

# A Fault Detection Mechanism of Tunnel based on Artificial Neural

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## Abstract

*This paper has made a qualitative and quantitative analysis by establishing the tunnel fault tree and giving the minimal cut sets of the faults in tunnel, and tested the data in tunnel combined with artificial neural network. The fault detection mechanism in this article has been simulated by MatLab and processed a lot of the actual data through the tunnel operating history. Experimental results show that: This fault detection mechanism is effective.*

**Keywords:** artificial neural, fault detection of tunnels, fault tree

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## 1. Introduction

With the acceleration of urbanization, urban transport is encountering an increasing pressure, while the tunnel under the city has significantly eased the pressure on urban traffic. But the tunnel is a very complex environment. In order to make the tunnel run safely and efficiently, and to avoid traffic accidents, the management of the tunnel for its daily operation requires an effective method. Tunnel intelligent monitoring and security management are new research topics.

This paper has combined with many tunnels in operation, Wuhan Shuiguohu tunnel, the underground passage of Wuhan Hankou Railway Station, Wuhan Zhongshan Road underpass and tunnels of the International Expo Center in Wuhan and so on. A set of effective failure detection mechanism has been established in this article, and this paper also has given a typical failure detection process and methods by analyzing and studying the actual failure detection mechanism.

## 2. The Fault Tree of the Intelligent Monitoring System in Tunnel

### 2.1. The Conception of the Fault Tree

Fault tree analysis technology is a complex technical tool, analyzing things logically and vividly. Fault tree analysis is called FTA for short, a technique developed by the American Telegraph Company Bell Labs in 1962. It has very distinctive features. It is not only intuitive, it's thinking clear, also its logic rigorous [1]. It can be used to do not only qualitative analysis, but also quantitative analysis. It is one of the primary analysis methods for safety system engineering. From this study, we can see its characteristics, integrity, expansibility, and abstraction. In addition, fault tree analysis is a major symbol of the development of safety systems engineering.

### 2.2. The Introduction of the Hardware of the Tunnel Monitoring System and the Fault Information of the Devices

The devices, installed in a typical tunnel, are generally divided into information collection devices and controllable devices. The information collection devices include vehicle inspection, temperature / humidity sensors, light sensors, wind speed / direction sensors and fire alarms. The controllable equipment covers fans, driveway lights, incandescent / sodium and so on.

Vehicle inspection is responsible for collecting the number and the speed of vehicles through the tunnel. A tunnel may be equipped with a few of vehicle inspection devices [2]. The

fault information of the vehicle inspection device generally includes power outage, communication failures, and data errors. Temperature / humidity sensors are used to gather the temperature and humidity inside the tunnel, a tunnel is generally installed with at least two sensors. Its fault information generally includes power outage, communication failure, detecting data errors. Light intensity sensor is responsible for collecting the light intensity inside the tunnel in order to contrast with the external light intensity, and its failure information generally includes power outages, communication failures, detecting data errors. Speed / direction sensor is responsible for collecting the information of the wind speed and its direction in the tunnel, and its failure information generally includes power outages, communication failures, and data acquisition errors. Fire alarm is responsible for detecting the fire safety conditions inside the tunnel, and its failure information generally includes power outages, communication failures, high rate of false positive, and so fault information. Fans are mainly used to reduce the CO concentration inside the tunnel and to improve its visibility, and can let off dense smoke when the tunnel fires, and its failure information generally includes power outages, communication failures, producing wind drop and so on [3]. Lighting in tunnel mainly provides light, and its failure information generally includes power outages, communication failures. Driveway lights is the traffic signal of tunnel, and its failure information generally includes power outages, communication failures.

