Prediction Method of Rope Skipping Energy Consumption Based on Smart Phone Sensor

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Abstract. Based on the built-in acceleration sensor of the smart phone, this paper studies the signal data processing of the sensor in the smart phone worn by the rope skipper in the process of rope skipping into intuitive energy consumption data. For this reason, the mathematical model of the sensor signal data processing is established, and the data is compared with the data generated by the professional test instrument, so as to provide reference for the future Smart phone sensors lay the foundation for the prediction of energy consumption in various sports. Methods: 50 volunteers were selected to participate in the experiment (25 male and 25 female), 40 in the control group and 10 in the study group. 50 volunteers participated in the experiment were wearing a Huawei mobile phone and a set of gas metabolism analyzer to complete the two parts of the test; the test action was the standard rope skipping action, and different times of rope skipping per minute were set. Before the experiment, the participants must be in good health, keep calm physiological state and control variables. After that, the standard rope skipping for five minutes is carried out, and the signal received by the sensor on the mobile phone is analyzed and generated by the test software and instrument, and the prediction equation with the age, height and weight of the tested person as the independent variable is established. The purpose is to explore and analyze the different prediction of energy consumption of rope skipping by different sensors on smart phones, and the rope skipping frequency is more effective for energy consumption under different frequencies per minute.

Keywords: Rope Skipping, Energy Consumption, Acceleration Motion Sensor, Smart Phone

1. Introduction
Daily sports activities have an inseparable relationship with the health level of the body. Scientific sports based on each person's own physical condition is conducive to human health and effective maintenance of physical function. The decline of body function will bring many diseases, such as cardiovascular and cerebrovascular diseases, common "three highs", bone health related diseases, and some chronic diseases [1]. The intensity of physical function is closely related to the intensity of exercise. Regular physical exercise can improve the body function and reduce the incidence rate of related diseases. Scientific and effective physical exercise, quantitative exercise process and goal has been an important topic of relevant scholars [2]. Especially in the upsurge of national fitness, many people only know how to do physical exercise blindly, but they don't know anything about the detection and evaluation of various physical indicators in physical exercise, or even have the slightest awareness of attention. It may cause irreversible damage to itself in the high intensity of physical exercise. In addition, different intensity of physical exercise on the strengthening degree of physical function is very different, only grasp the most appropriate exercise intensity can make physical exercise get the most efficient [3].

Rope skipping is a "national" way of physical exercise in China. Because of its low requirements for venues, small restrictions on sports links and other factors, it has become a hot way of physical exercise in China and even in the world [4]. And its mild and not violent form of exercise, suitable for the vast majority of people, so the audience of rope skipping and its vast [5]. In China's compulsory education, rope skipping has been added to its compulsory course early, which is enough to show its applicability [6]. Research shows that one hour of rope skipping is equivalent to three hours of running, which shows that rope skipping is an efficient aerobic exercise. Aerobic exercise mainly strengthens people's cardiopulmonary function. The enhancement of cardiopulmonary function is helpful for us to avoid cardiopulmonary function related diseases, which is a good way to strengthen our body [7]. As early as 20-30 years ago, rope skipping was added to the examination item in China's senior high school entrance examination. The reason is that the cardiopulmonary function exercised by rope skipping is the basis of many other sports, and the national consideration is comprehensive and profound [8].

Whether from the perspective of physical strength and social rationality of campus students, or from the perspective of fitness rope skipping itself and competitive value, the popularization and development of fitness rope skipping will become the main trend of the future society. With the development of technology, mobile sports software has also appeared, many people who love sports also began to use mobile sports software to monitor their physical exercise [9]. As we all know, rope skipping movement is repeated in the vertical direction. The acceleration sensor mainly monitors the motion data of X, y and Z axes in space. Combined with the human body space coordinate system, the energy consumption data is obtained by using the calculation formula of energy consumption value. Domestic research in this field is relatively backward. Therefore, in order to provide more convenient measurement methods for young sports lovers, relevant research is needed [10].

2. Algorithm

2.1. Quaternion algorithm

The pitch angle, roll angle and yaw angle are used in the design of motion state recognition algorithm. They are called Euler angle. In the process of getting Euler angle, quaternion is introduced to convert
Euler angle into quaternion. The quaternion is interpolated by spherical linear interpolation, and then the quaternion is converted into corresponding Euler angle.

