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AN ONLINE FOREWARNING MODEL FOR OIL & GAS STORAGE TANKS

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Abstract. *In recent years, oil and gas always leak even explode in the process of storage and transportation, which has caused enormous economic loss and environmental damage. Therefore, how to apply scientific methods to predicting the risk of a complex nonlinear system accurately and quickly has become a universal research. In this paper, we focus on static gas storage tanks, considering the correlation of the various forewarning indicators, excluding subjective factors as far as possible, and propose an online forewarning method based on principal component analysis and probabilistic neural network from the viewpoint of test modeling. In contrast with another method (Dynamic-Fuzzy Neural Network), this model has improved in terms of accuracy. When it comes to the computing time, the speed slightly decreases but does not affect the management decision. What is more, when the number of test sample is large the robustness of the model is good, which can provide the algorithm basis for the development of the relevant forewarning decision support system.*
Keywords: Oil & gas storage tanks, Forewarning model, Probabilistic neural network

1. **Introduction.** In recent years, oil and gas always leak even explode in the process of storage and transportation, which has caused enormous economic loss and environmental damage. The traditional forewarning method belongs to the “feedback control” management mode, that is to say, the corresponding management action is taken after the leakage accident occurs. The online intelligent forewarning of oil & gas storage and transportation facilities under the background of big data have become the frontier direction of this area. In this paper, we focus on the major needs of energy transport of our country, studying on forewarning models to provide online and accurate warning information for the safe operation of oil & gas storage facilities. Besides, this study also enriched the management theories and methods under big data environment.

As for the risk prediction of oil & gas storage and transportation facilities, Lu explored the leakage mechanism of large steel storage tanks under the action of combustible gas explosion from the aspects of explosion kinetics and plastic kinetics; Guo and others systematically studied risk situation and force situation of the static, modal and transient storage tank under the four representative seismic wave by the finite element analysis; Li and others studied on the oil storage tank leakage by numerical simulation, and pointed out that the larger the leakage aperture is, the greater the leakage flow rate is; Peng and others used the combined weighting method of comprehensive analytic hierarchy process and entropy method to propose a security early warning model for petrochemical wharf

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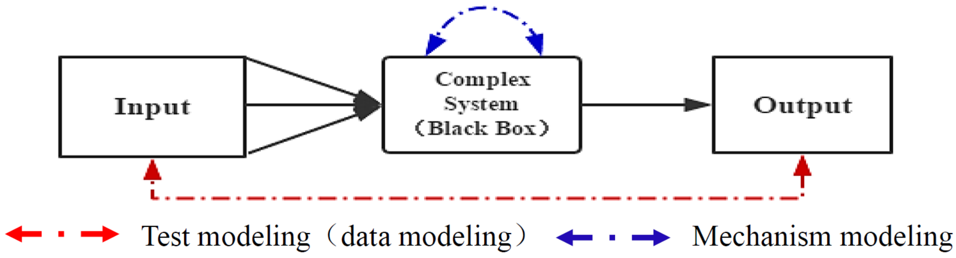


FIGURE 1. Two modeling methods from different viewpoints

storage tanks; Zhang and others studied the leakage mechanism and characterization rules of the drilling process, and proposed an early warning model constructed by a fuzzy expert system based on layered ideas. In summary, scholars at home and abroad have made very meaningful explorations, but they mainly used engineering mechanics methods to carry on mechanical analysis, revealed the leakage mechanism and then gave recommendations for preventive measures, which belongs to the category of mechanism modeling.

However, these methods are too hypothetical and only consider the key elements. Therefore, the guidance is not significant in management practices and the accuracy of forecasting needs to be improved.

