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Generating Pythagoras Quadruples in Symbolic 2-Plithogenic Commutative Rings

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Abstract:

This paper is dedicated to find a general algorithm for generating different solutions for Pythagoras non-linear Diophantine equation in four variables $x^2 + y^2 + z^2 = t^2$ in symbolic 2-plithogenic rings, which are known as Pythagoras quadruples.

Also, we present some examples about those quadruples in some finite symbolic 2-plithogenic rings.

Keywords: symbolic 2-plithogenic ring, Pythagoras quadruples, Diophantine equations

Introduction and Preliminaries

Symbolic n-plithogenic algebraic structures are a new generalization of classical algebraic structures, as they have serious algebraic properties to study.

In the previous literature, we can clearly note several algebraic studies that were interested in discovering the properties of these algebraic structures, for example we can find some applications of plithogenic structures in probability, ring theory, linear spaces, matrices, and equations [1-10].

Researchers have studied Pythagorean quadruples in the ring of ordinary algebraic numbers [11-14].

Several efficient algorithms for calculating these quadruples have been presented, as solutions to the corresponding Diophantine equation.

This has motivated us to study Pythagoras quadruples in the symbolic 2-plithogenic commutative case, where we find a general algorithm for generating different solutions for Pythagoras non-linear Diophantine equation in four variables $x^2 + y^2 + z^2 = t^2$ in symbolic 2-plithogenic rings.

Definition.

The symbolic 2-plithogenic ring of real numbers is defined as follows:

$$2 - SP_R = \{t_0 + t_1P_1 + t_2P_2; t_i \in R, P_1 \times P_2 = P_2 \times P_1 = P_2, P_1^2 = P_2^2 = P_2\}$$

The addition operation on $2 - SP_R$ is defined as follows:

$$(t_0 + t_1P_1 + t_2P_2) + (t'_0 + t'_1P_1 + t'_2P_2) = (t_0 + t'_0) + (t_1 + t'_1)P_1 + (t_2 + t'_2)P_2$$

The multiplication on $2 - SP_R$ is defined as follows:

$$\begin{aligned} (t_0 + t_1P_1 + t_2P_2)(t'_0 + t'_1P_1 + t'_2P_2) \\ = t_0t'_0 + (t_0t'_1 + t_1t'_0 + t_1t'_1)P_1 + (t_0t'_2 + t_1t'_2 + t_2t'_2 + t_2t'_0 + t_2t'_1)P_2 \end{aligned}$$

Main Discussion

Definition.

Let $T = t_0 + t_1P_1 + t_2P_2, S = s_0 + s_1P_1 + s_2P_2, K = k_0 + k_1P_1 + k_2P_2, L = l_0 + l_1P_1 + l_2P_2$ be four symbolic 2-plithogenic elements of a symbolic 2-plithogenic commutative ring

$2 - SP_R$, then (T, S, K, L) is called a symbolic 2-plithogenic Pythagoras quadruple if and only if $T^2 + S^2 + K^2 = L^2$.

Theorem.

Let $T = t_0 + t_1P_1 + t_2P_2, S = s_0 + s_1P_1 + s_2P_2, K = k_0 + k_1P_1 + k_2P_2, L = l_0 + l_1P_1 + l_2P_2 \in 2 - SP_R$, then (T, S, K, L) is a symbolic 2-plithogenic Pythagoras quadruple if and only if:

$(t_0, s_0, k_0, l_0), (t_0 + t_1, s_0 + s_1, k_0 + k_1, l_0 + l_1), (t_0 + t_1 + t_2, s_0 + s_1 + s_2, k_0 + k_1 + k_2, l_0 + l_1 + l_2)$ are three Pythagoras quadruples in R .

Proof.

