A Leakage Monitoring System of Pipeline in Heating Network

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ABSTRACT: *Supervisory control and data acquisition system (SCADA) is used to monitor the operating data of heating network. But it can do data acquisition and some simple operations only. So in this paper with the data collected by SCADA a leakage monitoring system of pipeline in heating network is designed by the Matble graphical user interface program (GUI). The theoretical basis of this monitoring is the heating network pressure graph theory and the theory of genetic algorithm. With the theory of genetic algorithm the data col-lected by SCADA could be optimized. The optimization avoid the erroneous data which due to measurement error. With the heating network graph theory the leakage monitoring system of pipeline could identify if there is a leakage in the operating conditions in heating pipe network. In the leakage monitoring system, the first step is to collect the initial data which optimized by genetic algorithm as a standard data and these data are stored as a fixed value. After that this system collects the real-time data of heating network and optimizes these data. Finally, the system compares the optimizing real-time data and the fixed value to determine whether there is a leakage. With the experiment the monitoring system which designed in this paper is proved to be very useful in leakage discrimination.*

Categories and Subject Descriptors:
H.5.2 [User Interfaces]: Graphical User Interfaces; **E.1 [Data Structures];** Graphs and Networks

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Genetic Algorithm, MATLAB

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1. Introduction

The leakage monitoring and control in urban central heating pipe network system is a major engineering problem need to be resolved. The characteristics of central heating pipe network system make the monitoring and early warning and control about pipe network become a problem. The leakage is a widespread problem in heating system. It can not only cause thermal pollution, but other more serious accidents [1]. Nowadays the most commonly used positioning technology in pipe network is based on noise. In addition, another technology is based on pressure wave detection. But it is greatly restricted in the actual project because it requires high precision. In the running process of pipe network, we only able to detect pressure and flow of relatively fixed point. These data do not reflect the trend of the entire network. It does not meet the requirements of pipe network optimization. But the trend surface of pressure could form a contiguous pressure surface based on discrete measurement data. After analysis of trends in system the leakage recognition software could be designed [2].

There are many application software have been used in the field of scientific research. Matlab is the most commonly used software. It is a system development environment and platform which is easy to use and scalable. It has powerful features in matrix calculation, symbolic computation and data visualization [3]. GUI module in Matlab is necessary for graphical interface design. GUI is also called graphical user interface. It includes a variety of graphical controls like button, text box, menu, plot axes and so on. On its interface, users create interface objects through activation of these controls. After modifying object’s properties and writing appropriate callback function, users complete the entire process of GUI design [4]. The GUI visualization of Matlab has been applied to various fields. For example, the simulation optimization platform of single-depot combined delivering vehicle routing problem which designed by GUI in Matlab to solve materials' combined delivering problem [5], the design about product line based on Matlab GUI programming to make the management of automotive electronic features more intuitive and provide more theoretical basis for change and development of products [6]. The application of matlab/sinulink, a kind of computer simulation software, to system simulation is discussed based on marine propeller simulation system. The experiment in it indicates that computer simulation system based on Matlab is credible, convenient, flexible and practicable [7].

With the development of heating sector, the requirement of heating network monitoring system is stricter. At present, majority of large-scale domestic heating network use the SCADA system. It is used to collect data, control equipments, measure, adjust the parameters and alarm [8]. But the existing feature of it does not fully meet the needs of users. In order to show the operating conditions of pipe network clearly, the new user interface must be introduced into the SCADA system.

Pressure diagram is a visual representation of the operating conditions of pipe network. The abscissa of it is the distance of each branch node from heat source. The ordinate of it is the pressure of each branch node. The display member of it is changing with the changes of the operating conditions of pipe network. The pressure diagram changes of heat pipe network system are necessary in the analysis of hydraulic conditions. It is because the pressure diagram comprehensively reflects the pressure of pipe network and users. During operation, it helps personnel who responsible for the operation and maintenance to analyze system. From this analysis, personnel could determine whether there is vaporization in pipe network; whether the pressure is over the bearing capacity of radiator and other ancillary equipment; whether there is emptied phenomenon in user's system and whether the pressure difference between supply and return pipe meet user's requirement [9].

