



Dot Products and Matrix Properties of 4×4 Strongly Magic Squares

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Abstract: Magic squares have been known in India from very early times. The renowned mathematician Ramanujan had immense contributions in the field of Magic Squares. A magic square is a square array of numbers where the rows, columns, diagonals and co-diagonals add up to the same number. The paper discuss about a well-known class of magic squares; the strongly magic square. The strongly magic square is a magic square with a stronger property that the sum of the entries of the sub-squares taken without any gaps between the rows or columns is also the magic constant. In this paper a generic definition for Strongly Magic Squares is given. The matrix properties of 4×4 strongly magic squares dot products and different properties of eigen values and eigen vectors are discussed in detail.

Keywords: Strongly Magic Square (SMS), Dot Products of SMS, Eigen Values of SMS, Rank and Determinant of SMS

1. Introduction

Magic squares date back in the first millennium B. C. E in China [1], developed in India and Islamic World in the first millennium C. E, and found its way to Europe in the later Middle Ages [2] and to sub-Saharan Africa not much after [3]. Magic squares generally fall into the realm of recreational mathematics [4, 5], however a few times in the past century and more recently, they have become the interest of more-serious mathematicians. Srinivasa Ramanujan had contributed a lot in the field of magic squares. Ramanujan's work on magic squares is presented in detail in Ramanujan's Notebooks [6]. A normal magic square is a square array of consecutive numbers from $1 \dots n^2$ where the rows, columns, diagonals and co-diagonals add up to the same number. The constant sum is called magic constant or magic number. Along with the conditions of normal magic squares, strongly magic square have a stronger property that the sum of the entries of the sub-squares taken without any gaps between the rows or columns is also the magic constant [7]. There are many recreational aspects of strongly magic squares. But, apart from the usual recreational aspects, it is found that these strongly magic squares possess advanced mathematical properties.

2. Notations and Mathematical Preliminaries

2.1. Magic Square

A magic square of order n over a field R where R denotes the set of all real numbers is an n^{th} order matrix $[a_{ij}]$ with entries in R such that

$$\sum_{j=1}^n a_{ij} = \rho \text{ for } i = 1, 2, \dots, n \quad (1)$$

$$\sum_{j=1}^n a_{ji} = \rho \text{ for } i = 1, 2, \dots, n \quad (2)$$

$$\sum_{i=1}^n a_{ii} = \rho, \sum_{i=1}^n a_{i,n-i+1} = \rho, \text{ for } j = 1, 2, \dots, n \quad (3)$$

Equation (1) represents the row sum, equation (2) represents the column sum, equation (3) represents the diagonal and co-diagonal sum and symbol ρ represents the magic constant. [8]

2.2. Magic Constant

The constant ρ in the above definition is known as the magic constant or magic number. The magic constant of the magic square A is denoted as $\rho(A)$.

2.3. Strongly Magic Square (SMS): Generic Definition

A strongly magic square over a field R is a matrix $[a_{ij}]$ of order $n^2 \times n^2$ with entries in R such that

$$\sum_{j=1}^{n^2} a_{ij} = \rho \text{ for } i = 1, 2, \dots, n^2 \quad (4)$$

$$\sum_{j=1}^{n^2} a_{ji} = \rho \text{ for } i = 1, 2, \dots, n^2 \quad (5)$$

$$\sum_{i=1}^{n^2} a_{ii} = \rho, \sum_{i=1}^{n^2} a_{i, n^2-i+1} = \rho \quad (6)$$

$$\sum_{l=0}^{n-1} \sum_{k=0}^{n-1} a_{i+k, j+l} = \rho \text{ for } i, j = 1, 2, \dots, n^2 \quad (7)$$

where the subscripts are congruent modulo n^2

Equation (4) represents the row sum, equation (5) represents the column sum, equation (6) represents the diagonal & co-diagonal sum, equation (7) represents the $n \times n$ sub-square sum with no gaps in between the elements of rows or columns and is denoted as $M_{0C}^{(n)}$ or $M_{0R}^{(n)}$ and ρ is the magic constant.

