Skin Physiology Analysis via Grey GM(1, N) and GM(0, N) Model

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Abstract

This paper focuses on the skin physiological factor relationship analysis using grey GM(1, N) and GM(0, N) model. First, skin physiological factor sampling are done for Taiwan female subjects aged from 18 ~ 52, where the factors include skin elasticity, pH value, skin pigmentation, skin surface lipids and skin epidermal hydration. With the acquired data, we can then establish the data model using grey theory. Here, we apply the grey GM(1, N) and GM(0, N) model to obtain the relationship weighting between the major factor and the other relational factors. Furthermore, according to the determined weightings, we proceed on the skin physiological factor relationship analysis to understand the skin characteristics under different age.

1. Introduction

Skin, the biggest organ in human body, not only can provide outer layer protection, but also can indicate both psychological and physiological reflections of a person. However, detailed skin condition is undetectable under human eye, where accurate instruments are required for physiological detections and skin status detections [1]-[3]. Current clinical skin detections mostly focus on simple analysis, for example, dry or oily skin detection, yet they lack of complete skin diagnose and skin physiological analysis under different age. This is because skin physiological analysis requires large amount of sample data, where the data require to satisfy some sampling restrictions. Then, traditional methods lead to great difficulties in clinical researches.

Grey system theory, first proposed by Professor Julong Deng in 1982 on international conference, has been developed for over 20 years and become one of the popular research areas [4, 5]. It includes grey relational generating operation (GRGO), grey relational analysis (GRA), localization grey relational grade (LGRG), globalization grey relational grade (GGRG), grey model (GM), grey decision making and grey control. In practical applications, it covers in a large of varieties such as sports, education, medical treatments, managements, and industrial aspects [6]-[11].

In most of the researches, grey theory takes an important part in theoretical analysis and numerical data modeling and analysis. Furthermore, the constructed data model is a non-functional type sequence model with characteristics of easy computing and the numerical data do not need to satisfy classical distribution. Hence, many researches apply grey theory in numerical analysis, factor analysis, and optimization problems. Especially in resent years,

grey theory has become more and more popular in biological information and technology, such as liver functional diagnosis [12].

Based on the above mentioned skin physiological analysis and grey theory application researches, we here establish the GM(1, N) and GM(0, N) model for relationship analysis of the skin physiological factors for further characteristic estimation. First, experimental data base is constructed according to the samples from different subjects including the following six factors: age, skin elasticity, skin pH value, skin pigmentation, skin surface lipids and skin epidermal hydration. Then, the relationship factors between these six physiology factors are derived using grey theory models to analyze the characteristics of their mutual relationship. From the grey relationship analysis, we arrive with the following conclusions:

(1) Along with the increase of age, skin elasticity decreases rapidly, the pH value decreases (skin tends to acid), and the skin epidermal hydration increases causing the skin to lose moisture capacity.
(2) To maintain skin elasticity, it is necessary to retain the skin pH value (pH value is direct proportion to skin elasticity) and the epidermal hydration. Besides, the more moisture is kept inside the skin, the better the skin elasticity.

The results can be used as further reference and skin care decisions for medical cosmetology and related researches.

This research is organized as follows. In Section 2, an introduction on the clinical testing of skin physiological and the analysis of gray relationship method is given. In Section 3, simulations and analysis results are presented. Finally, conclusions are given in Section 4.

2. Research Methods

2.1 Skin Physiological Detection

2.1.1 Physiological detection factors

The physiological factors in interest in this research are: age, skin elasticity, pH value, skin pigmentation, skin surface lipids and skin epidermal hydration [6, 7]. The subject and factor details are given below:

(1) Age: To achieve effectiveness in physiological analysis, the subject age is chosen from 18 to 52 and is separated into two groups at age 25.
(2) Skin physiological factors: skin elasticity, pH value, skin pigmentation, skin surface lipids and skin epidermal hydration.

2.1.2 Detection Design

(1) Detection condition: Ambient temperature at 20 ± 2℃, Relative humidity at 45 ±5%. Optimal sampling condition is detected under these conditions, thus, the temperature and humidity have to be initialized before sampling.
(2) Subjects: 50 – 60 subjects. The data are used for statistical analysis.
(3) Age and sex: 18 – 52 Taiwan females.
(4) Tested skin partition: With different skin partition, accompanies with different epidermal hydration, surface lipids and pigment, and etc.. In this research, we measured on both sides of the cheeks 3 times for each subject.
(5) Cleaning of the tested skin partition: Before detection, we use non-alcoholic scrub for cleaning and waited 3 hours after cleaning for the skin to recover.