We have:

$$T^2 = t_0^2 + [(t_0 + t_1)^2 - t_0^2]P_1 + [(t_0 + t_1 + t_2)^2 - (t_0 + t_1)^2]P_2,$$

$$S^2 = s_0^2 + [(s_0 + s_1)^2 - s_0^2]P_1 + [(s_0 + s_1 + s_2)^2 - (s_0 + s_1)^2]P_2,$$

$$K^2 = k_0^2 + [(k_0 + k_1)^2 - k_0^2]P_1 + [(k_0 + k_1 + k_2)^2 - (k_0 + k_1)^2]P_2,$$

$$L^2 = l_0^2 + [(l_0 + l_1)^2 - l_0^2]P_1 + [(l_0 + l_1 + l_2)^2 - (l_0 + l_1)^2]P_2,$$

The equation $T^2 + S^2 + K^2 = L^2$ is equivalent to:

$$t_0^2 + s_0^2 + k_0^2 = l_0^2 \quad (1)$$

$$(t_0 + t_1)^2 + (s_0 + s_1)^2 + (k_0 + k_1)^2 = (l_0 + l_1)^2 \quad (2)$$

$$(t_0 + t_1 + t_2)^2 + (s_0 + s_1 + s_2)^2 + (k_0 + k_1 + k_2)^2 = (l_0 + l_1 + l_2)^2 \quad (3)$$

Thus, the proof holds.

Theorem.

Let $(t_0, s_0, k_0, l_0), (t_1, s_1, k_1, l_1), (t_2, s_2, k_2, l_2)$ be three Pythagoras quadruples in R , then the corresponding Pythagoras quadruple in $2 - SP_R$ is (T, S, K, L) , where:

$$T = t_0 + [t_1 - t_0]P_1 + [t_2 - t_1]P_2,$$

$$S = s_0 + [s_1 - s_0]P_1 + [s_2 - s_1]P_2,$$

$$K = k_0 + [k_1 - k_0]P_1 + [k_2 - k_1]P_2,$$

$$L = l_0 + [l_1 - l_0]P_1 + [l_2 - l_1]P_2.$$

Proof.

We must compute $T^2 + S^2 + K^2$,

$$\begin{aligned} T^2 + S^2 + K^2 &= t_0^2 + (t_1^2 - t_0^2)P_1 + (t_2^2 - t_1^2)P_2 + s_0^2 + (s_1^2 - s_0^2)P_1 + \\ &+ (s_2^2 - s_1^2)P_2 + k_0^2 + (k_1^2 - k_0^2)P_1 + (k_2^2 - k_1^2)P_2 = (t_0^2 + s_0^2 + k_0^2) + \\ &+ (t_1^2 + s_1^2 + k_1^2 - t_0^2 - s_0^2 - k_0^2)P_1 + (t_2^2 + s_2^2 + k_2^2 - t_1^2 - s_1^2 - k_1^2)P_2 = l_0^2 + \\ &+ (l_1^2 - l_0^2)P_1 + (l_2^2 - l_1^2)P_2 = L^2. \end{aligned}$$

So that, the proof is complete.

Example.

We have $L_1 = (1, -1, i, 1), L_2 = (i, 1, -1, -1), L_3 = (-i, -1, 1, -1)$ are three Pythagoras quadruples in C .

The corresponding 2-plithogenic Pythagoras quadruple is (T, S, K, L) , where:

$$T = 1 + (-1 + i)P_1 - 2iP_2$$

$$S = -1 + 2P_1 - 2P_2$$

$$K = i + (-1 - i)P_1 + 2P_2$$

$$L = 1 - 2P_1 + 2P_2$$

On the other hand, we have:

$$T^2 = 1 - 2P_1,$$

$$S^2 = 1,$$

$$K^2 = -1 + 2P_1,$$

$$L^2 = 1 = T^2 + S^2 + K^2.$$

Example.

Consider the following three Pythagoras quadruples in Z_2 :

$$L_1 = (0,0,0,0), L_2 = (1,1,1,1), L_3 = (1,1,0,0)$$

For every triple $(L_i, L_j, L_s); 1 \leq i, j, s \leq 3$, we can get a symbolic 2-plithogenic pythagoras quadruple.

We will find some symbolic 2-plithogenic Pythagoras quadruple in $2 - SP_{Z_2}$.

