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Research on Fatigue Detection Method of Equipment Operators Based on Multi-Source Physiological Signals

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Abstract. In order to effectively detect the fatigue status of equipment operators, this paper proposes a fatigue detection model that integrates multi-source physiological signals to evaluate the fatigue level of equipment operators in order to improve the efficiency of military operations and training. This method selects various physiological signals such as human heart rate, heart rate variability, body temperature, respiratory rate, blood oxygen concentration, etc. according to the working environment and working characteristics of the equipment operator, and establishes the relationship between the characteristic values of various physiological parameters and fatigue levels , And then use the optimized support vector machine to perform fusion judgment on the feature values of multi-source physiological parameters, and obtain the fatigue state of the equipment operator. Experimental results show that this method can make a more accurate judgment on the fatigue state of equipment operators, and is of great significance for ensuring the efficiency of equipment operators' work and training.

Keywords: multi-source physiological signals, fatigue detection, feature fusion, support vector machine.

1. Introduction

After people perform physical or mental work continuously for a period of time, the phenomenon of conscious discomfort and decline of labor function is called fatigue. Fatigue is a psychological and physical phenomenon. During training and equipment operation, equipment operators not only have to pay high-intensity physical labor, but also are often in a highly stressed psychological state, which is extremely prone to fatigue. Excessive fatigue will have adverse effects on equipment operators, such as sluggishness, memory loss, and poor muscle coordination. These often lead to a decline in military operation efficiency and even accidents in severe cases. Exploring various factors that affect the fatigue of military equipment operators, using multi-source physiological signals to jointly obtain their fatigue levels, and taking targeted preventive and protective measures is of great significance for ensuring the combat effectiveness of military equipment operators.

Based on the existing research, this paper analyzes the work characteristics and fatigue characteristics of equipment operators, selects several kinds of physiological signals associated with them, such as heart rate, heart rate variability, body temperature, respiratory rate, blood oxygen Concentration, etc., select fatigue-related feature values from a variety of physiological signals, realize the fusion of multiple physiological feature parameters through the support vector machine method, establish a fatigue

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detection model, and identify the fatigue level of equipment operators to improve fatigue Accuracy and reliability of detection.

2. Fatigue Characteristics of Equipment Operators

2.1. Concept of Fatigue

Fatigue is a complex physical and psychological phenomenon. It is a subjective feeling of discomfort that is produced during sustained physical activity or overwork per unit of time, and objectively loses the ability to complete work when continuing to engage in activities or work [1] .

There are many ways to classify fatigue. According to the form of manifestation, it is divided into physical fatigue and mental fatigue; according to the length of time, it is divided into acute fatigue and chronic fatigue; according to the different parts of fatigue, it is divided into partial fatigue and general fatigue; according to the nature of fatigue, it is divided into physical fatigue, mental fatigue and psychological fatigue.

In the process of equipment operation, the operator is prone to fatigue due to changes in the physical and psychological state, leading to decline in physical function, decreased work ability, and sometimes fatigue and other symptoms. This state has a certain degree of complexity and is not caused by a single clear factor. Therefore, this paper uses the characteristics of multiple sources of physiological signals to jointly determine the degree of fatigue, thereby improving the accuracy and reliability of the determination results.

2.2. Causes and Tendencies of Equipment Operator Fatigue

The main causes and tendencies of equipment operator fatigue are as follows:

1) The operation is difficult, fast, strict, and high energy consumption. At present, some equipment operations mainly rely on the physical strength of the operators to complete. For example, the shell of a certain antiaircraft gun weighs 30 kilograms and needs to be placed on the gun feeder 10 times continuously and accurately within 50-60 seconds. The action essentials during operation must be correct and ensure safety. The operating load has factors such as weight, speed, duration and precision. Its labor intensity is extremely high, the energy consumption in the body is too fast, and the accumulation of fatigue substances are too much, which can easily cause fatigue.

2) The working environment is poor and the work and rest are unstable. In battlefield conditions, many activities of equipment operators consume physical strength and energy. For example, you need to operate under high temperature, severe cold, and humidity; fight persistently in the sound of rumbling cannons, deafening bombs, and poison-polluted air; poor rest during wartime; difficulty in nutritional supplements, even in the case of frailty or injury. In addition, it is difficult to predict when the battle will come, and we must be vigilant. Sustained tension, coupled with dangerous and cruel reality, completely break the law of life and rhythm of life, leading to the acceleration of the fatigue process. Obviously, the extremes of military life and combat activities (hardship, tension, danger, suddenness) will cause certain changes in the biochemical mechanism and central nervous system of equipment operators, resulting in fatigue.

3) Fatigue is systemic and tends to accumulate. Physical fatigue may be caused by overuse of a certain part of the body, and it begins to manifest as local fatigue. For example, if the observer's hand is observed for a long time, the eyes will feel dry and wet and swollen; the waist and arm pain of the artillery crusher. But what follows is systemic fatigue symptoms, such as fatigue, weakness of limbs, dizziness, general malaise, etc. At this time, even if the brain is not used much, a certain degree of mental fatigue will occur. If body fatigue is not eliminated in time, it can accumulate. Years of fatigue can lead to chronic fatigue and even illness.

