\zeta^*$-open set U such that $x \in U \subset S$.

Lemma 3.7.

Let $f:(X,m_X)\to(Y,m_Y)$ and $g:(Y,m_Y)\to(Z,m_Z)$ be two functions and $g\circ f:(X,m_X)\to(Z,m_Z)$ is $(M,Q,G\zeta^*)$-open. If g is continuous injective, then f is $(M,Q,G\zeta^*)$-open.

Proof:

Let U be a $(M,Q,G\zeta^*)$-open set in X, then $(g\circ f)(U)$ is m_X-open in Z. Since $g\circ f$ is $(M,Q,G\zeta^*)$-open. Again g is an injective continuous function, $f(U)=g^{-1}(g\circ f)(U)$ is m_X-open in Y. This shows that f is $(M,Q,G\zeta^*)$-open.

Theorem 3.8.

If $f:(X,m_X)\to(Y,m_Y)$ and $g:(Y,m_Y)\to(Z,m_Z)$ are two $(M,Q,G\zeta^*)$ -open functions, then $g\circ f:(X,m_X)\to(Z,m_Z)$ is a

$(M,Q,G\zeta^*)$-open function.

Proof:

Let F be any $\mathcal{M}_XG\zeta^*$-open set in X, since f is $(M,Q,G\zeta^*)$-open function, $f(F)$ is a m_X-open set in Y, we know that every m_X -open set is $\mathcal{M}_XG\zeta^*$ -open set[6], $f(F)$is an $\mathcal{M}_XG\zeta^*$-open set. Since g is a $(M,Q,G\zeta^*)$-open function, $g(f(F))$ is m_X -open in Z. That is $(g\circ f)(F)=g(f(F))$ is m_X-open set in Z and hence $g\circ f$ is a $(M,Q,G\zeta^*)$-open function.

Definition 3.9.

A function $f:(X,m_X)\to(Y,m_Y)$is called $(M,Q^*,G\zeta^*)$-open function if the image of every $\mathcal{M}_XG\zeta^*$-open subset of X is $\mathcal{M}_XG\zeta^*$-open in Y.

Therorem 3.10.

Let $f:(X,m_X)\to(Y,m_Y)$ and $g:(Y,m_Y)\to(Z,m_Z)$ be any two functions. Then

(i) If f is $\mathcal{M}_XG\zeta^*$-open and g is $(M,Q,G\zeta^*)$-open, then $g\circ f$ is m_X-open function.

(ii) If f is $(M,Q,G\zeta^*)$-open function and g is $\mathcal{M}_XG\zeta^*$-open function, then $g\circ f$ is $(M,Q^*,G\zeta^*)$-open function.

(iii) If f is $(M,Q^*,G\zeta^*)$-open function and g is $(M,Q,G\zeta^*)$-open function, then $g\circ f$ is $(M,Q,G\zeta^*)$-function.

Proof:

(i) Let F be any m_X-open set in X, since f is $\mathcal{M}_XG\zeta^*$-open function, $f(F)$ is a $\mathcal{M}_XG\zeta^*$-open set in Y. Since g is a $(M,Q,G\zeta^*)$-open function, $g(f(F))$ is m_X-open set in Z. That is $(g\circ f)(F)=g(f(F))$ is m_X-open set in Z and hence $g\circ f$ is a m_X-open function.

(ii) Let F be any $\mathcal{M}_XG\zeta^*$-open set in X, since f is $(M,Q,G\zeta^*)$-open function, $f(F)$ is a m_X-open set in Y. Since g is a $\mathcal{M}_XG\zeta^*$-open function, $g(f(F))$ is $\mathcal{M}_XG\zeta^*$-open set in Z. That is $(g\circ f)(F)=g(f(F))$ is $\mathcal{M}_XG\zeta^*$-open set in Z and hence $g\circ f$ is a $(M,Q^*,G\zeta^*)$-open function.

(iii) Let F be any $\mathcal{M}_X G\zeta^*$ -open set in X, since f is $(M, Q^*, G\zeta^*)$ -open function, $f(F)$ is a $\mathcal{M}_X G\zeta^*$ -open set in Y. Since g is a $(M, Q, G\zeta^*)$-open function, $g(f(F))$ is m_Z-open set in Z. That is $(g \circ f)(F) = g(f(F))$ is m_Z-open set in Z and hence $g \circ f$ is a $(M, Q, G\zeta^*)$-open function.

Definition 3.11.

A function $f:(X, m_X) \to (Y, m_Y)$ is said to be $(M, Q, G\zeta^*)$-closed if the image of each $\mathcal{M}_X G\zeta^*$-closed set in X is m_X-closed in Y.

Example 3.12.

Let $X = Y = \{a, b, c\}$ with $m_X = \{X, \varphi, \{a\}\}$ and $m_Y = \{X, \varphi, \{a\}, \{a, b\}, \{a, c\}, \{b, c\}\}$ be the m-space on (X, m_X) and (Y, m_Y) respectively. Here $\mathcal{M}_X G\zeta^*$ -closed set in (X, m_X) is $\{X, \varphi, \{b\}, \{c\}, \{b, c\}\}$ and m_Y-closed set in (Y, m_Y) is $\{Y, \varphi, \{a\}, \{b\}, \{c\}, \{b, c\}\}$. Define a function $f:(X, m_X) \to (Y, m_Y)$ by $f(a) = a, f(b) = b$ and $f(c) = c$, then f is $(M, Q, G\zeta^*)$-closed function. Since the image of each $(M, Q, G\zeta^*)$-closed set in (X, m_X) is m_X-closed set in (Y, m_Y).

Definition 3.13.