(6) Skin features: We test dry and oily skin half and half of the subjects 3 times individually. Skin sensitive subjects are not taken into consideration.

2.1.3 Equipments for Skin Detection:

(1) Skin elasticity (Cutometer): It uses the supersonic concept (sonar probe). Because skin elasticity tissue interlace with each other, each measuring points require to be sampled 4 time in different angle and is averaged for each data.

(2) Skin pH value (PC Skin-pH-Meter 905): The probe is improved from industrial pH detector, where the results are shown using professional software and LCD.

(3) Skin surface lipids (Sebumeter-810): A special translucent paper material that becomes transparent once it touches lipids is used. First, the clean material is scanned before and after the sampling, then, the sampled material is examined again to modify its transparent variation where the skin surface lipids can be obtained.

(4) Skin pigmentation (Mexameter MX16): The LAB value is measured based on absorption or reflex ion with a receiver that measures the light reflected by the skin.

(5) Skin epidermal hydration (Tewameter): Using a very sensitive microchip to capture the moisture molecules from the skin in order to measure the skin epidermal hydration.

In this research, 61 Taiwan female subjects are tested where the results are presented in Table 1. With these original experiment data, we can proceed on the skin physiological relationship factor analysis using grey system theory.

Table 1. Original tested data

Age	Elasticity	pH	Surface Lipids	Pigmentation	Epidermal Hydration
20	0.8	4.5	278	200	15
20	0.89	5.28	150	268	15
22	0.82	6.15	227	192	18.8
23	0.86	5.7	143	167	14.5
24	0.78	5.95	114	142	40.3
24	0.82	4.5	220	257	16
25	0.82	4.82	136	279	13
⋮	⋮	⋮	⋮	⋮	⋮
28	0.92	4.86	188	268	17
28	0.92	4.86	188	268	17
29	0.78	4.8	178	178	20
31	0.77	4.75	148	230	17
33	0.88	5.33	185	156	15
39	0.87	4.88	82	199	24
42	0.77	5.2	110	380	21

2.2 Grey Theory

The grey model in grey system theory consists of two types: GM(1, N) model and GM(0, N) model [4, 5]. In the following, the relationship analysis for both types is described individually.

2.2.1 GM(1, N) Model

First we consider that the data can be separated into two sequences: (1) Major sequence factor, which is the sequence that masters the system behaviors; (2) Influencing sequence factors, which are the sequences that influence the system behaviors. Here, the major sequence factor is defined as follows:

$$x_1^{(0)} = (x_1^{(0)}(1), x_1^{(0)}(2), \cdots, x_1^{(0)}(M))$$

where M is the sequence length. The influence sequence factors are

$$\begin{aligned} x_2^{(0)} &= (x_2^{(0)}(1), x_2^{(0)}(2), \cdots, x_2^{(0)}(M)) \\ x_3^{(0)} &= (x_3^{(0)}(1), x_3^{(0)}(2), \cdots, x_3^{(0)}(M)) \\ &\vdots \\ x_N^{(0)} &= (x_N^{(0)}(1), x_N^{(0)}(2), \cdots, x_N^{(0)}(M)) \end{aligned}$$

where N is defined as the original sequence number. In other words, $x_1^{(0)}$ and $x_i^{(0)}$ represents the major sequence and the influence sequence. Then, $x_i^{(1)}$ and $x_i^{(0)}$ are defined as 1-AGO sequences $(i = 1, 2 \cdots, N)$:

$$x_i^{(1)} = \left(\sum_{k=1}^{1} x_i^{(0)}(k), \sum_{k=1}^{2} x_i^{(0)}(k), \cdots, \sum_{k=1}^{M} x_i^{(0)}(k) \right)$$

