

A health management system for marine cell group

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Abstract. Storage battery plays an important role in the submarine. However, mechanism of its performance deterioration is so complex for the crew to master. A health management system for marine storage batteries is presented in the paper, so that scientific maintenance can be adopted to assure the working reliability of the battery. The system consists of an on-line monitoring subsystem and a performance prediction subsystem. In order to complete the key task of performance prediction, an intelligent forecasting model based on support vector machine is built, which can automatically find out the rule of performance deterioration from historical monitoring data. Validity of the performance prediction has been proved by testing results.

1. Introduction

Storage batteries are usually combined as cell group to supply power to all kinds of devices equipped in a submarine. Cell group is one of the most important devices in the submarine because it is usually the unique power resource while the submarine is under the water. Performance of the cell group plays an important role on the effectiveness of the submarine to finish its task. In consideration of working reliability and safety, it will be very helpful for the crew to master the actual health conditions of cell group so that decisions of scientific usages and rational maintenances can be made to the cell group. However, because of the complexity of both the external environment and the internal electro-chemistry reactions of the cell group, manual health management of the cell group has been proved to be a difficult work [1-3].

In order to solve the problem mentioned above, a Health Management System (HMS) for marine cell group is presented in the paper. The HMS consists mainly of two parts: an on-line monitoring subsystem and a performance prediction subsystem. The monitoring subsystem is designed to finish the task of on-line data collection, information display and alarm judgement. As to the key task of performance prediction, a prediction model based on Least Square-Support Vector Machine (LS-SVM) is built in the prediction subsystem.

2. Design on HMS for marine cell group

2.1 Performance deterioration of storage battery

It is usually required for the marine storage battery to supply relative larger output power, so lead-acid type rechargeable battery is widely used in the submarine. The battery stores or supplies electrical energy through a reversible electro-chemical reaction. During charging course of the battery, the positive active material of the battery is oxidized, producing electrons, and the negative material is reduced, consuming electrons. During discharging course of the battery, the process is reversed. However, during each charging or discharging course, there are usually undesirable and irreversible chemical reactions called cell reverse occurred inside the battery cell, which cause a permanent



damage to the cell. If the battery is operated with mistreatment, such as over charged or over discharged, the situation will become worse. Even if the battery is used repeatedly without mistreatment, it loses capacity as the number of charging and discharging cycles increase because of aging effect of the components. All the factors mentioned above cause performance deterioration in the battery, which also results in a general degradation of the cell group [4-5].

2.2 Health management strategy of cell group

Although the performance descending course of the battery is a continual developing course in most cases, but the descending tendency usually varies in a large range because of the complexity of the external usage environment and the internal electro-chemistry reactions of the storage battery. However, following phenomena can be observed and measured while the performance of the battery descends: voltage of the cell descends; charging time becomes longer; internal resistance will be enlarged; temperature of the battery becomes higher. That is to say, the information mentioned above can be used to judge the descending tendency of the battery performance. The problem is just how to find a way to give accurate performance judgement and prediction since the relationship between working parameters and performance conditions in a cell group is so complex. Manual health management for marine cell group has been proved to be a difficult work, but artificial intelligence is a powerful tool to solve this problem. For example, the LS-SVM algorithm has already been tested to have great ability to learn key knowledge from historical data [3, 6].

Based on the discussion mentioned above, health management strategy and information processing course of HMS for marine cell group are designed, as shown in figure 1. Four types of working parameters are measured on-line: voltage of the single battery, voltage of the cell group, electrical resistance of whole cell group, temperature of the cell group [5, 7]. Once the data are acquired, an alarm judgement is firstly completed. Furthermore, relative historical data are sent to a prediction model based on LS-SVM algorithm to give accurate prediction.

2.3 Construction of the HMS for marine cell group

Figure 2 shows the fundamental construction of the HMS for marine cell group. There are two primary parts: an on-line monitoring subsystem and a fault prediction subsystem.

2.3.1 On-line monitoring subsystem. There are many cell groups equipped in a submarine, each cell group is placed in a suitable space. According to this factor, a distributed monitoring subsystem is designed to collect the working parameters of all cell groups.

