

[DESCRIPTION]

[TITLE OF INVENTION]

SENSOR PLACEMENT POSITION SELECTION DEVICE, WATER LEAKAGE
AMOUNT ESTIMATION DEVICE, WATER LEAKAGE DIAGNOSTIC SYSTEM,
5 WATER LEAKAGE DIAGNOSIS METHOD, AND NON-TRANSITORY STORAGE
MEDIUM

[Technical Field]

[0001]

Embodiments of the present invention relate to a sensor placement position
10 selection device, a water leakage amount estimation device, a water leakage diagnostic
system, a water leakage diagnosis method, and a non-transitory storage medium.

[Background Art]

[0002]

In general, in investigation of water leakage in a water distribution pipeline
15 network, there is a primary investigation to investigate whether water leakage is present
or absent and a secondary investigation to specify a water leakage place. The primary
investigation is an investigation regularly performed by an investigator, and the
investigator investigates whether water leakage is present or absent in the water
distribution pipeline network using a sound detection bar. The secondary investigation
20 is an investigation performed at a place which has been determined as a place with a high
likelihood of water leakage as a result of the primary investigation, and a leakage place is
identified using a correlation-type water leakage probe. The primary investigation is
performed uniformly over a target area, and no consideration is given to which area to
investigate intensively.

25 [0003]

On the other hand, introduction of water smart meters is under consideration with the increasing awareness of environmental problems as a background. A water smart meter is installed in each house for the purpose of efficiently distributing water by measuring an amount of water used by a consumer. If water smart meters become

5 widespread, it is considered that a water leakage diagnostic system for performing water leakage diagnosis on a water distribution pipeline network can be configured by combination of water smart meters and water pressure sensors.

[0004]

However, there are currently no standards for efficiently placing water pressure

10 sensors required for water leakage diagnosis, and thus there is a likelihood of excessive placement of water pressure sensors causing an increase in management costs. For this reason, it is desirable to establish standards for efficiently placing water pressure sensors for performing water leakage diagnosis.

[Citation List]

15 [Patent Literature]

[0005]

[Patent Literature 1]

Japanese Unexamined Patent Application, First Publication No. 2013-178207

[Patent Literature 2]

20 Japanese Unexamined Patent Application, First Publication No. 2006-285389

[Patent Literature 3]

Japanese Unexamined Patent Application, First Publication No. 2010-48058

[Summary of Invention]

[Technical Problem]

25 [0006]

An object of the present invention is to provide a sensor placement position selection device capable of selecting an efficient placement position of a water pressure sensor, a water leakage amount estimation device, a water leakage diagnostic system, a water leakage diagnosis method, and a non-transitory storage medium.

5 [Solution to Problem]

[0007]

A sensor placement position selection device of embodiments includes an incidence matrix generator, a complementary tree extractor, and a selector. The incidence matrix generator, generates an incidence matrix representing a graph structure
10 of a water distribution pipeline network on the basis of information showing a connection configuration of pipelines configuring the water distribution pipeline network. The complementary tree extractor classifies the pipelines configuring the water distribution pipeline network into a pipeline serving as a tree configuring an open pipeline and a pipeline serving as a complementary tree configuring a closed pipeline along with the
15 tree in the water distribution pipeline network on the basis of the incidence matrix, and extracts the pipeline serving as a complementary tree. The selector selects nodes at both ends of the extracted pipeline serving as a complementary tree as an placement position of a water pressure sensor.

[Brief Description of Drawings]

20 [0008]

Fig. 1 is a diagram which shows a configuration of an outline of a water distribution system and a sensor placement position selection device 1 according to a first embodiment.

Fig. 2 is a functional block diagram which shows a functional configuration of
25 the sensor placement position selection device 1.

Fig. 3 is a diagram which shows an example of information stored by a water distribution pipeline network information storage 11 of the embodiment.

Fig. 4 is a diagram which shows an example of a water distribution pipeline network model.

5 Fig. 5 is a diagram which shows an example of water distribution pipeline network information.

Fig. 6 is a diagram which shows an example in which a water distribution pipeline network PN is regarded as one pipeline.

10 Fig. 7 is a functional block diagram which shows a functional configuration of a sensor placement position selection device 1a of a modified example.

Fig. 8 is a schematic diagram which shows an outline of a first method of aggregating graph structures.

Fig. 9 is a schematic diagram which shows an outline of a second method of aggregating graph structures.

