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H-G-Spaces and H-Limit sets

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ABSTRACT

This paper develops a generalisation of the classical Cartan G-space within the framework of H-topology, a setting introduced by Fadhil to broaden the notion of openness in topological spaces. Building on H-open sets, H-continuous functions, H-irresolute maps, and H-compact spaces, we introduce H-thin sets and H-Cartan G-spaces. We further define two types of H-limit sets, denoted $\Lambda^H(x)$ and $J^H(x)$, for an arbitrary point x in a G-space, and we establish several characterisation theorems relating these sets to the orbit structure and the H-Cartan property. Concrete examples are provided throughout to illustrate each concept and to demonstrate that the inclusion $\Lambda^H(x), J^H(x)$ can be strict.

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1. Introduction

One of the very important concepts in topological groups is the concept of group actions and there are several types of these actions. This paper studies an important class of actions namely, H- Cartan G – space. Let B be a subset of a topological space (X, T) . We denote the closure of A and the interior of A by $\overline{A}$ and A° , Fadhil [4],[5] introduced new types of open sets, which he defined as follows, a subset A of the topological space (X, T) is called H-open set if for every non- empty set U in $X, U \neq X$ and $U \in T, A \subseteq \text{int}(A \cup U)$. The complement of the H-open set is called H-closed. We denoted the family of all H-open set of a topological space (X, T) by T^H . They also introduced function $f: (X, T) \rightarrow (Y, \tau)$ is said to be H-continuous if the preimage of every open set in Y is H-open in X , and is said to be H-irresolute if the preimage of every H-open set in Y is H-open in X . Shallu S. et al. [7] extended these ideas to H-irresolute topological vector spaces, whose techniques we generalize here to the setting of group actions. Building on all these contributions, Zahra A.S. and Ahmed T.H. in [8] adopted the concepts introduce H-proper functions, which directly motivates the present paper. We introduce some definitions, remarks, propositions and theorems which are needed in the next sections, including H-thin sets and some of their properties, then we present a new definition for a new type of G-space which we called H-Cartan G-space and we

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also study the properties of that space, then we present the definition of H-limit set $\Lambda^H(x)$ and $J^H(x)$ and study the properties of these sets and the relationship between them and the H-Cartan G-space.

1.1 Remark [5]:

Let X be a space and $A \subseteq X, x \in X$ then:

- (i) Every neighborhood subset of a space X is H-neighborhood.
- (ii) Let (X, T) be a topological space and $A \subseteq X, x \in X$. Then A is H-neighborhood of x in X if and only if A is neighborhood of x in (X, T^H) .
- (iii) A is H-open if and only if it is an H-neighborhood of its points.
- (iv) A topological space X is completely regular if whenever F is a closed set in X and $x \in X, x \notin F$, there is a continuous function $f: X \rightarrow [0, 1]$, such that $f(x) = 0$ and $f(F) = 1$.
- (v) In every completely regular space X and every point $x \in X$ has a sequence $\{U_n\}_{n \in \mathbb{Z}^+}$ of open neighborhood such that $U_{n+1} \subseteq U_n \dots$ and $\bigcap_{n \in \mathbb{Z}^+} U_n = \{x\}$.

1.2 Remark[5]:

- (i) A function $f: (X, T) \rightarrow (Y, \tau)$ is H-continuous function if and only if $f: (X, T^H) \rightarrow (Y, \tau)$ is continuous.
- (ii) A function $f: (X, T) \rightarrow (Y, \tau)$ is H-irresolute function if and only if $f: (X, T^H) \rightarrow (Y, \tau^H)$ is continuous.

1.3 Theorem [1]:

Let X and Y be spaces, and $f: X \rightarrow Y$ be a function, $x \in X$. then f is continuous at x if and only if whenever a net (χ_d) in X and $\chi_d \alpha x$, then $f(\chi_d) \alpha f(x)$ in Y .

1.4 Proposition[1]:

- (i) Let (X, T) be a space, $x \in X$ and $A \subseteq X$. then $x \in \bar{A}$ if and only if there exist is a net $(\chi_d)_{d \in D}$ in A such that $\chi_d \alpha x$.
- (ii) Let X be a space and A be a subset of $X, x \in X$. then $x \in \bar{A}$ if and only if there is a net in A which converges to x .