Note: The n^{th} order sub square sum with k column gaps or k row gaps is generally denoted as $M_{kC}^{(n)}$ or $M_{kR}^{(n)}$ respectively.

2.4. Column/Row Dot Product of Two Magic Squares

Let C and C' or $(R$ and $R')$ be any two columns or (rows) of two magic squares A and A' of order n . If a_1, a_2, \dots, a_n and a'_1, a'_2, \dots, a'_n are the elements of C and C' or $(R$ and $R')$ respectively, then the dot product of C and C' or $(R$ and $R')$ denoted by $C \cdot C'$ or $(R \cdot R')$ is defined as

$$C \cdot C' \text{ or } R \cdot R' = \sum_{i=1}^n a_i \cdot a'_i \quad (8)$$

For example

Two magic squares A and B are given in such a way that

$$A = \begin{bmatrix} 16 & 5 & 4 & 9 \\ 2 & 11 & 14 & 7 \\ 13 & 8 & 1 & 12 \\ 3 & 10 & 15 & 6 \end{bmatrix} \text{ and } A' = \begin{bmatrix} 3 & 13 & 2 & 16 \\ 10 & 8 & 11 & 5 \\ 15 & 1 & 14 & 4 \\ 6 & 12 & 7 & 9 \end{bmatrix}$$

Then the column dot products of A and A' are given by

$$C_1 \cdot C'_1 = (16 \times 3) + (2 \times 10) + (13 \times 15) + (3 \times 6) = 281$$

$$C_1 \cdot C'_2 = (16 \times 13) + (2 \times 8) + (13 \times 1) + (3 \times 12) = 273$$

Also the row dot products of A and A' are given by

$$R_3 \cdot R'_4 = (13 \times 6) + (8 \times 12) + (1 \times 7) + (12 \times 9) = 289$$

3. Propositions and Theorems

3.1. Dot Products of 4×4 Strongly Magic Squares

3.1.1.

If $A = [a_{ij}]$ be an SMS of order 4 and if R_1, R_2, R_3, R_4 and C_1, C_2, C_3, C_4 be the rows and columns of SMS respectively, then

i) $R_1 R_2 = R_3 R_4$ ii) $R_1 R_4 = R_2 R_3$ and iii) $C_1 C_2 =$

$C_3 C_4$ iv) $C_1 C_4 = C_2 C_3$ or in general $R_i R_{i+1} = R_{i+2} R_{i+3}$ and $C_i C_{i+1} = C_{i+2} C_{i+3}$ where $i = 1, 2, 3, 4$ and the subscripts should be taken modulo 4

Proof

The general form of a 4x4 SMS is given by

$$\begin{bmatrix} a & b & c & d \\ \rho & c+d-\rho & a-c+\rho & b+c-\rho \\ \frac{\rho}{2}-c & \frac{\rho}{2}-d & \frac{\rho}{2}-a & \frac{\rho}{2}-b \\ c-a-\frac{\rho}{2} & \frac{3\rho}{2}-b-c & -\rho/2 & \frac{3\rho}{2}-c-d \end{bmatrix} \quad (9)$$

where ρ is the magic constant and $a, b, c, d \in R$. [9]

$$R_3 R_4 = \rho^2 + 2bd + ac - c^2 - 2\rho b - 2\rho d + cd + bc$$

$$R_1 R_2 = (a+c)\rho + 2bd + ac - c^2 + cd + bc - b\rho - \rho d$$

$$= [\rho - (b+d)]\rho + 2bd + ac - c^2 + cd + bc - b\rho - \rho d$$

$$= \rho^2 + 2bd + ac - c^2 - 2\rho b - 2\rho d + cd + bc$$

i. Hence $R_1 R_2 = R_3 R_4$

$$\text{ii. } R_1 R_4 = ac - a^2 - \frac{a\rho}{2} + \frac{3b\rho}{2} - b^2 - bc - \frac{\rho c}{2} + \frac{3\rho d}{2} - cd - d^2 = R_2 R_3$$

$$\text{iii. } C_1 C_2 = 2ab + cd + ac - bc - c^2 + \frac{\rho b}{2} + \frac{5\rho c}{2} - \frac{3\rho^2}{2} - \frac{3a\rho}{2} + \frac{\rho d}{2} = C_3 C_4$$

3.1.2.

