Road Icing Warning System Based on Support Vector Classification

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Abstract. Road icing seriously affects road driving in winter, which is one of the most disadvantageous meteorological conditions endangering traffic safety. It has important social significance and application value to accurately predict the freezing time of pavement and establish the early warning system for the freezing safety of roads. In this paper, the parameters of pavement temperature, freezing point temperature, friction coefficient, pavement water film thickness, ice content and pavement condition are collected by sensors, and support vector classification is used to judge whether the pavement will freeze in a certain time in future. With this road icing warning system, the freezing time of pavement can be predicted automatically in order to reduce traffic accidents and improve road safety in winter. The experimental data of Ji’nan Second Ring South Viaduct shows that the system can predict the pavement icing in future.

1. Introduction
In the modern society, the transportation industry has become an important pillar industry which is one of the most important social structure[1]. According to statistics, the economic losses and casualties caused by road traffic accidents in many countries of the world are greater than those caused by other accidents such as floods and fires[2]. Traffic safety accidents not only affect traffic safety and cause heavy losses to the property of the country and people, but also cause traffic congestion, seriously reduce the continuity of road transport, and bring great inconvenience to people’s normal traffic. When the road is frozen, drivers often do not know that the road has been frozen, which often leads to traffic safety accidents. Pavement icing will significantly reduce the anti-skid ability of the road surface, which is extremely harmful to road driving, and is one of the most unfavorable meteorological conditions affecting road driving safety in winter. Studies have shown that in all traffic safety accidents, traffic accidents caused by road icing are 10 times as many as those caused by road surface without ice[3]. Hundreds of people are killed or injured annually in the United States in accidents related to ice formation on roadways and bridge decks[4].

Intelligent transportation systems are advanced applications that inform vehicle drivers about road conditions. The main purpose of the intelligent transportation systems is to reduce either tangible or intangible loss for the drivers by ensuring the safety of passengers and vehicles[5].
In this paper, the parameters of pavement information such as pavement temperature, freezing point temperature, water film thickness and pavement condition are used, and the machine learning method of support vector classification (SVC) is used to predict whether the pavement will freeze in the future, so as to reduce traffic accidents and improve the road safety in winter.

The remainder of this paper is organized as follows: Section 2 reviews previous related work of this area; Section 3 gives a description of our construction of icing warning system; Section 4 gives the results on our real datasets and a comparison between the prediction time and actual time; Finally, we will draw some conclusion and give possible developments for further work.

2. Related Work

Early warning system can monitor and predict freezing in the street. In 1972, Sweden set up an early warning system for monitoring and issuing warning information on ice and snow on roads for the first time [6]. T. Meindl presents a reliable ice detection and forecasting system based on a special road weather information system and a neural network algorithm for ice event forecasting [7]. H. Tang and J. Feng proposes an icy detection system for highway pavement, which uses information of vibration spread, temperature and conductivity changes to judge road icy conditions [8]. Ice-forecasting of the highway’s dangerous section is presents according to the main factors influencing the road-icing, and the electrical characteristics reflected by the pavement ice layer [9]. The California Department of Transportation (Caltrans) deployed an icy-curve warning system (ICWS) on a 5-mi section of SR-36 in Lassen County, California, over Fredonyer Pass. The ICWS reduced annual crashes by 18%[10]. A numerical model to forecast road conditions, Model of the Environment and Temperature of Roads (METRo), has been developed to run at Canadian weather centers [11].

R. Omer and L. Fu investigates the feasibility of classifying winter road surface conditions using images from low cost cameras mounted on regular vehicles. RGB features along with gradients have been used as feature vectors. A Support Vector Machine (SVM) is trained using the extracted features and then used to classify the images into their respective categories [12]. Black ice is a thin coating of glazed ice on roadways or other transportation surfaces. T. Liu developed a prototype decision support system (DSS) to predict and detect black ice formation and pin point dangerous road sections[13]. J. Palutikof analyzed the relationship between accident casualty rate and snow thickness under ice and snow conditions, and found that there was a negative correlation between them, and established the model between them [14]. Norrman established an Expert System for Classifying Slipperiness on Roads (ESCSR), which takes the collected information of pavement temperature, temperature, dew point, relative humidity, wind speed and precipitation as the direct observation factors, and then combines the factors obtained by empirical formula with the factors estimated qualitatively to determine the type of skidding [15]. Li Rui analyzed the relationship between the wind speed and relative humidity. The result shows the surface humidity are beneficial to the formation of the ice phenomenon on the low-temperature pavement [16]. Using a neural network to train the experiment samples, Z. Xiong and J. Qin put forward the road surface ice prediction model [17]. Qiu Xin etc established the prediction analysis model of asphalt pavement temperature. And they proposed the discriminative criterion of icing condition of asphalt pavement in central area of Zhejiang Province in winter [18]. A. Fujimoto et al developed a one-dimensional time-dependent model for the prediction of freezing on a road surface [19]. K. Brzozowski presented preliminary concept for an information system on road conditions in the city’s transport network, which also makes it possible to carry out short-term weather prediction to provide users with early warning of impending deterioration of traffic conditions [20].

