Journal of Engineering and Applied Sciences 13 (24): 10375-10379, 2018
ISSN: 1816-949X

Some Generalized n-Tuplet Coincidence Point Theorems for Nonlinear Contraction Mappings

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Abstract: The purpose this of this study is to introduced a new concepts of generalized n-tupled coincidence point and generalized mixed gT-monotone property. Also, we established the generalized n-tupled coincidence point theorems and we study the existence and uniqueness of generalized n-tupled coincidence point theorems without continuous condition for mappings having generalized mixed gT-monotone property in generalized metric spaces.

Key words: Partially ordered metric spaces, mixed monotone property, n-tupled coincidence point, coupled common fixed point, monotone property, generalized mixed

INTRODUCTION

Bhaskar and Lakshmikantham (2006) introduced mixed monotone and established coupled fixed point theorem for mixed momnotone in partially ordered metric spaces. After their research, many researchers studied about coupled fixed point and fixed point in partially ordered metric spaces (Aydi *et al*., 2011a, b, 2012a-c, Berinde, 2011, 2012; Choudhury and Maity, 2011; Saadati *et al*., 2010; Samet, 2010; Shatanawi *et al*., 2011). Mustafa and Sims (2006) introduced the notion of a G-metric spaces as a generalization of the concept of a metric space, many researchers discussed research on the fixed point theory in par partially ordered G-metric space (Agarwal and Karapinar, 2013; Alghamdi and Karapinar, 2013; Bilgili and Karapinar, 2013; Ding and Karapinar, 2013; Jleli and Samet, 2012; Karapinar and Agarwal, 2013; Mustafa *et al*., 2008, 2009, 2011, 2012, 2013; Roldan *et al*., 2014; Samet *et al*., 2013; Shatanawi, 2010, 2011; Tahat *et al*., 2012).

Aydi *et al*. (2011) established coupled coincidence and coupled common fixed point results for a mixed g-monotone mapping in aipartially ordered G-metric space. As a continuation of this trend, many researchers have studied coupled coincidence point an coupled common fixed point results for a mixed g-monotone mapping in partially ordered G-metric space, for example (Aydi *et al*., 2012a-c; Chandok *et al*., 2013; Cho *et al*., 2012; Choudhury and Kundu, 2010; Karapinar *et al*., 2012; Shatanawi, 2011a, b; Chugh and Rani, 2016). In this study, we introduce the concepts of generalized n-tupled coincidence point and generalized mixed gT-monotone property and we prove the existence and uniqueness of generalized n-tupled coincidence point theorems without continuous condition for mappings having generalized mixed gT-monotone property in generalized metric spaces.

Now, we recall some definitions and properties introduced by Mustafa and Sims (2009) which are useful for the main results in this study.

MATERIALS AND METHODS

Definition (1.1): Let X be a non empty set, $G: X\times X\times X\to R_+$ be a function satisfying:

$$G1.\ G(x, y, z) = 0 \text{ if } x = y = z$$
$$G2.\ 0<G(x, x, y) \text{ for all } x, y \in X \text{ with } x \neq y$$
$$G3.\ G(x, x, y) \leq G(x, y, z) \text{ for all } x, y, z \in X \text{ with } y \neq z$$
$$G4.\ G(x, y, z) = G(x, z, y) = G(y, z, x) = , ..., \text{ (Symmetry in all three variable)}$$
$$G5.\ G(x, y, z) \leq G(x, a, a) + G(a, y, x, z) \text{ for all } x, y, z, a \in X$$

Then the function G is called generalized metric and the pair (X, G) is called a generalized metric space or more specially G-metric space.

Definition (1.2): Let (X, G) be a G-metrici space and let (x_n) be a sequence of points of X. We say that (x_n) is G-convergent to x if $\lim_{n, m\to\infty} G(x, x_n, x_m) = 0$ that is for any

$\varepsilon>0$ there exist $N\in\mathbb{N}$ such that $G(x, x_n, x_m)<\varepsilon$ for all $n, m\geq N$. We call x the limit of sequence and write $x_n\to x$ or $\lim_{n\to\infty} x_n = x$.

