

LEAK DETECTION DEVICE

Technical Field

[0001] The present invention relates to a leak detection device for monitoring the status of a water-distribution block constituting a distribution pipe network of waterworks facilities.

Background Art

[0002] Generally, a distribution pipe network of waterworks has various small and large leaks caused by, for example, pipe rupture and corrosion, and deterioration of packing for joints. If those leaks are discovered late, not only precious water resources may be wasted, but also damage such as sagging roads and flooding may be caused. So, it is desirable that such leaks should be discovered and repaired as early as possible.

[0003] Accordingly, in order to prevent leaks of the distribution pipe network, local researchers periodically patrol the relevant sites and use a method of checking whether any leak exists or not by using an acoustic bar or the like. However, the local researchers are required to have a high level of skills to accurately judge whether any leak exists or not by using the acoustic bar, so that a device for automatically analyzing a leak sound and judging whether any leak exists in the vicinity or not is suggested (for example, see Patent Literature 1).

[0004] Moreover, a device for stochastically estimating an area-based leak amount in the water-distribution block based on a component ratio calculated from information such as the pipe location, pipe age, pipe material, diameter, length, number of service connections of each pipe is suggested (for example, see Patent Literature 2).

[0005] Furthermore, a device for estimating a leak allocated amount of each node of a pipe network by means of optimization calculation for minimizing the difference between an estimated pressure value calculated by pipe network calculation (which may be sometimes referred to as pipe network analysis or hydraulic simulation) and a pressure value measured by a manometer is suggested (for example, see Patent Literature 3).

[0006] Furthermore, a system for recognizing a leak amount in a plurality of water-distribution blocks and providing information about which distribution pipe network should be checked intensively, by dividing the system into the plurality of water-distribution blocks by, for example, closing valves, and measuring a flow rate of water flowing into each water-distribution block during the night time is suggested (for example, see Patent Literature 4).

Citation List

Patent Literature

[0007] [Patent Literature 1] Japanese Patent Application Laid-Open (Kokai) Publication No. 2000-155066
[Patent Literature 2] Japanese Patent Application Laid-Open (Kokai) Publication No. 2009-192329
[Patent Literature 3] Japanese Patent Application Laid-Open (Kokai) Publication No. 2010-48058
[Patent Literature 4] Japanese Patent Application Laid-Open (Kokai) Publication No. 2011-191064

Summary of Invention

Problems to be Solved by the Invention

[0008] However, the method described in Patent Literature 1 uses the leak sound as a clue, so that only leaks at a short distance can be detected and, in fact, searching leaks in the entire pipe network requires much time and cost.

[0009] Moreover, the method described in Patent Literature 2 uses the device for estimating the area-based leak amount (hereinafter referred to as the “leak distribution”) in the water-distribution block for the purpose of enhancing efficiency of a leak search in the water-distribution block, and thereby stochastically estimates the leak amount by using the information such as the pipe age of each pipe. However, this estimated leak distribution does not necessarily correspond to actual leak distribution and it is difficult to always provide highly reliable search results. Also,

the leak positions cannot be estimated by pinpointing them, so that it is difficult to identify the individual leaks in the water-distribution block.

[0010] Furthermore, the estimation device described in Patent Literature 3 calculates the leak allocated amount of each node by means of the optimization calculation. However, it is necessary to perform a combination calculation to simultaneously decide the positions and amount of a plurality of leaks of various sizes. So, as the number of nodes or leaks in the pipe network increases, the calculation amount becomes enormous; and it is now difficult to apply this estimation device to the actual pipe network.

[0011] Furthermore, the method described in Patent Literature 4 is to recognize the leak amount of each water-distribution block for the purpose of enhancing efficiency of a leak search. However, if the area of a water-distribution block is large, it takes much time to identify the leak position(s) in the water-distribution block. So, it is possible to further divide the water-distribution block into smaller segments in order to shorten the time required to identify the leak position(s). However, in order to divide the water-distribution block into smaller segments, the cost required to place valves and prepare a pipe network increases and there are some limitations, for example, it becomes difficult to secure a necessary amount of water for, for example, fire fighting when the fire breaks out. Therefore, there is a limit to how far the water-distribution block can be divided into smaller segments.

[0012] Accordingly, if the conventional methods are used, the leak amount of each water-distribution block can be recognized; however, the problem is that it is difficult to estimate the leak distribution in the water-distribution block and identify the individual leaks in the water-distribution block.

[0013] The present invention was devised in light of the above-described circumstances and it is an object of the invention to provide a leak detection device capable of efficiently estimating leak distribution in a water-distribution block and identifying individual leaks in the water-distribution block.

Means for Solving the Problems

[0014] In order to achieve the above-described object, the present invention provides a leak detection device for monitoring the status of a water-distribution block, which is connected to a water resource and constitutes a distribution pipe network; wherein the leak detection device includes: a water demand database for storing water demand of nodes of the water-distribution block; a pipe network database for storing information about the nodes and pipes of the water-distribution block; a data collection unit for collecting a flow rate value of a communicating tube located between the water resource and the water-distribution block for connecting them to allow water to flow through them, and pressure values of a plurality of nodes of a trunk main for the water-distribution block; a pipe network calculation unit for estimating pressure values of the nodes of the entire water-distribution block and flow rate values of the pipes based on information stored in the water demand database and information stored in the pipe network database; and a trunk main leak estimation unit for estimating a leak amount of the entire water-distribution block based on the flow rate value of the communicating tube and the information stored in the water demand database and estimating virtual leak amounts of the plurality of nodes of the trunk main based on the leak amount of the entire water-distribution block, the pressure values of the plurality of nodes of the trunk main as collected by the data collection unit, and the pressure values of the plurality of nodes of the trunk main as estimated by the pipe network calculation unit.

Advantageous Effects of Invention

[0015] A leak detection device capable of efficiently estimating leak distribution in a water-distribution block, identifying individual leaks in the water-distribution block, and thereby enhancing efficiency of a leak search can be provided according to the present invention.

Brief Description of the Drawings

[0016] [Fig. 1] Fig. 1 is a diagram schematically showing a water distribution monitoring system equipped with a leak detection device according to Embodiment 1 of the present invention.