Some researchers use sensors to directly analyze pavement conditions. A back scattered light analysis was applied to quantify the slipperiness of road surface [21]. Various typed environmental sensors are installed on the vehicle and collects the sensor data with various road surfaces conditions while running along the street. From the collected sensor data, the road surface states are decided such as dry, wet, snowy, icy by sensor server. The decided road states can be share with the many vehicles
through V2V and V2I communication protocols [22]. A remote-controlled black-ice detection and warning system is proposed [23].

3. Construction Of Icing Warning System

Support vector machines (SVMs) is a bi-classification model. Its purpose is to find a hyperplane to class samples. The principle of classification is to maximize the interval, and ultimately to solve a convex quadratic programming problem.

Its classification problem is expressed mathematically as follows:

$$\min_{\alpha,\xi} \frac{1}{2}W^TW + C \sum_{i=1}^n \xi_i \text{ s.t. } y_i(W^T\phi(x_i) + b) \geq 1 - \xi_i$$

Where $$\xi_i \geq 0, i = 1, \ldots, n$$.

Its dual problem is:

$$\min_{\gamma} \frac{1}{2}e^TQe - e^T\gamma s.t. \gamma \leq C, y^T\gamma = 0$$

Where $$Q_{ij} = y_i y_j \phi(x_i)^T \phi(x_j), e = [1, \ldots, 1]^T$$. By solving the problem, the optimal solution of the problem (1) can be obtained by using the primal-dual relation. The optimal solution is $$W^* = \sum_{i=1}^n y_i \alpha_i \phi(x_i)$$. In this case, the classified hypersurface is $$W^T\phi(x_i) + b = 0$$. The decision function is:

$$f(x) = \text{sgn}(W^T\phi(x_i) + b^*) = \text{sgn}(y_i \alpha_i \phi(x_i)^T \phi(x_i) + b^*)$$

Formula (1) shows that the function of transformation in the algorithm is inner product $$\phi(x_i)^T \phi(x_i)$$. If a function is defined as: $$\mathcal{K}(x_i, x_j) = \phi(x_i)^T \phi(x_j)$$, this function is called kernel function. Usually, the kernel function in SVM is RBF radial basis Kernel Function. RBF Kernel Function is shown in Formula (4). It is Gauss kernel function.

$$\mathcal{K}(x_i, x_j) = e^x p\left(\frac{-||x_i - x_j||^2}{2\sigma^2}\right) = e^x p\left(-\gamma ||x_i - x_j||^2\right)$$

For a given classification problem, we don’t know the optimal value of $$C$$ and $$\gamma$$, so we need to find the best parameters. The aim is to find good pairs of parameters so that the classifier can accurately predict unknown data. It should be noted that it may not be useful to pursue high accuracy in the training set, but rather to be able to accurately test unknown data. Generally, grid search algorithm is used to find parameters $$C$$ and $$\gamma$$ [24]. The grid search consists of two steps: first, coarse grid search, and then fine grid search[25, 26].

Here, in order to make full use of the information and consider the time relationship between the information, the observation information of the current time and previous time is used to predict whether the road will freeze at the next moment. In system, the inputs are $$X(t)$$. The $$X(t)$$ are the pavement temperature, freezing temperature, pavement friction coefficient, thickness of water film, ice content, pavement condition, denoted as

$$x_1(t-1), x_2(t-1), x_3(t-1), x_4(t-1), x_5(t-1), x_6(t), x_7(t), x_8(t), x_9(t), x_10(t), x_11(t)$$

respectively. Features are 12-dimensional input variables. The outputs are icing warning value $$y(t+1)$$, which are the next moment of values of ice warning value.
The prediction steps are as follows:
1. Converting data into feature input of SVC $X(t)$;
2. Data scaling, usually scaling the data range to $[-1,+1]$ or $[0,1]$;
3. Selecting RBF Kernel Function $\kappa(x_i,x_j) = \exp (-\gamma \|x_i - x_j\|^2)$;
4. Using k-fold cross-validation method to find the best parameters $C$ and $\gamma$ for training data;
5. Training the whole training data with the best parameters $C$ and $\gamma$;
6. Testing the effect of ice warning.

We have collected data from several locations on second ring south elevated road of Ji’nan, China. These data are the pavement temperature, freezing temperature, pavement friction coefficient, thickness of water film, ice content, and pavement condition. Ice warning value indicates whether the road is currently icing or not. Fig. 1 is the data of Second Ring South Viaduct of Ji’nan, China. The data is from 12/5/2016 to 12/26/2016. Data acquisition interval is 10 minutes.

![Fig. 1 The Origin Data of Second Ring South Elevated Road](image-url)
Fig. 2 Normalized Data

Normalization is needed before model training. The normalized data are shown in Fig. 2. Using the data of first ten days as train data, the data for the next ten days are the test data. The train data of first ten days is shown in Fig. 3.
Once the parameters are selected, it can estimate a new sequence. The model verification is evaluated on the test data. The pavement icing forecasting and actual value of test data is shown in Fig. 3.

**Fig. 3 Train Data**

4. **Experiments**
In our experiment, the forecast data is from 12/5/2016 to 12/26/2016 on the other different position. The actual information values of pavement are shown in Fig. 4.

The forecast and actual value of pavement icing warning on the other different position is shown in Fig 5.
5. Conclusion

In this paper, we used the SVC method to predict the pavement icing warning. The results show that the model can predict the pavement icing warning accurately. Based on our research and method, it can reduce the damage caused by road icing. And that can reduce the occurrence of traffic accidents and improve the traffic management in our country.

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