If $A = [a_{ij}]$ be an SMS of order 4 and if R_1, R_2, R_3, R_4 and C_1, C_2, C_3, C_4 be the rows and columns of SMS respectively, then i) $R_1 C_1 = R_3 C_3$ ii) $R_1 C_2 = R_3 C_4$ iii) $R_1 C_3 = R_3 C_1$ iv) $R_1 C_4 = R_3 C_2$ v) $R_2 C_1 = R_4 C_3$

vi) $R_2 C_2 = R_4 C_4$ vii) $R_2 C_3 = R_4 C_1$ viii) $R_2 C_4 = R_4 C_2$ or in general $R_i C_j = R_{i+2} C_{j+2}$ where $i, j = 1, 2, 3, 4$ and the subscripts should be taken modulo 4

Proof

From the general form of a 4x4 SMS as in 3.1.1

$$\text{i) } R_1 C_1 = a^2 - c^2 + b\rho + \frac{\rho c}{2} + cd - ad - \frac{\rho d}{2}$$

$$R_3 C_3 = a^2 - c^2 + \frac{\rho c}{2} + cd - ad - \frac{\rho(a+c)}{2} + \frac{\rho b}{2} - \rho d + \rho^2/2$$

$$= a^2 - c^2 + \frac{\rho c}{2} + cd - ad - \frac{\rho(\rho - (b+d))}{2} + \frac{\rho b}{2} - \rho d + \rho^2/2$$

$$= a^2 - c^2 + b\rho + \frac{\rho c}{2} + cd - ad - \frac{\rho d}{2}$$

$$\text{ii) } R_1 C_2 = ab + bc - b\rho + \frac{c\rho}{2} - 2cd + \frac{3\rho d}{2}$$

$$R_3 C_4 = ab + bc - 2cd + \frac{\rho^2}{2} + \rho d - \frac{\rho a}{2} - \frac{3\rho b}{2}$$

$$= ab + bc - 2cd + \frac{\rho^2}{2} + \frac{3\rho d}{2} - \frac{\rho d}{2} - \frac{\rho a}{2} - \frac{\rho b}{2} - \rho b$$

