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Safety Monitoring Method of Underground Pipeline based on Machine Learning and Parameter Statistics

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Abstract: Safety is the primary prerequisite for the development of a city. Underground pipelines (UP) carry the development of a city. The research on the SM methods of UP has become a hot topic. This paper combines machine learning (ML) and parameter statistics (PS) to study and analyze the new method of underground pipeline SM. This paper briefly analyzes the layout principle of urban UP and the SM system of the spatial layout of UP, discusses the safety evaluation indexes of UP, combines ML and PS, and studies the new method of SM with bending stress as the most critical safety evaluation index of pipelines; At last, the experimental results show that the new method of merging ML and parameter statistical security monitoring proposed in this paper is effective and feasible.

1. Introduction

The urban gas transmission and distribution pipe network system is not always in a safe state. It is the consequence caused by a variety of reasons. Serious consequences may cause heavy casualties and property losses. Almost every year, most cities have many disasters caused by the failure of the gas transmission and distribution system. However, for the gas transmission and distribution system in a city, or the gas system in a system or component, how much risk it is, what form is the risk, and how to control or reduce these risks are important issues. Therefore, it is urgent to carry out risk assessment research on the urban gas transmission and distribution network system.

With the gradual deepening of people's understanding of the risk of underground pipeline accidents, many countries have gradually begun to establish underground pipeline safety management and evaluation systems suitable for their own underground pipeline conditions, and many underground pipeline companies have also successively developed corresponding software systems and constructed relevant analysis models [1]. Nazir Q proposed a fully online TCM system for ultrasonic metal welding (UMW) using sensor fusion and ML (ML) technology. A data acquisition (DAQ) system is designed and implemented to obtain the field sensing signals in the welding process. Then a large feature pool is extracted from the sensing signal, and the feature subset is selected, which is then used by the ML based classification model. Use experimental data to train, verify and test various classification models [2].

The rational spatial layout of UP can promote the intensive construction of pipelines and promote the development of urban underground pipeline corridor. From the perspective of the spatial layout of UP, according to the characteristics and principles of the spatial layout of pipelines, a new method of underground pipeline safety monitoring(SM) is studied and analyzed by integrating ML and PS; From the perspective of pipeline spatial layout, several important indexes affecting the safety of pipeline spatial layout are determined. According to the different laying sequence of UP in horizontal and vertical directions, the data of UP, road surface, road centerline and other data are used to achieve the extraction and statistical analysis of hidden pipelines in sequence. Through the dimensional analysis of the physical meaning of bending moment equation and the simplification of pipeline forces, a method for fitting the deformation of pipelines by using PS is proposed, which is reasonable through practical engineering inspection [3-4].

2. Research on New Method of Underground Pipeline SM

2.1. Layout Principle of Urban Underground Pipeline

2.1.1. Principles and Requirements for Horizontal Pipeline Layout

In order to make the underground pipeline layout meet the requirements of urban development, the following principles and requirements shall be followed in the planning and design of horizontal pipeline layout.

Unified coordinate system In order to avoid non connection and confusion of connection, elevation and coordinate system consistent with urban planning and design must be adopted in the early planning and design of UP; When making full use of existing pipelines for new pipeline planning and design, it is necessary to fully consider the layout of existing pipelines. Generally, only when the existing pipelines are not suitable for urban development, they will be removed or abandoned; Reserved development space In consideration of the needs of the future development of the city, the number of UP will inevitably increase. Therefore, during the planning and design of urban pipelines, the development space should be reserved as much as possible for the pipelines that may be added in the future; the underground pipeline shall be laid under the green belt, sidewalk or non-motor vehicle lane of the road as far as possible according to the layout location requirements. When the layout space is limited, the pipeline with relatively few maintenance times and deep burial depth can be laid under the ground of the motor vehicle lane, and the area where vehicles frequently pass shall be avoided as far as possible; Comply with the requirements of horizontal clear distance When conducting the comprehensive horizontal layout of UP, ensure that the horizontal distance between pipelines and between pipelines and buildings (structures) meet the requirements of relevant specifications [5-6].