Quaternion definition

\[ p = a\hat{i} + b\hat{j} + c\hat{k} + d \]  

(1)

Where, a, b, c, d are real numbers, \( \hat{i}, \hat{j}, \hat{k} \) are standard orthogonal bases of three bit space represented by three complex numbers, and have the following properties

\[ \hat{i} \ast \hat{i} = \hat{j} \ast \hat{j} = \hat{k} \ast \hat{k} = -1 \]  

(2)

Other representations of quaternion can be described easily, so we define a four-dimensional vector to represent quaternion.

\[ q = [w, x, y, z]^T \]  

(3)

\[ |q|^2 = w^2 + x^2 + y^2 + z^2 = 1 \]  

(4)

A quaternion can be constructed by rotating the axis and rotating the angle around the corresponding axis

\[ w = \cos(\alpha/2) \]  

(5)

\[ x = \sin(\alpha/2)\cos(\beta_x) \]  

(6)

\[ y = \sin(\alpha/2)\cos(\beta_y) \]  

(7)

\[ z = \sin(\alpha/2)\cos(\beta_z) \]  

(8)

Among them, the rotation angle around the rotation axis is \( \alpha \), and the components of the rotation axis in X, y and Z directions are \( \cos(\beta_x), \cos(\beta_y), \cos(\beta_z) \).

Transformation from Euler angle to Quaternion

\[
Q = \begin{bmatrix}
w \\
x \\
y \\
z
\end{bmatrix} = \begin{bmatrix}
\cos(\varphi/2)\cos(\theta/2)\cos(\psi/2) + \sin(\varphi/2)\sin(\theta/2)\sin(\psi/2) \\
\sin(\varphi/2)\cos(\theta/2)\cos(\psi/2) - \cos(\varphi/2)\sin(\theta/2)\sin(\psi/2) \\
\cos(\varphi/2)\sin(\theta/2)\cos(\psi/2) + \sin(\varphi/2)\cos(\theta/2)\sin(\psi/2) \\
\cos(\varphi/2)\sin(\theta/2)\sin(\psi/2) - \sin(\varphi/2)\cos(\theta/2)\cos(\psi/2)
\end{bmatrix}
\]  

(9)

Conversion from quaternion to Euler angle

\[
\begin{bmatrix}
\varphi \\
\theta \\
\psi
\end{bmatrix} = \begin{bmatrix}
\arctan \frac{2(wx + yz)}{1 - 2(x^2 + y^2)} \\
\arcsin \frac{2(wy - zx)}{2(wz + xy)} \\
\arctan \frac{2(wz + xy)}{1 - 2(y^2 + z^2)}
\end{bmatrix}
\]  

(10)
The range of arctan and arcsin is \([-\pi/2, \pi/2]\), which can't satisfy all angles and cover all orientations, so a tan2 is used to replace arctan. Yaw, pitch and roll are \(\psi, \theta\) and \(\varphi\), respectively.

\[
\begin{bmatrix}
\phi \\
n \psi
\end{bmatrix} = \begin{bmatrix}
\tan2(2(wx + yz), 1 - 2(x^2 + y^2)) \\
\arcsin(2(wy - zx)) \\
\tan2(2(wx + xy), 1 - 2(y^2 + z^2))
\end{bmatrix}
\] (11)

2.2. Uniform design method

There is no uniformity in the results of uniform design, so regression analysis or stepwise regression analysis is usually used

\[
\hat{y} = b_0 + b_1x_1 + b_2x_2 + \cdots + b_mx_m
\] (12)

Make \(x_{ik}\) represents factor \(x_i\) get the value in the kth test, \(y_k\) is the result of the kth test of the response value y.

\[
L_{ij} = \sum_{k=1}^{n}(x_{ik} - \bar{x}_i)(x_{jk} - \bar{x}_j) \quad i, j = 1, 2, 3, \ldots, m
\] (13)

\[
L_{iy} = \sum_{k=1}^{N}(x_{ik} - \bar{x}_i)(y_k - \bar{y}) \quad i = 1, 2, 3, \ldots, m
\] (14)

\[
L_{yy} = \sum_{i=1}^{N}(y_k - \bar{y})^2
\] (15)

\[
\bar{x}_i = \sum_{i=1}^{N}x_i \quad i = 1, 2, 3, \ldots, m
\] (16)

\[
\bar{y} = \frac{1}{N}\sum_{i=1}^{N}y_k
\] (17)

The coefficients of the regression equations are determined by the following normal equations:

\[
\begin{cases}
L_{11}b_1 + \cdots + L_{1m}b_m = L_{1y} \\
L_{m1}b_1 + \cdots + L_{mm}b_m = L_{my} \\
\end{cases}
\] (18)

The regression equation of quadratic relationship between each factor and response value is as follows

\[
y = b_0 + \sum_{i=1}^{m}b_i x_i + \sum_{i=1}^{T}b_{ij}x_i x_j (i \geq 1) + \sum_{i=1}^{m}b_{ii}x_i^2
\] (19)

\(x_i x_j\) reflects the interaction between factors \(x_i\), \(x_j\); \(x_i^2\) reflects the quadratic effect of factors, which can be transformed into multivariate linear equation by variable substitution (19).