Aiming at the disadvantages of mechanism modeling, a few scholars put forward the method of test modeling (data modeling). Put in another way, they only analyze the input and output of this complex non-linear system without any assumptions, regardless of the system's internal components, and then understand the risk situation. For example, Sun and others proposed a risk forewarning model based on dynamic fuzzy neural network (D-FNN). This model possesses the general characteristics of neural networks such as rapid self-learning ability and fault tolerance. However, there exist two significant problems in this research. First, there are too many parameters in this algorithm, and some of them depend on expert evaluation and have high subjectivity. Second, there is a certain correlation between the various forewarning indicators, which leads to a larger amount of computation and a bad effect on output in terms of accuracy.

In view of this, we focus on static oil & gas storage tanks, considering the correlation of the various forewarning indicators, excluding subjective factors as far as possible, and put forward an online forewarning method based on principal component analysis and probabilistic neural network from the viewpoint of test modeling. In contrast with another method (Dynamic-Fuzzy Neural Network), this model has improved in terms of accuracy. When it comes to the computing time, this forewarning speed slightly decreases but does not affect the management decision. What is more, when the number of test samples is large, the robustness of the model is good, which can provide the algorithm basis for the development of the relevant forewarning decision support system.

2. Problem Definition.

2.1. The selection of features. With related literature and experts' opinions in gas transportation enterprise, we select 4 factors named T, P, C and Q as potential indicators for oil & gas leak, following representative, independent and measurable principles. The explanation of each factor and the influences on oil & gas leakage are as Table 1.

2.2. The selection of the training samples. Chemical instruments display multidimensional time series data. With the extension of time, it will form a number of bursts of big data flow. Therefore, we adopt the method of systematic sampling, using SQL queries in the database of static oil & gas tanks from an oil & gas transportation enterprise. We record the feature values (P T C Q) of each point within the neighborhood of t-minutes

Table 1. Qualitative analysis of various potential indicators to oil & gas leakage

Potential Indicators	Unit	The way to the leakage influence (Qualitative Analysis)
Tank medium temperature (T)	°C	The medium is in high temperature, gas thermal motion intensifies, which makes the storage tank easy to "break the tank".
Tank medium pressure (P)	Mpa	With pressure increasing, the gas expands, leading to a higher concentration, making the storage tank easy to crack.
Gas concentration exceeded level (C)	%	The higher the concentration, the higher the molecular collision frequency, and it increases the pressure making the storage tank easy to crack.
Tank medium flow (Q)	m^3/h	With the high flow rate, the impact to the storage tank becomes larger, and the storage tank is easy to crack.

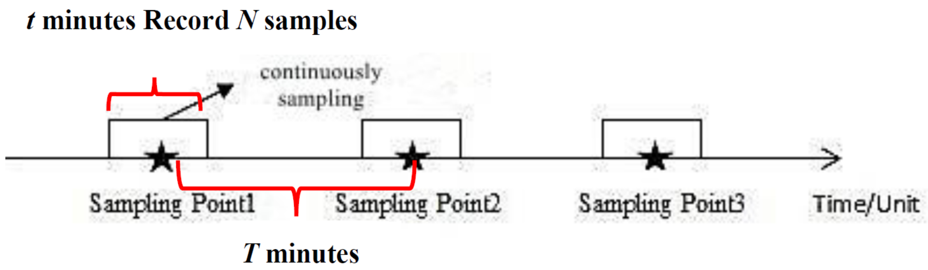


Figure 2. The method of extracting data

Table 2. Original data and risk level (by authoritative engineers) of N sets

Series	T/°C	P/Mpa	C/%	$Q/m^3 \cdot h^{-1}$	Risk level (Y)
1	21.732	3.985	0.017	35.856	1
2	19.452	4.123	0.009	14.942	1
⋮	⋮	⋮	⋮	⋮	⋮
51	18.004	5.652	0.005	6.120	2
52	26.452	2.956	0.020	29.452	2
⋮	⋮	⋮	⋮	⋮	⋮
101	30.125	4.652	0.001	89.126	3
102	28.753	6.456	0.008	47.561	3
⋮	⋮	⋮	⋮	⋮	⋮

of the sampling point, with the number of samples being N sets and the unit being T minutes. Specific methods are as Figure 2.

