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Monitoring LNG Vehicle with Multi-Sensors and a Revised Decision-Tree Algorithm

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Abstract: The safety status of LNG tank vehicle is monitored in real time by using a particular decision-tree algorithm. The Data acquisition system for the algorithm consists of 8 heterogeneous sensors installed on the LNG tank vehicle, which includes a gas sensor, a temperature and a humidity sensor, a pressure sensor, a liquid level sensor, an accelerometer, an angle sensor, and a door-switch sensor. Some data sets of different running modes of the tank vehicle were used to training the decision-tree, and the others were used to evaluate the status of the vehicle. A simulation system was also established to experimentally verify the accuracy of the algorithm and the results of the experiments show that the monitoring system is good enough for practice usage.

Keywords: Multi-sensors, Decision tree algorithm, LNG tank vehicle, Safety status.

1. Introduction

Human-made disaster due to accidents of hazardous chemicals transportation caused a tremendous calamity and casualty every year all over the world.

In the past 20 years, in one hand, rigorous managing measures and rules have been issued to prevent the disasters [1–7]. In China, many regulations had been completed in compulsory to the hazardous materials from storage, transportation, usage and waste. In United States, the research has being studied from 1968, and lots of dangerous experiments were made to get more accurate data. Since there are many accidents and many experiments data, dataset for the hazardous materials were established in Unites State, Italy and Germany to analysize the transportation rout, to prevent the danger occurred.

In another hand, with the development of the science and technology, various techniques have been studying to automatically monitor the status of the transportation vehicles [8–12]. And the sensor technologies have been developed rapidly, sensors began to be adopted to monitor the hazardous materials. And at the beginning, only one sensor was used to measure the data. Then the sensor system was established to monitor the whole process. Therefore, the process for transportation can be monitored in real time. It is very popular to monitor the process by GPRS in the recent years.

As the progress of industrialization, more and more LNG tanks are transported by vehicles or ships in mainland of China. This paper describes a monitoring system for LNG tank vehicle by using multiple sensors and decision-tree algorithm. The multiple systems were made by 8 heterogeneous sensors and all the data were transmitted by GPRS.

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Decision-tree classification techniques have been successfully used for a wide range of classification problems in aerospace [13], geography [14], computer [15], and industry control [16–17], respectively. In this paper, we assess the utility of decision tree classification algorithms for the task of safety status from 8 heterogeneous sensors' datasets. The techniques described here have substantial advantages for this problem because of their flexibility, intuitive simplicity, and computational efficiency.

2. Multiple Sensors Monitor System

Fig. 1 shows the framework of the system [18]. There are three segments: the guardian of the tank, the terminal detector and the remote control center. The guardian of the tank consists of 8 sensors for detecting the content of LNG tank and the vehicle's run status. Three of them are used to detect whether there is a leakage status in the LNG tank, which are pressure sensor, liquid level sensor and LNG sensor, respectively. For the leakage status, the LNG gas sensor would play an important role to make decision. Two of them are used to observe ambient environment which is temperature sensor and humidity sensor. When these two signals are very high, the tank will be dangerous with a higher probability. An accelerometer and an angle sensor are used to monitor the vehicle running modes. If there is an override or the angle is over, it shows the tank is also dangerous .The last one is used to check whether there is unlawfully opening of LNG inlet door of the tank.

All signals of the sensors are collected to the terminal detector. These data are preprocessed first and then transmit to the remote center. And these data including the vehicle's position which is obtained by GPS simultaneously will be sent to the remote control center though GPRS. The safety status of the vehicle will be determined by these data in the control center. Once there's any dangerous happened, the alarming information will be send to the drivers and transmitted to the remoter control center immediately. According to the degree of the safety status, different person can receive the information messages so that they can take some instant processes to avoid accident or to prevent lost.

