Research on keep away from falling based on SVM

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Abstract: Falling down is an unexpected problem that old people cannot ignore. Nowadays, the death rate from falls is increasing gradually. In China, falls have become the number one killer of people over 65 years old. Therefore, it's vital to analyze the human body balance features to prevent elderly people from falling. We are required to find 25 body balance features from the 42 monitoring points. And we build a feature extraction model and a balance risk assessment system. By comparing the analog computation and actual provided, we give our advice.

1. Introduction

Freely walking is one of the indicators to measure people's health and quality of life. For the frail elderly, the fall is an important factor directly threatening the elderly to walk independently. According to the World Health Organization (WHO), falls kill more than 300,000 people worldwide every year. In China, falls have become the number one killer of people over 65 years old. With the increase of age, the possibility of falls increases gradually, and the elderly with osteoporosis, bone fracture history or hypotension and other diseases also have a higher possibility of falls than the healthy elderly. As a result, many older people are too afraid to move for fear of falling, their physical function begins to decline and their behavior begins to shrink. Falls have a serious impact on the normal life of many elderly people, so it is necessary to assess the elderly's balance ability and give relevant advice

2. Problem Analysis

We analyzed the problems above. Then we took some important features into considered. According to those features, we made necessary assumptions and defined relevant notations. In order to solve those problems, we made works as follows:

1) First of all, we analyzed the meaning of balance. Then, we considered main aspects about human body balance. According the knowledge of human mechanics, we listed 25 body balance features.And we analyze these 25 body features then we gave the way to calculate.

2) Based on the 25 body features, we built a feature extraction model. we set up a support vector machine model to implement the binary classification of data. In this way, we can make a comprehensive body balance assessment for elderly people. We processed all the data provided by Annex 2, extracted the characteristics of these sample data, and trained the SVM model provided by Python Sklearn library.

3) According to the 25 indicators, we built a balance risk assessment system. We improved the previous model and used support vector regression to quantitatively evaluate different fall times of sample data. And according to the results we get, we give some concrete Suggestions for the elderly.

4) We made an analog computation and compared with the actual data provided. Through the comparative results we gave effectual suggestions for the elderly people with weak balance ability.

5) We tested our models and then we found there will be little change. Finally, we gave our models' strengths and weaknesses.

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3. Related Work

3.1 Assumptions and Justifications

To simplify our question, we make the following basic assumptions, each of which is properly justified.

We assume that the ground on the walk is uniform and there are not conditions for people to slip. Because of the elderly people who live in the city, marble floors or tiles can be seen everywhere in life.

We assume that the left part of human body is not the same as the right part.

We assume that no accidents occur during walking. Because emergencies are difficult to measure.

We don't take the first foot when walking into consideration. Because when people are walking, it is a habit to take the foot first. It can't be quantified.

3.2 Symbol Description

Table 1. Symbol Descriptio

Symbol	Description
G	**Center of gravity of the human body**
H	**Human height**
$\vec{e}_j$	**The moving direction of the person**
$\vec{e}_{tl\|r}$	**The direction of the foot**
J_m	**Monitoring Points' projected coordinates**
t_n	**The moment of the action**

4. Balance Features

4.1 The center of gravity

We calculated the center of gravity of the human body by torque synthesis. Based on the coordinate values of each joint provided by our 42 monitoring points. We set the barycentric coordinate formula of the human body as shown in Formula 1.

$$\begin{cases} X_G = \frac{\sum x_i * p_i}{P} \\ Y_G = \frac{\sum y_i * p_i}{P} \\ Z_G = \frac{\sum y_i * p_i}{P} \end{cases} \quad \square \qquad (1)$$

x_i, y_i, z_i is the coordinate of the center of gravity of the joint , P_i is the mass of the joint , and P is the body weight. Since the mass of the joint is not general, it is difficult to measure it. Therefore, we use the coefficient of the human body joint to replace the mass of the joint. After improvement, the calculation formula of the center of gravity of human body is shown as follows:

$$G_{Pos}(x,y,z) = \sum k_i \times j_i(x,y,z) \qquad (2)$$

G_{Pos} represents the position of the center of gravity, J_i represents the coordinates of a human body joint, and k_i represents the corresponding coefficient of this joint.

In this model, we calculate the Monitoring points through the coordinates of the 19 nodes of the joint. The Monitoring points that we use are shown in the red box.