1.5 Remark[8]:

Let (X, T) be a space, then:

- (i) Every H-limit point is limit point
- (ii) Every H-cluster point is cluster point
- (iii) if (χ_d) is a net in $X, x \in X$. then $\chi_d \xrightarrow{H} x$ in (X, T) if and only if $\chi_d \rightarrow x$ in (X, T^H) , and $\chi_d \alpha^H x$ in (X, T) if and only if $\chi_d \alpha x$ in (X, T^H) .

1.6 Proposition:

Let $f: X \rightarrow Y$ be a function, $x \in X$. Then:

- (i) f is H-continuous at x if and only if whenever a net $(\chi_d)_{d \in D}$ in X and $\chi_d \xrightarrow{H} x$ then $f(\chi_d) \rightarrow f(x)$.
- (ii) f is H-irresolute at x if and only if whenever a net $(\chi_d)_{d \in D}$ in X and $\chi_d \xrightarrow{H} x$ then $f(\chi_d) \xrightarrow{H} f(x)$.

Proof:

- (i) $\Rightarrow$ Let $x \in X$ and $(\chi_d)_{d \in D}$ be a net in X such that $\chi_d \xrightarrow{H} x$ [To prove that $f(\chi_d) \rightarrow f(x)$]. Let V be a open neighborhood of $f(x)$. Since f is H-continuous, then $f^{-1}(V)$ is H-neighborhood of x , but $\chi_d \xrightarrow{H} x$, then there is $\beta \in D$ such that $\chi_d \in f^{-1}(V), \forall d \geq \beta$. Then $f(\chi_d) \in f(f^{-1}(V)) \subseteq V$. Thus $f(\chi_d)$ is eventually in every open neighborhood of $f(x)$ then $f(\chi_d) \rightarrow f(x)$.
 $\Leftarrow$ Suppose that f is not H-continuous. Then there exists $x \in X$ such that f is not H-continuous at x . Then there exists an open set B in Y such that $f(x) \in B$ and $f(A) \not\subseteq B$ for each A is an H-open in X such

that $x \in A$. Thus there exists $\chi_A \in A$ and $f(\chi_A) \notin B$ for each A is H -open in X . Since $N_H(x)$ is a directed set. Then $(\chi_A)_{A \in N_H(x)}$ is a net in X and $\chi_A \xrightarrow{H} x$. But $f(\chi_A) \notin B$ for each $A \in N_H(x)$, then $f(\chi_A) \not\rightarrow f(x)$ and this is a contradiction. Then f is H -continuous.

- (ii) $\Rightarrow$ Let $x \in X$ and $(\chi_d)_{d \in D}$ be a net in X such that $\chi_d \xrightarrow{H} x$. Then by Remark (1.4.iii) $\chi_d \rightarrow x$ in (X, T^H) . Since $f: (X, T) \rightarrow (Y, \tau)$ is H -irresolute (Y, τ) , then by Remark (1.2.ii) $f: (X, T^H) \rightarrow (Y, \tau^H)$ is continuous. Thus by Theorem (1.3) $f(\chi_d) \rightarrow f(x)$ in (Y, τ^H) , so by Remark (1.5.iii) $f(\chi_d) \xrightarrow{H} f(x)$
 $\Leftarrow$ By Remark (1.5.iii) and Remark (1.2.ii) we have $f: (X, T^H) \rightarrow (Y, \tau^H)$ is continuous. Then f is H -irresolute.

1.7 Theorem:

Let $(\chi_d)_{d \in D}$ be a net in a space (X, T) and x_0 in X . Then $\chi_d \alpha^H x_0$ if and only if there exists a subnet $(\chi_{dm})_{dm \in D}$ of $(\chi_d)_{d \in D}$ such that $\chi_{dm} \xrightarrow{H} x_0$.