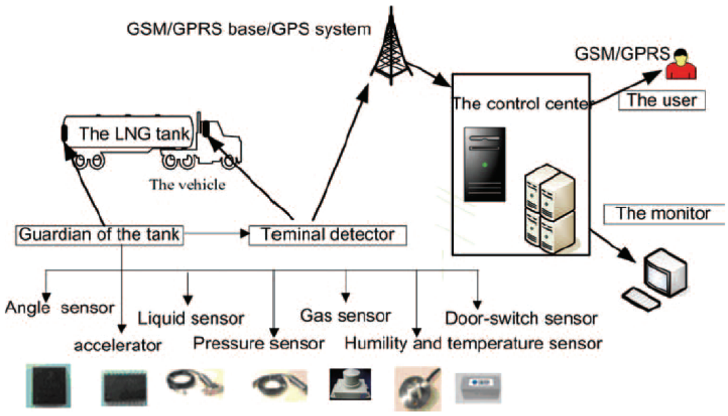


Fig. 1. The framework of the monitor system.

Fig. 2 shows the terminal detector. It consists of a main CPU, a DTU and other components. Among them, the main CPU chip is AD670 which is eight bits microcomputer for considering the data acquisition speed and accuracy. Data will be sent to the remote center through DTU (Data Terminate unit).
Fig. 3 shows the diagram of the software in the remote center. The program will monitor the port, for example, 5001 in the host computer. If there data undated in the port, the program will make decision by data fusion.

3. Decision- tree Detection and Diagnostics Algorithm

A decision tree learning algorithm was studied because it is much easier for human experts to interpret than the models produced by some competing algorithms such as neural networks or support vector machines. Having engineering experts examine the decision trees are very helpful for verifying them before deploying them [19].The decision tree algorithm automatically "learns" a decision tree by performing a search through the space of possible decision trees to find one that fits the training data. However, the key step in any decision tree estimation problem is to correct the tree for overfitting by pruning the tree back. In this paper, the revised decision tree algorithm is based on C4.5, but the weight coefficient is added. Here we choose the Weka 3-5-8 as the programming tool.

The particular decision tree for the content of the LNG tank is shown on Fig. 4. Here, G1 is the gas sensor's threshold value according to the LNG lower explosion limited, G1= 2 %. P1 is the pressure sensor's threshold value, P1 = 0.74 MPa. L1is the liquid level sensor's threshold value, L1 = 157 cm according to the tank's safety status, respectively. Whatever, the data from the liquid level sensor has been compensated by the angle sensor and the accelerator. GC1, PC1, LC1 and W1 are the weight coefficient for the different safety status. In Table 1, different values in different status are given according to the sensors' rang and the regulations [24-25].

The safety status data of the training datasets in this paper's experiments are from the real monitor system. These data is from the rehearsal in 2008. The router map was shown on Fig. 5. However, the dangerous status's data such as gas release, liquid release are from the simulation data by Matlab 7 according to the sensors' performance.

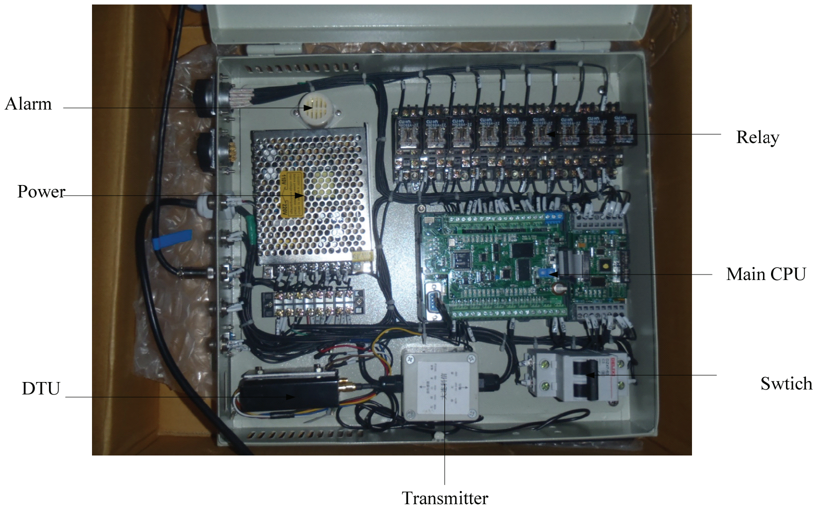


Fig. 2. The actual terminal detector.