2.3. Test method optimization

When the human body is exercising, the energy consumption will increase with the increase of the exercise intensity, but at the beginning of the exercise, the energy consumption can not be immediately increased to the level matching the exercise intensity, which is caused by the physiological inertia of the human metabolic system. At the same time, the subjects need to adapt to
the professional energy testing instrument, because the testing instrument is mask type to ensure its accuracy. Adapt to the movement discomfort caused by the mask, so as to avoid the impact on the subjects. Some researchers think that the energy consumption research of rope skipping needs 5 minutes to obtain stable data. In this study, the experimental personnel first need to wear the test equipment for 5 minutes of sit in, one is to adapt to the breathing under the instrument, the other is to keep the body stable before the experiment, and then carry out the standard rope skipping test for 5 minutes, which can ensure the stability and accuracy of the experimental data. The starting point of this experimental study is the general public. For the effectiveness of this experiment, people who often take rope skipping exercise can not participate in this experiment. Therefore, the three frequencies (60 times / min, 90 times / min, 120 times / min) selected in the fixed frequency group of this study are reasonable.

3. Model establishment

Spatial vertical axis ($AG_y$) The spatial sagittal axis ($AG_z$) Spatial coronal axis ($AG_x$) They represent the movement of the tester in the vertical direction, the movement in the front and back direction, and the movement in the left and right direction. $VM_2$ is the data activity of sagittal plane of human body, which is calculated by the following formula:

$$VM_2 = (\sqrt{AG_y^2 + AG_z^2})^{\frac{1}{2}}$$  

(20)

$VM_3$ is:

$$VM_3 = (\sqrt{AG_x^2 + AG_y^2 + AG_z^2})^{\frac{1}{2}}$$  

(21)

Rope skipping is a reciprocating motion based on the Y-axis of spatial coordinates, and the lateral motion is relatively small. Therefore, most of the effective test data are from ($[Ag]_y$) However, the influence of other space axes on energy consumption can not be ignored. Therefore, in order to ensure the preciseness of the experiment, we use the three-axis motion data to construct the equation.

$$VM_3 = (\sqrt{AG_y^2 + AG_x^2 + AG_z^2})^{\frac{1}{2}}$$  

(22)

4. Evaluation results

The subjects of this experiment are 50 college students, as shown in Table 1, 40 in the control group, 20 male and 20 female. There were 10 people in the study group, 5 men and 5 women. All the subjects were healthy and did not receive professional rope skipping training, but all the subjects had rope skipping level of more than 60 times per minute and kept good physical movement during the test. And use professional measuring instruments to measure the height and weight of the subjects, and calculate their BMI value, as shown in Table 1. The body weight was 0.1kg, and the error percentage was ± 0.2. The height was 0.1cm, and the error percentage was ± 0.1.

| Table 1. Basic information of subjects |
|---------------------------------------|
| Age (years) | Height (CM) | Body weight | BMI |

5
In view of the large individual variation in the study, the data of different rope skipping frequencies of the same subject may be correlated, and it will be difficult to identify the effective independent variables if the one-way ANOVA is applied. Therefore, the single factor repeated measurement design is used for comparative analysis. As can be seen from figure 1, the significance of spherical test ($P = 0.244$) is 0.05, and the results all follow the spherical hypothesis, it shows that there is no correlation between repeated measurement data.

|       |       |       |       |
|-------|-------|-------|-------|
| Man   | 20±2  | 174.8±4.8 | 68.3±6.2 | 22.9±7.4 |
| Woman | 20±2  | 162.5±4.5 | 54.8±5.6 | 21.2±1.8 |

The specific results of energy consumption and mett of different rope skipping frequencies are shown in Figure 2. It can be seen from the figure below that the average energy consumption of 60 times / min, 90 times / min and 120 times / min rope skipping is 6.78kcal/min, 8.99kcal/min and 9.54kcal/min respectively; the mett value is 6.01mets/min, 8.04mets/min and 8.84mets/min respectively. $P < 0.05$, with significant difference. According to the single factor repeated measurement design for different rope skipping frequencies, see Figure 2. The average energy consumption of male students at 60 times / min, 90 times / min and 120 times / min were 7.01kcal/min, 10.45kcal/min and 11.26kcal/min, respectively; and the mett values were 6.32mets/min, 8.61mets/min and 9.04mets/min, respectively. The average energy consumption of 60 times / min, 90 times / min and 120 times / min for female students was 5.89kcal/min, 7.96kcal/min and 8.95kcal/min, respectively, and that of mett was 5.84mets/rain, 7.68mets/min and 8.87mets/min, respectively.
Figure 2. Energy consumption and mettle under different rope skipping frequencies