### 2.3. The Establishment of Fault Tree of the Monitoring System

The fault tree of the intelligent monitoring system makes analysis by using down-way quantity analysis, getting the minimal cut sets (MCS). It is: {vehicle inspection device power failure}, {vehicle inspection device line fault}, {vehicle inspection device --- King View communication failure}, {vehicle inspection device data anomaly}, {CO / VI sensor power failure}, {CO / VI sensor line fault }, {CO / VI sensor --- King View communication failure}, {CO / VI data anomaly}, {fire sensor power failure}, {fire sensor line fault}, {fire sensor --- King View communication failure}, {fire alarm false high rate}, {FS / FX sensor power supply failure}, {FS / FX sensor line fault}, {FS / FX sensor --- King View communication failure}, {FS / FX sensor data anomaly}, {fan power failure}, {fan line fault} ,{fans --- King View communication failure}, {blower no achieving the desired effects}, {lighting power failure}, {lighting line fault}, {lighting --- King View communication failure}, {lighting no reaching the expected results}, {driveway lights power failure}, {lane light line failure}, {driveway lights --- King View communication failure}.

The fault tree, established according to the information of the hardware inside the tunnel, is shown as Figure 1:

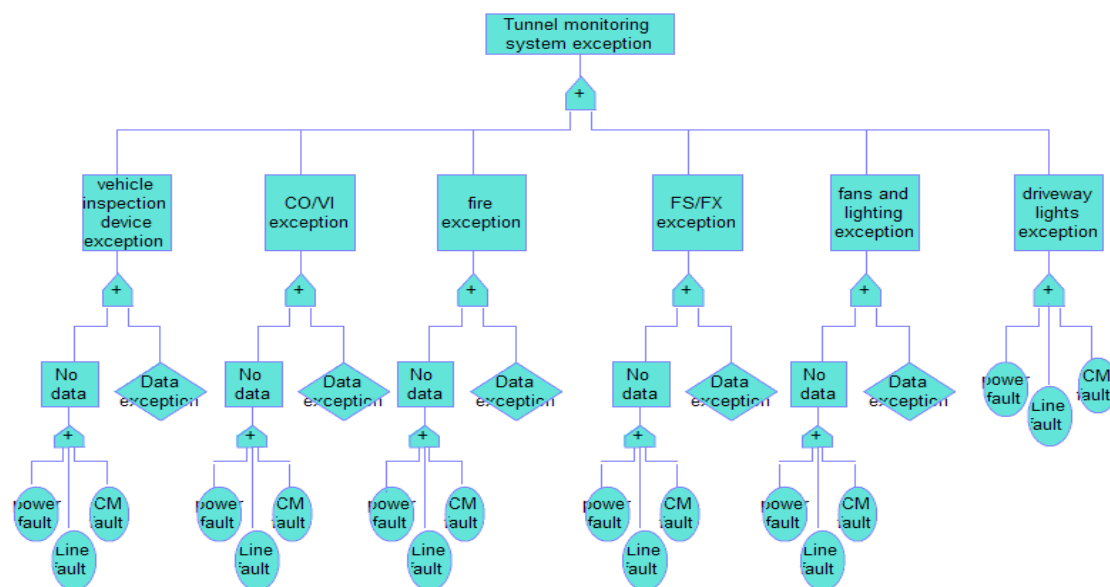


Figure 1. Fault Tree of the Monitoring System

### 3. Fault Detection of the Tunnel Based on the Neural Networks

#### 3.1. The Principle of Detecting Data Failures of Neural Networks

With the development and research of Neural Networks (NN), it is increasingly being used in the field of engineering controls, based on its inherent advantages, especially its system identification, adaptive control, modeling, and other areas. It could solve these problems appropriately, the uncertainty, severe non-linearity, hysteresis, time-varying control of complex systems, modeling and testing issues. Different environmental parameters inside the tunnel, the impact of the controllable device on environmental parameters are mutual restraint, mutual influence [4]. For example: CO concentration inside the tunnel at a time depends on the time of the fans running on, the number of the fans turned on, the wind speed and direction in tunnel, traffic and visibility of tunnels. The relationship, only considering the CO concentration and the traffic, is a substantially linear relationship. The high traffic, the greater CO concentration. On the contrary, the running time of the air blower, the number of fans, and the CO concentration are inversely proportional to speed. According to the characteristics that various parameters inside the tunnel are mutual impact and mutual restraint and a powerful self-adaption and learning ability, discriminability of the Neural Networks, it is a good way to solve the problem of data anomaly testing in the tunnel by using the Neural Network to ensure the process of testing data in tunnel. In order to monitor the tunnel intelligently, collecting and processing the abnormal data in tunnel are essential.