2. Theoretical Analysis

The pressure value of each node in heating network can be concatenated by straight line. These diagram which containing pressure and line is called pressure diagram. In Hydromechanics the pressure diagram is a straight line. But in actual run-off, this straight line can not be got accurately. In order to overcome this difficulty, graph theory calculation method need to be introduced into analysis model. Combined with the measured data like the pressure and flow rata of user by SCADA system, the data of each node in pipe network can be calculated. But the calculated data has a low accuracy. So the correction of genetic algorithm should be introduced into this calculation to optimize calculations. The pressure data which corrected by genetic algorithm is dependable.

2.1 Pressure Graph Theory

Currently the pipeline leak detection and location based on model is divided into transient model and homeostasis model. The homeostasis model is the leakage location by calculating the turning point of pressure gradient in leaking pipeline. The transient model is based on pipeline transient equations. But it still uses the turning point of pressure gradient on leakage location. So in this paper the homeostasis model is introduced to find a leak. The key of this model is the graph of pressure. When there is a leakage in heating network the graph of pressure will change. The end result of this change is that the straight line of diagram appears an obvious inflection point. In theory the inflection point of the polyline is the leakage point. The key of finding exact inflection point is getting an accurate pressure value of each node in heating pipe network. In order to solve these conundrum, some computational methods and optimization theory introduced in the design of GUI to compute data.

Graph theory is a branch of mathematics science. Its main research content is the graph which contains points and lines connecting the two points. Further explained, it discusses the relationship between two objects and the connection is carried out by what means [10]. The mathematical model of heating pipe network is formed by pipe sections and nodes which are sequential and interdependence. This model can be calculated by solving the equations which are written out through combining graph theory and linear algebra. Therefore, the principles of graph theory are effective in computing the flow and pressure values of each node in heating pipe network. It is an indispensable mean in hydraulic calculation and analysis of heating pipe network.

According to the actual requirements of project, there are four assumptions to facilitate establishment of pipeline network equations [11, 12]. The first is that the flow state of fluid in heat pipe network is incompressible and continuous. The second is that the hydraulic conditions of network are stable and the heat pipe network is balanceable. The third is that the flow regime in pipe is a complete turbulent flow and the pressure drop and the square of flow are proportional. The fourth is that ignore the influence of dynamic pressure in the process of analyzing. Under the above assumptions, the pipe network characteristic equations which based on steady flow could be established. It includes flow balance equations of nodes, loop drop equations and pressure drop equations of pipe network. Its flow equations of nodes are expressed as Equation (1).

$$A \, . \, G = Q \tag{1}$$

Where: A indicates the correlation matrix of pipe network; G represents the flow vector; Q is the flow vector of discharge of node. The discharge flow vector is a zerovector when the system does not leak.

The loop drop equations of it are showed as Equation (2).

$$B_f \Delta H - DH = 0 \tag{2}$$

where: B_f express the loop matrix of pipe network; ΔH express the drop vector between two nodes in one branch; DH express the vector of pump head in each pipe segment, it is zerovector when the pump does not exist in pipes.

The pressure drop equations of pipe network could be expressed as Equation (3).

$$\Delta H_i = S_i q_i^2 \qquad i = 1, 2, 3, ..., m \qquad (3)$$

where: S_i express the coefficient of resistance characteristics. It concerns the length, diameter and material of pipeline. It is to be calculated by Equation (5).

After the analysis of pipe network, the frequently used mathematical model of pipe network hydraulic condition is Equation (4), in pipe network modeling process.

$$\begin{cases} A\,G = Q \\ B_f\,\Delta H = 0 \\ \Delta H = S\,|\,G\,|\,G + Z - DH \end{cases} \qquad (4)$$

where: A represents the correlation matrix of pipe network; G represents the column vector of mass flow rata of each branch; Q represents the column vector of mass flow rata of each node; B_f represents the matrix of basic loop; S represents the resistance characteristics coefficient of pipe section; ΔH represents the vector of voltage drop of each branch; $|\,G\,|$ represents the absolute traffic matrix of pipe sections. The diagonal elements of this matrix are the absolute data of flow; Z represents the column vector of potential energy difference of two nodes in the branch; DH represents the column vector of pump head in pipe sections. It is zero when there is not a pump in pipe section.