15 Fig. 10 is a diagram which shows a specific example when different placement positions are selected.

Fig. 11 is a functional block diagram which shows a functional configuration of a water leakage amount estimation device 2 according to a second embodiment.

20 Fig. 12 shows a specific example of a relationship between an effective water pressure difference in virtual pipelines at a certain time and a differential pressure of respective pipelines.

Fig. 13 is a block diagram which outlines the formulation of a constrained non-linear optimization problem.

25 Fig. 14 is a diagram which shows an example of simulation results of water leakage amount estimation.

Fig. 15 is a diagram which shows an example of a screen on which a water leakage amount is displayed by an output unit 22.

[Description of Embodiments]

[0009]

5 Hereinafter, a sensor placement position selection device, a water leakage amount estimation device, a water leakage diagnostic system, a water leakage diagnosis method, and a non-transitory storage medium of embodiments will be described with reference to drawings.

[0010]

10 (First embodiment)

Fig. 1 is a schematic diagram which shows an outline of a water distribution system according to a first embodiment. In this water distribution system, water (purified water) stored in a distribution reservoir 70 is supplied to a water distribution pipeline network PN including households, business places, and the like by pumps and valves. The amount of water flowing into the water distribution pipeline network PN is detected by a flow sensor 80.

[0011]

A plurality of nodes represented by white circles in Fig. 1 are set in the water distribution pipeline network PN for the sake of convenience. In Fig. 1, smart meters are attached to the plurality of nodes. The smart meters are attached to, for example, households, business places, or the like to which water is supplied, and detect the amount of water used in the households, the business places, or the like every 30 minutes to one hour or so. Arrows pointing downward from respective nodes represent an outflow of water due to water usage by consumers or leakage.

25 [0012]

The sensor placement position selection device selects an placement position of water pressure sensors so that it is possible to estimate an amount of water leakage at each node from each node of the water distribution pipeline network.

[0013]

5 Fig. 2 is a functional block diagram which shows a functional configuration of the sensor placement position selection device 1 of the first embodiment.

The sensor placement position selection device 1 includes a central processing unit (CPU), a memory, an auxiliary storage device, and the like connected by a bus, and executes a sensor placement position selection program. The sensor placement position selection device 1 functions as a device including a water distribution pipeline network information storage 11, an input unit 12, an output unit 13, an incidence matrix generator, 14, a complementary tree extractor 15, and an placement position selector 16 by execution of the sensor placement position selection program. All or some of the functions of the sensor placement position selection device 1 may also be realized by using hardware such as an application specific integrated circuit (ASIC), a programmable logic device (PLD), and a field programmable gate array (FPGA). The sensor placement position selection program may be recorded on a computer readable recording medium. The computer readable recording medium is, for example, a portable medium such as a flexible disk, a magneto-optical disk, a ROM, or a CD-ROM, or a storage device such as a hard disk embedded in a computer system. The sensor placement position selection program may be transmitted via an electric communication circuit.

[0014]

The water distribution pipeline network information storage 11 is configured using a storage device such as a magnetic hard disk device or a semiconductor storage device.

25

[0015]

The input unit 12 is configured using an input device such as a keyboard, a mouse, a touch panel, or a switch, and receives an input of user's operation.

[0016]

- 5 The output unit 13 (display unit) is configured to include a display device such as a liquid crystal display (LCD) or an organic electroluminescence (EL) display, a display control unit, a printer, and a speaker, and outputs information on the selected placement positions of water pressure sensors.

[0017]

- 10 The incidence matrix generator, 14 generates an incidence matrix for applying graph theory to the water distribution pipeline network on the basis of information stored in the water distribution pipeline network information storage 11. The incidence matrix is a matrix which shows a graph structure (connection configuration) of the water distribution pipeline network.

15 [0018]

The complementary tree extractor 15 extracts pipelines which serve as a complementary tree from pipelines configuring the water distribution pipeline network on the basis of the incidence matrix generated by the incidence matrix generator, 14. The complementary tree is one of the types of branches configuring the graph structure.

- 20 The branches configuring the graph structure are classified into a tree and a complementary tree, and a set of branches which do not create closed circuits is called a tree, and a set of branches which are not included in a tree is called a complementary tree (Cotree). Specifically, the complementary tree extractor 15 classifies the pipelines configuring the water distribution pipeline network into pipelines serving as a tree and
- 25 pipelines serving as a complementary tree, and extracts the pipelines classified as a

complementary tree.