Let $z_1^{(1)}$ is the average generation of adjacent data sequence of $x_1^{(1)}$:

$$z_1^{(1)}(k) = 0.5x_1^{(1)}(k) + 0.5x_1^{(1)}(k-1) \quad , \; k \geq 2$$

The grey differential equations of the GM(1,N) model is :

$$\frac{d\,x^{(1)}(k)}{d\,t} + ax_1^{(1)}(k) = \sum_{i=2}^{N} b_i x_i^{(1)}(k)$$

where a and b_i are determined coefficients; k = 1, 2,…, M. According to the GM(1,N) model form, the constructed 1-AGO sequence is:

$$x_1^{(0)}(k) + az_1^{(1)}(k) = \sum_{i=2}^{N} b_i x_i^{(1)}(k) \tag{1}$$

The above equation (1) is the GM(1, N) model. Where a it the system develop factor; $b_i x_i^{(1)}(k)$ is the driving terms; b_i is the driving factors which is the relationship weighting factors（or relationship factors）; $\hat{a} = [a, b_2, \cdots b_N]^T$ is the parameter vector.

Submitting all the above parameters into (1) with k = 1, 2, …, M, we can arrive with the following matrix

$$\begin{bmatrix} x_1^{(0)}(2) \\ x_1^{(0)}(3) \\ \vdots \\ x_1^{(0)}(M) \end{bmatrix} = \begin{bmatrix} -z_1^{(1)}(2) & x_2^{(1)}(2) & \cdots & x_N^{(1)}(2) \\ -z_1^{(1)}(3) & x_2^{(1)}(3) & \cdots & x_N^{(1)}(3) \\ \vdots & \cdots & & \\ -z_1^{(1)}(M) & x_2^{(1)}(M) & \cdots & x_N^{(1)}(M) \end{bmatrix} \begin{bmatrix} a \\ b_2 \\ \vdots \\ b_N \end{bmatrix}$$

Thus, $\hat{a}$ can be obtained using the least square method where the details are as follows.

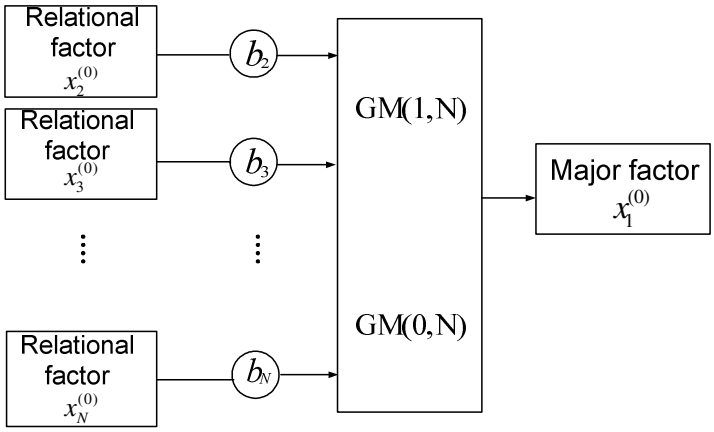

Figure 1. Block diagram of the relationship analysis

Theorem 1: Assume $x_1^{(0)}$ is the system major sequence, $x_i^{(0)}$ $(i = 2\cdots, N)$ is the influencing sequences, $x_i^{(1)}$ is the 1-AGO sequence, $z_1^{(1)}$ and $x_1^{(1)}$ is the average generation of adjacent data sequence. Thus the least square estimation of $\hat{a} = [a, b_2, \cdots b_N]^T$ is

$$\hat{a} = (B^T B)^{-1} B^T Y$$

where

$$Y = \begin{bmatrix} x_1^{(0)}(2) \\ x_1^{(0)}(3) \\ \vdots \\ x_1^{(0)}(M) \end{bmatrix}, B = \begin{bmatrix} -z_1^{(1)}(2) & x_2^{(1)}(2) & \cdots & x_N^{(1)}(2) \\ -z_1^{(1)}(3) & x_2^{(1)}(3) & \cdots & x_N^{(1)}(3) \\ \vdots & \cdots & \cdots & \cdots \\ -z_1^{(1)}(M) & x_2^{(1)}(M) & \cdots & x_N^{(1)}(M) \end{bmatrix}$$

From Theorem 1, we can obtained the parameter vector and the GM(1,N) model as

$$\frac{dx_1^{(1)}}{dt} + ax_1^{(1)} = b_2 x_2^{(1)} + b_3 x_3^{(1)} + \cdots + b_N x_N^{(1)}. \quad (2)$$

Summarizing the above GM(1,N) model, the grey system model can be illustrated as Figure 1, where the system input is influencing sequences and the system output is major sequence. By utilizing relational factors and GM(1,N) model, we can construct the function of the input and output sequences to furthermore understand the input-output relationship.