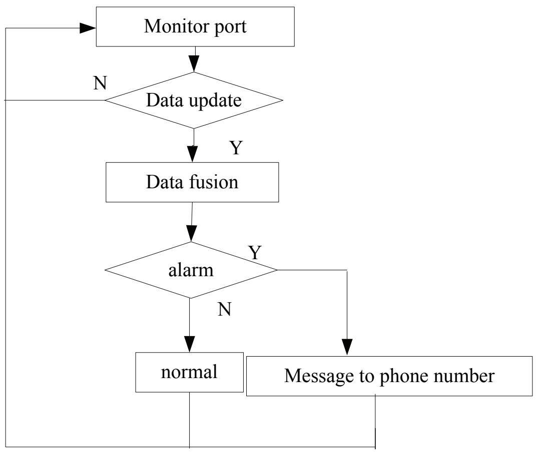


Fig. 3. The software diagram for the control center.

Table 1. The threshold value for sensors.

Sensor's Name (Unit)	Threshold value		Safety value	Sensor range
	Grade II	Grade I		
LNG (ppm)	10000	5000	<2000	0~20000
Pressure (ppm)	1000	700	300~500	0~1500
Liquid level (cm)	170.7	157.1	<157	0~300
Temperature (°C)	>80	<-20	-10 ~ +40	-40 ~ +120
Humidity (%RH)	>90	<10	10~90	0~90
Angle (°)	20	10°	-10~+10	-90 ~ +90
Accelerator (g)	2	1.1	<0.4	-2~2
Door switch	/	Open	/closed	Open, closed
Velocity (km/h)	80	60 km/h	0~77	0~100

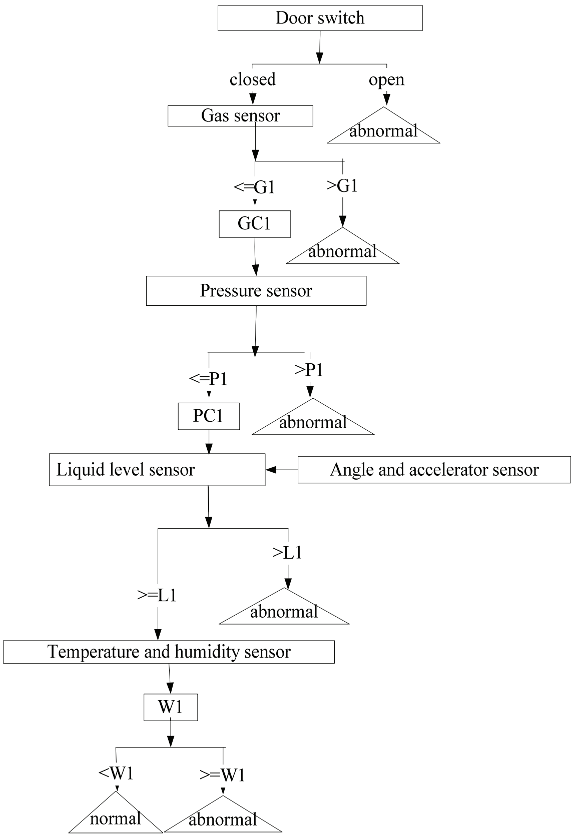


Fig. 4. The revised decision tree of the content in the LNG tank.

Fig. 5. The route map of the rehearsal on 2008.

Fig. 6 depicted the typical response parameters of the gas sensor, the liquid level sensor and the pressure sensor in a gas leakage status. The signal from the gas sensor began to rise rapidly. Meanwhile, the signal from the liquid level would slowly decrease and the signal from the pressure sensor would change more slowly than the one from the liquid level.

Fig. 7 shows the parameters in a normal status. All sensor's data are in the range of the safety value which is shown in the Table 1.

Fig. 8 shows the parameters in LNG liquid release status. The signal from the pressure sensor first increase and then decrease, the signal from the liquid level sensor decrease, but the signal from the gas sensor has not response for the operations.

These data mentioned above were obtained under the conditions of the ambient environment shown in Table 2.

The first experiment, two datasets were used to train the decision tree. These two sets each had an anomaly at the same liquid level, but it started at two different sample times. The decision tree learning algorithm was provided with 8 sensor values for each time step, 500 seconds lasted. The resulting tree had 19 nodes shown on Fig. 4. A third dataset was used to test the tree, which had an anomaly at the same liquid level but again with a different sample time. When applied to this test dataset, the tree was 99.9982 % accurate which is extremely high accuracy. Only one time-step was classified wrong.