In a relatively static storage tank, the data on the chemical instruments are structured and have no significant changes. However, due to the material corrosion, extreme weather, constructions and others, tank may break down, which leads to the oil & gas leakage. As a result, the data may wave. According to the experience of authoritative engineers, the data is classified into different risk levels. To be specific, "Extremely dangerous" corresponds to the number 1, "General risk" corresponds to the number 2, and "Security" corresponds to the number 3, the results are as Table 2.

2.3. **The preprocessing of data.** On the basis of Clausius-Clapeyron equation in physical chemistry, as for a closed system, there exist[1]:

$$PV = nRT$$
$$C_f = \frac{n}{V}$$
$$C = \frac{C_f}{C_0}$$

Then we can get the equation as follows:

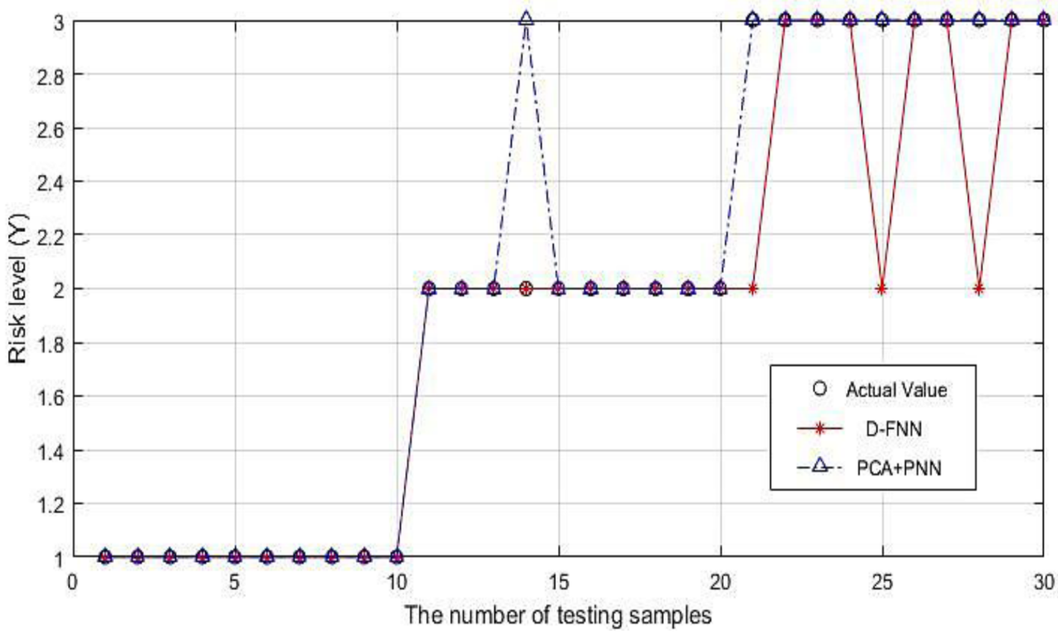
$$P = CC_0RT$$

Among them, P – system pressure, V – gas volume in the system, n – amount of substance, R – equation of state of the gas state, T – system temperature, C_f – actual concentration of gas in the system, C_0 – gas standard concentration.

That is to say, there is a certain correlation between C T P. Therefore, principal component analysis (PCA) is used to process the data in advance. As a result, 4 dimensions are reduced to the non-significant correlation of the 2 dimensions, which are named as forewarning indicators, which are X_1, X_2.

At this time, the risk online forewarning problem is converted into how to find the relationship between risk level (Y) and the monitoring target X_1, X_2.