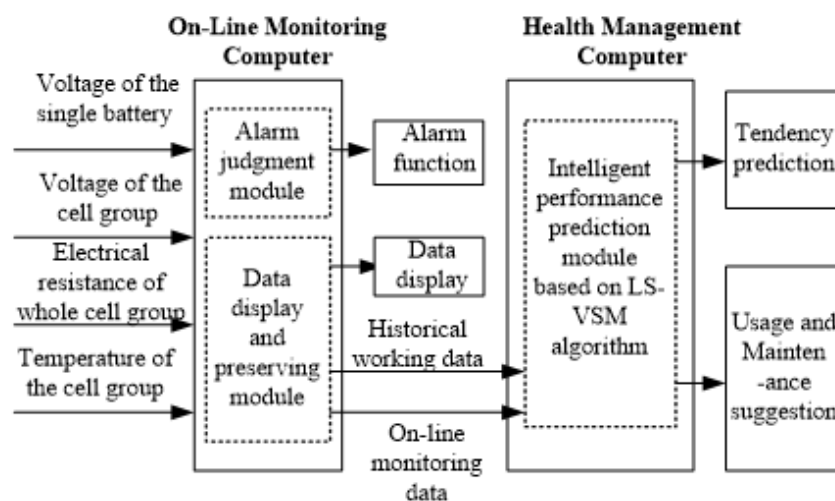


Figure 1. Information processing course of the HMS

Sensors are equipped within the cell group so that the essential working parameters can be measured. By means of a set of wireless communication unit, all measured parameters are transferred to the monitoring computer. In the monitoring computer, the parameters are firstly compared with their alarming-setting values, if exceed the setting value, an alarm will be presented by the computer. Then, the data are saved with a certain sampling time and structure in the hard disk of the computer and then displayed by mean of data and diagram in the monitor.

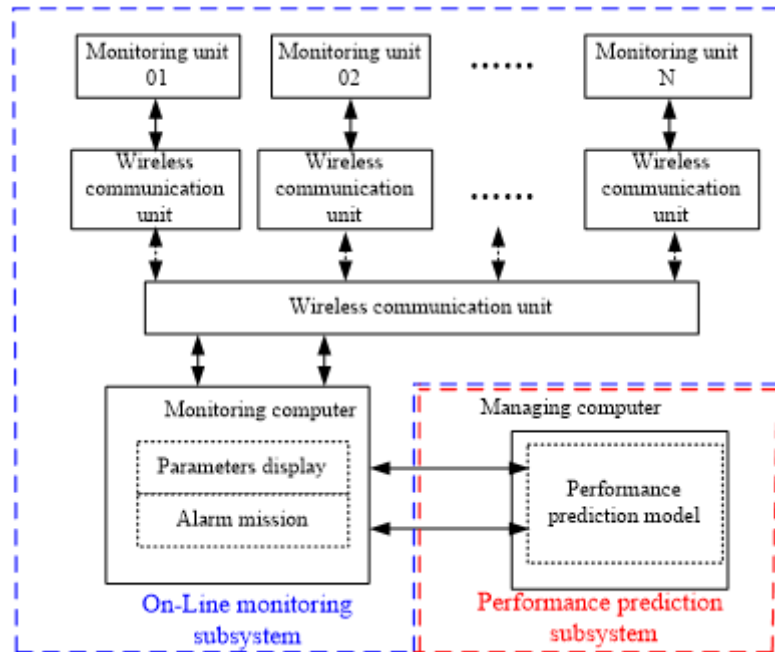


Figure 2. Fundamental Construction of the System

2.3.2 Performance prediction subsystem. A managing computer is engaged in the HMS to perform the function of performance prediction. A model based on LS-SVM algorithm is built in the managing computer. The performance prediction model should be well trained before it is engaged to give performance prediction. While making prediction, the on-line monitored working parameters and recent historical data saved in the hard disk of the monitoring computer are firstly sent to the performance prediction model in the managing computer, and then developing tendencies of both voltage, resistance and temperature can be made automatically by the model based on the historical data. Estimated time points when faults maybe occur will be presented to the crew to help them to take correct maintenance operations.

3. Prediction algorithm of LS-SVM

The LS-SVM is a supervised learning algorithm and should be well trained before it works. Suppose that the training dataset is:

$$D = \{(x_i, y_i) | i = 1, 2, 3, \dots, N\}, x_i \in R^n, y_i \in R$$

where x_i , y_i is the input data and y_i is the output data of the training dataset. The optimal problems in the primal space can be described as:

$$\min_{w, b, e_k} J(w, e_k) = \frac{1}{2} w^T w + \frac{1}{2} \gamma \sum_{k=1}^N e_k^2 \quad (1)$$

Subject to:

$$y_k = w^T \varphi(x_k) + b + e_k, k = 1, 2, \dots, N \quad (2)$$

where $J(\cdot)$ is the loss function, γ is the adjustable constant, $\varphi(\cdot)$ is the non-linear mapping function in kernel space, b is the bias term, e_k is the error variable. In order to solve the problem of non-linear classification, the aim of mapping function in kernel space is try to pick out features from primal space and mapping training data into a vector of a high dimensional feature space.

In order to solve the optimal function, the Lagrangian function may be defined as:

$$L(w, b, e_k, \alpha_k) = J(w, e_k) - \sum_{k=1}^N \alpha_k \{w^T \varphi(x_k) + b + e_k - y_k\} \quad (3)$$

where α_k is the Lagrange multiplier.