Proof:

$\Rightarrow$ Let $(\chi_{dm})_{dm \in D}$ such that $\chi_d \alpha^H x_0$ in (X, T) . Then by Remark (1.5.iii) $\chi_d \alpha x_0$ in (X, T^H) , so by Proposition (1.4.ii) there exists a subnet $(\chi_{dm})_{dm \in D}$ of $(\chi_d)_{d \in D}$ such that $\chi_d \rightarrow x_0$ in (X, T^H) . Then by Remark (1.5.iii) $\chi_d \xrightarrow{H} x_0$.

$\Leftarrow$ By same way we will proof only if part.

1.8 Proposition:

Let G be a topological group and $(g_d)_{d \in D}$ be a net in G . Then:

- (i) If $g_d \xrightarrow{H} e$, then $g_d g \xrightarrow{H} g$ (or $g_d g \xrightarrow{H} g$) for each $g \in G$.
(ii) If $g_d \xrightarrow{H} \infty$, then $g_d g \xrightarrow{H} \infty$ (or $g_d g \xrightarrow{H} \infty$) for each $g \in G$.
(iii) If $g_d \xrightarrow{H} \infty$, then $g_d^{-1} \xrightarrow{H} \infty$.

Proof:

- (i) Since $r_g: G \rightarrow G$ is continuous and open, where r_g is right translation by g . Then r_g H -irresolute. Thus by Proposition (1.6.ii) $g_d g \xrightarrow{H} g$ for each $g \in G$.
(ii) Let $g_d \xrightarrow{H} \infty$ and $g \in G$. suppose that $g_d g \xrightarrow{H} g_1$, for some $g_1 \in G$. Since r_g is H -irresolute, then by Proposition (1.6.ii) $r_g^{-1}(g_d g) \xrightarrow{H} r_g^{-1}(g_1)$. Then $g_d \xrightarrow{H} g_1 g^{-1}$, a contradiction. Thus $g_d g \xrightarrow{H} \infty$.
(iii) Let $g_d^{-1} \xrightarrow{H} g$. Since $v: G \rightarrow G$ is H -irresolute, then $g_d \xrightarrow{H} g^{-1}$. Thus if $g_d \xrightarrow{H} \infty$, then $g_d^{-1} \xrightarrow{H} \infty$.

1.9 Proposition [8]:

A space (X, T) is an H -compact space if and only if every net in X has H -cluster point in X .

2. H-cartan G – space and H- limit set of point

2.1 Definition:

Let X be a G – space. A subset A of X is said to be H – thin relative to a subset B of X if the set $((A, B)) = \{g \in G / gA \cap B \neq \emptyset\}$ has an H – neighborhood whose closure is H – compact in G . If A is H – thin relative to itself, then it is called H – thin.

2.2 Remark:

The H – thin sets have the following properties:

- (i) Since $(gA \cap B) = g(A \cap g^{-1}B)$ it follows that if A is H – thin relative to B , then B is H – thin relative to A .
- (ii) Since $(gg_1A \cap g_2B) = g_2(g_2^{-1}g g_1A \cap B)$ it follows that if A is H – thin relative to B , then so are any translates gA and gB .
- (iii) If A and B are H – relative thin and $K_1 \subseteq A$ and $K_2 \subseteq B$, then K_1 and K_2 are H – relatively thin.
- (iv) Let X be a G – space and K_1, K_2 be H – compact subset of X , then $((K_1, K_2))$ is H – closed in G .
- (v) If K_1 and K_2 are H – compact subset of G – space X such that K_1 and K_2 are H – relatively thin, then $((K_1, K_2))$ is an H – compact subset of G .

Proof:

The prove of (i), (ii), (iii) and (v) are obvious.