Table 2. Human Joints And Their Coefficients

Human joints	Coefficient
The center of gravity of the head	0.0706
shoulder	0.0356
Midpoint of two shoulders	0.2391
Elbow	0.0580
Wrist	0.0192
The center of gravity of the hand	0.0180
Hip	0.1297
Midpoint of two Hips	0.1879
Knee	0.1630
Ankle	0.0643
Heel	0.0158

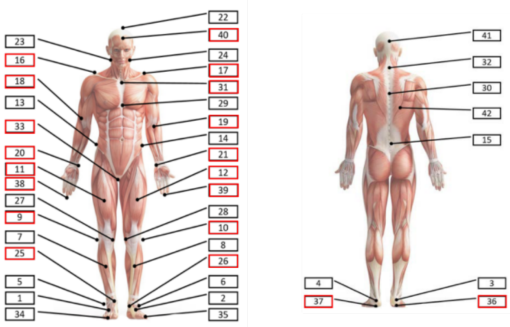

Figure 1 19 Monitoring Points For Center of gravity determination

Through the algorithm and monitoring points data, the direction value of the center of gravity in three directions can be determined.

$$\begin{cases} G_x = \sum_{i=1}^{19} k_i \times j_x \\ G_y = \sum_{i=1}^{19} k_i \times j_y \\ G_z = \sum_{i=1}^{19} k_i \times j_z \end{cases} \quad (3)$$

In order to obtain the corresponding the features of the center of gravity, we take the change of the direction value of the center of gravity in three directions, and take the variance of all the changes to obtain the change features of the direction of the center of gravity. The obtained features are as follows:

$$\Delta G_r = G_r|_{t_2} - G_r|_{t_1} \quad r = (x, y, z)$$

$$\Delta G_r = G_r|_{t_2} - G_r|_{t_1} \quad r = (x, y, z) \quad (4)$$

4.2 Steps

The feature of steps can be used to measure a person's walking habits. The step, the angle of the foot and the first foot out all affect the balance of the body. Hence we selected 5 main features to describe how the steps affect human body balance.

- Step size

The step size that can affect on the balance of the body is related to height[2]. If the step size was too large or too small, it would affect the balance of the body. The definition of step size is calculated based on the center of the foot. Clearly, the distance between the center of the feet after one step is the stride.

$$\overrightarrow{SA} = J_{t_1}(x,y,z)|_{\min z} - J_{t_2}(x,y,z)|_{\min z} \tag{5}$$

- Step frequency

Not only the step size but the step frequency can affect people's balance ability. The definition of step frequency is the number of times when two legs alternate in unit time during walking or running. Step frequency is the same as the step size, which is correlated with height.

First $t_n = t|_{z=\min}$ n=1,2,...

Then $ST = t_n - t_{n-1}$

We can obtain: $Sf = \frac{1}{ST}$

- Step width

Step width refers to the transverse distance between two feet, that is, the sum of the transverse distance between the midpoint of two feet. According to the feature of gait, the narrower the step width is, the worse the balance stability will be. Since it is difficult to calculate the step width while walking, we simplified the process of calculating the step width..The principle is shown in Fig.2.

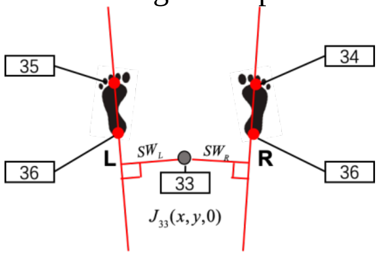

Figure 2 The Principle of Step Width Calculation

We use four monitoring points (34,45,36, and 37, respectively). The left foot determines a straight line through monitoring point 34 and 37, and the right foot also determines a straight line through monitoring point 35 and 36, and monitoring point 33 is the midpoint of human crotch, and approximate treatment of step width is realized by adding the distance between points and two straight lines.

We define the step width is:

$$SW_t = t|_{\min(|z_1 - z_2|)} \tag{6}$$

- Toe Out Angle

Toe out angle[3] is defined as the Angle between the center line (the long axis of the foot, the line from the midpoint of the heel to the second toe) running through the sole of one side of the foot and the forward direction. Toe out angle on the left foot and right foot also affects the balance of the body. The principle is shown in figure 3.

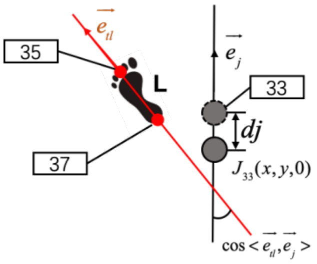

Figure 3 The Principle of Toe Out Angle Calculation

We choose two consecutive landing of the same foot to calculate the toe out angle, the moving vector of the midpoint of the crotch of the person represents the moving direction of this person,. The vector pointing from the toe point to the heel at the moment of landing represents the direction of the foot, the cosine of the foot clamping of the two vectors can be calculated to represent the toe out angle.