[Fig. 2] Fig. 2 is a diagram schematically showing processing by a trunk main leak estimation unit for the leak detection device shown in Fig. 1.

[Fig. 3] Fig. 3 is a flowchart illustrating processing by the trunk main leak estimation unit for the leak detection device shown in Fig. 1.

[Fig. 4] Fig. 4 is a flowchart illustrating processing by an area forming unit for the leak detection device shown in Fig. 1.

[Fig. 5] Fig. 5 is a table showing a data example of an area DB (database) for the leak detection device shown in Fig. 1.

[Fig. 6] Fig. 6 is a diagram schematically showing processing by a spot leak estimation unit for the leak detection device shown in Fig. 1.

[Fig. 7] Fig. 7 is a flowchart illustrating processing by the spot leak estimation unit for the leak detection device shown in Fig. 1.

[Fig. 8] Fig. 8 is a screen example output by an input/output unit for the leak detection device shown in Fig. 1.

[Fig. 9] Fig. 9 is a diagram schematically showing processing by a trunk main leak estimation unit for a leak detection device according to Embodiment 2 of the present invention.

[Fig. 10] Fig. 10 is a flowchart illustrating processing by the trunk main leak estimation unit for the leak detection device according to Embodiment 2 of the present invention.

[Fig. 11] Fig. 11 is a flowchart illustrating processing by a trunk main leak estimation unit for a leak detection device according to Embodiment 3 of the present invention.

[Fig. 12] Fig. 12 is a schematic diagram showing part of the configuration of a leak detection device according to another embodiment of the present invention.

Detailed Description of Preferred Embodiments

[0017] Next, a leak detection device according to embodiments of the present invention will be explained below with reference to the attached drawings. Incidentally, the embodiments described below are examples given for the purpose of describing this invention, and it is not intended to limit the invention only to these embodiments. Accordingly, this invention can be utilized in various ways unless the utilizations depart from the gist of the invention.

[0018] (Embodiment 1)

Fig. 1 is a diagram schematically showing a water distribution monitoring system equipped with a leak detection device according to Embodiment 1 of the present invention.

[0019] Referring to Fig. 1, a water distribution monitoring system 100 according to Embodiment 1 includes water distribution equipment 101 and a leak detection device 102 which is connected to the water distribution equipment 101 and monitors the status of the water distribution equipment 101.

[0020] The water distribution equipment 101 includes; a service reservoir 131 which a water resource; a distribution pipe network 132 connected to the service reservoir 131 to allow water, which is supplied from the service reservoir 131, to be distributed; and remote sensors 141 to 153 placed at nodes of the distribution pipe network 132.

[0021] Incidentally, Embodiment 1 is configured so that water-distribution blocks 133 and 134 are placed in the distribution pipe network 132; however, in fact, the number of water-distribution blocks may be one or three or more. If there is one water-distribution block, the distribution pipe network and the water-distribution block are substantially synonymous. For ease of explanation, it is assumed that the water-distribution block 134 has the same configuration as that of the water-distribution block 133, and an explanation about the water-distribution block 134 has been omitted.

[0022] The water-distribution block 133 is connected to the service reservoir 131 via a communicating tube 135 which is placed between the service reservoir 131 and

the water-distribution block 133 for connecting them to allow water to flow through them. This water-distribution block 133 has water pipes connected like a net and serves a role as a network for supplying water to consumers.

[0023] According to the present invention, a path with the largest flow rate among paths for the water-distribution block 133 is called a “trunk main” and paths other than the trunk main are called “branches.” The trunk main can be identified by following a pipe with the largest flow rate from an inlet of the water-distribution block 133 towards the downstream. Also, the joint locations of water pipes, the locations where remote sensors are placed, and the locations where there is a water demand in the water-distribution block 133 are called “nodes” and each water pipe connecting the nodes is called a “pipe.” Furthermore, a “path” means a pipe link that can trace the pipes from upstream to downstream.

[0024] The communicating tube 135 is provided with a remote sensor 141 for measuring a flow rate of water flowing into the water-distribution block 133. Also, each node of the trunk main in the water-distribution block 133 is provided with a remote sensor 142 to 145 for measuring the pressure of the relevant node and each node of a branch in the water-distribution block 133 is provided with a remote sensor 146 to 153 for measuring the pressure of the relevant node. These remote sensors 141 to 153 are connected to the leak detection device 102 via a communication network and send the measured data to a data collection unit 114 for the leak detection device 102.

[0025] The leak detection device 102 is a general computer system composed of a CPU, storage devices (such as RAM, hard disks, flash memories), and an input/output unit 116 (such as a keyboard and a display). The storage devices store an area forming unit 111, a pipe network calculation unit 112, a trunk main leak estimation unit 113, a data collection unit 114, and a spot leak estimation unit 115 as programs and the CPU executes these programs. Also, the storage devices store a water demand DB (database) 121, a pipe network DB (database) 122, and an area DB (database) 123 as data in a format such as tables and these databases can be

used when executing the above-mentioned programs. Furthermore, the input/output unit 116 serves a role as an interface with, for example, a person in charge of monitoring the water-distribution block 133.

[0026] The water demand DB 121 is water demand data at the nodes in the water-distribution block 133, which are estimated by using past record data. With a general distribution pipe network, a water meter is placed at a water pipe for supplying water to a consumer and an operator reads the water meter in cycles of, for example, once every two months, so that the water usage by each consumer can be recognized. Since the water usage does not change substantially and water usage patterns of each season, day of the week, and time of day can be estimated to a certain degree based on properties (such as a residence, a factory, or a shop) of the relevant customer, the water demand at each time of day can be predicted. Particularly, regarding a major customer, the water demand with respect to the entire water-distribution block 133 can be predicted precisely in detail by using a method of accurately recognizing water usage patterns by placing a water meter capable of storing the flow rate of each time of day or recognizing the water demand on a real-time basis by placing a smart meter equipped with a communication function. Incidentally, there are some known techniques as methods for predicting the water demand, so any detailed explanations about them have been omitted.