Take tunnel vehicle inspection controller as an example to illustrate how BP Neural Networks detect data collecting anomaly of the vehicle inspector. Vehicle inspection is mainly used to collect the number of vehicles entering the tunnel and vehicles' real-time speed at a certain time. In a period of time, the number of vehicles entering the tunnel, can affect the concentration of CO inside the tunnel, wind direction, wind speed and visibility. While the CO concentration mainly depends on the number of fans opened in the tunnel and the running time, and the visibility has a relationship with the number of lights and the lighting intensity. Therefore, input the concentration of CO inside the tunnel (  $co(t)$  ), wind speed (  $fs(t)$  ), visibility (  $vi(t)$  ), the number of the fans running at a certain time (  $ff\_count(t)$  ), the running time of the fans (  $ff\_time(t)$  ), the number of the lights turning on (  $zm\_count(t)$  ), and the light intensity in tunnel (  $gq(t)$  ) into the Neural Networks. That is to say, the input vector of BP Neural Networks is  $\{co(t), fs(t), vi(t), ff\_count(t), ff\_time(t), zm\_count(t), gq(t)\}$ .  $t$  Refers to the  $t$  sample. In order to reduce data errors in the input vector, take the average of several data of each vector in tunnel as the actual input of Neural Networks in  $a$

seconds. For example: in  $a$  seconds,  $co(t) = \sum_{n=1}^s co_n(t) / s$ , in which the  $s$  is the number of the data of the CO concentration in tunnel, collected by the CO sensor. How to determine the Value of  $a$  should make some appropriate adjustments, based on the frequency of collecting the CO concentration, the actual magnitude of CO concentration and the experiment effect of the actual samples.

Take the average of samples in a period of time as the Input of the experimental samples. Then the inputs of the variable in this period can be considered to be homogeneous. So no large errors occur in the experimental data because of an abnormal testing data, guaranteeing the accuracy of data inputted. Take  $coll(t)$  as the output of Neural Networks.

#### 3.2. The Design of the Neural Networks Structure

The design of the Networks structure primarily covers the number of hidden layers, the number of neurons in each layer. Theory proof that Networks, with bias, at least one S-type hidden layer and a linear output layer, can approximate any rational function. But some random uncertainties exist in the control system of the actual tunnel (Eg: weather, people, environment, etc.). That is to say, the model of tunnel intelligent monitoring system is an uncertain stochastic system. Therefore, when training the Networks by using only one hidden layer, there is a need to increase the number of neurons in this layer, only in this way can the error precision be

improved. But Actual Operation shows that even adding a lot neurons into the Neural Networks with only one hidden layer, the required precision is still hardly reached. Therefore, Neural Networks training needs to select more than one hidden layers, but too much hidden layers will make the Neural Networks become very complicated. That will increase burden on Neural Networks control and the training time of the Neural Networks [5]. The data abnormal Neural Networks of the intelligent monitoring system in the tunnel will use two hidden layers after overall consideration.

According to the concentration of CO ( $co(t)$ ), wind speed ( $fs(t)$ ), visibility ( $vi(t)$ ), the number of the fans running ( $fj\_count(t)$ ), the running time of the fans ( $fj\_time(t)$ ), the number of the lights turning on ( $zm\_count(t)$ ), and the light intensity ( $gq(t)$ ) in a period of time, the traffic flow in this period of time can be inferred. Therefore, the number of neurons of the input layer in the Neural Networks is 7, the number of neurons of the output layer in the Neural Networks is 1. The hidden layer of the Networks structure is preferably  $16 \times 22$  nodes, which is proved through training different neural samples and comparing the experimental data. As is shown in Figure 2:

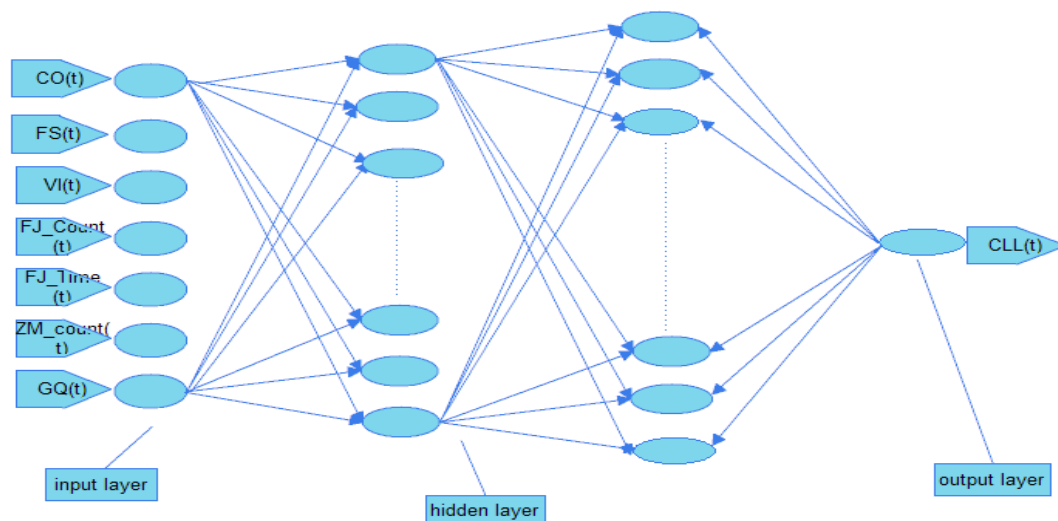


Figure 2. The Neural Networks Model of the Vehicle Inspection for Testing Data Errors

### 3.3. The Selection of the Activation Function

According to the particularity and random uncertainties of the Neural Networks model, the selection of the sigmoid function is a relatively good choice. The sigmoid function has the characteristics, smoothness and robustness. On the other hand, the derivative of the function can be expressed by a certain expression of the function [6]. At this rate, when using the function for the actual calculation, the consumption of a computer system, in the process of computing and storage, can be effectively solved. Then using the sigmoid function can significantly improve the convergence speed of the Networks in the structural model of the same Networks, which is very important to some more complex Neural Networks. In order to simplify network design, the linear transfer function (Purelin) is used into the output layer, so that the final output of the network can be any value.

### 3.4. The Selection of Sample Data Based on the Fault Detection Model

The tunnel detection and control is a very complex process. The amount of data collected is very large and the selection of the sample in the Neural Networks occupies a very important position. That, whether the data of the sample vectors enjoys popularity and representation or not, largely affect the learning of the Neural Networks. It is an extremely

tedious work to select an appropriate training samples, from massive amounts of data generated by in the tunnel monitoring system. And in the process of gathering information, some errors may occur, even to be large errors relative to the real data may be erroneous data. Removal of such data is the important part of the work of the sample. The tunnel monitoring data has the following characteristics:

- 1) Huge amount of data
- 2) The same data changed in relatively small extent
- 3) The data may be wrong data in a period of time
- 4) The data has a big redundancy
- 5) Detecting data in a certain range (for example: the CO concentration has a range and the tested data are generally not outside this range)
- 6) According to the actual operating conditions of the tunnel, there is a wide gap between traffic flows of different periods in a day. (Eg: 7:00 to 9:00 (in the morning), 11:00 to 14:00 (at noon) and 17:00 to 21:00 (in night) have large traffic flow)

According to the above features, the selection of the training sample of the Neural Networks should follow the following principles:

- 1) Training samples is randomly selected: for a huge amount of monitoring data, if taking all the monitoring data as the training samples, that will greatly increase the training time of the neural network and it is not necessary to collect such samples in the training process.
- 2) The standardization of training samples: Since the tunnel monitoring data is changed in a certain range, there is a need to standardize some sample data to reduce the error caused by the selection of the error data.
- 3) According to the testing data in tunnel with the characteristics of the smaller amplitude of variation, some good training data is better to take more before and after the sample, which is based on the nearest neighbor rule.
- 4) Select the samples of the detected data within a period of time selected, and then obtain the average value to reduce the error caused by the error data to network training.
- 5) Selectively select the sample in every period of time of every day, to increase the selection coverage of the sample and improve the quality of training of the Neural Networks [7].