The flow of hot water in heating pipe network is in the square district of the resistance. The resistance characteristics coefficient in this district usually expressed as Equation (5).

$$S = 6.88 \times 10^{-9}\,\frac{K^{0.25}}{d^{5.25}}\,(l + l_d)\rho \qquad (5)$$

where: d is the inner diameter of pipe section, m; l is the length of pipe section, m; l_d is equivalent length of local resistance of pipe section, m; K is the equivalent absolute roughness of pipe section, m, it is $0.5mm$ for the pipe network of outdoor; ρ is the density of heat medium, kg/m^3.

The model of pipe network has been simplified in modeling process. l_d is determined by experiment. K is determined by estimates. Due to that the parameters accuracy are not enough, there is deviation in calculation. In order to obtain a more precise calculated data, the genetic algorithms have been introduced into calculation. This algorithm correct calculated data to thereby obtain a precise data of resistance characteristic coefficient.

2.2 Genetic Algorithm

Genetic algorithm (GA) is one of random search algorithms which learn from natural selection and natural genetic mechanisms [13]. It makes the population evolving and converges to the optimal solution by selecting, crossing and varying. The characteristic of genetic algorithm is that it can get the next search information by the objective function only. The usefulness of objective function is to evaluate the fitness of individual. The individual which has a high degree of adaptation has a higher probability to genetic to next generation. The individual which has a low degree of adaptation has a lower probability to genetic to next generation. The function which measures the fitness of individual is called fitness function. In optimization problem, the fitness function is the objective function.

In this paper the objective function is defined as Equation (6).

$$\min F(S) = \sum_{i=1}^{N} (P_{ic} + P_{is})^2 \qquad (6)$$

The constraint condition is showed as Equation (7).

$$\begin{cases} \sum G_{m,ij} + Q_i = 0 \qquad (i = 1, 2, 3...) \\ P_{ij} = S_{ij}|G_{m,ij}|\,G_{m,ij} - dH_{ij} \quad (i = 1, 2, 3...) \\ S_{\min} \le S_{ij} \le S_{\max} \qquad (i = 1, 2, 3...) \end{cases} \qquad (7)$$

where: P_{ic} represents the measured pressure, KPa; P_{is} represents the calculated pressure, KPa; $G_{m,ij}$ represents the mass flow in pipe section which associated with the node i, t/h; Q_i represents the outflow mass flow of node i, t/h; N represents the number of node; d_{Hij} represents the pump head connected to the node i, m; S_{min} represents the lowest limit of the coefficient of drag characteristics of each pipe section in the pipe network vector, $Pa{\cdot}h^2/t^2$; S_{max} represents the supreme limit of the coefficient of drag characteristics of each pipe section in the pipe network vector, $Pa{\cdot}h^2/t^2$.

In these constraints, the coefficient of characteristics of each pipe section in the heat pipe network can be corrected within engineering error when the balance of heat pipe network hydraulic can be kept. The deviation between the node pressure data calculated by figure in the pipe network and measured can be decreased.

2.3 Improved Genetic Algorithm

In fact, the resistance characteristic coefficient of pipe is uncertain. This uncertainty exists in heating pipe network design calculations and operation. The resistance characteristic coefficient is random variable. Its average value is used generally in the design phase. It is not changeless because of the corrosion of pipe and fouling after putting into operation [14]. It is an important basic amount in the analysis of system. In order to get a more accurate data of resistance characteristic coefficient, the genetic algorithm should be improved. The improved genetic algorithm has a guiding role to evolution. It reduces the blindness of search significantly. At the same time, it increases the probability of algorithm search for the optimal solution. It avoids the deception of basic genetic algorithm at some extent and avoids falling into local optimum and improves the ability of global optimization [15]. There are some improved methods like hybrid genetic algorithm and interactive genetic algorithm and others. But it is divided into two categories. One of them mainly concentrated in the research of the mechanism of the internal operators and the choice of parameters. The others mainly concentrated in combining with other algorithms to improve the efficiency of genetic algorithm. In fact, the efficiency of GA is not a single reflection of operator or parameter. It is the balanced outcome of operator and parameter.