2.1.2. Principles and Requirements for Vertical Pipeline Layout

The layout of UP in the vertical space shall be based on the horizontal layout and in combination with the specific conditions of the pipeline layout area. In order to make the layout of UP meet the requirements of urban development, the vertical layout of pipelines in planning and design should follow the following principles and requirements.

The burial depth shall be reduced as much as possible for the vertical layout of the pipeline location. On the basis of meeting various pipeline operation requirements and relevant burial depth specifications, the burial depth of the pipeline shall be reduced as much as possible to reduce the construction cost and facilitate the later overhaul and maintenance of the pipeline [7-8]. When laying UP, necessary protective measures shall be appropriately added. For sections with heavy equipment or large transport vehicles, necessary protective measures shall be taken for pipelines that may bear heavy pressure to prevent damage to pipelines when equipment or vehicles pass through; In order to facilitate the daily management and maintenance of UP, comprehensive pipe trenches and other laying methods shall be used as far as possible. In areas where the underground space is relatively small and there are many types of UP, especially in traffic throat areas, comprehensive pipe trenches and other advanced technologies shall be used as far as possible for pipeline laying, provided that the technical and economic conditions are met; Priority shall be given to pipelines with special burial requirements [9-10].

2.2. Underground Pipeline Space Layout SM System

2.2.1. Data Extraction and Fusion

Establish the mapping relationship between various types of data and the information required for the safety analysis of the spatial layout of UP. Use the spatial analysis method of ArcGIS and data editing tools to extract the information required for analysis. The extraction process is shown in Figure 1.

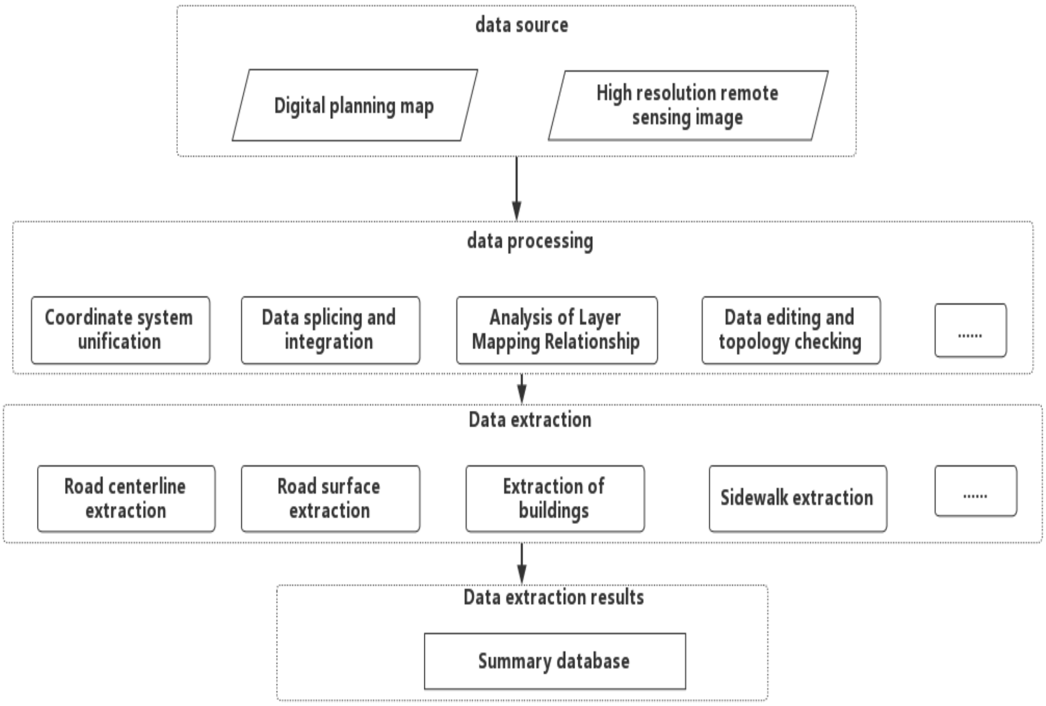

Figure 1. Data extraction process

The data extraction process is as follows:

(1) Coordinate transformation, projection transformation and other methods are used to unify the data into the same coordinate system and elevation datum.