(iv) Let $g \in \overline{((K_1, K_2))}^H$. Then by Proposition (1.4.ii) there is a net $(g_d)_{d \in D}$ in $((K_1, K_2))$ such that $g_d \xrightarrow{H} g$. Then we have net $(k_d^1)_{d \in D}$ in K_1 such that $g_d k_d^1 \in K_2$, since K_2 is H – compact, then by Theorem (1.7) there exists a subnet $(g_{d_m} k_{d_m}^1)$ of $(g_d k_d^1)$ such that $g_{d_m} k_{d_m}^1 \xrightarrow{H} k_0^2$, where $k_0^2 \in K_2$. But $(k_{d_m}^1)$ in K_1 and K_1 is H – compact, thus there is a point $k_0^1 \in K_1$ and a subnet of $k_{d_m}^1$ say itself such that $k_{d_m}^1 \xrightarrow{H} k_0^1$, Theorem (1.7). Then by Proposition (1.6.ii) $g_{d_m} k_{d_m}^1 \xrightarrow{H} g k_0^1 = k_0^2$, which mean that $g \in ((K_1, K_2))$, therefore $((K_1, K_2))$ is H – closed in G .

2.3 Definition:

A G – space X is said to be an H – Cartan G – space if every point in X has an H – thin H – neighborhood.

2.4 Proposition:

If X is H – Cartan G – space, then each orbit of x is H – closed in X and stabilizer group of G is H – compact.

Proof:

Let $y \in \overline{Gx}^H$. Then there is a net $(y_d)_{d \in D}$ in Gx such that $y_d \xrightarrow{H} y$. Since X is an H – Cartan G – space, then y has H – thin H – neighborhood U . Since $y_d \in Gx$, then there exists a net $(g_d)_{d \in D}$ in G such that $y_d = g_d x$ for each $d \in D$. Fixed d_0 and $(g_d g_{d_0}^{-1})(g_{d_0} x) = g_d x$ so $g_d g_{d_0}^{-1} \in ((U, U))$ and by Proposition (1.9) $g_d g_{d_0}^{-1}$ has H – cluster point g . Then by Proposition (1.7) there exists a subnet of $g_d g_{d_0}^{-1}$, say itself, such that $g_d g_{d_0}^{-1} \xrightarrow{H} g$, then $g_d x \xrightarrow{H} g g_{d_0} x$ and $y = g g_{d_0} x$, so $y \in Gx$. Thus Gx is H – closed in X . Now, let $x \in X$, then there exists an H – thin H – neighborhood V of x . Clearly Gx is H – closed in G and since $Gx \subseteq ((V, V))$, Hence Gx is H – compact.

2.5 Definition:

Let X be a G – space and $x \in X$. Then:

- (i) $\Lambda^H(x) = \{y \in X: \text{there is a net } (g_d)_{d \in D} \text{ in } G \text{ with } g_d \xrightarrow{H} \infty \text{ such that } g_d x \xrightarrow{H} y\}$ is called H -limit set of x .
- (ii) $J^H(x) = \{y \in X: \text{there is a net } (g_d)_{d \in D} \text{ in } G \text{ and there is a net } (\chi_d)_{d \in D} \text{ in } X \text{ with } g_d \xrightarrow{H} \infty \text{ and } \chi_d \xrightarrow{H} x \text{ such that } g_d x \xrightarrow{H} y\}$ is called H - first prolongation limit set of x .

2.6 Proposition:

Let X be a G – space and $x \in X$. Then:

- (i) $\Lambda^H(x)$ and $J^H(x)$ are invariant sets under G .
- (ii) The orbit $\gamma(x)$ is H – closed if and only if $\Lambda^H(x)$ is a subset of $\gamma(x)$.
- (iii) If $x \notin \Lambda^H(x)$, then the stabilizer subgroup G_x of G is H – compact.
- (iv) $\overline{\gamma(x)}^H = \gamma(x) \cup \Lambda^H(x)$
- (v) $y \in J^H(x)$ if and only if $x \in J^H(y)$.
- (vi) If X is discrete G – space, then $\Lambda^H(x) = J^H(x)$ for each $x \in X$.
- (vii) If $x \in J^H(x)$, then for each $y \in \gamma(x)$, $y \in J^H(y)$.
- (viii) If $y \in J^H(x)$, then for each $z \in \gamma(x)$, $y \in J^H(z)$.

(ix) $g\Lambda^H(x) = \Lambda^H(gx) = \Lambda^H(x)$ and $gJ^H(x) = J^H(gx) = J^H(x)$ for each $g \in G$.