[0027] Furthermore, the difference between the actual water demand, which can be recognized by using the water meter, and the flow rate of water flowing into the water-distribution block 133 is called a “non-revenue water amount.” The non-revenue water amount includes, other than leaks, for example, water taken from fire hydrants or the like and an amount of water which could not be measured by the meter. It should be noted that generally a rate of water other than the leaks in the non-revenue water amount is small, so that for ease of explanation, such water will be hereinafter collectively referred to as the “leak.”

[0028] The pipe network DB 122 stores, for example, the connection relationship between pipes and nodes, pipe diameters, lengths, roughness coefficients, the

elevations of the nodes, and the elevation and water level of the service reservoir, which are necessary to perform a pipe network calculation described later.

[0029] The area DB 123 stores area numbers and area coefficients calculated by the area forming unit 111 described later.

[0030] The area forming unit 111 forms a plurality of areas in the water-distribution block 133. Incidentally, processing by the area forming unit 111 will be explained later in detail.

[0031] The pipe network calculation unit 112 estimates (or simulates) the pressures of nodes and the flow rates of pipes at one time of day or a plurality of times of day based on data stored in the water demand DB 121 and the pipe network DB 122. Incidentally, calculation to perform this simulation is called the pipe network calculation. Since this pipe network calculation itself is a known technique, its detailed explanation has been omitted. The pipe network calculation unit 112 receives data from the area forming unit 111, the trunk main leak estimation unit 113, and the spot leak estimation unit 115, performs the pipe network calculation based on these pieces of data, and returns the calculation results to each one of them. This series of processing will be hereinafter referred to simply as “to perform the pipe network calculation.”

[0032] The pipe network calculation can be performed when there is a leak from the water-distribution block 133. There are two methods of setting a leak amount to a node by means of the pipe network calculation. One method is to set an emitter coefficient representing the size and shape of a leak hole and this method has the following characteristics: the larger the emitter coefficient is, the larger the leak amount becomes; and the higher the pressure of the node is, the larger the leak amount becomes. Another method is to add the leak amount to original water demand of the relevant node and use the result as new water demand. When the former method is adopted, it will be stated in the following explanation that the emitter coefficient is set to the relevant node; and when the latter method is adopted, it will be stated that the leak amount is set to the relevant node.

- [0033]** The trunk main leak estimation unit 113 estimates the leak distribution of the water-distribution block 133. Specifically speaking, the trunk main leak estimation unit 113 estimates virtual leak amounts of a plurality of nodes of the trunk main for the water-distribution block 133. The estimated amount of the leak from these nodes corresponds to an approximate leak amount of each of a plurality of areas formed by the area forming unit 111. Processing by the trunk main leak estimation unit 113 will be explained later in detail.
- [0034]** The data collection unit 114 collects the data measured by the remote sensors 141 to 153. The data collected by the data collection unit 114 are used by the trunk main leak estimation unit 113 and the spot leak estimation unit 115.
- [0035]** The spot leak estimation unit 115 estimates individual leak positions and leak amounts in the water-distribution block 133. Incidentally, a spot leak means a leak with a comparatively large leak amount. Processing by the spot leak estimation unit 115 will be explained later in detail.
- [0036]** The input/output unit 116 displays, for example, the estimation results by the area forming unit 111, the trunk main leak estimation unit 113, and the spot leak estimation unit 115 on a screen or the like and shows them to, for example, a person in charge of monitoring the status of the water-distribution block 133. Also, the input/output unit 116 executes processing for, for example, displaying more detailed estimation results or the like in accordance with commands or the like input by, for example, the person in charge of monitoring the water-distribution block.
- [0037]** Next, the details of processing by the trunk main leak estimation unit 113, processing by the area forming unit 111, and processing by the spot leak estimation unit 115 will be explained in order. Fig. 2 is a diagram schematically showing the processing by the trunk main leak estimation unit 113 for the leak detection device 102 shown in Fig. 1; and the upper half is a diagram showing the water-distribution block 133 and the lower half is a graph plotting a piezometric head of nodes of the trunk main. Incidentally, for ease of explanation, some pipes and remote sensors are omitted and the water-distribution block 133 is indicated in a tree form in Fig. 2.

[0038] Referring to Fig. 2, F represents a node where the remote sensor 141 is placed and an inflow amount to the water-distribution block 133 is measured. N_m ($m=1$ to e ; and m is an integer) represents a node group at which remote sensors are placed on the trunk main; and among N_m ($m=1$ to e), the farthest upstream node is N_1 and the farthest downstream node is N_e . Incidentally, for the sake of convenience, Fig. 2 shows N_m with $m=1$ to 4. In other words, N_1 to N_4 are a group of nodes where the remote sensors 142 to 145 are placed on the trunk main; and the remote sensors 142 to 145 measure the pressure at the respective nodes.

[0039] Now, it is assumed that there is a leak from node L1 of a branch diverging from N_1 and Q_1 represents its leak amount. As compared to a case where there is no leak from L1, water including an additional amount of water equal to the leak amount Q_1 flows into the water-distribution block 133, passes through N_1 , reaches L1, and flows out of the pipe. If attention is paid only to the trunk main under the above-described circumstance, it is possible to assume that N_1 has a virtual leak of the leak amount Q_1 . Since the actual leak is located at L1, it only seems that N_1 has a leak, but it is simply a virtual leak.

[0040] Point A in the graph shown in Fig. 2 is a node at an outlet of the service reservoir 131. In this example, for ease of explanation, it is assumed that the water demand exists only at a terminal end of the relevant branch and a pipe diameter and a roughness coefficient are constant. Incidentally, the “piezometric head” means a value obtained by replacing a sum of pressure energy and potential energy of the water with height. When the water flows through the pipe, the energy reduces due to friction. So, the piezometric head normally reduces towards the downstream. Also, a line segment or polygonal line connecting the piezometric heads of nodes is called a “hydraulic grade line” and a gradient of the hydraulic grade line is called a “hydraulic gradient.” The hydraulic gradient can be estimated based on the flow rate, length, diameter, and roughness coefficient of the relevant pipe by using, for example, the Hazen-Williams formula. To the contrary, if the length, diameter, and roughness coefficient of the pipe are known, the flow rate can

be reversely calculated from the hydraulic gradient. The graph shows that the larger the flow rate is, the more the energy reduces due to friction; and as a result, the hydraulic gradient increases (the gradient becomes steep).