(2) Splice, cut and standardize the framing data within the analysis scope.

(3) Establish the mapping relationship between the required analysis information and DLG data [11].

(4) Extract urban road centerline, road surface, ground buildings (structures), roadways, sidewalks, green belts and other information.

(5) According to the spatial relationship between the data, topological check and coordinate system check are performed on the classified data extracted in the previous process. The extracted road centerline data, road surface data, ground buildings (structures) data, roadway data, sidewalk data and other data are stored in ArcGIS in the form of layers to provide data basis for subsequent analysis [12-13].

2.2.2. Indicator System

In the whole process of safety evaluation of underground pipeline spatial layout, whether the selection of evaluation index system is reasonable or not is directly related to the reliability of the final evaluation results. A scientific and reasonable index system is one of the key factors to ensure the overall safety evaluation quality. In the actual comprehensive evaluation, the more evaluation indicators, the better, but not the less, the better. The key lies in the role of evaluation indicators in the evaluation [14]. Therefore, the composition structure and quantity selection of evaluation indicators in the evaluation system must be reasonable. It is necessary to avoid the interference to the results caused by too many indicators and repetition, as well as the incompleteness of the results caused by too few indicators or lack of certain indicators. Therefore, the selection of each evaluation index should objectively reflect the different information of the evaluation object in all aspects, and try to make the final evaluation index comprehensive, scientific, reasonable and applicable [15-16].

2.3. Safety Evaluation Index of Underground Pipeline

The safety analysis of underground pipeline under the disturbance of tunnel excavation becomes extremely important. During the tunnel excavation construction period, the underground pipeline is in a safe state for most of the time. When affected by various adverse factors of tunnel construction, such as unreasonable design, over excavation or too fast shield tunneling, there will be engineering hidden dangers of excessive and too fast pipeline settlement. The accumulation of hidden dangers to a certain extent will lead to engineering accidents [17]. As shown in Figure 2.

Therefore, this paper first outlines the underground pipeline, then introduces the deformation monitoring of the pipeline in the project, and finally focuses on the safety control standards and evaluation indicators of pipeline deformation.

For the deformation of UP caused by tunnel excavation, the current research focuses on the longitudinal bending deformation of UP, which considers the longitudinal stress yield of pipelines caused by tunnel excavation. Longitudinal bending is caused by the influence of longitudinal bending moment. The main reasons are: uneven settlement of soil mass or bottom scouring, such as soil erosion under pipe sockets, flowing into waterways or damaged sewers; Soil movement due to tidal water; Vertical movement of stratum caused by large-area excavation; The change of water content leads to the rise and fall of the stratum; Uneven settlement of foundation. The main causes of axial strain are: Poisson effect (due to internal pressure); Temperature stress, that is, when the pipeline is constrained by the surrounding soil mass due to thermal expansion and cold contraction, the stress will be generated; The stratum moves horizontally [18].