Definition (1.3): Let (X, G) be a G-metric space, a sequence (x_n) is called G-cauchy sequence if for any $\varepsilon>0$ there exist $N\in\mathbb{N}$ such that $G(x_n, x_m, x_l)<\varepsilon$ for all $n, m, l\geq N$ that is $G(x_n, x_m, x_l)\to 0$ as $n, m, l\to\infty^+$.

Proposition (1.4): Let (X, G) be a G-metric space. A mapping is called G-continuous at $x\in X$ if and if it is G-sequentially continuous at x that is whenever (x_n) is G-convergent to x then $(f(x_n))$ is G-convergent to f(x).

Proposition (1.5): A G-metric space (X, G) is called G-complete if every G-cauchy sequence is G-convergent in X, G.

RESULTS AND DISCUSSION

Now, we introduce the concept of generalized n-tupled coincidence point and mixed gT-monotone property as follows:

Definition (2.1): Let $(X, \leq)$ be a partially ordered set. If $f: X^n\to X$, $g: X\to X$ are there mappings. An element $(x_1, x_2, ..., x_n)\in X^n$ is called generalized n-tupled coincidence point of f, g and T if:

$$\begin{aligned} f(x_1, x_2, ..., x_n) &= gT(x_1) \\ f(x_2, x_3, ..., x_n, x_1) &= gT(x_2) \\ &\vdots \\ f(x_n, x_1, ..., x_{n-1}) &= gT(x_n) \end{aligned}$$

Remark (2.2): If g is the identity mapping then $(x_1, x_2, \ldots, x_n$ is alled n-tupled concidence point of f and T (Imdad *et al*., 2013). If g and T are the identity mappings then $(x_1, x_2, \ldots, x_n)$ is called n-tupled fixed point of f (Imdad *et al*., 2013).

Definition (2.3): Let $(X, \leq)$ be a partially ordered set. If $f: X^n\to X$ and T, $g: X\to X$ are three mappings, we say that f have mixed gT-monotone property if:

- $f(x_1, x_2, ..., x_n)$ is monotone gT-increasing if n is odd
- $f(x_1, x_2, ..., x_n)$ is monotone gT-decreasing if n is even

That is for each $x_1, x_2, ..., x_n\in X$:

$$\begin{aligned} &y_1, z_1 \in X, \quad gT(y_1)\leq gT(z_1)\Rightarrow \\ &f(y_1, x_2, x_3, \ldots, x_n)\leq f(z_1, x_2, x_3, \ldots, x_n) \\ &y_2, z_2 \in X, gT(y_2)\leq gT(z_2)\Rightarrow \\ &f(x_1, y_2, x_3, \ldots, x_n)\geq f(x_1, z_2, x_3, \ldots, x_n) \\ &\qquad\vdots \\ &y_n, z_n \in X, \quad gT(y_n)\leq gT(z_n)\Rightarrow \\ &f(x_1, x_2, \ldots, y_n)\leq f(x_1, x_2, \ldots, z_n)(\text{if n is odd}) \\ &y_n, z_n \in X, \quad gT(y_n)\leq gT(z_n)\Rightarrow \\ &f(x_1, x_2,\ldots, y_n)\geq f(x_1, x_2, \ldots, z_n)(\text{if n is even}) \end{aligned}$$

Remark (2.4):

- If T is the identity mapping then f has mixed g-monotone property (Chugh and Rani, 2016)
- If T and g are the identity mappings then f is said to have the mixed monotone property

Now, we considered the following is the set of all mappings $\varnothing: [0, \infty)\to[0, \infty)$ increasing mapping such that $\varnothing(t)\leq t\,\forall t>0$:

- $\varnothing(0) = 0$ and $\lim_{n\to 0} \varnothing^n(t) = 0$ where $\varnothing^n$ denotes the n the iterate of $\varnothing$

K is that set of all mappings $f: X^n\to X$ and g, $T: X\to X$ such that:

- $gT(X)$ is complete subspace of X containing $f(X^n)$
- f, T and g are commute and the only g, T are continuous mappings
- f has mixed n-tupled gT-monotone property