[0019]

The placement position selector 16 selects nodes at both ends of the pipelines serving as a complementary tree which are extracted by the complementary tree extractor 15 as the placement positions of water pressure sensors, and outputs information on the selected placement position to the output unit 13.

[0020]

Based on a pipeline network model described below, it is known that water pressure sensors required for estimation of water leakage amount at each node may be installed at the nodes at both ends of the pipelines serving as a complementary tree.

[0021]

[Construction of a pipeline network model]

A motion equation of an uncompressed fluid flowing through a water distribution pipeline network is represented by Equation (1). In Equation (1), i, j are node numbers. v_{ij} is a flow rate of water in a pipeline ij (a pipeline connecting a node i and a node j). L_{ij} is a length [m] of the pipeline ij . ρ is a water density [kg/m^3]. H_i is a height of the node i . D_{ij} is a diameter [m] of the pipeline ij . λ_{ij} is a pipeline frictional resistance of the pipeline ij . $p_i(t)$ represents a pressure at time t of the node i and $p_j(t)$ represents a pressure at time t at the node j .

[0022]

[Math. 1]

$$\frac{dv_{ij}(t)}{dt} = \frac{1}{\rho L_{ij}} \{p_i(t) - p_j(t)\} + \frac{g}{L_{ij}} (H_i - H_j) - \frac{\lambda_{ij}}{2D_{ij}} v_{ij}(t) |v_{ij}(t)|$$

... Equation (1)

[0023]

The water distribution pipeline network information storage 11 stores

information on a pipeline length, a pipeline diameter, pipeline frictional resistance, and

node altitude in addition to a connection relationship between nodes. Fig. 3 is a

5 diagram which shows an example of the information stored in the water distribution

pipeline network information storage 11 of the embodiment. As illustrated, information

on an effective water head [m], a classification, an installation altitude [m], and the like

of each node in addition to the number of nodes or the number of pipelines is described

in association with a node number in the water distribution pipeline network information

10 storage 11. Moreover, information on node numbers (that is, a connection relationship

between nodes) of a start point and an end point of each node, pipeline length (length), a

pipeline friction coefficient, and the like is described in association with a pipeline

number in the water distribution pipeline network information storage 11.

[0024]

15 Equation (2) is obtained by representing Equation (1) in a matrix expression.

[0025]

[Math. 2]

$$\mathbf{dP} = \mathbf{L} \frac{d\mathbf{V}}{dt} + \mathbf{RV} \cdot |\mathbf{V}| - \mathbf{dE}$$

... Equation (2)

[0026]

20 In Equation (2), $[\cdot]$ represents a vector obtained by multiplying a vector by each

component. In addition, $|(\text{vector})|$ represents a vector obtained by converting each

component of a vector into an absolute value. Components of each matrix and a vector

in Equation (2) are represented by Equations (3) to (7).

[0027]

[Math. 3]

$$\mathbf{L} = \rho \begin{bmatrix} L_{12} & 0 & 0 & 0 \\ 0 & L_{23} & 0 & 0 \\ 0 & 0 & \ddots & \vdots \\ 0 & 0 & \cdots & L_{45} \end{bmatrix} \quad \dots \text{Equation (3)}$$

[0028]

5

[Math. 4]

$$\mathbf{R} = \frac{\rho}{2} \begin{bmatrix} L_{12}\lambda_{12} / D_{12} & 0 & 0 & 0 \\ 0 & L_{23}\lambda_{23} / D_{23} & 0 & 0 \\ 0 & 0 & \ddots & \vdots \\ 0 & 0 & \cdots & L_{45}\lambda_{45} / D_{45} \end{bmatrix} \quad \dots$$

Equation (4)

[0029]

[Math. 5]

$$\mathbf{dE} = \rho \mathbf{g} \begin{bmatrix} H_1 - H_2 \\ H_2 - H_3 \\ \vdots \\ H_4 - H_5 \end{bmatrix} = \mathbf{E}_i - \mathbf{E}_j$$

10

... Equation (5)

[0030]

[Math. 6]

$$\mathbf{V} = \begin{bmatrix} v_{12} \\ v_{23} \\ \vdots \\ v_{45} \end{bmatrix} \quad \dots \text{Equation (6)}$$

[0031]

[Math. 7]

$$\mathbf{dP} = \begin{bmatrix} p_1 - p_2 \\ p_2 - p_3 \\ \vdots \\ p_4 - p_5 \end{bmatrix} \quad \dots \text{Equation (7)}$$

5 [0032]

In addition, a mass conservation equation at each node is expressed by Equation (8).