The toe out angle is established as follows:

$$TOA = \cos < \overrightarrow{e_{i|i_r}}, \overrightarrow{e_j} > = \frac{\overrightarrow{e_{i|i_r}} \cdot \overrightarrow{e_j}}{|\overrightarrow{e_{i|i_r}}||\overrightarrow{e_j}|} \quad (7)$$

- Stride Length

Stride length is defined as the vertical straight-line distance between two consecutive stops of the same side foot, that is, the vector when the z coordinate of the same foot heel is taken as the minimum position, which is equivalent to the sum of left and right steps. The change of step length can be used to see the stability of walking.The stride length is established as follows:

$$\overline{SL}_{L|R} = J_1(x,y,z)|_{z=\min} - J_2(x,y,z)|_{z=\min} \quad (8)$$

The module length of the vector is stride length, and a stride length sequence is obtained by adding the stride length of left and right feet. Then we obtain:

$$SL = \sum_{i=0}^{N} SL_{L_i} + \sum_{i=0}^{M} SL_{R_i} \quad (9)$$

4.3 Motion

- Max Knee Angle

The max knee angle is an important feature, which is defined as the maximum bending angle of the knee joint when the foot lifting process reaches the maximum during the step phase[2] process. The principle is shown in figure 4 below .

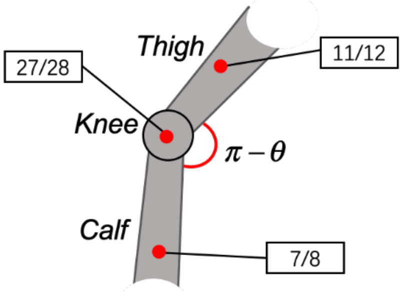

Figure 4: The Principle of Knee Angle Calculation

Six Monitoring Points are used in the figure above, where point 11, 27 and 7 provide right leg data, point 12, 28 and 8 provide left leg data, and the bending angle is implemented in the form of cosine of the vector.The vector is defined as follows:

$$\begin{cases} \overline{TK} = \overline{J_{11|12}} - \overline{J_{27|28}} \\ \overline{KC} = \overline{J_{27|28}} - \overline{J_{7|8}} \end{cases} \quad (10)$$

- The first queMax hip flexion angle

Hip joint is the connection between the femur and hip joints, the definition of max hip flexion angle is a step in the process of max knee flexion angle. The process of the hip is a very important balance related feature. Given that we do not have the hip sensors, so we use thighbone approximate hip flexion angle and the trunk into perspective. The principle is shown in figure 5.

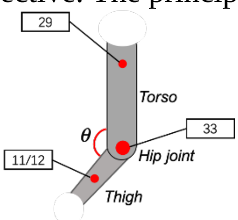

Figure 5: The Principle of hip flexion Angle Calculation

Four monitoring points are used in the figure above. Monitoring point 11 and 12 respectively provide right and left thigh data, monitoring point 29 and 33 respectively provide human body trunk data, and the realization of bending angle is expressed in the form of cosine of the vector.

- Ankle flexion interval

Ankle joint is the joint connect the leg bone with the foot. The angle flexion interval is defined as the angle range of ankle joint bending in the process of standing phase, swinging phase and stride phase, which is an important balance correlation feature. Its principle is shown in figure 6.

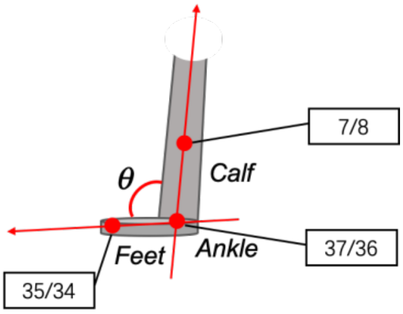

Figure 6: The Principle of Ankle flexion interval e Calculation

Six monitoring points are used in the figure above. monitoring point 35, 37 and 8 provide the data of the left ankle joint, monitoring point 34, 36 and 7 provide the data of the right ankle joint. The curved angle interval is implemented in the form of cosine values of vectors, and the two vectors are defined as follows:

$$\begin{cases} \overrightarrow{AC} = \overrightarrow{J_{7|8}} - \overrightarrow{J_{37|36}} \\ \overrightarrow{AF} = \overrightarrow{J_{35|34}} - \overrightarrow{J_{37|36}} \end{cases} \tag{11}$$

- Forward bending angle of head

Elderly people tend to have the hunchback, which causes forward bending angle of head. It will appear an angle between the torso and head, which can make human imbalance or even worse. Therefore, the forward bending angle of the head, which is defined as the bending Angle of the head relative to the spine part of the back. The principle of this feature is shown in figure 7.