[0041] A polygonal line A-B1-C1-D1 of the graph shown in Fig. 2 is a hydraulic grade line when there is no leak from the water-distribution block 133. A polygonal line A-B2-C2-D2 is a hydraulic grade line when there is a leak from L1. A polygonal line A-B2-C3-D3 is a hydraulic grade line when it is assumed that there is a leak not from L1, but from Ne on the trunk main (N4 in Embodiment 1). Point B1 and point B2 correspond to N1; point C1, point C2, and point C3 correspond to N2; and point D1, point D2, and point D3 correspond to N4.

[0042] A hydraulic gradient of a line segment A-B2 part is steeper than that of a line segment A-B1 because its flow rate is higher by the leak amount Q_1 of L1. Referring to Fig. 2, you can tell that the hydraulic grade line varies depending on whether there is any leak or not, the position of the leak(s), and the leak amount. It is possible to estimate whether there is any leak or not, the position of the leak(s), and the leak amount by utilizing the above-described characteristic.

[0043] When there is a leak from L1, the coordinates of point A can be calculated from the elevation and water level of the service reservoir 131; and the gradient of the line segment A-B2 can be calculated according to, for example, the Hazen-Williams formula once the flow rate at F is measured. The coordinates of point B2 and point C2 can be calculated by measuring pressures by the remote sensors at N1 and N2 and adding the elevation to them; and, therefore, the gradient of the line segment B2-C2 can be calculated. When the gradient of the line segment A-B2 is compared with that of the line segment B2-C2 and if the gradient of the line segment B2-C2 is smaller than that of the line segment A-B2, you can tell that there is a virtual leak from N1 (actually, a leak from L1). The difference between the flow rate, which is calculated from the gradient of the line segment B2-C2, and the flow rate at F is the leak amount. The outline of the processing by the trunk main leak estimation unit 113 is to repeat the above-described processing with respect to Nm

($m=1$ to $e-1$) sequentially from upstream and estimate the virtual leak amount at nodes of the trunk main.

[0044] If there is a virtual leak from a node of the trunk main as can be seen from Fig. 2, there is an actual leak from around the node or from a branch diverging from around the node. In other words, a virtual leak amount from the node of the trunk main is approximately equal to the leak amount from around the node or from an area composed of a node of a branch diverging from the vicinity of the above node.

[0045] Next, specific processing by the trunk main leak estimation unit 113 will be explained in accordance with a flowchart shown in Fig. 3.

[0046] N_m ($m=1$ to e) is a group of nodes at which the remote sensors (the remote sensors 142 to 145 in Fig. 2) are set on the trunk main. Also, a variable representing the leak amount of N_m ($m=1$ to e) is defined as Q_m ($m=1$ to e). Furthermore, Q_0 is used as a temporary variable representing the leak amount.

[0047] In step S201, the variable Q_0 is initialized. Specifically speaking, a leak amount of the entire water-distribution block 133 is assigned to the variable Q_0 . The leak amount of the entire water-distribution block 133 is calculated by subtracting a total amount of water demand at one time of day of all the nodes of the water-distribution block 133 as stored in the water demand DB 121 from a flow rate of water flowing into the water-distribution block 133. Next, the processing proceeds to step S202.

[0048] In step S202, m is set to 1 and the variables Q_1 to Q_e which represent the leak amount are set to zero. Then, the processing proceeds to step S203.

[0049] In step S203, the leak amount at N_m is provisionally decided and this value is assigned to Q_m . However, the variable Q_m should be a value equal to or less than Q_0 . Then, the processing proceeds to step S204.

[0050] In step S204, a value ($Q_0 - Q_m$) obtained by subtracting Q_m from Q_0 is assigned to Q_e . Then, the processing proceeds to step S205.

[0051] In step S205, the pipe network calculation is performed by setting the leak amounts of N_1 to N_e to Q_1 to Q_e . The pressure at $N(m+1)$ located one node

downstream of N_m is estimated by means of the pipe network calculation. Specifically speaking, when m is 3, the pressure at N_4 is estimated. Then, the processing proceeds to step S206.

[0052] In step S206, an absolute value d , which is the difference between the pressure value estimated by the pipe network calculation and the pressure value measured by the remote sensor, is calculated with respect to $N_{(m+1)}$ which is one node downstream of N_m . Then, the processing proceeds to step S207.

[0053] In step S207, the pressure difference d is compared with a preset threshold value. If the pressure difference d is equal to or more than the threshold value (step S207: YES), the processing returns to step S203, another value is assigned to Q_m , and the processing is executed again. On the other hand, if the pressure difference d is less than the threshold value (step S207: NO), the processing proceeds to step S208.

[0054] In step S208, whether $m+1$ is equal to e or not is judged. If $m+1$ is not equal to e (step S208: NO), the processing proceeds to step S209. If $m+1$ is equal to e (step S208: YES), it means all calculations of Q_m ($m=1$ to e) have been completed and, therefore, the processing is terminated.

[0055] In step S209, 1 is added to m and a value obtained by subtracting Q_m from Q_o ($Q_o - Q_m$) is assigned to Q_o and the processing then returns to step S203.

[0056] The specific flow of the processing by the trunk main leak estimation unit 113 has been described above. Incidentally, regarding the processing for calculating Q_m from step S203 to step S207, it is desirable that the processing should be speeded up by using algorithms such as a hill-climbing method. Regarding the correspondence relationship with Fig. 2, the processing for calculating Q_m from step S203 to step S207 corresponds to the part for calculating the gradient of the line segment B2-C2 in Fig. 2. Q_o corresponds to the gradient of the line segment A-B2 and $Q_o - Q_m$ corresponds to the gradient of the line segment B2-C2. As described above, the trunk main leak estimation unit 113 recognizes that there is a virtual leak from a node of the trunk main and estimates the relevant leak amount. This leak

amount is an approximate leak amount of each area formed by the area forming unit 111.

[0057] Next, the details of processing by the area forming unit 111 will be explained in accordance with a flowchart shown in Fig. 4. Incidentally, a flow of processing for assigning an area number to a certain node N_i will be explained below.