$$\begin{aligned}
&= ab + bc - 2cd + \frac{\rho^2}{2} + \frac{3\rho d}{2} - \rho/2(a + b + d) - \rho b \\
&= ab + bc - 2cd + \frac{\rho^2}{2} + \frac{3\rho d}{2} - \rho/2(\rho - c) - \rho b \\
&= ab + bc - b\rho + \frac{c\rho}{2} - 2cd + \frac{3\rho d}{2} = R_1C_2 \\
&\text{iii) } R_1C_3 = ab - bc + b\rho - \frac{\rho d}{2} + \frac{\rho c}{2} \\
&R_3C_1 = ab - bc + \frac{b\rho}{2} - \frac{a\rho}{2} + \frac{\rho^2}{2} - \rho d \\
&= ab - bc + b\rho - \frac{\rho(a + b)}{2} + \frac{\rho^2}{2} - \rho d \\
&= ab - bc + b\rho - \frac{\rho(\rho - (c + d))}{2} + \frac{\rho^2}{2} - \rho d \\
&= ab - bc + b\rho - \frac{\rho d}{2} + \frac{\rho c}{2} = R_1C_3 \\
&\text{iv) } R_3C_2 = ad + b^2 - d^2 - cd + \frac{\rho^2}{2} + \rho d - \frac{a\rho}{2} - 3\rho b/2 \\
&R_1C_4 = ad + b^2 - d^2 - cd - b\rho + \frac{c\rho}{2} + 3\rho d/2 \\
&= ad + b^2 - d^2 - cd - b\rho + \frac{\rho(\rho - (a + b + d))}{2} + 3\rho d/2 \\
&= ad + b^2 - d^2 - cd + \frac{\rho^2}{2} + \rho d - \frac{a\rho}{2} - \frac{3\rho b}{2} = R_3C_2 \\
&\text{v) } R_4C_3 = 2c^2 - 2ac + bc + 2ap - 2cp - ab + \frac{\rho^2}{2} - \rho c/2 \\
&\quad - b\rho + \rho d/2 \\
&R_2C_1 = 2c^2 - 2ac + bc + 2ap - 2cp - ab + \rho d + \frac{a\rho}{2} \\
&\quad - b\rho/2 \\
&= 2c^2 - 2ac + bc + 2ap - 2cp - ab + \rho d \\
&\quad + \rho(\rho - (b + c + d)) - \frac{b\rho}{2} \\
&= 2c^2 - 2ac + bc + 2ap - 2cp - ab + \frac{\rho^2}{2} - \frac{\rho c}{2} - b\rho \\
&\quad + \frac{\rho d}{2} = R_4C_3 \\
&\text{vi) } R_2C_2 = 3cd + d^2 - ad - b^2 - 2bc + \frac{7\rho b}{2} - 3\rho d + \frac{a\rho}{2} \\
&R_4C_4 = 3cd + d^2 - ad - b^2 - 2bc - \frac{7\rho d}{2} + 3\rho b + \frac{\rho^2}{2} \\
&\quad - \frac{\rho c}{2} \\
&= 3cd + d^2 - ad - b^2 - 2bc + \frac{7\rho(b - d)}{2} - \frac{\rho(b + c)}{2} \\
&\quad + \frac{\rho^2}{2}
\end{aligned}$$

$$\begin{aligned}
&= 3cd + d^2 - ad - b^2 - 2bc + \frac{7\rho(b - d)}{2} \\
&\quad - \frac{\rho(\rho - (a + d))}{2} + \frac{\rho^2}{2} \\
&= 3cd + d^2 - ad - b^2 - 2bc + \frac{7\rho b}{2} - 3\rho d + \frac{a\rho}{2} = R_2C_2 \\
&\text{vii) } R_4C_1 = 2\rho c + 2ac - c^2 - a^2 + ad - cd - 2ap + \frac{\rho^2}{2} \\
&\quad - \rho b - \frac{\rho c}{2} + \frac{\rho d}{2} \\
&R_2C_3 = 2\rho c + 2ac - c^2 - a^2 + ad - cd - 2ap + \rho d + \frac{\rho a}{2} \\
&\quad - \frac{\rho b}{2} \\
&= 2\rho c + 2ac - c^2 - a^2 + ad - cd - 2ap + \rho d \\
&\quad + \frac{\rho(\rho - (b + c + d))}{2} - \frac{\rho b}{2} \\
&= 2\rho c + 2ac - c^2 - a^2 + ad - cd - 2ap + \frac{\rho^2}{2} - \rho b - \frac{\rho c}{2} \\
&\quad + \frac{\rho d}{2} = R_4C_1 \\
&\text{viii) } R_2C_4 = \rho d - \frac{b\rho}{2} + \frac{\rho a}{2} + bc - ab - \frac{\rho^2}{2} \\
&R_4C_2 = \frac{\rho^2}{2} - \rho b + \frac{\rho d}{2} - \frac{\rho c}{2} + bc - ab \\
&= \frac{\rho^2}{2} - \frac{\rho b}{2} - \frac{\rho(b + c)}{2} + \frac{\rho d}{2} + bc - ab \\
&= \frac{\rho^2}{2} - \frac{\rho b}{2} - \frac{\rho(\rho - (a + d))}{2} + \frac{\rho d}{2} + bc - ab \\
&= \rho d - \frac{b\rho}{2} + \frac{\rho a}{2} + bc - ab - \frac{\rho^2}{2} = R_2C_4
\end{aligned}$$

3.1.3.