### 3.5. The Mat Lab Simulation Experiment

The historical data of the actual traffic, collected in Wuhan Shuiguohu tunnel in a month, makes the Neural Networks do self-adaptive training. Make the Neural Networks do self-adaptive training, using a lot of the historical data, the model of training the neural network is as shown in 3:

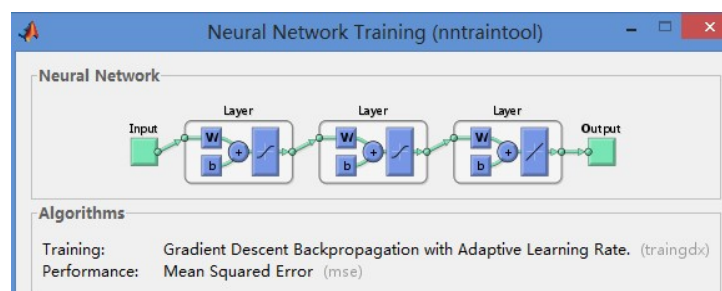


Figure 3. The Structure of the Neural Networks

The simulation of the system takes Wuhan Shuiguohu Tunnel as research objects, Wuhan Shuiguohu tunnel is a bi directional and four lane tunnel, with a length of over 1700 meters. The tunnel can be divided into three sections. There is some open space left between each section, which is effectively regulating the tunnel environment. The max speed in the tunnel is 80KM / H. The number of the vehicles through the tunnel is roughly 35 every minute, and roughly 75 per minute at peak times. Based on the actual condition of Wuhan Shuiguohu tunnel, the neural network training below has been done, using a lot of the actual data through the tunnel operating history. Then use the Neural Networks finishing to do the testing of data

anomaly of the traffic flow collected by the vehicle inspection. After a large number of historical data and repeated training of the Networks, predict the traffic flow of the tunnel and finally draw a set of curves for the comparison between the actual value and the predicted value of the traffic flow, as is shown in Figure 4:

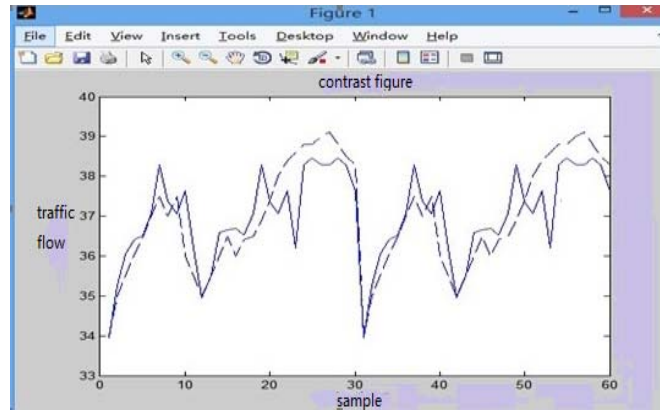


Figure 4. The Comparison Chart of Traffic Forecasts

In the above figure, the solid line represents the actual traffic flow of the sample in a minute, while the dotted line represents the predicted traffic flow of the Neural Networks, trained by the seven input vectors using the same sample, the CO concentration, light intensity, the time of the fan opened, fans' number, visibility, wind speed, lighting number in the tunnel. Not difficult to find, from the comparison chart, that the degree of fitting of the solid line is better than the dashed line. It can generally be considered that the model of data anomaly detection for vehicle inspection device can properly predict traffic flow.

#### 4. The Summary

The simulation results show that the combination of the fault tree analysis and the fault detection mechanism of artificial Neural Networks can properly predict accidents in the tunnel to occur. There is no doubt that the analysis has a broad application prospect in the safety management of the tunnel.

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