[0058] The area forming unit 111 assigns the area number from 1 to e to all the nodes of the water-distribution block 133, thereby forming area 1 to area e . A group of nodes at which the remote sensors are placed on the trunk main is defined as N_m ($m=1$ to e); and a variable representing a leak amount of N_m ($m=1$ to e) is defined as Q_m ($m=1$ to e). Also, a leak amount per one general leak is defined as Q_u .

[0059] Firstly, in step S301, the leak amount of the node N_i is set to Q_u . Then, the processing proceeds to step S302.

[0060] In step S302, the pipe network calculation is performed to estimate the pressure of N_m ($m=1$ to e) and an inflow amount of water to the water-distribution block 133. These values correspond to values measured by the remote sensor when assuming that there is a leak from N_i . Then, the processing proceeds to step S303.

[0061] In step S303, the trunk main leak estimation unit 113 calculates the virtual leak amount Q_m ($m=1$ to e) of N_m ($m=1$ to e). However, instead of the pressure and flow rate measured by the remote sensor, the pressure and flow rate estimated by the pipe network calculation in step S302 are used. Then, the processing proceeds to step S304.

[0062] In step S304, an area coefficient K_{im} ($m=1$ to e) for the node N_i is calculated by dividing Q_m ($m=1$ to e) by the total amount of Q_m . Also, the index number m attached to the largest Q_m of Q_m ($m=1$ to e) is defined as the area number. The area number and the area coefficient are stored in the area DB 123.

[0063] The flow of the processing executed by the area forming unit 111 for assigning the area number to a certain node N_i has been described above. The

above-described processing is repeated with respect to all the nodes of the water-distribution block 133 and the area number and the area coefficient for all the nodes are stored in the area DB 123.

[0064] Fig. 5 is a data example of the area DB 123 in which the area number and the area coefficient are stored. One line indicates the area number and the area coefficient of one node. If there is a leak from a node in an area formed by the area forming unit 111, the largest virtual leak occurs at a node of the trunk main, whose index is the same number as the relevant area number. Furthermore, a rate of the virtual leak amount which occurs at a plurality of nodes of the trunk main is the area coefficient. Referring back to Fig. 2, if there is a leak from L1, the largest virtual leak occurs at the node N1 of the trunk main.

[0065] Fig. 6 is an example in which areas are formed in the water-distribution block 133; and four areas are formed with broken lines as boundaries of the areas. Referring to Fig. 6, there are leaks from nodes L1 to L4. Some area has one leak, while some area has a plurality of leaks. The leak amount of each area can be approximately calculated as a virtual leak amount of the nodes N1 to N4 of the trunk main by the trunk main leak estimation unit 113. More precisely, the leak amount of each node L1 to L4 is allocated to the relevant node N1 to N4 of the trunk main at the rate of the area coefficient and the total of these leak amounts is indicated as the virtual leak amount of the nodes N1 to N4 of the trunk main.

[0066] Next, the outline of processing by the spot leak estimation unit 115 will be explained with reference to Fig. 6.

[0067] The spot leak estimation unit 115 estimates the position and leak amount of an individual leak by returning (relocating) the virtual leak amount of the node of the trunk main to the node from which there is an actual leak in the water-distribution block 133, in accordance with the rate of the area coefficient. Accordingly, the above-described two-step method of firstly estimating the virtual leak amount of the nodes of the trunk main and then calculating the position and leak amount of

individual leaks has the following advantages in terms of estimation of the individual leaks.

[0068] The first advantage is that how the individual leaks exist in the water-distribution block 133 can be estimated to a certain degree. For example, if there is an area whose leak amount is apparently larger than that of other areas, there is a high possibility that there may be a leak with a particularly large leak amount or many leaks may exist in the relevant area. Therefore, many leaks can be estimated efficiently by intensively searching the relevant area. For example, referring to Fig. 6, the leak from L1 is indicated mainly at N1 as a virtual leak. Similarly, the leaks from L2 and L3 are indicated mainly at N3 and the leak from L4 is indicated mainly at N4. Accordingly, if the leak amounts of L1 to L4 are almost the same, the virtual leak amount of N3 becomes larger and the virtual leak amount of N2 becomes smaller.

[0069] The second advantage is that if there are a plurality of leaks in the water-distribution block 133, these leaks can be separated and easily estimated. For example, referring to Fig. 6, the pressure of L1 is not only determined by the leak amount of L1, but also influenced by the leak amounts L2 to L4. This is because water at the flow rates of not only the leak L1, but also the leaks L2 to L4 flows into the water-distribution block 133, thereby reducing the pressure of L1. Similarly, the pressure of each L2 to L4 is influenced by the leak amount of nodes other than the relevant node. Specifically speaking, a plurality of leaks have the property of influencing each other. It is desirable that the leak amounts of L1 to L4 can be determined at the same time; however, since the dimension of the search space increases according to the number of leaks, computational complexity increases rapidly, thereby making it impossible to perform the calculation. Furthermore, it is actually necessary to decide not only the leak amount, but also the leak position at the same time, so that the computational complexity also increases because of that reason.

[0070] When estimating the leak amount of L1, it is possible according to the present invention to minimize the influence of the leaks L2 to L4 by presuming virtual leaks

at the nodes of the trunk main. This is because the flow rate of water from the inlet of the water-distribution block to L1 stays about the same no matter whether an actual leak position is located at L2 to L4 or at N2 to N4 on the trunk main. The flow rate does not change because most water of the flow rate from the inlet of the water-distribution block to L2 to L4 passes through N2 to N4 on the trunk main. The same applies to a case where each of L2 to L4 is estimated.

[0071] Next, the specific flow of processing by the spot leak estimation unit 115 will be explained in accordance with a flowchart shown in Fig. 7.

[0072] A group of nodes at which remote sensors are placed on the trunk main is defined as N_m ($m=1$ to e); and a variable representing a virtual leak amount of N_m ($m=1$ to e) is defined as Q_m ($m=1$ to e). Also, a group of nodes at which remote sensors are placed, including N_m ($m=1$ to e), in the entire water-distribution block 133 is defined as N_s ($s=1$ to g). Furthermore, nodes in the water-distribution block 133 are represented by N_i ($i=1$ to n) and a variable indicating an emitter coefficient of N_i is defined as C_i ($i=1$ to n). Furthermore, an area coefficient regarding the node N_i is represented by K_{im} ($i=1$ to n ; $m=1$ to e).