2.2.2 GM(0, N) Model

GM (0, N) model is a special case of GM(1, N) model with no derivatives which is classified as static factor analysis. It is a special type of multiple regressive modeling that

distinct from traditional ones. Traditional multiple regressive modeling uses the original data sequence as foundation where GM(0, M) model uses the 1-AGO sequence of the original data as foundation. The GM(0, N) model is as follows.

$$\begin{aligned} x_1^{(1)}(k) &= a + \sum_{j=2}^{N} b_j x_j^{(1)}(k) \\ &= a + b_2 x_2^{(1)}(k) + b_3 x_3^{(1)}(k) + \cdots + b_N x_N^{(1)}(k) \end{aligned}$$

where $x_i^{(1)}$ is the 1-AGO sequence of every $x_i^{(0)}$ $(i = 1, 2 \cdots, N)$. If we submit all the sequence factors into (6) where k = 1, 2,…, M, we can arrive with the following matrix equation

$$\begin{bmatrix} x_1^{(1)}(2) \\ x_1^{(1)}(3) \\ \vdots \\ x_1^{(1)}(M) \end{bmatrix} = \begin{bmatrix} 1 & x_2^{(1)}(2) & \cdots & x_N^{(1)}(2) \\ 1 & x_2^{(1)}(3) & \cdots & x_N^{(1)}(3) \\ \vdots & \cdots & & \\ 1 & x_2^{(1)}(M) & \cdots & x_N^{(1)}(M) \end{bmatrix} \begin{bmatrix} a \\ b_2 \\ \vdots \\ b_N \end{bmatrix}$$

Hence, using least square method solves the parameter vector $\hat{a} = [a, b_2, \cdots b_N]^T$. As same as GM(1, N) model, the relational weighting of GM(0, N) model can be obtained from the following theorem.

Theorem 2: Let $x_1^{(0)}$ be the major sequence, $x_i^{(0)}$ $(i = 2, 3, \cdots, N)$ be the influencing sequences, and $x_i^{(1)}$ is the 1-AGO sequence of $x_i^{(0)}$ for $i = 1, 2, \cdots, N$. Therefore, the least square estimation of $\hat{a} = [a, b_2, \cdots b_N]^T$ is

$$\hat{a} = (B_0^T B_0)^{-1} B_0^T Y_0$$

where

$$B_0 = \begin{bmatrix} x_2^{(1)}(2) & x_3^{(1)}(2) & \cdots & x_N^{(1)}(2) \\ x_2^{(1)}(3) & x_3^{(1)}(3) & \cdots & x_N^{(1)}(3) \\ \cdots & \cdots & \cdots & \cdots \\ x_2^{(1)}(M) & x_3^{(1)}(M) & \cdots & x_N^{(1)}(M) \end{bmatrix}, \quad Y_0 = \begin{bmatrix} x_1^{(1)}(2) \\ x_1^{(1)}(3) \\ \vdots \\ x_1^{(1)}(M) \end{bmatrix}$$

Therefore, grey model structure of the influence sequences and major sequence can be represented as Figure 1 once $\hat{a}$ is derived. The b_j is the relationship factor between the input influence sequences and output major sequence, which can be used to understand the relational degree between the individual data.