The crossover probability (*Pc*) and the mutation probability (*Pm*) are the key of *GA*. They determine the convergence of GA. Pc determines the generation rate of new individual. The old individual genetic patterns more easily are broken destroyed at the same time. On the other hand, the *Pc* delay the generation of new individuals and cause the algorithm precocious and even stagnant when it is too small. *Pm* is the key factor in deciding to jump out of the local optimal solution. When it is too smallÿit makes it is difficult to generate a new model. The alternative to this situation, it makes *GA* to become pure random search algorithm when it is too high. The improved method in this paper is hybrid genetic algorithm. The flowchart of this hybrid adaptive algorithm is showed as Figure 1. It is the algorithm which combined with genetic algorithm and local optimization. It explores the best value in solution space with a certain probability and it has global optimization. In it the *Pc* and *Pm* can be changed automatically with fitness. When the population is more concentrated in fitness, *Pc* and *Pm* will increase. It protects individuals with high fitness while out individuals with low fitness. It can provide the best value of *Pc* and *Pm*. It ensures the convergence of genetic algorithms while maintains population diversity.

The pressure and flow values of each node in heating pipe network could be obtained by this genetic algorithm. The

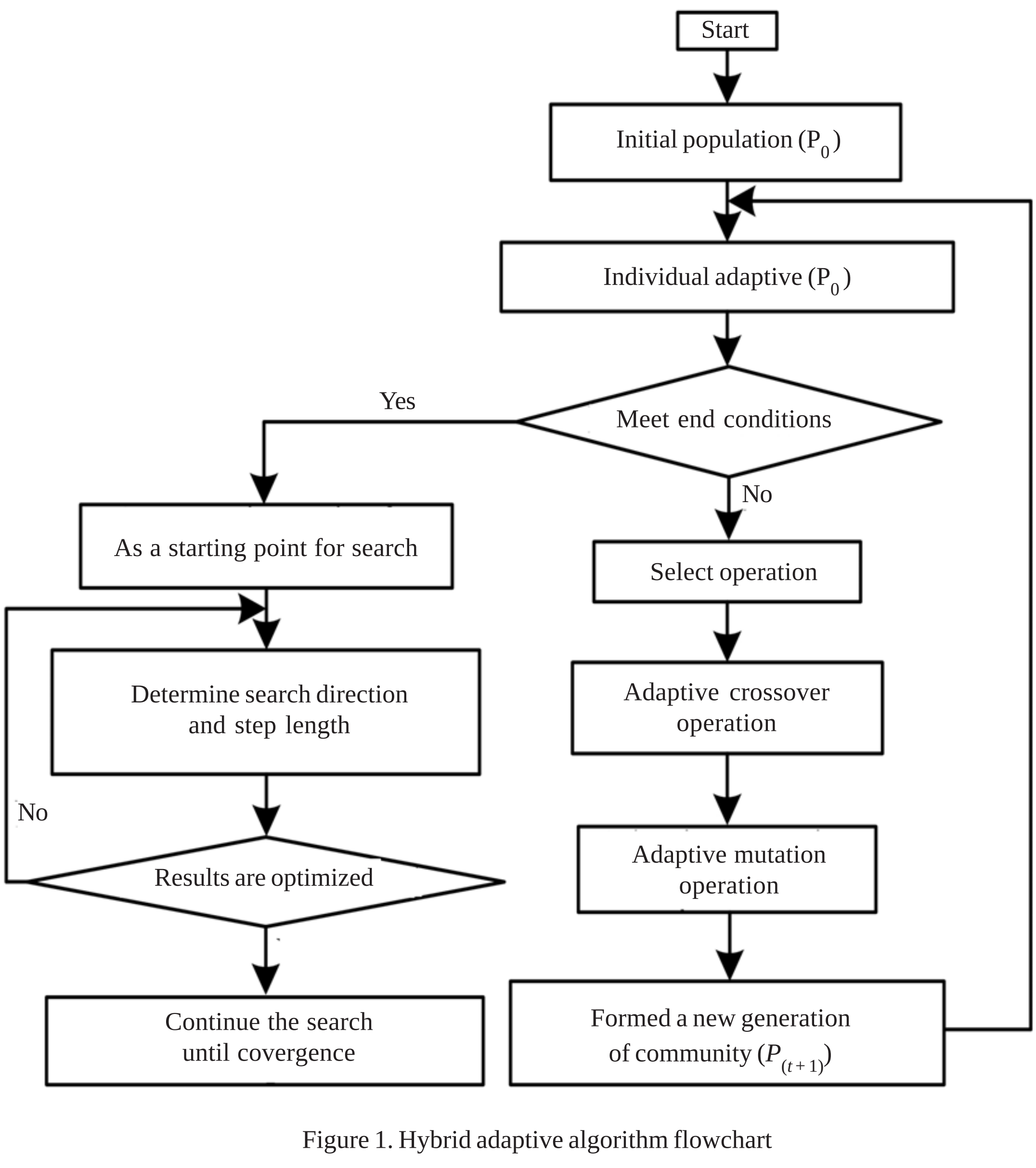

Figure 1. Hybrid adaptive algorithm flowchart

monitoring system of hydraulic regime in heating network designed with GUI use the calculated values which after optimized identify whether there is a leak in the pipe network.

By the hybrid adaptive algorithm the data of resistance characteristic coefficient become rational and scientific. The monitoring system of pipeline in heating network uses it and pressure graph theory to calculate the data of every node in heating network. The formula is as Equre (8).

$$\Delta P = S|G|G \quad (8)$$