[0073] Firstly, in step S401, the variable C_i which represents the emitter coefficient of N_i is initialized. Specifically speaking, C_i ($i=1$ to n) is set to zero. Then, the processing proceeds to step S402.

[0074] In step S402, N_i is selected as one of the nodes of the water-distribution block 133 and the emitter coefficient of N_i is provisionally determined and assigned to the variable C_i . Then, the processing proceeds to step S403.

[0075] In step S403, the pipe network calculation is performed by setting the emitter coefficient of N_i to C_i , thereby estimating the pressure of N_s ($s=1$ to g) and the pressure of N_i . Then, the processing proceeds to step S404.

[0076] In step S404, the difference between the pressure value estimated by the pipe network calculation and the pressure value measured by the remote sensor is calculated with respect to each of N_s ($s=1$ to g). Furthermore, its geometrical

average value is calculated and the pressure difference is defined as d . Then, the processing proceeds to step S405.

[0077] In step S405, the pressure difference d is compared with a preset threshold value. If the pressure difference d is equal to or more than the threshold value (step S405: YES), the processing returns to step S402, another value is assigned to C_i , and the processing is executed again. However, if the number of times the processing for the node N_i from step S402 to step S405 is executed is equal to or more than a previously designated number of times, C_i is reset to zero, a node other than node N_i is reselected, and then the processing is executed again instead of assigning another value to C_i and then executing the processing again. On the other hand, if the pressure difference d is less than the threshold value (step S405: NO), the processing proceeds to step S406.

[0078] In step S406, the value of Q_m ($m=1$ to e) is updated. Specifically speaking, the emitter coefficient C_i of N_i is multiplied by the square root of the pressure value of N_i , which was estimated by the pipe network calculation, and then multiplied by the area coefficient K_{im} of N_i , and a value obtained by subtracting the above-calculated value from Q_m is assigned to Q_m . The value obtained by multiplying the emitter coefficient C_i by the square root of the pressure value of N_i is an estimated value of the leak amount of N_i . Since the leak of N_i is indicated at the node N_m ($m=1$ to e) of the trunk main at the rate of the area coefficient, the value obtained by multiplying the estimated value of the leak amount of N_i by the area coefficient K_{im} is a virtual leak amount which is indicated at each node N_m ($m=1$ to e) of the trunk main. As a result of subtracting this value from Q_m , the leak at N_i will be subtracted from the virtual leak amount Q_m ($m=1$ to e) of the nodes of the trunk main. Then, the processing proceeds to step S407.

[0079] In step S407, the total amount of Q_m ($m=1$ to e) is compared with a preset threshold value. If the total amount is equal to or less than the threshold value (step S407: YES) or if the number of times the processing from step S402 to step S407 is executed is equal to or more than the designated number of times (step S407: YES),

the processing is terminated. On the other hand, if the total amount is more than the threshold value and the number of times of the execution of the processing is less than the predetermined number of times (step S407: NO), the processing returns to step S402 and the processing is executed again.

[0080] The flow of the specific processing by the spot leak estimation unit 115 has been described above. Incidentally, when selecting N_i in step 402, it is desirable that a node in an area with a large leak amount should be prioritized and selected. Moreover, it is desirable that the processing for calculating the value of C_i from step S402 to step S405 should be speeded up by using algorithms such as the hill-climbing method.

[0081] Incidentally, it is desirable that the above-described processing should be executed at a plurality of times of day in order to estimate individual leaks more precisely. Specifically speaking, it is desirable that Q_m ($m=1$ to e) at a plurality of times of day should be calculated in advance, the pipe network calculation at the plurality of times of day should be performed in step S403, an average value of the pressure difference d at the plurality of times of day should be calculated in step S404, and Q_m ($m=1$ to e) at the plurality of times of day should be updated in step S406.

[0082] Fig. 8 is an example of a screen on which the input/output unit 116 outputs, for example, the estimation results of the trunk main leak estimation unit 113, the area forming unit 111, and the spot leak estimation unit 115. The left side of the screen displays, for example, the water-distribution block 133, the arrangement of the remote sensors, and the positions of the estimated individual leaks. Also, the upper right part of the screen displays a graph showing an approximate leak amount of each area in the water-distribution block 133; the middle right part of the screen displays a graph showing the relationship between the approximate leak amount of each area and time transition; and the lower right part of the screen displays a table showing the leak positions and leak amounts of the individual areas. Incidentally,

the leak position of an individual area is indicated as the position (X, Y) corresponding to the X axis and the Y axis shown in Fig. 8.

[0083] Referring to Fig. 8, it is estimated that there are a leak of 4.0 at the position (0.5, 1) in area 1 (#1), a leak of 1.5 at the position (2.5, 4) in area 2 (#2), a leak of 6.0 at the position (0.5, 5) in area 3 (#3), and a leak of 5.0 at the position (3.5, 6) in area 4 (#4).

[0084] Accordingly, the time required for the leak search can be shortened by identifying the individual leaks in the water-distribution block 133.

[0085] (Embodiment 2)

Next, a leak detection device according to Embodiment 2 of the present invention will be explained with reference to the relevant drawings. They are diagrams schematically showing processing by a trunk main leak estimation unit of the leak detection device according to Embodiment 2 of the present invention.

[0086] As shown in Fig. 9, the major difference between the leak detection device according to Embodiment 2 and the leak detection device according to Embodiment 1 is that remote sensors 242, 243, and so on for measuring a flow rate of a trunk main are placed instead of the remote sensors 142 to 145 for measuring the pressure of the trunk main; remote sensors (not shown) for measuring a flow rate of branches are placed instead of the remote sensors 146 to 153 for measuring the pressure of the branches; and a virtual leak amount of a node N_m ($m=1$ to e) between nodes of a node group F_m ($m=1$ to $e-1$) at which the remote sensors are placed is estimated. Furthermore, not the pressure value difference of $N(m+1)$, but the flow rate value difference of the node group F_m is used as a reference for estimating the virtual leak amount of the node N_m of the trunk main. Incidentally, other components and processing of Embodiment 2 are the same as those of Embodiment 1.