Proof:

- (i) Let $y \in \Lambda^H(x)$ and $g \in G$. Then there is a net $(g_d)_{d \in D}$ in G with $g_d \xrightarrow{H} \infty$ and $g_d x \xrightarrow{H} y$. It is clear that $(gg_d)_{d \in D}$ is a net in G with $gg_d \xrightarrow{H} \infty$, Proposition (1.8.ii). Since the action is H - irresolute, thus $(gg_d) \cdot x \xrightarrow{H} gy$ which implies that $gy \in \Lambda^H(x)$ and hence $\Lambda^H(x)$ is invariant. The proof of $J^H(x)$ is similar.
- (ii) $\Rightarrow$ Let $y \in \Lambda^H(x)$, then there is a net $(g_d)_{d \in D}$ in G such that $g_d \xrightarrow{H} \infty$ and $g_d x \xrightarrow{H} y$. Since $g_d x \in \gamma(x)$ and $(g_d x)_{d \in D}$ is a net in $\gamma(x)$, then by Proposition (1.4.ii) $y \in \overline{\gamma(x)}^H$. But $\gamma(x)$ is H - closed then $y \in \gamma(x)$, so $\Lambda^H(x) \subseteq \gamma(x)$.
 $\Leftarrow$ Let $y \in \overline{\gamma(x)}^H$. Then by Proposition (1.4.ii) there exists $(y_d)_{d \in D}$ is a net in $\gamma(x)$ such that $y_d \xrightarrow{H} y$, then $\forall d \in D$ there is $g_d \in G$ such that $y_d = g_d x$. Then $(g_d)_{d \in D}$ is a net in G and $g_d x \xrightarrow{H} y$. Now either $g_d \xrightarrow{H} g$ or $g_d \xrightarrow{H} \infty$. If $g_d \xrightarrow{H} g$ then $g_d x \xrightarrow{H} gx = y$, which implies that $y \in \gamma(x)$. If $g_d \xrightarrow{H} \infty$, then $y \in \Lambda^H(x) \subseteq \gamma(x)$, then $\gamma(x)$ is H - closed.
- (iii) Let $x \notin \Lambda^H(x)$ and suppose that G_x is not H - compact. Then there is a net $(g_d)_{d \in D}$ in G such that $g_d \xrightarrow{H} \infty$. Since $g_d x = x$, i.e. $g_d x \xrightarrow{H} x$ then $x \in \Lambda^H(x)$ which is a contradiction, thus G_x is H - compact.
- (iv) The proof of (iv) is obvious
- (v) Let $y \in J^H(x)$, then there is a net $(g_d)_{d \in D}$ in G with $g_d \xrightarrow{H} \infty$ and there is a net $(\chi_d)_{d \in D}$ in X with $\chi_d \xrightarrow{H} x$ and $g_d \chi_d \xrightarrow{H} y$. Put $y_d = g_d \chi_d \xrightarrow{H} y$. Then by Proposition (1.8.iii) $g_d^{-1} \xrightarrow{H} \infty$ and $g_d^{-1} y_d = g_d^{-1} g_d \chi_d = \chi_d \xrightarrow{H} x$ thus $x \in J^H(y)$. The converse is similar.
- (vi) The proof of (vi) is obvious.
- (vii) Let $x \in J^H(x)$. and $y \in \gamma(x)$. Since $J^H(x)$ is invariant, then for each $y \in \gamma(x)$, $y \in J^H(x)$, therefore $x \in J^H(y)$. (by v) and since $J^H(y)$ is invariant, then $y \in J^H(y)$.
- (viii) Let $y \in J^H(x)$. from (v), $x \in J^H(y)$. Since $J^H(y)$ is invariant, then for each $z \in \gamma(x)$, $z \in J^H(y)$. and by (v) $y \in J^H(z)$ for each $z \in \gamma(x)$.
- (ix) The proof of (ix) is obvious.

2.7 Proposition:

Let X be a G - space. Then X is H - Cartan G - space if and only if $x \notin J^H(x)$. for each $x \in X$.