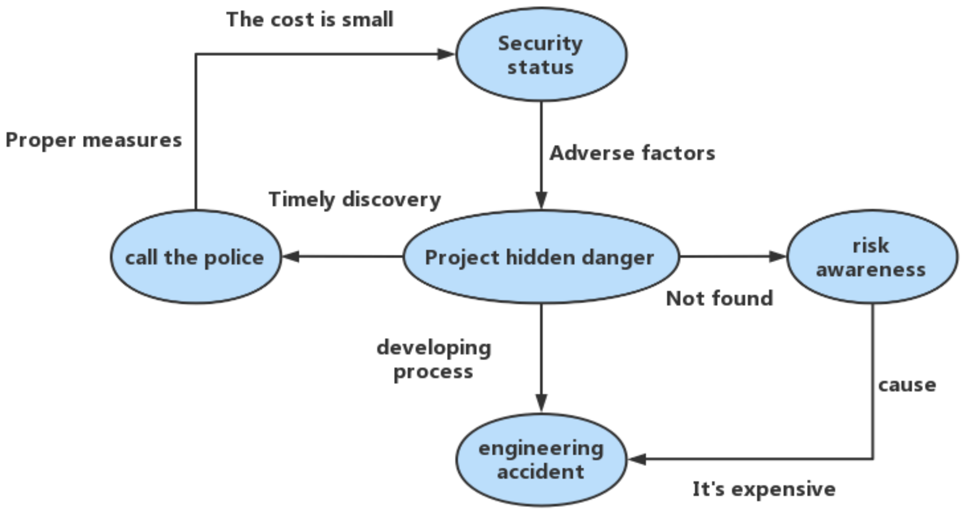

Figure 2. Schematic diagram of engineering safety analysis

3. Fusion ML

The bending stress of pipeline caused by tunnel excavation shall be taken as the safety evaluation index. The surrounding soil layer shall be displaced, which will lead to the displacement of the nearby underground pipeline. In this process, the bending stress caused by the uneven settlement of the soil mass is the most significant, which will cause pipeline fracture. At this time, the yield stress of the longitudinal bending stress is the main failure mode.

In the preliminary evaluation of flexible pipeline deformation, due to the concealment of pipeline joint position, it can be assumed that the joint is a rigid connection to calculate the pipeline bending stress. If the calculated bending stress suddenly changes, the reduction of bending moment caused by joint rotation shall be considered. At this time, it can be assumed that the pipeline joint is just above the tunnel center, which is the most unfavorable condition. The pipe segment is considered to be completely rigid (without bending). Theoretically, for completely flexible joint pipelines (rubber sliding type, bolt mechanical type and other socket connection modes), the joint is considered as a rational "hinge" that cannot transmit bending moment, so the bending moment at the joint can be relieved strictly according to the moment distribution method in structural mechanics, and then the joint angle of the pipeline can be calculated.

According to the statistical data of pipeline deformation parameters, calculate the transverse bending and axial bending among many influence factors of the pipeline; the matching correlation between data is determined according to pattern recognition. The specific method is as follows: first, pairing assignment, using uncertainty reasoning to determine the matching correlation between data indicators, and using covariance matrix to describe; Secondly, the joint distribution function of the parameters is obtained, and then the full conditional distribution PDF of each parameter is obtained. In order to obtain the GroupLASSO block matrix, select the initial cluster center and relevant parameters, combine intelligent reasoning and uncertainty reasoning technology to obtain the joint probability density function of distribution parameters and super parameters, respectively calculate the full condition distribution function SEIPR of each parameter, and calculate the statistical dependence between parameters (the growth degree of evidence to trust), that is, direct or indirect causality, correlation and defect.

On the premise that observation H is given, the conditional probabilities of evidence K1, K2,..., Kn are Pr (K1 | H), Pr (K2 | H),..., Pr (Kn | H) respectively, then the conditions for combining evidence are:

$$\begin{aligned} &\Pr(k_1 \wedge k_2 \wedge ...k_n \mid H) = \min[\Pr(K_n \mid H)] \\ &= \Pr(K_1 \mid H) \wedge \Pr(K_2 \mid H) \wedge ...\Pr(K_n \mid H) \end{aligned} \quad (1)$$