2.3. Selection of Physiological Signals

In the training process of equipment operators, physiological parameters will show a certain regularity as the degree of fatigue increases, and the degree of fatigue can be directly or indirectly reflected by

changes in human physiological parameters. Since the use of a single physiological signal feature to determine the degree of fatigue has certain defects, we use multiple physiological signal characteristics to jointly determine the degree of fatigue, thereby improving the accuracy of the determination result.

Equipment operators generally work in a closed cabin environment or in a field environment. Generally, they have to work continuously for a long time in a hot environment. As the working time increases, the physiological parameters of the body's heat storage and circulation function, such as heart rate and body temperature , Blood pressure will also show regular changes. Ma Qiang, Liu Hongtao and others studied and analyzed the physiological responses of amphibious armored vehicle drivers when they completed different tactical actions during sea training. The results showed that the driver's heart rate, blood pressure, body temperature, respiratory rate and ventilation increased during sea training. While the blood oxygen saturation shows a downward trend, the driver of the amphibious armored vehicle bears the physical load, and is affected by the task and working environment. The psychological tension is high, which intensifies the degree of fatigue reaction. Physiological parameters will show certain regularity [2].

The manual handling process is very similar to the gunner loading and transportation process, and the two can be compared. Guo Fu and others explored the fatigue law of the body during manual handling operations and the influence of working time and load on body fatigue[3]. The results show that as the working time increases and the load increases, the heart rate presents an upward trend in the early stage of the handling operation, and then stabilizes; the heart rate variability index low frequency/high frequency increases and is positively affected by the workload.

Oxygen is one of the most important substances to maintain the normal life activities of the human body. Human fatigue is closely related to the supply of oxygen in cell metabolism, and hypoxia is an important cause of human fatigue. Blood oxygen saturation reflects the oxygen supply level of the human body. If the tissue supply is insufficient, it will cause hypoxia. Short-term hypoxia can cause fatigue, lethargy, nausea and other uncomfortable symptoms. Li Puhong and others measured the blood oxygen saturation of the tissues after the completion of different processes by eight production workers. The results showed that there is a close relationship between blood oxygen saturation and fatigue, and fatigue can cause significant blood oxygen saturation levels decrease, making the breathing rate faster[4].

Through the above analysis, the physiological parameters related to fatigue of equipment operators mainly choose the following parameter characteristic values:

a) Heart rate.
b) Heart rate variability.
c) Body temperature.
d) Respiratory rate.
e) Blood oxygen concentration.

3. Support Vector Machine Theory

Support Vector Machine (SVM), which is a small sample machine learning method, based on the principle of minimizing structural risk of Statistical Learning Theory (SLT) and VC dimension theory. SVM method makes limited Seek the best recognition effect between the training accuracy and promotion ability of the sample data, in order to expect the constructed classification model to have better learning ability for unknown data. Compared with traditional machine learning methods, SVM is more suitable for small sample, nonlinear, high-dimensional pattern classification and recognition problems [5, 6].

The main idea of support vector machine is to establish a classification hyperplane as a decision plane, so that the isolation edge between positive and negative examples is maximized [7].

The common support vector machine model, its specific form is as follows:

Suppose two types of separable sample sets(x_i,y_i),$i=1,2,\ldots n$,$x_i \in R^n$,$y_i\{-1,1\}$ is the category number, and the mathematical equation of the hyperplane is:

$$f(x)=w\cdot x+b=0 \quad (1)$$

If the hyperplane can correctly separate the two types of sample sets, the sample sets satisfy the condition:

$$yi\ [w\cdot xi+b]\geqslant 1, i=1,2,\ldots,n \tag{2}$$

The distance from any point xi in the sample set to the hyperplane is:

$$Di=\frac{|f(xi)|}{||w||} \tag{3}$$

Suppose there is a t,for any sample in the set:

$$yi\cdot di=\frac{|f(xi)|}{||w||},\ yi\geq t \tag{4}$$

Then t is called the margin of the hyperplane f(x), which is used to characterize the minimum distance between the sample point and the hyperplane. The smaller the margin, the worse the classification ability of the hyperplane.

It can be seen from the formula di that the larger the margin, the smaller the ||w||, thus turning the problem of finding the optimal classification surface into a quadratic constrained optimization problem, for a given sample (xi, yi), i=1, 2,…,n, solve w, b of the minimum value of the quadratic functional:

$$\min[\frac{1}{2}||w||^2] \tag{5}$$

$$\text{s.t.}\quad yi\ [w\cdot xi+b]\geq 1 \qquad i=1,2,\ldots,n \tag{6}$$

Convert the original problem into a Lagrangian dual problem for optimization, and define the Lagrangian function of the original problem as:

$$L(\alpha,\omega,b)=\frac{1}{2}||w||^2-\ \sum_{i=1}^{n}\alpha_i[y_i(\omega\cdot x_i+b)-1] \tag{7}$$

In the formula, $\alpha i\geqslant 0$ is called Lagrangian multiplier. According to KKT condition, find the minimum value of Lagrangian function for ω and b.