Theorem (2.5): Let $(X, G, \leq)$ be a partially ordered generalized metric space, $f: X^n\to X$ and g, $T: X\to X$ are three mappings lies in K and satisfy the equations conditions:

$$\begin{aligned} &\forall\, x_1, x_2, ..., x_n, y_1, y_2, ..., y_n\in X \text{ and } t>0 \\ &G(f(x_1, x_2, \ldots, x_n), f(y_1, y_2, \ldots, y_n), t) \\ &\leq \varnothing\left\{\max\left\{\begin{matrix}\varnothing_1 G(gT(x_1), gT(y_1), t), \varnothing_2 G(gT(x_2), gT(y_2)\ it) \\ , \ldots, \varnothing_n G(gT(x_n), gT(y_n), t)\end{matrix}\right\}\right\} \end{aligned} \tag{1}$$

$$\begin{aligned} &gT(x_0^{\,1})\leq f(x_0^{\,1}, x_0^{\,2}, \ldots, x_0^{\,n}) \\ &gT(x_0^{\,2})\geq f(x_0^{\,2}, x_0^{\,3}, \ldots, x_0^{\,n}, x_0^{\,1}) \\ &\qquad\vdots \\ &gT(x_0^{\,n})\leq f(x_0^{\,n}, x_0^{\,1}, x_0^{\,2}, \ldots, x_0^{\,n-1})\text{if n is odd} \\ &gT(x_0^{\,n})\geq f(x_0^{\,n}, x_0^{\,1}, x_0^{\,2}, \ldots, x_0^{\,n-1})\text{if n is even} \end{aligned} \tag{2}$$

If the following conditions hold:

- Every increasing sequence $<x_n>$ converge tox implies $x_n \leq x \forall n \in N$
- Every decreasing sequence $<y_n>$ iconverge to y implies $y_n \geq y \forall n \in N$

Then f, g and T have an generalized n-tuplet coincidencei point.

Proof: We can constructi sequencesi lies in gT(X)

$$<gT(x_k^1)>, <gT(x_k^2)>, \ldots, <gT(x_k^n)> \in gT(x)$$

Such that:

$$\begin{aligned} &gT(x_k^1) \to r^1 = gT(x^1) \in gT(X) \\ &gT(x_k^2) \to r^2 = gT(x^2) \in gT(X) \\ &\vdots \\ &gT(x_k^n) \to r^n = gT(x^n) \in gT(X) \end{aligned}$$

Considering the hypothesis 1 and 2 give in the theorem, we get:

$$\begin{aligned} &gT(x_k^1) \leq gT(x^1) = r^1 \\ &gT(x_k^2) \geq gT(x^2) = r^2 \\ &\vdots \\ &gT(x_k^n) \leq gT(x^n) = r^n (\text{if } n \text{ is odd}) \\ &gT(x_k^n) \geq gT(x^n) = r^n (\text{if } n \text{ is even}) \end{aligned}$$

Since, g and T are continuous mapping then, we have:

$$\begin{aligned} &gT(gT(x_k^1)) \to gT(r^1) \\ &gT(gT(x_k^2)) \to gT(r^2) \\ &\vdots \\ &gT(gT(x_k^n)) \to gT(r^n) \end{aligned}$$

And hence:

$$\begin{aligned} &gT(gT(x_k^1)) \leq gT(r^1) \\ &gT(gT(x_k^2)) \geq gT(r^2) \\ &\vdots \\ &\vdots \\ &gT(gT(x_k^n)) \leq gT(r^n) \text{ if } n \text{ is odd} \\ &gT(gT(x_k^n)) \geq gT(r^n) \text{ if } n \text{ is even} \end{aligned}$$

Choose t satisfy:

$$\begin{aligned} &G(gT(r^1), f(r^1, r^2, \ldots, r^n), t) \leq \\ &G\left(f(r^1, r^2, \ldots, r^n), t, gT\left(gT(x_{k+1}^1)\right)\right) \\ &= G\left(f(r^1, r^2, \ldots, r^n), gT\left(gT(x_{k+1}^1)\right), t\right) \\ &= G\begin{pmatrix} f(r^1, r^2, \ldots, r^n), \\ f\left(gT(x_k^1), gT(x_k^2), \ldots, gT(x_k^n)\right), t \end{pmatrix} \\ &\varnothing\left\{\max\left\{\begin{matrix} \varnothing_1 G\left(gT(r^1), gT(gT(x_k^1)), t\right), \varnothing_2 G\begin{pmatrix} gT(r^2), \\ gT\left(gT(x_k^2)\right), t \end{pmatrix} \\ , \ldots, \varnothing_n G\left(gT(r^n), gT\left(gT(x_k^n)\right), t\right) \end{matrix}\right\}\right\} \\ &\varnothing\left\{\max\left\{\begin{matrix} G\left(gT(r^1), gT\left(gT(x_k^1)\right), t\right), G\left(gT(r^2), gT\left(gT(x_k^2)\right), t\right) \\ , \ldots, G\left(gT(r^n), gT\left(gT(x_k^n)\right), t\right) \end{matrix}\right\}\right\} \end{aligned}$$