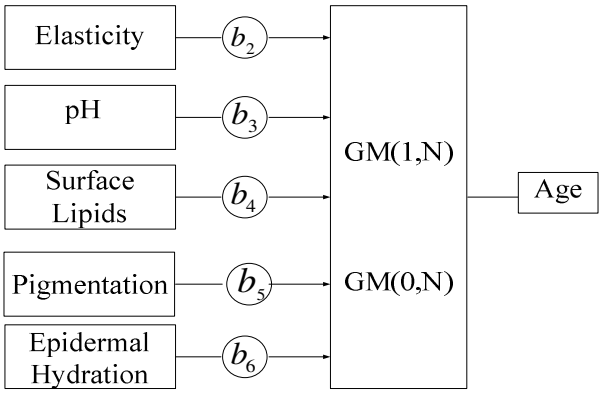

Figure 2. Block diagram of the age relationship analysis

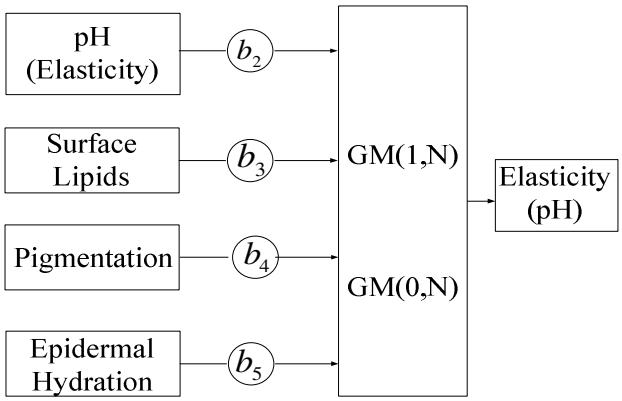

Figure 3. Block diagram of the skin elasticity (pH value) relationship analysis

2.2.3 Relationship Analysis

In the above mentioned GM(1, N) and GM(0, N) model, the grey system can be considered as an approximation model with input and output sequences, where the relationship between the two sequences are derived though the system parameter vector. For skin physiological factor relationship analysis, it is important to select the appropriate major sequence factor in which the sequence data is the system output sequences. The other physiological factors are the relational sequence factors. The relationship weightings in $\hat{a}$ can be obtained using Theorem 1 and Theorem 2, for showing the relationship between input and output factors. The relationship analysis is as follows:

(1) When analyzing the relationship between age and the other physiological factors, consider the block diagram in Figure 2.

(2) When analyzing the relationship between skin elasticity (or pH value) and the other physiological factors as the block diagram in Figure 3. When considering pH value as the major factor, we exchange pH value with skin elasticity in Figure 3.

3. Analysis Results

The sample data in this research are based on 61 Taiwan females age from 18 to 52 and the tested results are given in Table 1. Through the grey theory mentioned in the previous section, we can find the relationship of the skin physiology factors.

First, we proceed on the age relational factor analysis where the structure is shown as Figure 2. Here, age is defined as major sequence and submitted into GM(0, N) and GM(1, N) model to find out the relationship weighting b_i between the major sequence and the other sequences. The analysis results are given in Figure 4 and we can see that age to skin elasticity, skin pH value, and skin epidermal hydration have the highest relativity, where the weighting increases with its influence. From the weighting factors, it is obvious that the skin elasticity and pH value decrease with age. Moreover, the skin epidermal hydration increases with age causing the skin to lose its moisture capability. For more detailed results, the average data are given in Table 2.

From Table 2, the relationship between the skin elasticity and age is

$$\text{Age below } 25 > \text{Age over } 25$$

The relationship between the pH value and age:

$$\text{Age below } 25 > \text{Age over } 25$$

The relationship between the skin epidermal hydration and age:

$$\text{Age below } 25 < \text{Age over } 25$$

To carry on the research, we neglect the age influence and focus on the relationship between skin elasticity and pH value to the other skin physiology factors as shown in Figure 3. We remove the age factor and separate the age groups into above and below 25 years old, then, let skin elasticity as the major sequence. The relational factors is obtained by using GM(1, N) and GM(0, N) model, where the results are given in Figure 5 and Figure 6. With the same age separation, the relational results using pH value as the major sequence are shown in Figure 7 and Figure 8.

Table 2. Average value of individual factors

Average	Elasticity	pH	Surface Lipids	Pigmentation	Epidermal Hydration
Under age 25	0.81675	5.24775	172.225	230.25	16.8475
Above age 25	0.785714	5.098095	130.619	267.7143	21.1

	Elasticity	PH Value	Epidermal hydration	Surface Lipids	Pigmentation
GM(0,N)	30.8782	2.2461	0.8167	0.0569	0.0301
GM(1,N)	18.9117	5.0822	1.1289	0.0027	0.035