These calculations provide the data foundation for the leakage point in the pipeline of heating network the pressure data of nodes will be different with the calculation data when there is not a leakage. In this paper the monitoring system is be designed with this difference.

3. Design of GUI

In order to achieve requirements of visualization, a user-friendly simulation and optimization software is designed with Matlab. This design includes the design of GUI interface and the design of callback spooler.

3.1 Main Interface of Design

The main interface of heating network monitoring system is shown as Figure 2. It imports the data collected by SCADA system pipe network monitoring system by the data button. There are two tables which show the real-time pressure data and flow rata for each measurement point. There are two dynamic figures which show the pressure data and flow rata of user below the tables. At the same time there are two tables showing the rata of change of pressure and flow rata of user relative to normal conditions. Using the displaying data, engineers could clearly understand the hydraulic status of each user. In the lower-left corner of this interface there is the system diagram of pipe network. In the lower-right corner of this interface there is the pressure diagram which corrected by hybrid genetic algorithm. With this interface, the staff of heat transfer station could clearly understand the hydraulic status of each user and the pressure distribution of entire system.

3.2 Functions of Heating Pipe Network Monitoring System

The flowchart of this monitoring system is showed as Figure 3.

There are two phases in the process operation of the software. The first step is that system collects initial operating data of heating network and optimizes it. The initial data which optimized is stored into the system as a standard data (SD). The second step is that the system receives real time operating data (OD) and optimizes them. The optimized data is used to compare with the standard data. With these data the fluctuation rate could be calculated by Equation (9). This system determines whether there is leakage in heating pipe network by determining the size of fluctuation rate.