But:

$$gT\left(gT(x_k^1)\right) \to gT(r^1), \; gT\left(gT(x_k^2)\right) \to gT(r^2)$$

And:

$$gT\left(gT(x_k^n)\right) \to gT(r^n)$$

Which is implies by definition G-convergent in G-metric space:

$$G\left(gT(r^1), f(r^1, r^2, \ldots, r^n), t\right) = 0 \Rightarrow f(r^1, r^2, \ldots, r^n) = gT(r^1)$$

Also, choose t^0 satisfy:

$$\begin{aligned} &G\left(gT(r^2), f(r^2, r^3, \ldots, r^1), t^0\right) \leq G\left(f(r^1, r^2, \ldots, r^n), t^0, gT\left(gT(x_{k+1}^2)\right)\right) \\ &= G\left(f(r^2, r^3, \ldots, r^1), gT\left(gT(x_{k+1}^2)\right), t^0\right) \\ &= G\left(f(r^2, r^3, \ldots, r^1), f\left(gT(x_k^2), gT(x_k^3), \ldots, gT(x_k^1), t^0\right)\right) \\ &\varnothing\left\{\max\left\{\begin{matrix} \varnothing_1 G\left(gT(r^2), gT(gT(x_k^2), t^0)\right), \varnothing_2 G\begin{pmatrix} gT(r^3), \\ gT(gT(x_k^3), t^0 \end{pmatrix} \\ , \ldots, \varnothing_n G\left(gT(r^1), gT(gT(x_k^1)), t^0\right) \end{matrix}\right\}\right\} \\ &\varnothing\left\{\max\left\{\begin{matrix} G\left(gT(r^2), gT(gT(x_k^2), t^0)\right), G\begin{pmatrix} gT(r^3), \\ gT(gT(x_k^3)), t^0 \end{pmatrix} \\ , \ldots, G\left(gT(r^1), gT(gT(x_k^1)), t^0\right) \end{matrix}\right\}\right\} \end{aligned}$$

But:

$$gT\left(gT(x_k^1)\right) \to gT(r^1), \; gT\left(gT(x_k^2)\right) \to gT(r^2)$$

And:

$$gT\left(gT\left(x_k^{\,n}\right)\right) \rightarrow gT\left(r^n\right)$$

Which is implies by definition G-convergent in G-metric space:

$$G\left(gT\left(r^2\right), f\left(r^1, r^2, ..., r^1\right), t\right) = 0 \Rightarrow f\left(r^2, r^3, ..., r^1\right) = gT\left(r^2\right)$$

Continue these processes: Choose t* satisfy:

$$\begin{aligned}
&G\left(gT\left(r^n\right), f\left(r^n, r^1, ..., r^{n-1}\right), t^*\right) \\
&\leq G\left(f\left(r^n, r^1, ..., r^{n-1}\right), t^*, gt\left(gT\left(x_{k+1}^{\,n}\right)\right)\right) \\
&= G\left(f\left(r^n, r^1, ..., r^{n-1}\right), gt\left(gT\left(x_{k+1}^{\,n}\right)\right), t^*\right) \\
&= G(f\left(r^n, r^1, ..., r^{n-1}\right), f\begin{pmatrix} gT\left(x_k^{\,n}\right), gT\left(x_k^{\,1}\right), ..., \\ gT\left(x_k^{\,n-1}\right)), t^* \end{pmatrix} \\
&\leq \varnothing \max\begin{Bmatrix} \varnothing_1 G\left(gT\left(r^n\right), gt\left(gT\left(x_k^{\,n}\right)\right), t^*\right), \varnothing_2 G\begin{pmatrix} gT\left(r^1\right), \\ gt\left(gT\left(x_k^{\,1}\right)\right), t^* \end{pmatrix} \\ , ..., \phi_n G\left(gT\left(r^{n-1}\right), gt\left(gT\left(x_k^{\,n-1}\right)\right), t^*\right) \end{Bmatrix} \\
&\leq \varnothing \max\begin{Bmatrix} G\left(gT\left(r^n\right), gt\left(gT\left(x_k^{\,n}\right)\right), t^*\right), G\begin{pmatrix} gT\left(r^1\right), \\ gt\left(gT\left(x_k^{\,1}\right)\right), t^* \end{pmatrix} \\ , ..., G\left(gT\left(r^{n-1}\right), gt\left(gT\left(x_k^{\,n-1}\right)\right), t^*\right) \end{Bmatrix}
\end{aligned}$$