If $A = [a_{ij}]$ be an SMS of order 4 and if R_1, R_2, R_3, R_4 and C_1, C_2, C_3, C_4 be the rows and columns of SMS respectively, then i) $R_i R_i = R_{i+2} R_{i+2}$ and ii) $C_i C_i = C_{i+2} C_{i+2}$ i.e. i. 1) $R_1 R_1 = R_3 R_3$ i. 2) $R_2 R_2 = R_4 R_4$ ii. 1) $C_1 C_1 = C_3 C_3$ ii. 2) $C_2 C_2 = C_4 C_4$

Proof

From the general form of a 4x4 SMS as in 3.1.1

$$\begin{aligned}
&\text{i. 1) } R_1 R_1 = a^2 + b^2 + c^2 + d^2 \\
&R_3 R_3 = \left(\frac{\rho}{2} - c\right)^2 + \left(\frac{\rho}{2} - d\right)^2 + \left(\frac{\rho}{2} - a\right)^2 + \left(\frac{\rho}{2} - b\right)^2 \\
&\quad = a^2 + b^2 + c^2 + d^2 = R_1 R_1 \\
&\text{i. 2) } R_2 R_2 = (\rho)^2 + (c + d - \rho)^2 + (a - c + \rho)^2 \\
&\quad + (b + c - \rho)^2 \\
&= a^2 + b^2 + d^2 + 3c^2 + 2bc - 2ac + 2cd + 4\rho^2 - 6\rho c \\
&\quad + 2\rho a - 2\rho b - 2\rho d
\end{aligned}$$

$$\begin{aligned}
R_4 R_4 &= a^2 + b^2 + d^2 + 3c^2 + 2bc - 2ac + 2cd + 5\rho^2 \\
&\quad - 7\rho c + \rho a - 3\rho b - 3\rho d \\
&= R_2 R_2 - 2\rho a + \rho^2 - \rho c - \rho b - \rho d + \rho a \\
&= R_2 R_2 - 2\rho a + \rho^2 - \rho c - \rho(\rho - (a + c)) + \rho a = R_2 R_2 \\
\text{ii. 1) } C_1 C_1 &= 2a^2 + \frac{3}{2}\rho^2 + 2c^2 - 2\rho c - 2ac + a\rho = C_3 C_3 \\
\text{ii. 2) } C_2 C_2 &= 2b^2 + 2c^2 + 2d^2 + \frac{7}{2}\rho^2 + 2cd - 5\rho c - 3\rho d \\
&\quad + 2bc - 3\rho b = C_4 C_4
\end{aligned}$$

3.2. Eigen Values of 4x4 Strongly Magic Squares

3.2.1.

The eigen values of 4x4 SMS are $\rho, 0, \varphi, -\varphi$, where $\varphi^2 = [(a-d)^2 - (b+c)^2 + 4(\rho b + cd \pm \rho d)]$.

$$\begin{vmatrix}
a-\lambda & b & c & d \\
\rho & c+d-\rho-\lambda & a-c+\rho & b+c-\rho \\
\frac{\rho}{2}-c & \frac{\rho}{2}-d & \frac{\rho}{2}-a-\lambda & \frac{\rho}{2}-b \\
c-a-\frac{\rho}{2} & \frac{3\rho}{2}-b-c & -\rho/2 & \frac{3\rho}{2}-c-d-\lambda
\end{vmatrix} = 0 \quad (10)$$

Simplifying (10) the characteristic polynomial can be written as

$$\lambda^4 - \lambda^3 \rho - \lambda^2 \varphi^2 + \lambda \rho \varphi^2 = 0; \text{ where } \varphi^2 = [(a-d)^2 - (b+c)^2 + 4(\rho b + cd \pm \rho d)]$$

or in case of factorized form expressed by $\lambda(\lambda - \rho)(\lambda - \varphi)(\lambda + \varphi) = 0$.

This completes the proof

3.2.2.

Sum of the eigen values of a SMS of order $n^2 \times n^2$ is the magic constant.

Proof

Let λ be the eigen value of a SMS.