$$F = \frac{SD - OD}{SD} \times 100\% \quad (9)$$

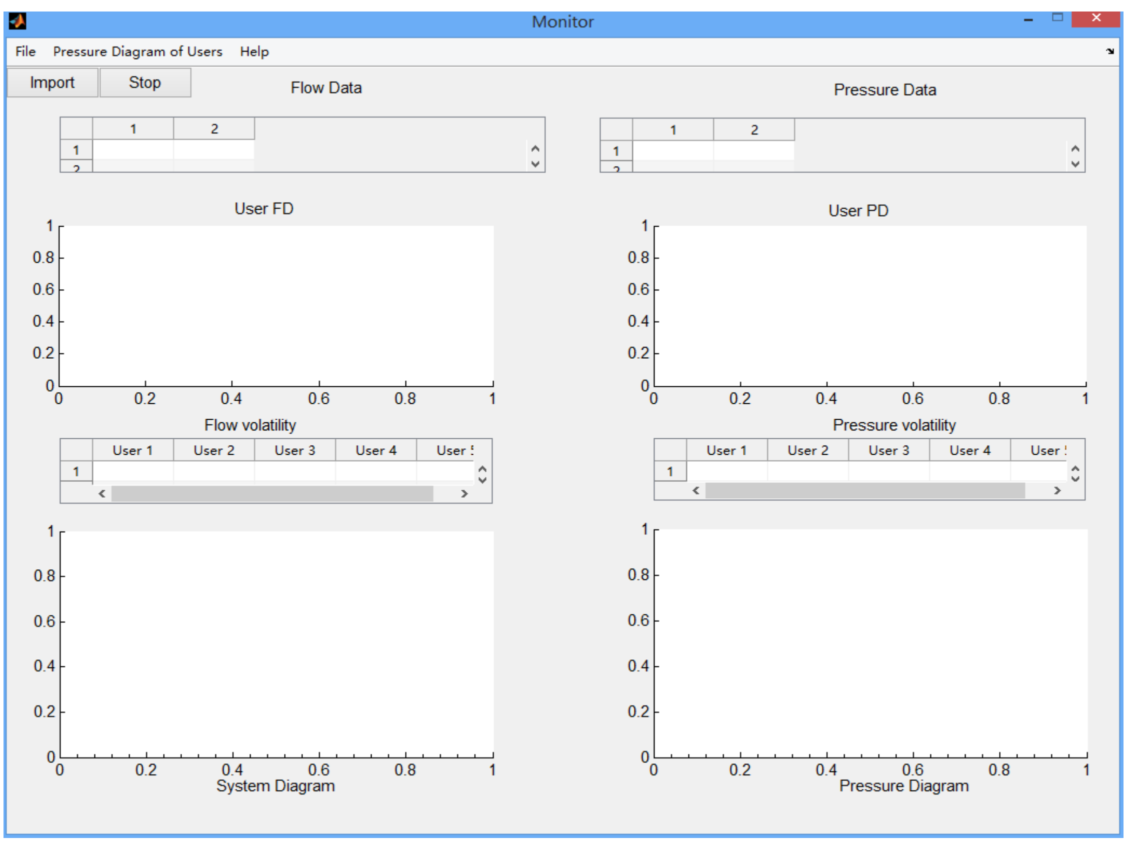

Figure 2. The main interface of heating pipe network system

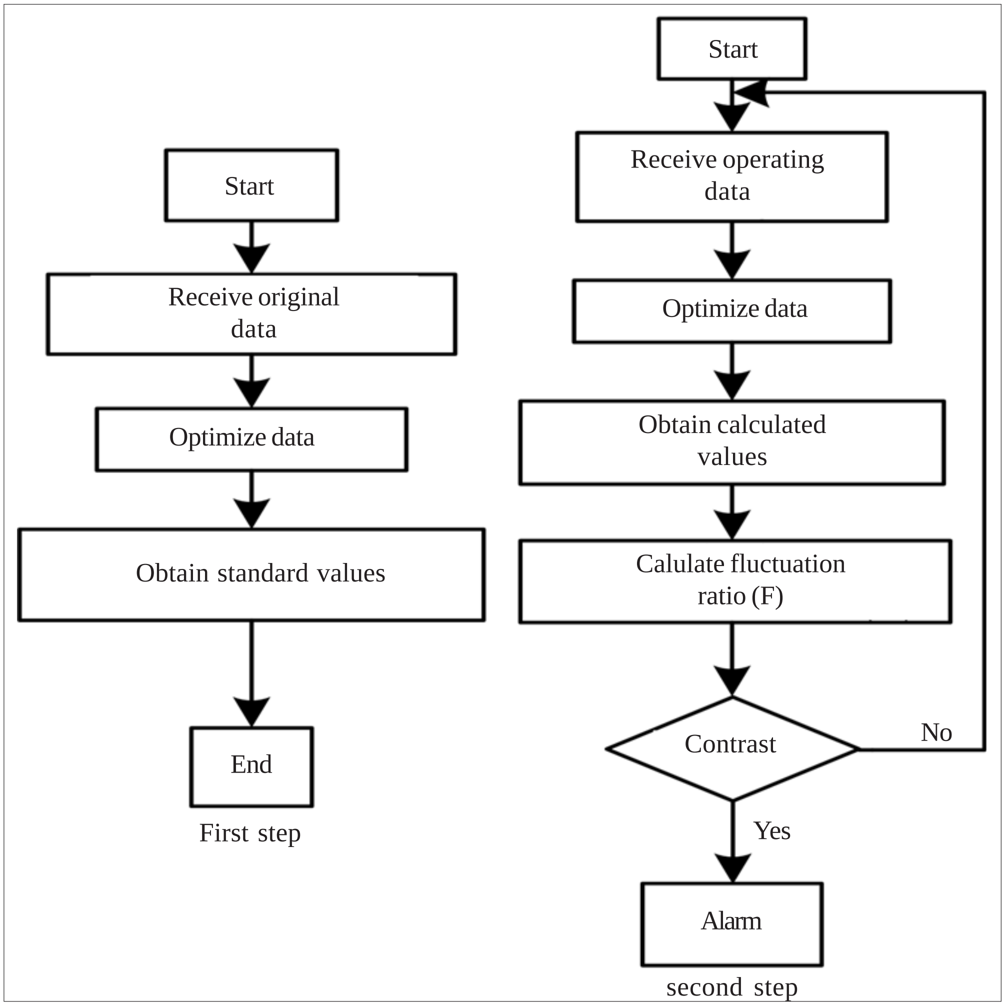

Figure 3. System flowchart

NO.	Original PD(KPa)	Running PD(KPa)	No.	Original PD(KPa)	Running PD(KPa)
1	38.60	38.10	11	15.21	14.98
2	34.95	34.57	12	13.94	13.82
3	33.80	33.40	13	12.53	12.35
4	32.63	31.69	14	19.64	19.38
5	32.30	31.73	15	23.41	23.17
6	30.98	30.52	16	13.62	13.43
7	30.57	30.11	17	23.43	23.20
8	23.70	23.32	18	17.92	17.63
9	18.25	18.02	19	26.76	26.38
10	16.21	16.01	20	20.12	19.87

Table 1. Data Collected by SCADA System

This software can monitor different pipe network system. Users use the open button in drop-down menu of file to choose system diagram. After that the monitoring system could identify pipeline automatically and receive real-time data which collected by SCADA system. By simulating the heating network system the analog data which showed in Table 1 could be got.

The monitoring system receives these data, optimizes them and then compares them with the standard data. The flow data and pressure values of users would be drawn in the course of system operation. The flow histogram when there is not a leakage is showed as Figure 4. The pressure histogram when there is not a leakage is showed as Figure 5. The flow histogram of users when there is a leakage is showed as Figure 6. The pressure diagram of users when there is a leakage is showed as Figure 7. The comparison chart of pressure when there is not a leakage is showed as Figure 8. The comparison chart of pressure when there is a leakage is showed as Figure 9.