But:

$$\begin{aligned}
&gT\left(gT\left(x_k^1\right)\right) \text{ is G-convergent to } gT\left(r^1\right) \\
&gT\left(gT\left(x_k^2\right)\right) \text{ is G-convergent to } gT\left(r^2\right) \\
&\quad\vdots \\
&gT\left(gT\left(x_k^{n-1}\right)\right) \text{ is G-convergent to } gT\left(r^{n-1}\right) \\
&gT\left(gT\left(x_k^n\right)\right) \text{ is G-convergent to } gT\left(r^n\right)
\end{aligned}$$

Which is implies by definition of G-convergent in G-metric space:

$$G\left(gT\left(r^n\right), f\left(r^n, r^1, ..., r^{n-1}\right), t^*\right) = 0$$

hence, $f(r^n, r^1, ..., r^{n-1}) = gT(r^n)$. So $(r^n, r^1, ..., r^{n-1})$ is a generalized n-tupled coincidence point of f, G and T.

Corollary (2.6): Let (X, G, ≤) be a partially ordered generalized metricispace, f: $X^n \rightarrow X$ and g, T: $X \rightarrow X$ are three mappings lies in K. Under the same assumptions of theorem (1) but:

$$\begin{aligned}
&G\left(f^r\left(x_1, x_2, ..., x_n\right), f^r\left(y_1, y_2, ..., y_n\right), t\right) \\
&\leq \varphi\left\{\frac{1}{n}\begin{Bmatrix} \varnothing_1 G\left(gT^r\left(x_1\right), gT^r\left(y_1\right), t\right) + \varnothing_2 G\left(gT^r\left(x_2\right), gT^r\left(y_2\right), t\right) + , ..., \\ + \varnothing_n G\left(gT^r\left(x_n\right), gT^r\left(y_n\right), t\right) \end{Bmatrix}\right\}
\end{aligned}$$

Then f, G and T have an generalized n-tupled concidence point.

Corollary (2.7): Let (X, G, ≤) be a partially ordered generalized metric space, f: $X^n \rightarrow X$ and g, T: $X \rightarrow X$ are three mappings lies in K. Under the same assumptions of theorem (1) but:

$$\begin{aligned}
&G\left(f^r\left(x_1, x_2, ..., x_n\right), f^r\left(y_1, y_2, ..., y_n\right), t\right) \leq \\
&\varphi\left\{\frac{1}{n}\begin{Bmatrix} k_1 G\left(gT^r\left(x_1\right), gT^r\left(y_1\right), t\right) + k_2 G\left(gT^r\left(x_2\right), gT^r\left(y_2\right), t\right) + , ..., \\ + k_n G\left(gT^r\left(x_n\right), gT^r\left(y_n\right), t\right) \end{Bmatrix}\right\}
\end{aligned}$$

Such that, $k_i \in (0, 1]$ for all i = 1, 2, ..., n. Then f, g and T have a generalized n-tupled coincidence point.

Remark (2.8): If T = I (identity map) and f has mixed g-monotone property then, we get, f and g have n-tupled coincidence point. If T = g = I (identity map) and f has mixed monotonei property then, we get f has n-tupled fixed point.

CONCLUSION

In this study, we introduce the concepts of generalized n-tupled coincidence point and generalized mixed gT-monotone property and we prove the existence and uniqueness of generalized n-tupled coincidence point theorems without continuous condition for mappings having generalized mixed gT-monotone property in generalized metric spaces.

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