[0033]

[Math. 8]

$$\mathbf{A}(\mathbf{SV}) = \mathbf{q} + \mathbf{l} \quad \dots \text{Equation (8)}$$

10

[0034]

A of Equation (8) is an incidence matrix. S is a cross-sectional area [m²] represented by a square matrix with zero diagonal. q is a vector which sets an amount of water used at each node i as an element. l is a vector which sets a water leakage amount at each node i as an element. An element S_{ij} of a matrix S is derived from Equation (9) from the diameter [m] of the pipeline ij.

15

[0035]

[Math. 9]

$$S_{ij} = \frac{\pi}{4} D_{ij}^2 \quad \dots \text{Equation (9)}$$

[0036]

[Generation of an incidence matrix]

5 An incidence matrix A is a matrix generated on the basis of a directed graph, and is generated as a $p \times k$ matrix when the number of nodes is p and the number of pipelines is k. Each element A_{pk} of the incidence matrix A is determined by the following definitions.

$A_{pk} = -1$: when the node p is a start point in a pipeline k

10 $A_{pk} = 1$: when the node p is an end point in the pipeline k

$A_{pk} = 0$: when the node p is neither the start point nor the end point in the pipeline k

[0037]

Hereinafter, a mass conservation equation will be described as a model of the
15 water distribution pipeline network with reference to Fig. 4. Fig. 4 is a diagram which shows an example of the water distribution pipeline network PN which is different from Fig. 1. Circles in Fig. 4 represent nodes, and lines connecting respective circles represent pipelines. Numbers in the circles indicate node numbers. In addition, numbers in parentheses attached to respective pipelines indicate pipeline numbers. Fig.
20 5 is a diagram in which the information stored in the water distribution pipeline network information storage 11 corresponding to the water distribution pipeline network PN shown in Fig. 4 is illustrated.

[0038]

In a case of the water distribution pipeline network PN shown in Fig. 4, the incidence matrix A is represented by following Equation (10).

[0039]

[Math. 10]

$$\mathbf{A} = \begin{matrix} & \begin{matrix} (1) & (2) & (3) & (4) & (5) & (6) \end{matrix} \\ \begin{matrix} \textcircled{1} \\ \textcircled{2} \\ \textcircled{3} \\ \textcircled{4} \\ \textcircled{5} \end{matrix} & \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & 1 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 1 & 1 & 0 \\ 0 & 0 & -1 & -1 & 0 & 1 \\ 0 & 0 & 0 & 0 & -1 & -1 \end{bmatrix} \end{matrix} \quad \dots \text{Equation (10)}$$

[0040]

As described above, each row of the incidence matrix A corresponds to a node, and each column corresponds to a pipeline. The following Equation (11) is obtained by applying the model shown in Figs. 4 and 5 to Equation (8). l_i in Equation (11) is a water leakage amount of each node and is unknown.

[0041]

[Math. 11]

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & 1 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 1 & 1 & 0 \\ 0 & 0 & -1 & -1 & 0 & 1 \\ 0 & 0 & 0 & 0 & -1 & -1 \end{bmatrix} \begin{bmatrix} S_{12} & 0 & 0 & 0 & 0 & 0 \\ 0 & S_{23} & 0 & 0 & 0 & 0 \\ 0 & 0 & S_{24} & 0 & 0 & 0 \\ 0 & 0 & 0 & S_{34} & 0 & 0 \\ 0 & 0 & 0 & 0 & S_{35} & 0 \\ 0 & 0 & 0 & 0 & 0 & S_{45} \end{bmatrix} \begin{bmatrix} v_{12} \\ v_{23} \\ v_{24} \\ v_{34} \\ v_{35} \\ v_{45} \end{bmatrix} \\
= \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \\ q_5 \end{bmatrix} + \begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ l_4 \\ l_5 \end{bmatrix}$$

... Equation (11)

[0042]

Here, dP that is an effective water pressure difference and a pressure value P_i of

5 each node have a relationship of Equation (12) when P_1 is set as zero.