[0087] Fig. 10 is a flowchart illustrating processing by the trunk main leak estimation unit of the leak detection device according to Embodiment 2. As mentioned above, the major difference between the leak detection device according to Embodiment 2

and the leak detection device according to Embodiment 1 is part of the processing by the trunk main leak estimation unit 113. Therefore, the specific processing by the trunk main leak estimation unit 113 will be explained in accordance with a flowchart in Fig. 10.

[0088] As shown in Fig. 10, the processing by the trunk main leak estimation unit 113, which is different from Embodiment 1, is step S1006 and step S1007. Specifically speaking, in Embodiment 2, after the same processing as the processing from step S201 to S205 shown in Fig. 2 is executed, the processing proceeds to step S1006. In step S1006, the flow rate difference of the node group F_m ($m=1$ to $e-1$), at which the remote sensors are placed, is calculated. Then, the processing proceeds to step S1007.

[0089] In step S1007, the flow rate difference calculated in step S1006 is compared with a preset threshold value. Then, the processing proceeds to step S208. Subsequently, the same processing as that of Embodiment 1 is executed.

[0090] (Embodiment 3)

Next, a leak detection device according to Embodiment 3 of the present invention will be explained with reference to the relevant drawings. Fig. 11 is a flowchart illustrating processing by a trunk main leak estimation unit of the leak detection device according to Embodiment 3 of the present invention.

[0091] The main difference between the leak detection device according to Embodiment 3 and the leak detection device according to Embodiment 1 is that both the remote sensors for measuring the pressure of the trunk main and the remote sensors for measuring the flow rate of the trunk main are placed; both the remote sensors for measure the pressure of the branches and the remote sensors for measuring the flow rate of the branches are placed; and the pressure is measured by the remote sensors placed at the nodes N_m ($m=1$ to e) of the trunk main and the flow rate is measured by the remote sensors placed at node F_m ($m=1$ to $e-1$) between N_m ($m=1$ to e) and N_{m+1} .

[0092] Specifically speaking, both the pressure value difference of $N(m+1)$ and the flow rate value of F_m are used as a reference for estimating the virtual leak amount of the node N_m of the trunk main. Specifically speaking, for example, a weighted average value is calculated according to a ratio of measurement accuracy of the remote sensors for measuring the pressure to measurement accuracy of the remote sensors for measuring the flow rate and is then compared with a preset threshold value. Incidentally, other components and processing and the like according to Embodiment 3 are the same as those of Embodiment 1 or Embodiment 2.

[0093] Fig. 11 is a flowchart illustrating a flow of processing by the trunk main leak estimation unit 113 according to Embodiment 3 of the present invention. The processing by the trunk main leak estimation unit 113, which is different from Embodiment 1 or Embodiment 2, is processing in step S1106, step S1107, and step S1108. Specifically speaking, in Embodiment 3, the same processing as that from step S201 to S205 shown in Fig. 2 is executed and then, the processing proceeds to step S1006. In step S1106, the pressure difference of the node $N(m+1)$ is calculated. Then, the processing proceeds to step S1107.

[0094] In step S1107, the flow rate difference of the node F_m is calculated. Then, the processing proceeds to step S1108.

[0095] In step S1108, a weighted average value is calculated according to the pressure difference calculated in step S1106 and the flow rate difference calculated in step S1107 and is then compared with a preset threshold value. Then, the processing proceeds to step S208. subsequently, the same processing as that of Embodiment 1 or Embodiment 2 is executed.

[0096] Incidentally, in Embodiment 1 to Embodiment 3 described above, the remote sensors placed in the water-distribution block 133 always measure the latest values, the data collection unit 114 collects data of such values, and the trunk main leak estimation unit 113 repeatedly estimates the virtual leak amount of the nodes of the trunk main, thereby making it possible to always monitor the leak distribution in the

water-distribution block 133; and if the virtual leak amount of the nodes of the trunk main increases rapidly and reaches and exceeds the preset threshold value, it is desirable that a warning or the like should be issued. Specifically speaking, for example, a warning message may be displayed on the screen or the like, a warning sound may be emitted, or short mail may be sent to, for example, a portable terminal carried by a person in charge of monitoring the status of the water-distribution block. As a result, it is possible to always estimate the leak distribution in the water-distribution block 133 and reduce the time required to repair a leak(s) upon a sudden increase of the leak amount by issuing a warning.

[0097] Furthermore, another embodiment of the present invention may be configured as shown in, for example, Fig. 12 so that valves 300, 301, 302, and so on may be placed at pipes diverging from the trunk main of the water-distribution block 133; and if a virtual leak amount from a node of the trunk main rapidly increases to reach or exceed a preset threshold value, the valve of a pipe diverging from the node of the trunk main whose leak amount has rapidly increased (the valve 300 in Fig. 12) may be closed. As a result, the leak amount can be reduced effectively by closing the valve as described above.

[0098] Furthermore, the leak detection device 102 according to the present invention is not limited to a general computer system; however, it may be implemented by hardware by designing part or whole of it with, for example, an integrated circuit, or it may be constituted from a plurality of devices by using, for example, cloud computing, or similar functions may be realized by using other information equipment.

[0099] Furthermore, the water distribution equipment 101 may be configured so that it includes, for example, a pump between the service reservoir 131 and the water-distribution block 133; or water may not be directly distributed from the service reservoir 131 to the water-distribution block 133, but may be distributed via another water-distribution block.

[0100] Furthermore, regarding lines which represent, for example, exchanges of information in the aforementioned drawings, only those which are considered to be necessary for the explanation are indicated and not all lines are necessarily indicated with respect to products. In fact, it may be presumed that almost all the components are mutually connected.

Reference Signs List

[0101] 100 water distribution monitoring system; 101 water distribution equipment; 102 leak detection device; 111 area forming unit; 112 pipe network calculation unit; 113 trunk main leak estimation unit; 114 data collection unit; 115 spot leak estimation unit; 116 input/output unit; 131 service reservoir; 132 distribution pipe network; 133, 134 water-distribution blocks; 135 communicating tube; 141 to 153 remote sensors; and 300 valve.