Following equations can be obtained based on the Karush-Kuhn-Tucker (KKT) condition [8,9], which is a necessary and sufficient condition for the optimal solution of the object function in the problem of non-linear optimization.

$$\begin{cases} \partial L / \partial w = 0 & \rightarrow w = \sum_{k=1}^n \alpha_k \varphi(x_k) \\ \partial L / \partial b = 0 & \rightarrow \sum_{k=1}^n \alpha_k = 0 \\ \partial L / \partial e_k = 0 & \rightarrow \alpha_k = \mu e_k \\ \partial L / \partial \alpha_k = 0 & \rightarrow w^T \varphi(x_k) + b + e_k - y_k = 0 \end{cases} \quad (4)$$

Where $k = 1, 2, \dots, n$. The output value $y(x)$ of the new input vector x can be calculated by means of the following formula:

$$y(x) = \sum_{k=1}^n \alpha_k K(x, x_k) + b \quad (5)$$

where $K(x, x_k)$ is called the kernel function, which can usually be described as:

$$K(x, x_k) = \varphi(x)^T \varphi(x_k) \quad (6)$$

Many functions can be adopted as the kernel function, the radial basis function (RBF) is one of the most popular kernel function for SVM. The RBF kernel can be described as the following formula:

$$K(x, x_k) = \exp \left(-\|x - x_k\|^2 / 2\sigma^2 \right) \quad (7)$$

where σ^2 is the squared bandwidth, which is optimized through an external optimization technique during the training process of SVM.

4. Testing results of performance prediction

Performance prediction is the key function of the HMS for marine cell group. In order to test its validity, an experiment is completed to check the accuracy of the prediction results. A set of marine cell group is chosen as testing object, who has served in a submarine for a certain period. The test is completed with following steps:

- (1) Collecting the historical monitored voltage, temperature and resistance data of the cell group.
- (2) Pre-treating the collected data to build the training data set, including invalid data eliminating, data standardization and so on.
- (3) Training the prediction model with LM-SVM algorithm using the training data set.
- (4) Presenting input data different from the training data set to the prediction model and acquire the prediction results.
- (5) Acquiring actual working data from the submarine after a period of time.
- (6) Making a comparison between the prediction results and the actual work data.

Figure 3 and 4 show partial comparison results between the prediction results and the actual work data. Figure 3 shows the comparison result of cell voltage; and figure 4 shows the comparison result of cell temperature. It can be seen from the comparison results that the model based on LM-SVM algorithm has an excellent prediction performance.

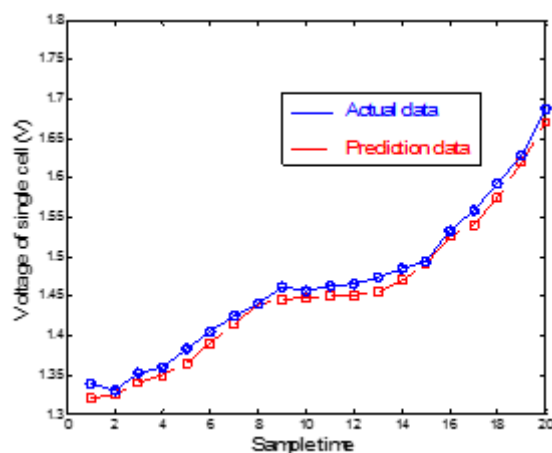


Figure 3. Comparison result of cell voltage

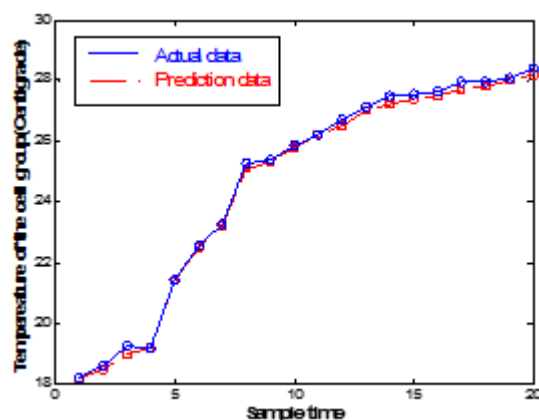


Figure 4. Comparison result of cell group temperature

5. Conclusion

Performance of storage battery usually deteriorates during usage, which brings negative effect on the using reliability and safety. It is difficult to master the performance developing tendency manually because of the complex deterioration mechanism. A health management system for marine cell group is introduced in the paper. Important parameters are collected and sent wirelessly to a computer to complete on-line monitoring function including parameters display and alarm judgement. In order to realize performance prediction, an intelligent forecasting model based on support vector machine is built, with which the system can learn knowledge from the historical data and make accurate prediction. With help of the system, maintenance decisions for marine cell group can be made scientifically.

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