The sample corresponding to αi is the support vector, and the optimal classification decision function is:

$$F(x)=sgn\{\sum_{i=1}^{k}\alpha_i y_i(x_i\cdot x)+b\} \tag{8}$$

4. A fatigue Detection Model for Equipment Operators Based on Multi-Source Physiological Signals

Based on the stability and reliability advantages of multi-source information fusion, the fatigue detection model extracts characteristic values of various physiological signals such as heart rate, blood oxygen, body temperature, and respiratory rate. The optimized support vector machine is used to fuse the eigenvalues, and then input into the trained network model, and finally the fatigue state of the tester can be judged through the decision rules.

In this experiment, a number of school students with good physical condition were recruited as subjects. The subjects simulated the training and homework process of equipment operators during the experiment, and collected multiple subjects through the wearable physiological measuring instrument. The characteristic values of physiological parameters, and let the subjects fill in the fatigue rating (FAI) to get the fatigue level of the subjects. In this experiment, a total of 300 sets of experimental raw data were collected, and the training set and test set were extracted from the raw data using MATLAB, and the support vector machine was optimized by the cross-validation method, and then the optimized support vector machine was trained with the training set. Fatigue detection model, and finally use the obtained fatigue detection model to predict the fatigue degree of the test set, and obtain the detection accuracy rate. The algorithm flow is shown in Figure 1.



Fig. 1 Fatigue testing model process

Use MATLAB to extract the training set and test set from the original data, and use the cross-validation method to optimize the support vector machine, and the selection results of the penalty parameter c and the parameter g are shown in Figure 2. The x-axis indicates that C takes the logarithm value with the base of 2, the y-axis indicates that G takes the value after the logarithm with the base of 2, and the z-axis indicates that the corresponding C and G are taken After the corresponding optimization support vector machine accuracy. According to the graph, the optimal parameters are C = 0.25, G = 1.3195.

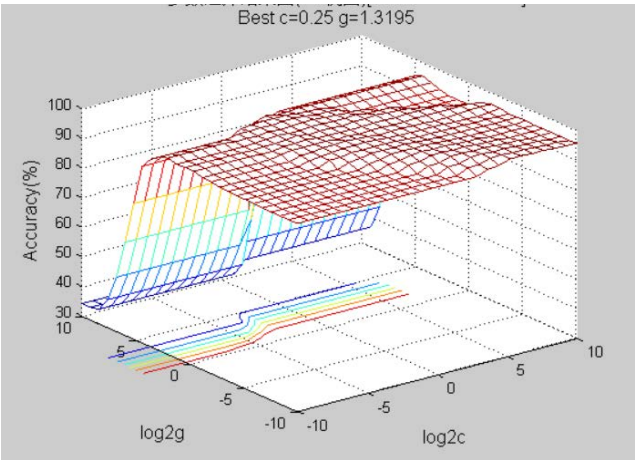


Fig. 2 Support vector machine parameter selection result graph

Using the best parameters obtained above, the SVM model can be trained and classified for prediction. Finally, the classification accuracy of this model is 95.6%. The classification results are shown in Figure 3, in which the classification label 1 represents soberness, 2 represents mild fatigue, and 3 represents fatigue.

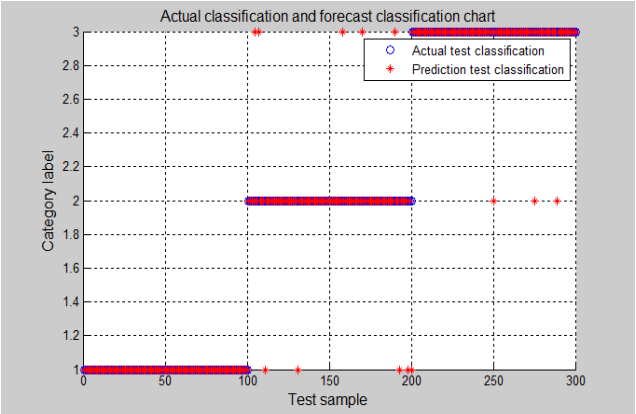


Fig. 3 Model classification result chart

5. Conclusion

In this paper, on the premise of fully analyzing the fatigue characteristics of equipment operators, a variety of physiological signals, such as human heart rate, heart rate variability, body temperature, respiratory rate and blood oxygen concentration, are selected to establish the relationship between the characteristic values of various physiological parameters and the fatigue level. Then, the support vector machine model is optimized by cross validation method, and the multi-source physiological parameter eigenvalues are fused and judged to the fatigue state of equipment operators. The experimental results

show that this method can accurately judge the fatigue state of equipment operators, which is of great significance for ensuring the operation and training efficiency of equipment operators.

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