The conditions for extracting evidence are:

$$\begin{aligned} &\Pr(K_1 \vee K_2 \vee ...K_\mathrm{n} \mid H) = \max\left[\Pr(K_1 \mid H)\right] \\ &= P\mathrm{r}(\mathrm{K}_1 \mid \mathrm{H}) \vee \Pr(\mathrm{K}_2 \mid \mathrm{H}) \vee ...\Pr(\mathrm{K}_\mathrm{n} \mid \mathrm{H}) \end{aligned} \quad (2)$$

Formula (1) is used to obtain the norm+regular term function from the log likelihood estimation of the result of equation (2), and the soft threshold of the parameter is solved by using the asymptotic gradient projection algorithm. Considering the constraints of robust linear programming, the following important conclusions are obtained:

$$\Pr ob(d_i^k x - b_i \le \lambda_i) \le \delta_i, i = 1,2... \quad (3)$$

In the above formula, the coefficient vector di, di~N (di, $\sum_i$), for a fixed x, $d_i^k x$ follows the $\left(\overset{-T}{\mathrm{d}_i} X, X^T \sum_i x\right)$ Gaussian distribution.

Based on the property of rigid connection of gas pipeline in practical engineering, the concealment of flexible pipeline joint position (which can be simplified) and the complexity of solving the approximate angle of pipeline theoretically. At the same time, considering the basic and necessary role of solving pipeline bending stress in the research of pipeline safety properties, this paper takes bending stress as the most critical pipeline safety evaluation index, and does not specifically describe the calculation of pipeline joint angle.

According to the plane strain problem, we can consider the pipeline as a deep beam on the foundation and as a pure bending beam. Then the bending moment and stress of the pipeline are:

$$H = E_p I_p \frac{\gamma^2 S_p}{\gamma x^2} \quad (4)$$

$$\delta_p = E_p \eta_p = \frac{D_p}{2} E_p \frac{\gamma^2 S_p}{\gamma x^2} \quad (5)$$

Among them, EP and Ip are pipeline material and specification parameters, which are easy to obtain. $\frac{\gamma^2 S_p}{\gamma x^2}$ is the curvature of pipeline deformation, which is the key to solve the bending moment and stress of pipeline caused by tunnel excavation.

According to the mechanical properties of materials, in order to ensure the normal and safe use of the pipeline, the longitudinal bending stress of the pipeline shall be less than the allowable stress value, otherwise fracture or leakage will occur. The allowable stress values of different pipes are shown in Table 1.

Table 1. Allowable stress of different pipes

Piping materials	Yield stress/Mpa	Ultimate stress/Mpa	Initial stress/Mpa	safety factor	Design bending stress/Mpa	Allowable stress/Mpa
Pit cast iron	-	144	13.8- 38. 6	2.4	58	19.3-44.1
Rotating cast iron	-	206	20.7-52. 4	2.4	82.3	30.3- 62. 1
Ductile iron	300	421	33. 1-71.7	1.3	336	264.3-302. 9
Grade A steel	208	332	41.4-82.8	1.46	123.0	41. 4-82.8
Grade B steel	243	413	41.4-82.8	1.46	144.5	62.1-103.4
Polyethylene PE800	-	8.8	0.13-0. 26	2	4.5	4.04-4. 17
Polyethylene PE100	-	12	0.28-0. 56	2	5.7	4.94-5.22

4. Test and Analysis of Underground Pipeline SM Experiment Combining ML and PS

On the establishment of the database, the operation safety evaluation system of urban underground gas pipeline uses SQL Server 2008 database, which has strong usability, scalability, data security and stability. Table design is mainly divided into several categories. The first category is related to users, including user tables, group tables, permission tables, etc. The second type is systematic business tables. Relevant information of the login user of the risk assessment system of the buried gas pipeline network is saved, including login name, login password, user name, position, department, contact address, telephone number, etc. The risk assessment results of a pipeline in the buried gas pipeline network are saved.