Then $\sum \lambda_i = \text{trace of } A; i = 1, 2 \dots n^2$

$$\sum \lambda_i = \rho \quad (\text{Since trace of } A \text{ is the magic constant})$$

Thus sum of the eigen values of a SMS is the magic constant ρ .

3.2.3.

$(1, 1, 1, \dots, 1)^T$ is the eigen vector corresponding to the eigen value ρ of a strongly magic square A .

Proof

The eigen vector X of a matrix A with eigen value λ is given by $AX = \lambda X$.

By using the fact that the one of the eigen value is ρ and the row sum is also ρ ; we have

$(1, 1, 1, \dots, 1)^T$ as the eigen vector corresponding to eigen value ρ . Clarifies the proof have to illustration in the following form

The particular 4x4 SMS Sri Rama Chakra is given by

$$A = \begin{bmatrix} 16 & 5 & 4 & 9 \\ 2 & 11 & 14 & 7 \\ 13 & 8 & 1 & 12 \\ 3 & 10 & 15 & 6 \end{bmatrix}$$

Proof

The general form of a 4x4 SMS is given by

$$\begin{bmatrix}
a & b & c & d \\
\rho & c+d-\rho & a-c+\rho & b+c-\rho \\
\frac{\rho}{2}-c & \frac{\rho}{2}-d & \frac{\rho}{2}-a & \frac{\rho}{2}-b \\
c-a-\frac{\rho}{2} & \frac{3\rho}{2}-b-c & -\rho/2 & \frac{3\rho}{2}-c-d
\end{bmatrix}$$

where ρ is the magic constant and $a, b, c, d \in R$. [9]

The characteristic polynomial of A is given by $|A - \lambda I| = 0$

i.e.,

Assume $(1, 1, 1, 1)^T$ be the eigen vector, X .

Then $AX = \lambda X$ gives

$$\begin{bmatrix} 16 & 5 & 4 & 9 \\ 2 & 11 & 14 & 7 \\ 13 & 8 & 1 & 12 \\ 3 & 10 & 15 & 6 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 34 \\ 34 \\ 34 \\ 34 \end{bmatrix} = 34 \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

Remark: 1. $(1, 1, 1, \dots, 1)^T$ is the eigen vector for a SMS and its transpose

2. It can be observed that the eigenvalues except for ρ and 0 of strongly magic square will be either 0 or $\pm \lambda$

Corollary:

The eigen values of a magic square cannot be all positive.

Proof

From the Remark 2, the result is obtained

3.3. Determinant and Rank of 4x4 Strongly Magic Squares

3.3.1.

The determinant of a 4x4 SMS is always 0.

Proof

The general form of a 4x4 SMS is given by

$$A = \begin{bmatrix}
a & b & c & d \\
\rho & c+d-\rho & a-c+\rho & b+c-\rho \\
\frac{\rho}{2}-c & \frac{\rho}{2}-d & \frac{\rho}{2}-a & \frac{\rho}{2}-b \\
c-a-\frac{\rho}{2} & \frac{3\rho}{2}-b-c & -\rho/2 & \frac{3\rho}{2}-c-d
\end{bmatrix}$$

where ρ is the magic constant and $a, b, c, d \in R$. [9]

It can be verified that $|A| = 0$.

3.3.2.

The rank of a 4×4 strongly magic square is always 3.

Proof

The general form of a 4×4 SMS is given by

$$A = \begin{bmatrix} a & b & c & d \\ \rho & c+d-\rho & a-c+\rho & b+c-\rho \\ \frac{\rho}{2}-c & \frac{\rho}{2}-d & \frac{\rho}{2}-a & \frac{\rho}{2}-b \\ c-a-\frac{\rho}{2} & \frac{3\rho}{2}-b-c & -\rho/2 & \frac{3\rho}{2}-c-d \end{bmatrix}$$

where ρ is the magic constant and $a, b, c, d \in \mathbb{R}$.

It can be verified using matlab which is the rank given above SMS A is 3.

3.3.3.

The rank of a 4×4 SMS A and AA^T are equal.