A function $f:(X, m_X) \to (Y, m_Y)$ is said to be $\mathcal{M}_X G\zeta^*$-closed if the image of every m_X-closed set in X is $\mathcal{M}_X G\zeta^*$-closed in Y.

Lemma 3.14.

If a function $f:(X, m_X) \to (Y, m_Y)$ is $(M, Q, G\zeta^*)$-closed function, then $f^{-1}(m_X int(A)) \subset (\mathcal{M}_X Int_{G\zeta^*}(f^{-1}(A))$ for every subset A of Y.

Proof.

This proof is similar to the proof of Lemma 3.5.

Definition 3.15.

A function $f:(X, m_X) \to (Y, m_Y)$ is called $(M, Q^*, G\zeta^*)$-closed functionif the image of every $\mathcal{M}_X G\zeta^*$-closed subset of X is $\mathcal{M}_X G\zeta^*$-closed in Y.

Theorem 3.16.

If $f:(X, m_X) \to (Y, m_Y)$ and $g:(Y, m_Y) \to (Z, m_Z)$ are two $(M, Q, G\zeta^*)$ -closed functions, then $g \circ f:(X, m_X) \to (Z, m_Z)$ is a $(M, Q, G\zeta^*)$-closed function.

Proof.

Let F be any $\mathcal{M}_xG\zeta^*$-closed set in X, since f is $(M,Q,G\zeta^*)$-closed function, $f(F)$ is a m_y -closed set in Y , we know that every m_y -closed set is $\mathcal{M}_xG\zeta^*$-closed set[6], $f(F)$ is an $\mathcal{M}_xG\zeta^*$-closed set. Since g is a $(M,Q,G\zeta^*)$-closed function, $g(f(F))$ is m_x -closed in Z . That is $(g\circ f)(F)=g(f(F))$ is m_x-closed set in Z and hence $g\circ f$ is a $(M,Q,G\zeta^*)$-closed function.

Theorem 3.17.

Let $f:(X,m_x)\to(Y,m_y)$ and $g:(Y,m_y)\to(Z,m_z)$ be any two functions. Then

(i) If f is $\mathcal{M}_xG\zeta^*$-closed function and g is $(M,Q,G\zeta^*)$-closed function, then $g\circ f$ is m_x-closed function.

(ii) If f is $(M,Q,G\zeta^*)$-closed function and g is $\mathcal{M}_xG\zeta^*$-closed function, then $g\circ f$ is $(M,Q^*,G\zeta^*)$-closed function.

(iii) If f is $(M,Q^*,G\zeta^*)$-closed function and g is $(M,Q,G\zeta^*)$-closed function, then $g\circ f$ is $(M,Q,G\zeta^*)$-closed function.

Proof.

(i) Let F be any m_x-closed set in X, since f is $\mathcal{M}_xG\zeta^*$-closed function, $f(F)$ is a $\mathcal{M}_xG\zeta^*$-closed set in Y. Since g is a $(M,Q,G\zeta^*)$-closed function, $g(f(F))$ is m_x-closed set in Z. That is $(g\circ f)(F)=g(f(F))$ is m_x closed set in Z and hence $g\circ f$ is a m_x closed function.

(ii) Let F be any $\mathcal{M}_xG\zeta^*$-closed set in X, since f is $(M,Q,G\zeta^*)$-closed function, $f(F)$ is a m_x-closed set in Y. Since g is a $\mathcal{M}_xG\zeta^*$-closed function, $g(f(F))$ is $\mathcal{M}_xG\zeta^*$-closed set in Z. That is $(g\circ f)(F)=g(f(F))$ is $\mathcal{M}_xG\zeta^*$-closed set in Z and hence $g\circ f$ is a $(M,Q^*,G\zeta^*)$-closed function.

(iii) Let F be any $\mathcal{M}_xG\zeta^*$ -closed set in X , since f is $(M,Q^*,G\zeta^*)$-closed function, $f(F)$ is a $\mathcal{M}_xG\zeta^*$ -closed set in Y . Since g is a $(M,Q,G\zeta^*)$-closed function, $g(f(F))$ is m_x-closed set in Z. That is $(g\circ f)(F)=g(f(F))$ is m_x -closed set in Z and hence $g\circ f$ is a $(M,Q,G\zeta^*)$-closed function.

Theorem 3.18.

Let $f:(X,m_x)\to(Y,m_y)$ and $g:(Y,m_y)\to(Z,m_z)$ be any two functions such that $g\circ f:(X,m_x)\to(Z,m_z)$ is $(M,Q,G\zeta^*)$-closed.

(i) If f is $\mathcal{M}_xG\zeta^*$-irresolute surjective, then g is m_x-closed.

(ii) If g is $\mathcal{M}_xG\zeta^*$-continuous injective, then f is $(M,Q^*,G\zeta^*)$-closed.

Proof. (i) Suppose that F is an arbitrary m_x-closed set in Y. As f is $\mathcal{M}_xG\zeta^*$-irresolute, $f^{-1}(F)$ is $\mathcal{M}_xG\zeta^*$ -closed in X. Since $g\circ f$ is $(M,Q,G\zeta^*)$-closed and f is surjective, $\left(g\circ f(f^{-1}(F))\right)=g(F)$, which is m_x-closed in Z. This implies that g is a m_x-closed function.

(ii) Suppose F is any $\mathcal{M}_xG\zeta^*$-closed set in X. Since $g\circ f$ is $(M,Q,G\zeta^*)$-closed, $(g\circ f)(F)$ is m_x closed in Z Again g is a $\mathcal{M}_xG\zeta^*$-continuous injective function, $g^{-1}(g\circ f(F))=f(F)$, which is $\mathcal{M}_xG\zeta^*$-closed in Y. This shows that f is $(M,Q^*,G\zeta^*)$-closed.

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