Let us write the following quadruples:

$$\begin{cases} Y_1 = 0 \\ \dot{Y}_1 = 0 \\ Y_1'' = 0 \\ Y_1''' = 0 \end{cases}$$

$$\begin{cases} Y_2 = P_2 \\ \dot{Y}_2 = P_2 \\ Y_2'' = P_2 \\ Y_2''' = P_2 \end{cases}$$

$$\begin{cases} Y_3 = 0 \\ \dot{Y}_3 = 0 \\ Y_3'' = P_2 \\ Y_3''' = P_2 \end{cases}$$

$$\begin{cases} Y_4 = P_1 + P_2 \\ \dot{Y}_4 = P_1 + P_2 \\ Y_4'' = P_1 + P_2 \\ Y_4''' = P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_5 = P_1 + P_2 \\ \dot{Y}_5 = P_1 + P_2 \\ Y_5'' = 0 \\ Y_5''' = 0 \end{cases}$$

$$\begin{cases} Y_6 = 0 \\ \dot{Y}_6 = 0 \\ Y_6'' = P_1 + P_2 \\ Y_6''' = P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_7 = 1 + P_1 \\ \dot{Y}_7 = 1 + P_1 \\ Y_7'' = 1 + P_1 \\ Y_7''' = 1 + P_1 \end{cases}$$

$$\begin{cases} Y_8 = 1 + P_1 \\ \dot{Y}_8 = 1 + P_1 \\ Y_8'' = 0 \\ Y_8''' = 0 \end{cases}$$

$$\begin{cases} Y_9 = 0 \\ \dot{Y}_9 = 0 \\ Y_9'' = 1 + P_1 \\ Y_9''' = 1 + P_1 \end{cases}$$

$$\begin{cases} Y_{10} = 1 \\ \dot{Y}_{10} = 1 \\ Y_{10}'' = 1 \\ Y_{10}''' = 1 \end{cases}$$

$$\begin{cases} Y_{11} = 1 + P_2 \\ \dot{Y}_{11} = 1 + P_2 \\ Y_{11}'' = 1 + P_2 \\ Y_{11}''' = 1 + P_2 \end{cases}$$

$$\begin{cases} Y_{12} = 1 + P_2 \\ \dot{Y}_{12} = 1 + P_2 \\ Y_{12}'' = 1 \\ Y_{12}''' = 1 \end{cases}$$

$$\begin{cases} Y_{13} = 1 + P_1 + P_2 \\ \dot{Y}_{13} = 1 + P_1 + P_2 \\ Y_{13}'' = 1 + P_1 + P_2 \\ Y_{13}''' = 1 + P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_{14} = 1 \\ \check{Y}_{14} = 1 \\ Y_{14}'' = 1 + P_1 + P_2 \\ Y_{14}''' = 1 + P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_{15} = 1 + P_1 + P_2 \\ \check{Y}_{15} = 1 + P_1 + P_2 \\ Y_{15}'' = 1 \\ Y_{15}''' = 1 \end{cases}$$

$$\begin{cases} Y_{16} = P_1 \\ \check{Y}_{16} = P_1 \\ Y_{16}'' = P_1 \\ Y_{16}''' = P_1 \end{cases}$$

$$\begin{cases} Y_{17} = 1 \\ \check{Y}_{17} = 1 \\ Y_{17}'' = P_1 \\ Y_{17}''' = P_1 \end{cases}$$

$$\begin{cases} Y_{26} = P_1 \\ \check{Y}_{26} = P_1 \\ Y_{26}'' = 1 \\ Y_{26}''' = 1 \end{cases}$$

$$\begin{cases} Y_{27} = 1 \\ \check{Y}_{27} = 1 \\ Y_{27}'' = 0 \\ Y_{27}''' = 0 \end{cases}$$

$$\begin{cases} Y_{32} = 1 \\ \check{Y}_{32} = 1 \\ Y_{32}'' = P_2 \\ Y_{32}''' = P_2 \end{cases}$$

$$\begin{cases} Y_{33} = 1 + P_2 \\ \check{Y}_{33} = 1 + P_2 \\ Y_{33}'' = P_2 \\ Y_{33}''' = P_2 \end{cases}$$