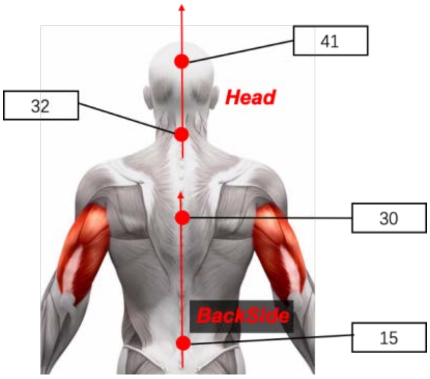

Figure7: Forward bending angle of head Calculation

We use four monitoring points. Monitoring Point 15 and 30 provide data for the direction vector of the spine, monitoring point 32 and 41 provide data for the direction vector of the head. The forward bending angle of head is calculated and implemented in the form of cosine of the vector.

$$\begin{cases} \overrightarrow{HD} = \overrightarrow{J_{41}} - \overrightarrow{J_{31}} \\ \overrightarrow{BS} = \overrightarrow{J_{30}} - \overrightarrow{J_{15}} \end{cases} \tag{12}$$

- Horizontal head lateral angle

The horizontal head lateral angle is defined as the angle at which the head is bent relative to the shoulder. The horizontal head angle relative to the torso will change human body balance. The principle of this feature is shown in Fig.8.

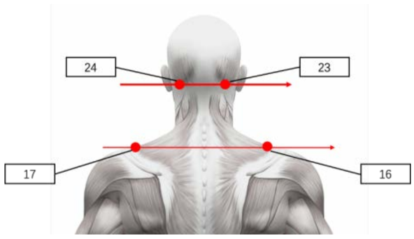

Figure 8: The Principle of horizontal head lateral angle Calculation

There are 4 monitoring points used in the figure. Monitoring point 16 and 17 provide data for the direction vector of shoulders. Monitoring point23 and 24 provide data for the horizontal vector of heads. The calculation and implementation of lateral bending angle of heads are expressed in the form of cosine values of vectors

- Swing arm angle

Swing arm angle is defined as the angle between the humerus of the arm and the trunk during the stride phase. It can also be used to indicate the swing arm amplitude. The principle of this feature is shown in Fig.9.

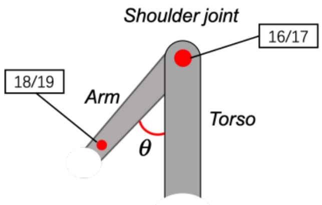

Figure 9: The Principle of swing arm angle

Four monitoring points are used in the figure above. Monitoring point 17 and 19 are used to mark the direction vector of left swing arm. Monitoring point 16 and 18 are used to mark the direction vector of the right swing arm. In addition, Monitoring point 29 and 31 are not shown in the figure. They are used to indicate the direction vector of the trunk. The calculation and implementation of the swing arm Angle of the arm is expressed in the form of cosine of the vector

- Swing elbow angle

The swing elbow angle is defined as the angle between the humerus and the ulna (radius) of the arm, which is similar to the swing arm Angle. The principle of this feature is shown in figure 10.

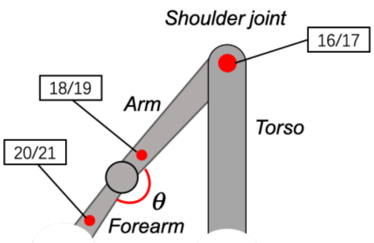

Fig.10: The Principle of Swing elbow angle Calculation

We used six monitoring points. Monitoring points 21,20,18 and 19 are used to mark the direction vector of the swing arm of the left and right forearm. Monitoring point 18,19,16 and 17 are used to indicate the direction vector of the humeral swing arm of the left and right hands. The calculation and implementation of the bending Angle of the forearm is expressed in the form of cosine of the vector.

- Swing arm frequency

The swinging arm frequency is also an important basis for measuring the balance, and it is defined as the number of times when the arm swings to the highest point in two directions (front and back) in one second. The swinging arm period is defined as follows:

$$\Delta AFt_{L|R} = t_1\big|_{z=\max(z)} - t_2\big|_{z=\max(z)} \quad (13)$$

The inverse of the swinging arm frequency to the period of the swinging arm is shown in formula 14.

$$Arf_{L,R} = \frac{1}{\Delta AFt} \tag{14}$$

We used two monitoring points. Monitoring point 38,39 at the fingertips were used to mark the swinging frequency of the left and right hands respectively.