In terms of trend (see Figure 2), the energy consumption and mett of male and female students increase with the increase of rope skipping frequency, but after 90 times / minute, the rising trend of energy consumption and mett of male and female students gradually slows down. From the numerical comparison, boys' energy consumption and mett of three rope skipping frequencies are greater than girls' energy consumption and mett of three rope skipping frequencies. It can be seen that due to the different physiological structure of men and women, the average value of energy consumed by rope skipping and its mett value are not in the same level, so in the future, the prediction of rope skipping consumption should fully consider the differences between men and women, and predict by gender.

5. Conclusion
With the development of science and technology, human energy consumption detection equipment emerge in endlessly. But everyone has and uses a smart phone. In today's highly digital society, it can be said that without a mobile phone, it will be difficult in the modern society. So the prediction method of rope skipping energy consumption in this paper is based on smart phone sensors. Intelligent integrated with multiple sensors, this paper only studies the prediction method from the common acceleration sensors on smart phones. The main research direction of this paper is the data obtained from the smart phone, through the calculation and analysis of mathematical algorithm, through the specific mathematical model to calculate the energy consumption of rope skipping. Compared with the professional energy consumption prediction instrument, the result of prediction is almost the same. Therefore, the energy consumption prediction method of rope skipping based on smart phone sensor is feasible. This method can use local materials, smart phone is something everyone has, fully shows its convenience. It is very necessary to predict the energy consumption in the era of national fitness, and in this paper, combined with smart phone sensors, the best frequency of rope skipping can be calculated by mathematical method, which is also an important research topic in the prediction of energy consumption of rope skipping, which can make people jump rope to achieve the most effective and most able to adapt to the body function, and its application prospect is promising. It's very extensive.

References

[1] Dong K, Deng J, Ding W, et al. Versatile Core–Sheath Yarn for Sustainable Biomechanical Energy Harvesting and Real-Time Human-Interactive Sensing[J]. Advanced energy materials, 2018, 8(23):1801114.1-1801114.12.

[2] Lee D J, Lee S B. Effect of Rope Skipping and Wireless Rope Skipping Exercise on Growth Factors and Physical Fitness[J]. Journal of the Korean society for Wellness, 2019, 14(2):489-497.

[3] Chon T J, Sung D J, Jeon J Y, et al. Enhancing Psychological and Physical Fitness Factors of Korea Middle School Students by Introducing Rope Skipping[J]. Iranian Journal of Public Health, 2018, 47(12):1965-1966.

[4] Kirthika V S, Sudhakar S, Selvam S. The Effect of Skipping rope Exercise on Physical and Cardiovascular fitness among Collegiate Males[J]. Research Journal of Pharmacy and Technology, 2019, 12(10):4831-4835.

[5] De Oliveira E M, Cyrino Oliveira F L. Forecasting mid-long term electric energy consumption through bagging ARIMA and exponential smoothing methods[J]. Energy, 2018, 144(FEB.1):776-788.

[6] Wang F, Liu W, Wang T, et al. To Reduce Delay, Energy Consumption and Collision through Optimization Duty-Cycle and Size of Forwarding Node Set in WSNs[J]. IEEE Access, 2019, PP(99):1-1.

[7] Meysam Y, Rasool K, Pouyan T. Energetic-exergetic analysis of an air handling unit to reduce energy consumption by a novel creative idea[J]. International journal of numerical methods for heat & fluid flow, 2019, 29(10):3959-3975.
[8] Yu S, Chen H, Brown R A. Hidden Markov Model-Based Fall Detection With Motion Sensor Orientation Calibration: A Case for Real-Life Home Monitoring[J]. IEEE Journal of Biomedical and Health Informatics, 2018, 22(6):1847-1853.

[9] Yurtman A, Barshan B. Novel Non-Iterative Orientation Estimation for Wearable Motion Sensor Units Acquiring Accelerometer, Gyroscope, and Magnetometer Measurements[J]. IEEE Transactions on Instrumentation and Measurement, 2020, 69(6):3206-3215.

[10] Sarker I H. Research issues in mining user behavioral rules for context-aware intelligent mobile applications[J]. Iran Journal of Computer Science, 2019, 2(1):41-51.