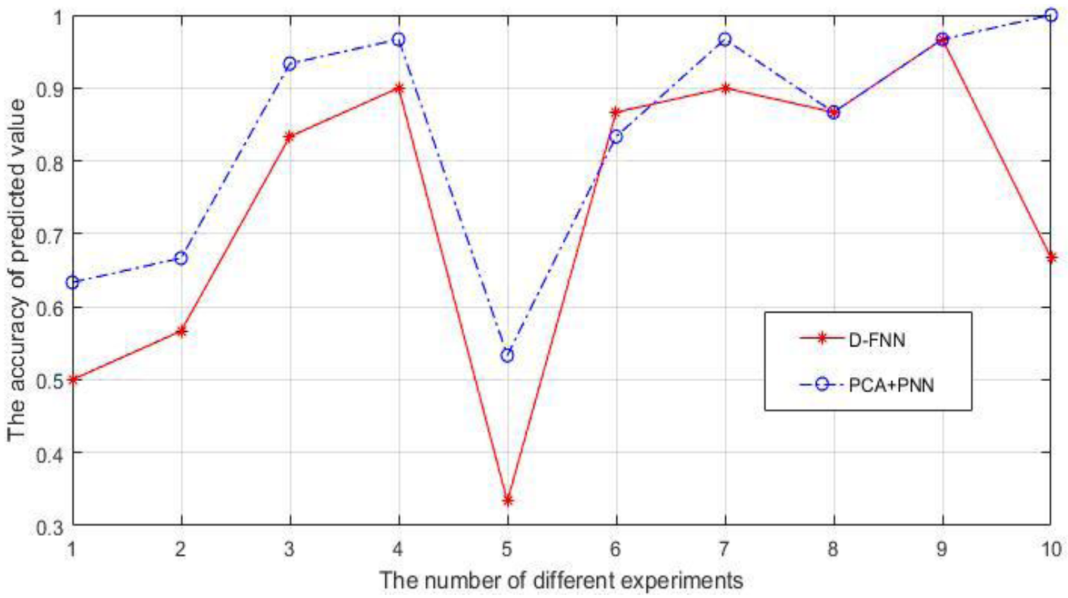
3. **Methodology and Results.** As for the same group input and output of the oil storage tank system (in Table 2), we use "PCA+PNN" and "D-FNN" forewarning methods for training, testing and simulation, and then get results as Figures 3 and 4.



Accuracy: 96.67% (PCA+PNN) VS 90% (D-FNN)

FIGURE 3. The predicted risk level of testing samples via different algorithms (1 experiment)

[1]The Clausius-Clapeyron equation can also be used for qualitative analysis of non-ideal gases (actual storage process).



Accuracy: 83% (PCA+PNN) VS 73% (D-FNN)