5. Analysis and Model

5.1 Analysis

For this Question, we divide the existing data into two categories, balance and imbalance. In the process of classification, the weights corresponding to the above 25 features are obtained to determine the contribution of features to the balance. In order to do this, we set up a support vector machine model to implement the binary classification of data.

5.2 Model

Support vector machine (SVM)[4] is a binary classification model. Its purpose is to find a hyperplane to segment samples. The principle of partition is to maximize the margin, which is transformed into a convex quadratic programming problem. The reason of margin maximization is that the classification prediction confidence expressed by the distance between each point and the separation hyperplane is high, and the classification effect is the best when the margin is the maximum. Support vector machines can be divided into the following three forms.

When the training sample are linearly separable, through hard interval maximization, it learns a linearly separable support vector machine (SVM).

When the training sample is approximately linearly separable, through soft maximum interval, it learns a linear support vector machine.[5]

When the training sample is linearly indivisible, through nuclear techniques and soft maximum interval, it learns a nonlinear support vector machine.

For the above three cases, the solution process of the principle of support vector machine is shown as follows:

1) In the sample space, the partition hyperplane can be described by the following linear equation.

$$\boldsymbol{\omega}^T \circ \boldsymbol{x} + \boldsymbol{b} = \mathbf{0} \tag{15}$$

2) w is the normal vector, which determines the direction of the hyperplane. B is the displacement, which determines the distance between the hyperplane and the origin. It is assumed that the above hyperplane can correctly classify the training samples. That is, the training samples satisfies as follows:

$$\begin{cases} \boldsymbol{\omega}^T \circ \boldsymbol{x}_i + \boldsymbol{b} \geq +1, \boldsymbol{y}_i = +1 \\ \boldsymbol{\omega}^T \circ \boldsymbol{x}_i + \boldsymbol{b} \leq -1, \boldsymbol{y}_i = -1 \end{cases} \tag{16}$$

3) As shown in figure 11 below, take a two-dimensional plane as an example. Introduce the definition of boundary and interval, the dotted line is called boundary, and the distance between the two dotted lines is called margin.

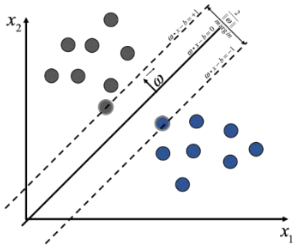

Figure11 The diagrammatic sketch of SVM

4) The optimization problem of the above formula is convex quadratic optimization problem. Dual problem can be obtained by using Lagrange multiplier on the above formula

$$L(\omega,b,a)=\frac{1}{2}\|\omega\|^2+\sum_{i=1}^{m}a_i(1-y_i\,\varphi(\omega^T x_i+b)) \tag{17}$$

5) Dual problem can be obtained by Lagrange multiplier. The dual form of the above equation is below.

$$\max_a \sum_{i=1}^{m}a_i-\frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m}a_i a_j y_1 y_j \phi(x_i)^T\phi(x_j) \tag{18}$$

6) The KKT condition for the above process is below.

$$\begin{cases} a_i\geq 0 \\ y_i f(x_i)\geq 1-\xi_i \\ a_i(y_i f(x_i)-1+\xi_i)=0 \\ \xi_i\geq 0,\mu_i\xi_i=0 \end{cases} \tag{19}$$

5.3 Model Solution

After training our SVM model, we get the weight coefficient of the target function through Formula84. Its significance is to characterize the contribution of different characteristics to the equilibrium factors. The larger the absolute value of the weight coefficient is, the greater the influence it has on the balance of the elderly, and the smaller the influence it has on the balance is, the weaker it is. We sorted the weight coefficients in the above table, and obtained the sorting diagram of fig.12 as shown below.

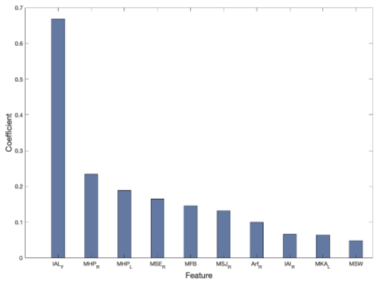

Figure 12 The sorting diagram

We can get subordinate conclusions by analyzing the weight coefficient. Maximum of left knee flexion angle is the most important factor that affects the walking balance of the elderly. Besides, left swing arm frequency is also important factors.

Due to the small number of test sets, we evaluated the model by cross-validation, and the final accuracy was 0.9143. Due to the small sample space, the accuracy could well represent the influence characteristics of balance.

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