Proof

By taking the general form as in 3.3.2

$$AA^T = [b_{ij}] \text{ where } i, j = 1, 2, 3, 4 \text{ such that}$$

$$b_{11} = a^2 + b^2 + c^2 + d^2$$

$$b_{12} = a\rho + c(a-c+\rho) + b(c+d-\rho) + d(b+c-\rho)$$

$$b_{13} = -a\left(c - \frac{\rho}{2}\right) - c\left(a - \frac{\rho}{2}\right) - b\left(d - \frac{\rho}{2}\right) - d\left(b - \frac{\rho}{2}\right)$$

$$b_{14} = -a(a-c+\rho/2) - (c\rho)/2 - b(b+c - (3\rho)/2) - d(c+d - (3\rho)/2)$$

$$b_{21} = a\rho + c(a-c+\rho) + b(c+d-\rho) + d(b+c-\rho)$$

$$b_{22} = (a-c+\rho)^2 + (b+c-\rho)^2 + (c+d-\rho)^2 + \rho^2$$

$$b_{23} = -\rho(c - \rho/2) - (a - \rho/2)(a-c+\rho) - (b - \rho/2)(b+c-\rho) - (d - \rho/2)(c+d-\rho)$$

$$b_{24} = \rho(a-c+\rho/2) - (b+c-\rho)(c+d-(3\rho)/2) - (b+c-(3\rho)/2)(c+d-\rho) - (\rho * (a-c+\rho))/2$$

$$b_{31} = -a\left(c - \frac{\rho}{2}\right) - c\left(a - \frac{\rho}{2}\right) - b\left(d - \frac{\rho}{2}\right) - d\left(b - \frac{\rho}{2}\right)$$

$$b_{32} = -\rho(c - \rho/2) - (a - \rho/2)(a-c+\rho) - (b - \rho/2)(b+c-\rho) - (d - \rho/2)(c+d-\rho)$$

$$b_{33} = \left(a - \frac{\rho}{2}\right)^2 + \left(b - \frac{\rho}{2}\right)^2 + \left(c - \frac{\rho}{2}\right)^2 + \left(d - \frac{\rho}{2}\right)^2$$

$$b_{34} = \left(c - \frac{\rho}{2}\right)\left(a - c + \frac{\rho}{2}\right) + \frac{\rho\left(a - \frac{\rho}{2}\right)}{2} + \left(b - \frac{\rho}{2}\right)\left(c + d - \frac{3\rho}{2}\right) + (d - \rho/2)(b+c - (3\rho)/2)$$

$$b_{41} = -a(a-c+\rho/2) - (c\rho)/2 - b(b+c - (3\rho)/2) - d(c+d - (3\rho)/2)$$

$$b_{42} = -\rho(a-c+\rho/2) - (b+c-\rho)(c+d-(3\rho)/2) - (b+c-(3\rho)/2)(c+d-\rho) - (\rho(a-c+\rho))/2$$

$$b_{43} = (c-\rho/2)(a-c+\rho/2) + (\rho(a-\rho/2))/2 + (b-\rho/2)(c+d-(3\rho)/2) + (d-\rho/2)(b+c-(3\rho)/2)$$

$$b_{44} = \left(b+c - \frac{3\rho}{2}\right)^2 + \left(c+d - \frac{3\rho}{2}\right)^2 + \left(a-c + \frac{\rho}{2}\right)^2 + \rho^2/4$$

Using Matlab it can be easily verified that rank of A and AA^T is 3

4. Conclusion

While magic squares are recreational in grade school, they may be treated somewhat more seriously in different mathematical courses. The study of strongly magic squares is an emerging innovative area in which mathematical analysis can be done. Here some advanced properties regarding strongly magic squares are described. Despite the fact that magic squares have been studied for a long time, they are still the subject of research projects. These include pure mathematical research, much of which is connected with the algebra and combinatorial geometry of polyhedra (see, for example, [10]). Physical application of magic squares is still a new topic that needs to be explored more. There are many interesting ideas for research in this field.

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