Figure 4. The accuracy of 10 experiments via different algorithms

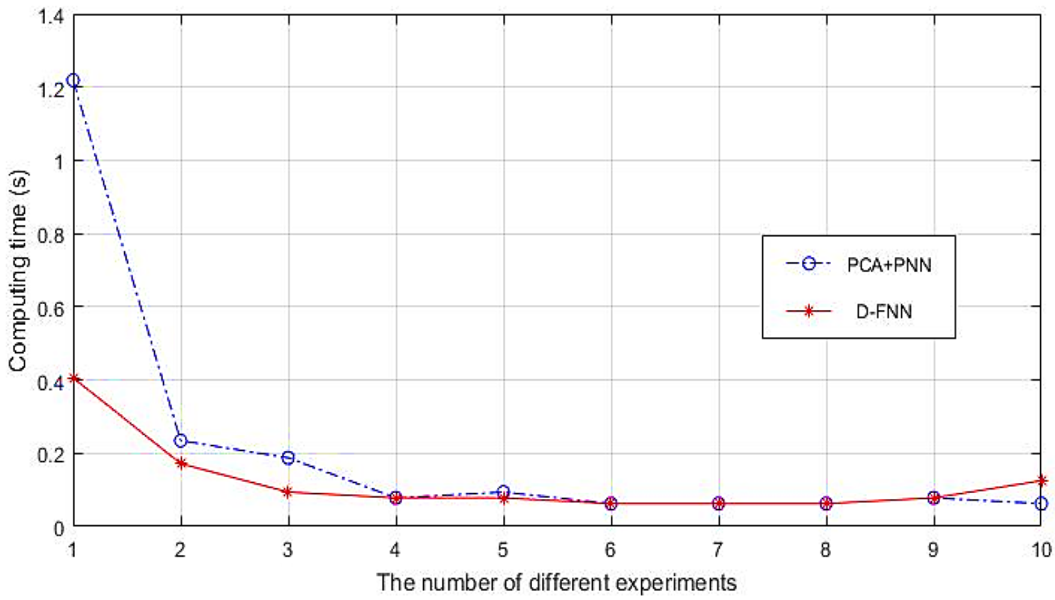


Figure 5. The computing time of 10 experiments via different algorithms

From Figures 3 and 4, in terms of accuracy, "PCA+PNN" increases by 6.67% in 1 experiment and by 10% in 10 experiments. The forecast accuracy rate has increased, but it takes a certain amount of time and reduces the speed of emergency management. Therefore, we use MATLAB as the operating environment, and analyze the computing time of the two algorithms, and then get Figure 5.

In the 10 groups of experiments, the average operation time of "PCA+PNN" is 0.2156 seconds and that of "D-FNN" is 0.1578 seconds, and the difference between them is only 0.06 seconds, which is lower than the person's reaction time to critical situation (0.2 seconds). In a word, "PCA+PNN" almost does not affect the speed of emergency management.

Moreover, the data with many features displayed by chemical instrument will form exponential growth of "big data" as time goes by, and the accuracy of forecasting may

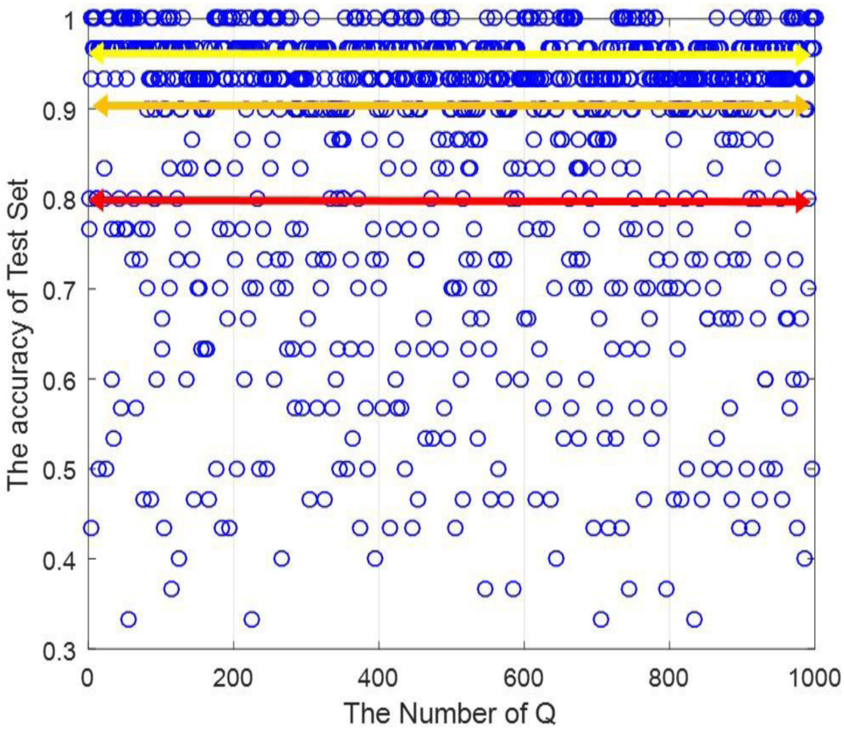


FIGURE 6. The accuracy of 1000 test sets (PCA+PNN)

fluctuate. In this paper, 1000 sets of test samples are randomly selected to obtain the results in Figure 6.