$$\begin{cases} Y_{35} = 1 \\ \check{Y}_{35} = 1 \\ Y_{35}'' = P_1 + P_2 \\ Y_{35}''' = P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_{36} = 1 + P_1 + P_2 \\ \check{Y}_{36} = 1 + P_1 + P_2 \\ Y_{36}'' = P_1 + P_2 \\ Y_{36}''' = P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_{37} = P_1 \\ \check{Y}_{37} = P_1 \\ Y_{37}'' = 0 \\ Y_{37}''' = 0 \end{cases}$$

$$\begin{cases} Y_{38} = 1 \\ \check{Y}_{38} = 1 \\ Y_{38}'' = 1 + P_1 \\ Y_{38}''' = 1 + P_1 \end{cases}$$

$$\begin{cases} Y_{39} = P_1 \\ \check{Y}_{39} = P_1 \\ Y_{39}'' = 1 + P_1 \\ Y_{39}''' = 1 + P_1 \end{cases}$$

$$\begin{cases} Y_{40} = 0 \\ \check{Y}_{40} = 0 \\ Y_{40}'' = 1 \\ Y_{40}''' = 1 \end{cases}$$

$$\begin{cases} Y_{44} = 0 \\ \check{Y}_{44} = 0 \\ Y_{44}'' = 1 + P_2 \\ Y_{44}''' = 1 + P_2 \end{cases}$$

$$\begin{cases} Y_{45} = P_2 \\ \check{Y}_{45} = P_2 \\ Y_{45}'' = 1 \\ Y_{45}''' = 1 \end{cases}$$

$$\begin{cases} Y_{46} = P_2 \\ \check{Y}_{46} = P_2 \\ Y_{46}'' = 1 + P_2 \\ Y_{46}''' = 1 + P_2 \end{cases}$$

$$\begin{cases} Y_{47} = 0 \\ \check{Y}_{47} = 0 \\ Y_{47}'' = 1 + P_1 + P_2 \\ Y_{47}''' = 1 + P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_{48} = P_1 + P_2 \\ \check{Y}_{48} = P_1 + P_2 \\ Y_{48}'' = 1 \\ Y_{48}''' = 1 \end{cases}$$

$$\begin{cases} Y_{49} = P_1 + P_2 \\ \check{Y}_{49} = P_1 + P_2 \\ Y_{49}'' = 1 + P_1 + P_2 \\ Y_{49}''' = 1 + P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_{50} = 0 \\ Y'_{50} = 0 \\ Y''_{50} = P_1 \\ Y'''_{50} = P_1 \end{cases}$$

$$\begin{cases} Y_{51} = 1 + P_1 \\ Y'_{51} = 1 + P_1 \\ Y''_{51} = 1 \\ Y'''_{51} = 1 \end{cases}$$

$$\begin{cases} Y_{52} = 1 + P_1 \\ Y'_{52} = 1 + P_1 \\ Y''_{52} = P_1 \\ Y'''_{52} = P_1 \end{cases}$$

$$\begin{cases} Y_{53} = P_1 \\ Y'_{53} = P_1 \\ Y''_{53} = P_1 + P_2 \\ Y'''_{53} = P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_{54} = P_1 + P_2 \\ Y'_{54} = P_1 + P_2 \\ Y''_{54} = P_1 + P_2 \\ Y'''_{54} = P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_{55} = P_1 \\ Y'_{55} = P_1 \\ Y''_{55} = P_2 \\ Y'''_{55} = P_2 \end{cases}$$

$$\begin{cases} Y_{56} = P_1 + P_2 \\ Y'_{56} = P_1 + P_2 \\ Y''_{56} = P_2 \\ Y'''_{56} = P_2 \end{cases}$$

$$\begin{cases} Y_{57} = P_2 \\ Y'_{57} = P_2 \\ Y''_{57} = P_1 \\ Y'''_{57} = P_1 \end{cases}$$

$$\begin{cases} Y_{58} = P_2 \\ Y'_{58} = P_2 \\ Y''_{58} = P_1 + P_2 \\ Y'''_{58} = P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_{59} = 1 + P_1 + P_2 \\ Y'_{59} = 1 + P_1 + P_2 \\ Y''_{59} = 1 + P_1 \\ Y'''_{59} = 1 + P_1 \end{cases}$$