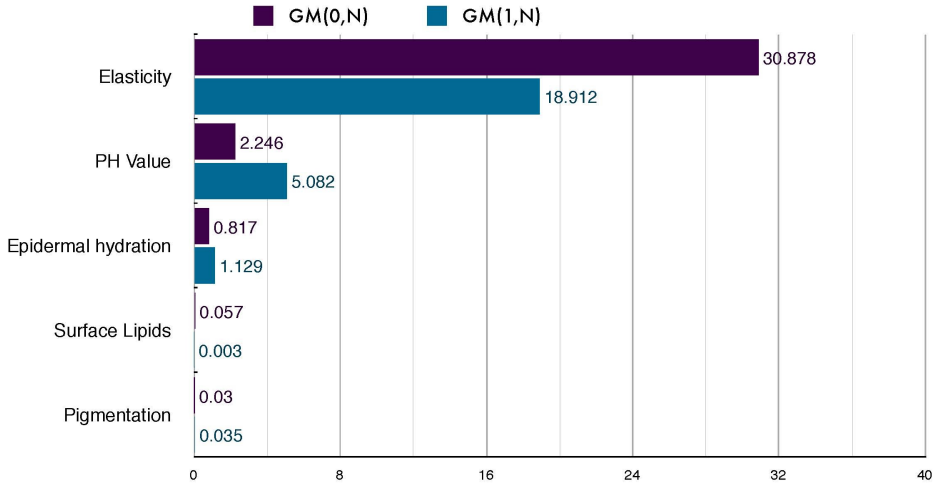

Figure 4. Age as the major sequence

	PH Value	Epidermal hydration	Surface Lipids	Pigmentation
GM(0,N)	0.0775	0.0044	0.0024	0.0004
GM(1,N)	0.1101	0.0163	0.0033	0.0012

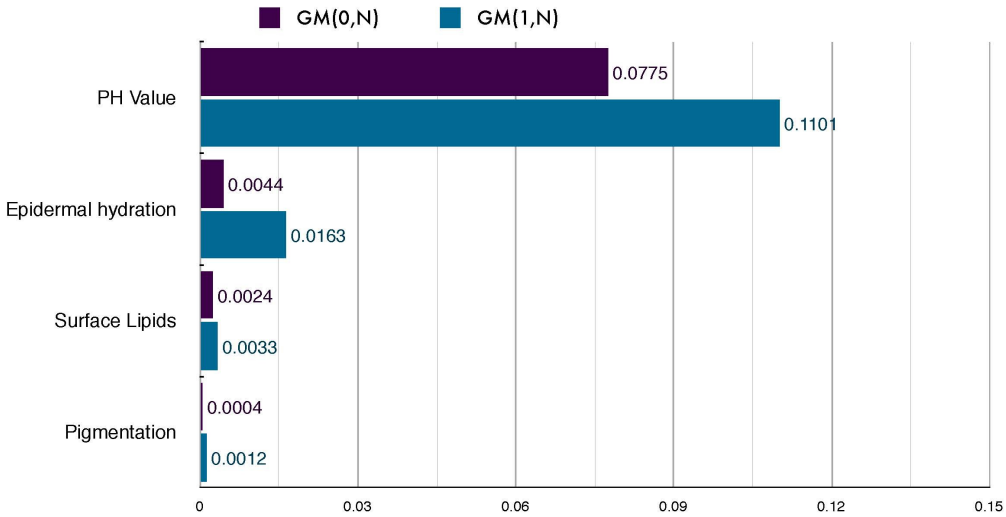

Figure 5. Skin elasticity weighting for age under 25

	PH Value	Epidermal hydration	Surface Lipids	Pigmentation
GM(0,N)	0.1231	0.0021	0.0012	0.0002
GM(1,N)	0.1718	0.0298	0.0017	0.0018