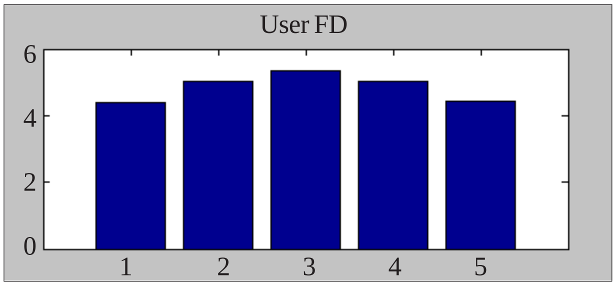

Figure 4. Initial Flow Histogram

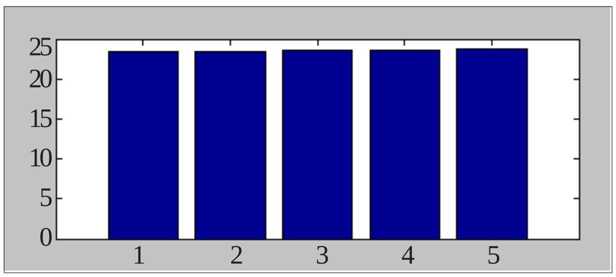

Figure 5. Initial Pressure Histogram

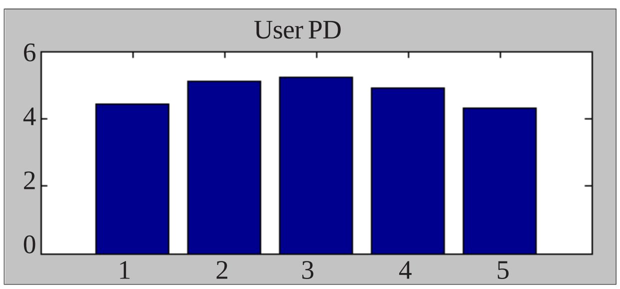

Figure 6. Real-time Flow Histogram

In Figure 9 the real-time hydraulic diagram is different with the initial pressure diagram. The volatility of this condition is more than a value. The value is related with the measurement accuracy of meters. So the monitoring system identify that there is a leakage in heating network. After comparison the alarm interface appears when the system finds leakage. The system is scientific after the verification of analog system.

4. Conclusion

In this paper a monitoring system of pipeline in heating network is designed based on the GUI platform of Matlab. This system used the optimized resistance coefficient by hybrid adaptive genetic algorithm and pressure graph theory to calculate pressure value of each node in heating network. In this system the original pipe network data is calculated as a standard value. It serves as a constant volume in system. After that, the system collects the real-time data of heating network by SCADA system. It optimizes these live data and compares them with the standard. If the volatility of live data and standard is more than a value which is related with the measurement accuracy of meters, the system identify there is a leakage in heating network. With the laboratory simulation equipment the system is feasible. In experimental process it shows a good identifiably in simulation system of heating network. With its help the leakage phenomenon in network can be automatically identified quickly and accurately.

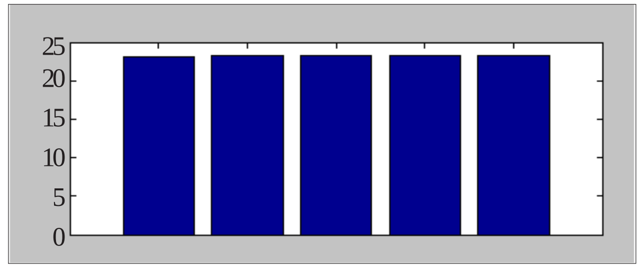

Figure 7. Real-time Pressure Histogram

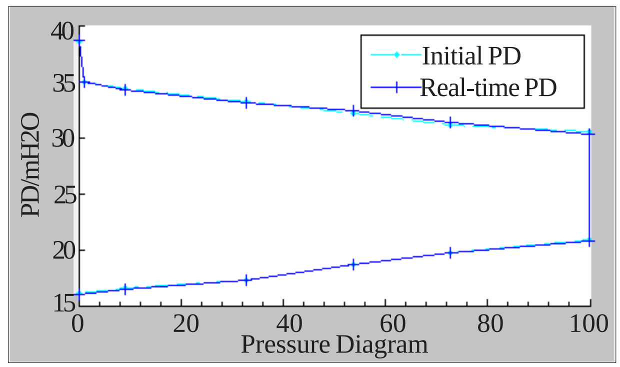

Figure 8. Normal Pressure Diagram

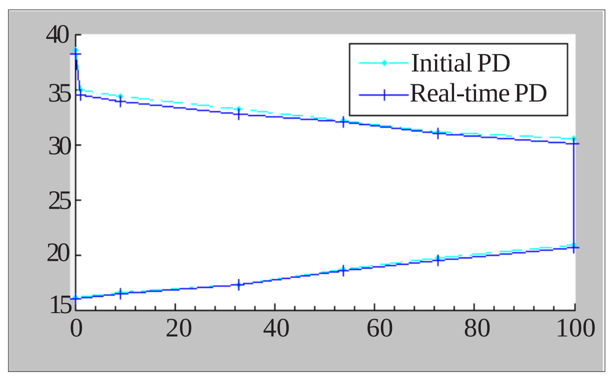

Figure 9. Leak Condition Pressure Diagram

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