In the second experiment, a dataset was selected as follows: four safety statuses named *N1*, gas senor wrong; *N2*, liquid sensor wrong; *N3,* gas leakage and *N4*, Liquid release. Six datasets for each safe status with different liquid level was simulated in LNG tank. The liquid levels are 10 cm, 50 cm, 100 cm, 150 cm, 200 cm and 250 cm, respectively. The decision tree was trained using 6 of these datasets, and tested on the remaining 18. The decision tree decided there was an anomaly or has another status (out of the four safety statuses). From Table 3, the total false alarm rate of these experiments is only 0.001 % from the decision tree, which is considered perfectly. From Table 4, the max missed detection rate is 0.04 % when the liquid level was the 10 cm and the safety status is *N3*. For the status *N3,* the tree does not have a good job until the liquid level reaches 150 cm and greater. The missed detection rate is zero when the safety status *N1* is in different liquid level or *N2* is in different liquid level. It can be seen that the tree performs very well. For the status *N4*, the tree performs well for liquid level 100 cm and greater.

Table 2. The ambient environment parameters.

Sensor		Conditions
1.	Temperature sensor	23 °C ~24 °C
2.	Humidity sensor	40~45 %RH
3.	Door-switch sensor	closed
4.	Velocity	59~62 km/h
5.	Angle sensor	3’~4’

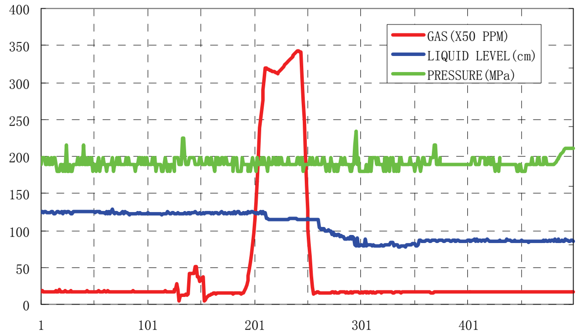


Fig. 6. Part of the response data in gas leakage status.

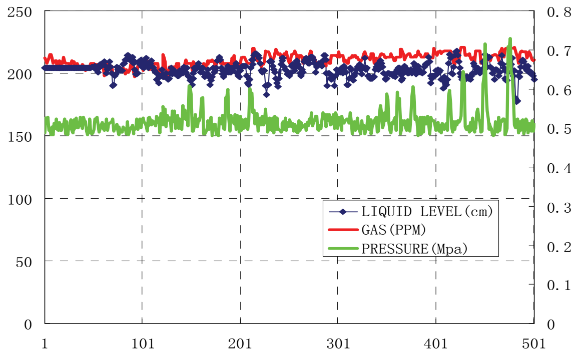


Fig. 7. Part of the response data in a normal status.

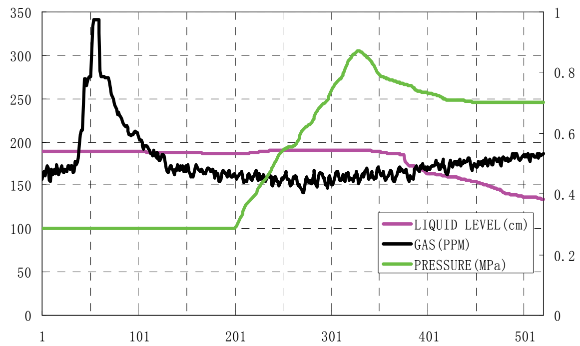


Fig. 8. The typical response curve when the LNG liquid released.

Table 3. The false alarm rates.

Safety status		The false alarm rates
1.	Gas senor wrong	0.000 %
2.	Liquid sensor wrong	0.000 %
3.	Gas leakage	0.000 %
4.	Liquid release	0.001 %

Table 4. Missed detection rates.