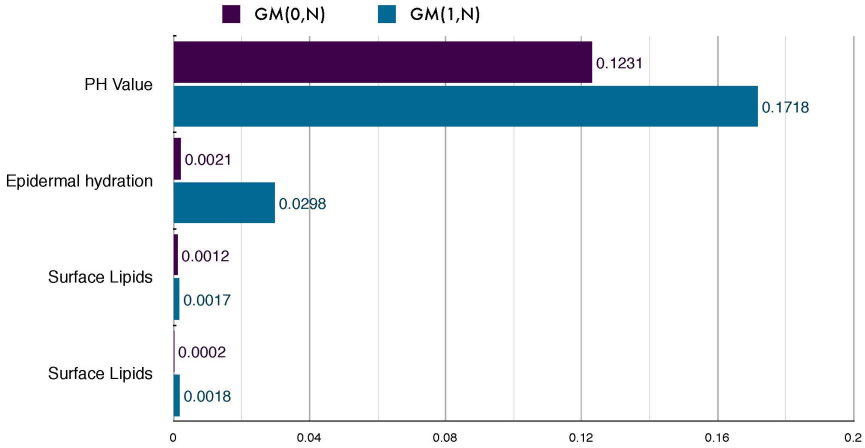

Figure 6. Skin elasticity weighting for age above 25

According to the above results, skin elasticity, pH value, and epidermal hydration have greater relevance in the two age groups. Meaning that in order to maintain skin elasticity, it is necessary to maintain skin pH value (the pH value is direct proportion to skin elasticity) and reduce skin epidermal hydration. The less skin epidermal hydration, the more moisture is kept inside the skin and the better skin elasticity is obtained.

	Elasticity	Epidermal hydration	Surface Lipids	Pigmentation
GM(0,N)	7.1354	0.0974	0.0211	0.0058
GM(1,N)	5.3653	0.0109	0.0103	0.0021

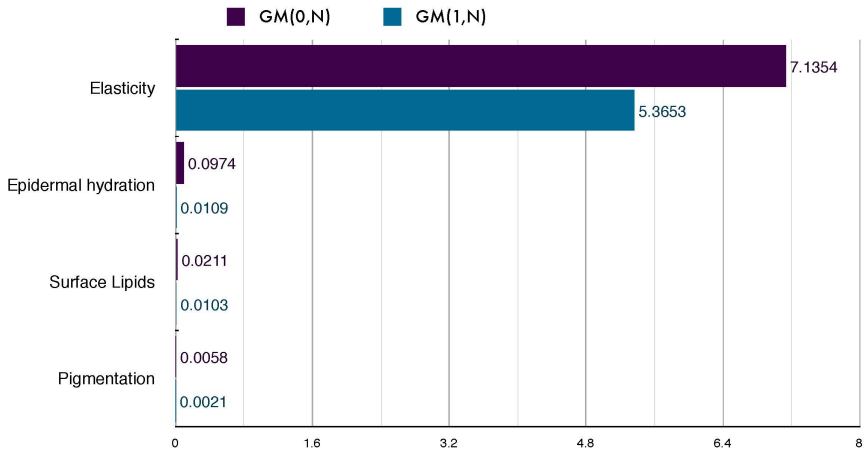

Figure 7. pH value weighting for age under 25

	Elasticity	Epidermal hydration	Surface Lipids	Pigmentation
GM(0,N)	4.3601	0.1004	0.0015	0.001
GM(1,N)	3.8258	0.0123	0.0018	0.0075

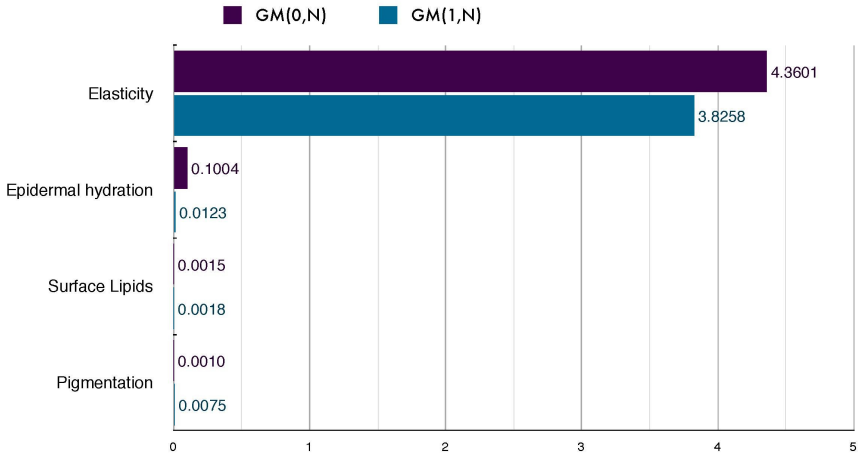

Figure 8. pH value weighting for age above 25

4. Conclusions

Traditional skin physiology estimation methods use statistics analysis, so that large data samples are required. With restricted conditions, it usually causes the clinical research results lack of authenticity and unsuitable to apply in practical use. By using the grey system modeling, the relationship of the physiology factors can be indirectly obtained along with easy computing such that the disadvantages of traditional methods are overcome. Moreover, the result is contributory for skin physiology relationship analysis and provides future decision-making in skin preservation.

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