$$\begin{cases} Y_{60} = 1 + P_1 \\ Y'_{60} = 1 + P_1 \\ Y_{60}'' = P_2 \\ Y_{60}''' = P_2 \end{cases}$$

$$\begin{cases} Y_{61} = 1 + P_1 + P_2 \\ Y'_{61} = 1 + P_1 + P_2 \\ Y_{61}'' = P_2 \\ Y_{61}''' = P_2 \end{cases}$$

$$\begin{cases} Y_{62} = 1 + P_1 \\ Y'_{62} = 1 + P_1 \\ Y_{62}'' = P_2 \\ Y_{62}''' = P_2 \end{cases}$$

$$\begin{cases} Y_{63} = P_2 \\ Y'_{63} = P_2 \\ Y_{63}'' = 1 + P_2 \\ Y_{63}''' = 1 + P_2 \end{cases}$$

$$\begin{cases} Y_{64} = P_2 \\ Y'_{64} = P_2 \\ Y_{64}'' = 1 \\ Y_{64}''' = 1 \end{cases}$$

$$\begin{cases} Y_{65} = 1 + P_2 \\ Y'_{65} = 1 + P_2 \\ Y_{65}'' = 1 \\ Y_{65}''' = 1 \end{cases}$$

$$\begin{cases} Y_{66} = 1 + P_2 \\ Y'_{66} = 1 + P_2 \\ Y_{66}'' = 1 + P_1 + P_2 \\ Y_{66}''' = 1 + P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_{67} = 1 + P_2 \\ Y'_{67} = 1 + P_2 \\ Y_{67}'' = P_1 + P_2 \\ Y_{67}''' = P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_{68} = 1 + P_2 \\ Y'_{68} = 1 + P_2 \\ Y_{68}'' = 1 \\ Y_{68}''' = 1 \end{cases}$$

$$\begin{cases} Y_{69} = 1 + P_1 \\ Y'_{69} = 1 + P_1 \\ Y_{69}'' = P_1 \\ Y_{69}''' = P_1 \end{cases}$$

$$\begin{cases} Y_{70} = 1 + P_1 + P_2 \\ Y'_{70} = 1 + P_1 + P_2 \\ Y_{70}'' = P_1 \\ Y_{70}''' = P_1 \end{cases}$$

$$\begin{cases} Y_{71} = P_1 + P_2 \\ Y'_{71} = P_1 + P_2 \\ Y_{71}'' = 1 \\ Y_{71}''' = 1 \end{cases}$$

$$\begin{cases} Y_{72} = P_1 \\ Y'_{72} = P_1 \\ Y_{72}'' = 1 + P_1 + P_2 \\ Y_{72}''' = 1 + P_1 + P_2 \end{cases}$$

$$\begin{cases} Y_{73} = P_1 + P_2 \\ Y'_{73} = P_1 + P_2 \\ Y_{73}'' = 1 + P_2 \\ Y_{73}''' = 1 + P_2 \end{cases}$$

$$\begin{cases} Y_{74} = P_1 \\ Y'_{74} = P_1 \\ Y_{74}'' = 1 + P_2 \\ Y_{74}''' = 1 + P_2 \end{cases}$$

$$\begin{cases} Y_{75} = 1 + P_1 \\ Y'_{75} = 1 + P_1 \\ Y_{75}'' = 1 + P_2 \\ Y_{75}''' = 1 + P_2 \end{cases}$$

$$\begin{cases} Y_{76} = 1 + P_1 + P_2 \\ Y'_{76} = 1 + P_1 + P_2 \\ Y_{76}'' = 1 + P_2 \\ Y_{76}''' = 1 + P_2 \end{cases}$$

$$\begin{cases} Y_{77} = 1 \\ Y'_{77} = 1 \\ Y_{77}'' = 1 + P_2 \\ Y_{77}''' = 1 + P_2 \end{cases}$$

Conclusion.

In this paper, we have studied Pythagoras quadruples in symbolic 2-plithogenic commutative rings, where necessary and sufficient conditions for a symbolic 2-plithogenic quadruple (x, y, z, t) to be a Pythagoras quadruple.

Also, we have presented some related examples that explain how to find 2-plithogenic quadruples from classical quadruples.

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