What is claimed is:

1. A leak detection device for monitoring the status of a water-distribution block, which is connected to a water resource and constitutes a distribution pipe network,

the leak detection device comprising:

a water demand database for storing water demand of nodes of the water-distribution block;

a pipe network database for storing information about the nodes and pipes of the water-distribution block;

a data collection unit for collecting a flow rate value of a communicating tube located between the water resource and the water-distribution block for connecting them to allow water to flow through them, and pressure values of a plurality of nodes of a trunk main for the water-distribution block;

a pipe network calculation unit for estimating pressure values of the nodes of the entire water-distribution block and flow rate values of the pipes based on information stored in the water demand database and information stored in the pipe network database; and

a trunk main leak estimation unit for estimating a leak amount of the entire water-distribution block based on the flow rate value of the communicating tube and the information stored in the water demand database and estimating virtual leak amounts of the plurality of nodes of the trunk main based on the leak amount of the entire water-distribution block, the pressure values of the plurality of nodes of the trunk main as collected by the data collection unit, and the pressure values of the plurality of nodes of the trunk main as estimated by the pipe network calculation unit.

2. A leak detection device for monitoring the status of a water-distribution block, which is connected to a water resource and constitutes a distribution pipe network,

the leak detection device comprising:

a water demand database for storing water demand of nodes of the water-distribution block;

a pipe network database for storing information about the nodes and pipes of the water-distribution block;

a data collection unit for collecting a flow rate value of a communicating tube located between the water resource and the water-distribution block for connecting them to allow water to flow through them, and flow rate values of a plurality of pipes of a trunk main for the water-distribution block;

a pipe network calculation unit for estimating pressure values of nodes of the entire water-distribution block and the flow rate values of the pipes based on information stored in the water demand database and information stored in the pipe network database; and

a trunk main leak estimation unit for estimating a leak amount of the entire water-distribution block based on the flow rate value of the communicating tube and the information stored in the water demand database and estimating virtual leak amounts of the plurality of nodes of the trunk main based on the leak amount of the entire water-distribution block, the flow rate values of the plurality of pipes of the trunk main as collected by the data collection unit, and the flow rate values of the plurality of pipes of the trunk main as estimated by the pipe network calculation unit.

3. The leak detection device according to claim 2, wherein the data collection unit further collects pressure values of the plurality of nodes of the trunk main for the water-distribution block; and

wherein the trunk main leak estimation unit estimates the virtual leak amounts of the plurality of nodes of the trunk main based on the leak amount of the entire water-distribution block, the flow rate values of the plurality of pipes of the trunk main as collected by the data collection unit, the pressure values of the plurality of nodes of the trunk main as collected by the data collection unit, the flow rate values of the plurality of pipes of the trunk main as estimated by the pipe network calculation unit, and the pressure values of the plurality of nodes of the trunk main as estimated by the pipe network calculation unit.

4. The leak detection device according to claim 1, wherein the water-distribution block includes the trunk main and branches diverging from the trunk main;
wherein the nodes are provided on the trunk main and the branch;

wherein the data collection unit further collects pressure values of a plurality of nodes of the branch for the water-distribution block; and

wherein the trunk main leak estimation unit estimates virtual leak amounts of the plurality of nodes of the trunk main and the branches based on the leak amount of the entire water-distribution block, the pressure values of the plurality of nodes of the trunk main as collected by the data collection unit, the pressure values of the plurality of nodes of the branch as collected by the data collection unit, the pressure values of the plurality of nodes of the trunk main as estimated by the pipe network calculation unit, and the pressure values of the plurality of nodes of the branch as estimated by the pipe network calculation unit.

5. The leak detection device according to claim 2, wherein the water-distribution block includes the trunk main and branches diverging from the trunk main;

wherein the nodes are provided on the trunk main and the branches;

wherein the data collection unit further collects flow rate values of a plurality of pipes of the branches for the water-distribution block; and

wherein the trunk main leak estimation unit estimates virtual leak amounts of the plurality of nodes of the trunk main and the branches based on the leak amount of the entire water-distribution block, the flow rate values of the plurality of pipes of the trunk main as collected by the data collection unit, the flow rate values of the plurality of pipes of the branches as collected by the data collection unit, the flow rate values of the plurality of pipes of the trunk main as estimated by the pipe network calculation unit, and the flow rate values of the plurality of pipes of the branches as estimated the pipe network calculation unit.

6. The leak detection device according to any one of claims 1 to 3, further comprising an area forming unit and an area database,

wherein the area forming unit sets leak amounts to nodes in the water-distribution block;

wherein the trunk main leak estimation unit estimates the virtual leak amounts of the plurality of nodes of the trunk main; and

wherein the area forming unit calculates area numbers and area coefficients relating to the nodes, to which the leak amounts are set, and stores them in the area database.

7. The leak detection device according to claim 6, further comprising a spot leak estimation unit,

wherein the data collection unit further collects pressure values of nodes other than those of the trunk main of the water-distribution block; and

wherein the spot leak estimation unit estimates positions and leak amounts of individual leaks in the water-distribution block based on the virtual leak amounts of the plurality of nodes of the trunk main as estimated by the trunk main leak estimation unit, the area coefficients stored in the area database, the pressure values of the nodes other than those of the trunk main as collected by the data collection unit, and the pressure values of the nodes of the entire pipe network as estimated by the pipe network calculation unit.

8. The leak detection device according to any one of claims 1 to 3, wherein the data collection unit repeats always collecting the latest pressure values and flow rate values of the water-distribution block; and

wherein the trunk main leak estimation unit estimates the virtual leak amounts of the plurality of nodes of the trunk main based on the latest pressure values and flow rate values as collected by the data collection unit and then issues a warning when the leak amount increases rapidly.

9. The leak detection device according to claim 1 or claim 2, wherein the pipes diverging from the trunk main in the water-distribution block are equipped with valves;

wherein the data collection unit repeats always collecting the latest pressure values and flow rate values of the water-distribution block; and

wherein the trunk main leak estimation unit estimates the virtual leak amounts of the plurality of nodes of the trunk main based on the latest pressure values and flow rate values as collected by the data collection unit; and if the leak amount increases rapidly, the trunk main leak estimation unit closes the valve placed at the pipe diverging from a node of the trunk main whose leak amount has increased rapidly.