If we know the load distribution on the pipeline, we can know to use PS to fit the deformation curve. According to Rankine's earth pressure theory, the earth pressure is a function of one degree. However, due to many factors affecting the earth pressure of buried pipes, such as soil property, pipe stiffness, pipe burial method, excavation and construction technology, the field measured earth pressure results are not consistent with the classical earth pressure theory, so it is difficult to obtain a unified expression of the earth pressure distribution. In addition, there is the problem of pipe soil interaction, which makes the above problems more complex.

According to the above analysis, in order to test its rationality, the PS is used to fit the underground pipeline SM of fusion ML analyzed above, and the fitting curve is derived to obtain the pipeline curvature curve as shown in Table 2 and Figure 3.

Table 2. Data sheet of pipeline curvature curve

	3	6	9	12	15	18	21	24	27	30	33
Pipeline settlement	10	15	18	24	27	28	27	26	25	20	17
Fitting curvature	21	19	18	18	19	20	21	23	25	27	32
Three point common circular curvature		21	16	9	8	12	13	14	10	9	24

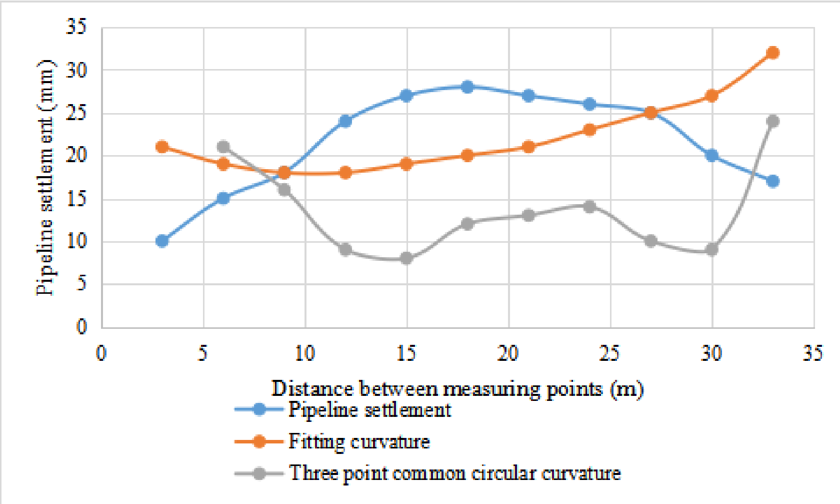

Figure 3. Fitting curve and curvature curve of pipeline settlement

It can be seen that the curvature calculated by PS is continuous and smooth, which reflects the curve form requirements of structural deformation. Although its corresponding boundary conditions are difficult to control, for the pipeline deformation curve fitted by the least squares method, what is concerned here is the maximum curvature close to the maximum deformation area of the pipeline, and the curvature problems at both ends of the curve are temporarily ignored; Through the dimensional analysis of the physical meaning of the bending moment equation and the simplification of the force on the pipeline, a method of fitting the deformation of the pipeline by using the sixth degree polynomial is proposed, and the approximation method of fitting the parameter statistical curve is used to fit the discrete points (monitoring data) of the pipeline settlement into a curve, which eliminates certain monitoring errors, and the fitting results can better conform to the reality.

5. Conclusion

This paper combines ML and PS methods to provide scientific means and tools for the scientific planning, construction and effective reduction of urban underground pipeline network safety risks. However, due to my limited knowledge and ability level, this paper also has shortcomings: the determination of this paper's integration of ML SM is based on the characteristics of the spatial layout of UP and the full understanding of the spatial layout of pipelines. However, the spatial layout of UP is extremely complex, and there are many factors affecting the safety, so the selection of evaluation factors has a certain subjectivity. When evaluating the hidden danger of pipeline occupation, the severity of the hidden danger is determined only from the direct and indirect occupation of buildings and structures. The impact of building type, floor number and other information on the severity of the hidden danger is not further identified from the perspective of buildings and structures, and the impact of different pipelines is not considered, which needs further research and analysis.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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