The results show that when the test sample is 1000, the average prediction accuracy of "PCA+PNN" is 85% and the variance is 0.033. While, the average accuracy of "D-FNN" is 81% and the variance is 0.05. This shows that when there are many test samples, the prediction accuracy of "PCA+PNN" has improved. The rate of increase is not large, but the accuracy of prediction is more evenly distributed, indicating that the robustness of "PCA+PNN" is better.

4. **Conclusions and Future Work.** In this paper, we focus on static oil & gas storage tanks, considering the correlation of the various forewarning indicators, excluding subjective factors as far as possible, and put forward an online forewarning method based on principal component analysis and probabilistic neural network:

4.1. **In terms of accuracy.**

- When the number of test samples is small, "PCA+PNN" has improved in contrast with "D-FNN".
- When the number of test sample is large, though the "PCA+PNN" has improved, the rate of increase is not large. Interestingly, the accuracy of prediction is more evenly distributed, indicating that the robustness of "PCA+PNN" is better.

4.2. **From the viewpoint of forewarning speed.**

- Though the forewarning time of "PCA+PNN" is longer than that of "D-FNN", "PCA+PNN" almost does not affect the speed of emergency management.

4.3. **Significance.**

- This study can provide the algorithm basis for the development of the relevant forewarning decision support system.

When the test sample is large, the improvement rate of the prediction accuracy rate may decrease. Therefore, how to embed the reinforcement learning theories into the model to further improve the accuracy of the prediction and increase the anti-jamming of the external environment are the next steps.

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REFERENCES

[1] T. Wang, T. Li et al., Risk assessment and online forewarning of oil & gas storage and transportation facilities based on data mining, *Procedia Computer Science*, vol.112, pp.1945-1953, 2017.
[2] S. Lu, *The Study on the Failure Mechanism of Large Steel Storage Tank under Combustible Gas Explosion*, Ph.D Thesis, Harbin Institute of Technology, 2012.
[3] H. Guo, *Finite Element Analysis of Static Dynamic of 100 m^3 Large Storage Tank in A Port*, Master Thesis, Dalian University of Technology, 2006.
[4] B. Geng, Cause analysis and preventive measures of crack in pressure pipe, *China Petroleum and Chemical Standards and Quality*, vol.4, pp.45-50, 2013.
[5] Y. Sun, S. Peng et al., Petrochemical wharf storage tank area safety early warning research progress, *Journal of Waterway Port*, vol.35, no.3, pp.438-444, 2014.
[6] H. Zhang, Q. Li, L. Zhang and L. Mi, Early intelligent kick warning in well drilling based on fuzzy expert system, *Journal of Southwest Petroleum University (Science & Technology Edition)*, vol.38, no.2, pp.916-920, 2016.
[7] Q. Jiang, *Mathematical Model*, 4th Edition, Higher Education Press, Beijing, 2009.
[8] N. Xie and S. Liu, Discrete GM $(1, 1)$ and mechanism of grey forecasting model, *Systems Engineering – Theory & Practice*, vol.25, no.1, pp.93-99, 2005.
[9] J. Sun and G. Chen, Study on early warning technology of major hazardous source accidents, *Science and Technology of Production Safety in China*, vol.6, no.2, pp.44-50, 2010.
[10] Z. Dang, The security problems and protection technologies of petroleun and natural gas storage and transportation, *Journal of Chemical Industry of Guangdong Province*, vol.40, no.24, pp.61-62, 2013.
[11] M. Quiñones-Grueiro and C. Verde, Comments on the applicability of "An improved weighted recursive PCA algorithm for adaptive fault detection", *Control Engineering Practice*, vol.58, pp.254-255, 2017.
[12] X. Xu, L. Xie and S. Wang, Multimode process monitoring with PCA mixture model, *Computers & Electrical Engineering*, vol.40, no.7, pp.2101-2112, 2014.
[13] I. Parberry, *Probabilistic Neural Networks*, MIT Press, 1990.
[14] Anthony Zaknich, *Artificial Neural Networks: An Introductory Course*, http://www.maths.uwa.edu.au/~rkealley/ann_all/ann_all.html, 2002.