Proof:

$\Rightarrow$ If X is an H - Cartan G - space. Let $x \in J^H(x)$, then there is a net $(g_d)_{d \in D}$ in G with $g_d \xrightarrow{H} \infty$ and there is a net $(\chi_d)_{d \in D}$ in X with $\chi_d \xrightarrow{H} x$ such that $g_d \chi_d \xrightarrow{H} x$. Since $x \in X$ and X is an H - Cartan G - space, then x has an H - open neighborhood U such that $((U, U))$ is H - relative thin. Then $((U, U))$ is H - relative compact. Thus there is $d \in D$, χ_d and $g_d \chi_d$ are in U . So that g_d is in $((U, U))$. Then $(g_d)_{d \in D}$ contains a convergent subnet, this is contradiction.

$\Leftarrow$ Suppose that X is not an H - Cartan G - space. Then there is a point x in X such that x has no H - neighborhood H - relative thin. Since X is completely regular, then by Remark (1.1.v) the point x has a sequence $\{U_n\}_{n \in \mathbb{Z}^+}$ of an H - open neighborhood such that $U_{n+1} \subset U_n \dots$ and $\bigcap_{n \in \mathbb{Z}^+} U_n = \{x\}$. Then $((U_n, U_n))$ is not H - relative thin. We can choose an H - open neighborhood U of e in G such that $G_x \subseteq U$ and it is H - relative compact. Then there is a sequence $(g_n)_{n \in \mathbb{N}}$ in $((U_n, U_n)) - U$. Since g_n in G then there is a sequence $(\chi_n)_{n \in \mathbb{N}}$ in U_n such that $g_n \chi_n$ is in U_n . Since $\bigcap_{n \in \mathbb{Z}^+} U_n = \{x\}$, then $\chi_n \xrightarrow{H} x$ and $g_n \chi_n \xrightarrow{H} x$. Since $x \notin J^H(x)$, then $(g_n)_{n \in \mathbb{N}}$ has an H - convergent subsequence, say (g_{n_k}) with $g_{n_k} \xrightarrow{H} g$. Thus $g_{n_k} \chi_{n_k} \xrightarrow{H} x$, $\chi_{n_k} \xrightarrow{H} x$ and $g_{n_k} \xrightarrow{H} x$, imply that $x = xg$. Hence g is in G_x and hence g_{n_k} is in U for large n_k and this is contradiction.

2.8 Proposition:

Let X be an H -Cartan G -space, then $\Lambda^H(x) = \phi$, for each $x \in X$.

Proof:

Suppose that there is a point $y \in X$ such that $y \in \Lambda^H(x)$. Then there is a net $(g_d)_{d \in D}$ in G with $g_d \xrightarrow{H} \infty$ such that $g_d x \xrightarrow{H} y$. Let U_y be an H -thin H -neighborhood of y . Then there is $d_0 \in D$ such that $g_d x \in U_y$ for each $d \geq d_0$, we get $g_d g_{d_1}^{-1} g_{d_1} x = g_d x \in U_y$, thus $g_d g_{d_1}^{-1} \in ((U_y, U_y))$ which has H -compact closure. Hence the net $g_d g_{d_1}^{-1}$ has H -convergent subnet, say itself, i.e, there is $g_0 \in G$ such that $g_d g_{d_1}^{-1} \xrightarrow{H} g_0$, then $g_d \xrightarrow{H} g_0 g_{d_1}$, which is a contradiction, therefore $y \notin \Lambda^H(x)$, since y is arbitrary, thus $\Lambda^H(x) = \emptyset$.

2.9 Proposition:

Let X be a G -space if $\Lambda^H(x) = \emptyset$, for each $x \in X$. Then the orbit $\gamma(x)$ is not H -compact.

Proof:

Suppose that $\gamma(x)$ is H -compact. Since $\Lambda^H(x) = \emptyset$, then there is net $(g_d)_{d \in D}$ in G with $g_d \xrightarrow{H} \infty$ $(g_d x)_{d \in D}$ is a net in $\gamma(x)$. Since $\gamma(x)$ is H -compact, then by Proposition (1.9) $g_d x \xrightarrow{H} y$ for some $y \in X$. Hence $y \in \Lambda^H(x)$ which is a

contradiction with $\Lambda^H(x) = \emptyset$ for each $x \in X$.

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