Missed detection rates (%)		**Safety status**			
		1	**2**	**3**	**4**
Liquid level (cm)	10	0.00	0.00	0.04	0.02
	50	0.00	0.00	0.01	0.01
	100	0.00	0.00	0.01	0.00
	150	0.00	0.00	0.00	0.00
	200	0.00	0.00	0.00	0.00
	250	0.00	0.00	0.00	0.00

4. The Threshold Value and the Revised C4.5

This section will detect the error rate in threshold value and the revised C4.5. Fig. 9 shows a response curve from a LNG gas sensor during the tank vehicle transportation. In the rectangle, there data were from the disturbance when the vehicle was through a chemical plant. If there is an alarm generate, there is an error happened.

The error rate for the threshold vale algorithm is 1.5 %, because when the data is over 10000 ppm, the alarm signal would generate. But for the revised C4.5, the error rate is zero. Compared with the C4.5 which is from the weak 3-5-8, the error rate reached 1 %. From these results, the revised C4.5 has a perfect accuracy.

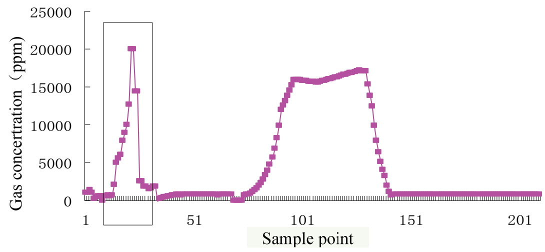
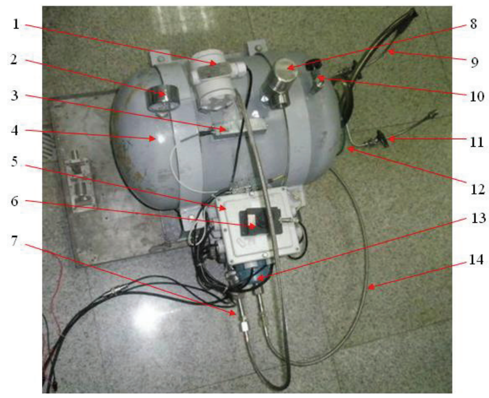


Fig. 9. The response cieve from a LNG gas sensor in transportation.

5. Algorithm Verification

A simulation tank cavity was made to verify the algorithm. The system is shown in Fig. 10. The AHRS system can collect the X, Y and Z accelerator. During the process, the content of the tank is water for the safety. Nitrogen was injected above the water to keep the tank's pressure. The ambient environment temperature was the same mentioned above. The liquid level is 282 cm. Table 5 and Table 6 shows the results. The accuracy is 100 % after making decision by the revised C4.5 algorithm.



1. Pressure transformer, 2. Pressure sensor, 3. AHRS system, 4. Simulated tank cavity, 5. Signal collector, 6. Gas sensor, 7. Gas pipe, 8. Safety valve, 9. Liquid inlet, 10. Gas outlet, 11. Gas inlet, 12. Liquid outlet, 13. Differential transformer, 14. Liquid pipe.

Fig. 10. The simulation system for verification.

Table 5. The results of situation assessment in grade I.

No.	Characteristics	Times	Result	Accuracy
1.	Collision	10	Alarm	100 %
2.	Tilt	10	Alarm	100 %
3.	Increasing pressure; over-pressure	10	Alarm	100 %
4.	Overdrive; overdrive and tilt; overdrive and increasing pressure	10	Alarm	100 %
5.	Collision; tilt; over-pressure	10	Alarm	100 %
6.	Tilt and over-pressure	10	Alarm	100 %
7.	Overdrive; Collision; tilt over-pressure; overdrive and tilt	10	Alarm	100 %
8.	Overdrive and Collision; tilt increasing pressure and over-pressure	10	Alarm	100 %

Table 6. The results of situation assessment in grade II.

No.	Characteristics	Times	Result	Accuracy
1	Collision	10	Alarm	100 %
2	Tilt	10	Alarm	100 %
3	Increasing pressure	10	Alarm	100 %
4	Release gas	10	Alarm	100 %
5	Gas leakage	10	Alarm	100 %

4. Conclusions

A decision tree was used to detect the safety status of the LNG tank in this paper. Testing the tree on a separate set of data showed that the decision tree has very low false alarm rates. And it has very low missed detection rates.

Due to the quantity limitation of the anomaly dataset, the accuracy from the decision tree which is one of the supervised detection algorithms has a discount. Therefore, unsupervised anomaly detection algorithms that are trained using only nominal data are probably more suitable for this work.

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