[0043]

[Math. 12]

$$d\mathbf{P} + d\mathbf{E} = \begin{bmatrix} P_1 - P_2 + E_1 - E_2 \\ P_2 - P_3 + E_2 - E_3 \\ P_2 - P_4 + E_2 - E_4 \\ P_3 - P_4 + E_3 - E_4 \\ P_3 - P_5 + E_3 - E_5 \\ P_4 - P_5 + E_4 - E_5 \end{bmatrix} = \mathbf{A}^T (\mathbf{P} + \mathbf{E}) = \begin{bmatrix} 1 & -1 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 & 0 \\ 0 & 1 & 0 & -1 & 0 \\ 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & 1 & 0 & -1 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} P_1 + E_1 \\ P_2 + E_2 \\ P_3 + E_3 \\ P_4 + E_4 \\ P_5 + E_5 \end{bmatrix}$$

... Equation (12)

10 [0044]

Then, Equation (13) is obtained based on Equations (2) and (12).

[0045]

[Math. 13]

$$\frac{d\mathbf{V}}{dt} = -\mathbf{L}^{-1}\mathbf{R}\mathbf{V} \cdot |\mathbf{V}| + \mathbf{L}^{-1}(\mathbf{A}^*_{\mathbf{t}}^T (\mathbf{P} + \mathbf{E}))$$

... Equation (13)

[0046]

Based on Equation (13), it is possible to calculate a flow rate of water flowing through each pipeline. For example, it is possible to solve a non-linear simultaneous ordinary differential equation of Equation (13) by using a Newton-Raphson method and the like. Other methods may be used as a method of solving the non-linear simultaneous ordinary differential equation of Equation (13).

[0047]

Here, $\mathbf{A}^*$ is an irreducible incidence matrix obtained by removing a row corresponding to an arbitrary node from the incidence matrix $\mathbf{A}$. In the following, a first line of the incidence matrix $\mathbf{A}$ is set to be removed. The irreducible incidence matrix $\mathbf{A}^*$ obtained from the incidence matrix $\mathbf{A}$ shown in Equation (10) is represented by Equation (14). Then, a matrix $\mathbf{A}^*_{\mathbf{t}}$ is a sub-matrix only of a rear column when the irreducible incidence matrix $\mathbf{A}^*$ is rearranged so that the complementary tree is in a front column.

[0048]

[Math. 14]

$$\mathbf{A}^* = \begin{bmatrix} \cancel{1} & \cancel{0} & \cancel{0} & \cancel{0} & \cancel{0} & \cancel{0} \\ -1 & 1 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 1 & 1 & 0 \\ 0 & 0 & -1 & -1 & 0 & 1 \\ 0 & 0 & 0 & 0 & -1 & -1 \end{bmatrix}$$

... Equation (14)

[0049]

Hereinafter, the matrix A^*_t will be described. When a graph structure forms a closed circuit (loop), it is possible to obtain a law in which a pressure loss becomes zero if going around the loop. That is, if tracing the loop from a node which is a start point and returning to the start point, $dP=0$. Equation (15) is obtained by expressing this by an equation.

[0050]

[Math. 15]

$$\mathbf{BdP} = \mathbf{0}$$

... Equation (15)

[0051]

10 In Equation (15), B is a basic closed loop matrix, and is an $i \times k$ matrix in which each row i corresponds to a basic closed loop F_i of a graph and each column k corresponds to each branch (pipeline) of the graph. Each element B_{ik} of the basic closed loop matrix B is determined by the following definitions.

15 $B_{ik}=-1$: a case in which the closed loop F_i contains a branch k in a negative direction

$B_{ik}=1$: a case in which the closed loop F_i contains the branch k in a positive direction

$B_{ik}=0$: a case in which the closed loop F_i does not contain the branch k

[0052]

20 In a case of the model shown in Figs. 3 and 4, the basic closed loop matrix B is represented by Equation (16).

[0053]

[Math. 16]

$$\mathbf{B} = \begin{matrix} & \begin{matrix} (1) & (2) & (3) & (4) & (5) & (6) \end{matrix} \\ \begin{matrix} (1) \\ (2) \end{matrix} & \begin{bmatrix} 0 & -1 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 1 & -1 \end{bmatrix} \end{matrix} \quad \dots \text{Equation (16)}$$

[0054]

In this manner, a closed loop uniquely determined by a set of arbitrary complementary tree and an arbitrary tree is referred to as a basic closed loop. The number of basic closed loops of a graph is equal to the number of complementary trees. The basic closed loop matrix B can be obtained by a relationship of Equation (17) between the irreducible incidence matrix A* and the basic closed loop matrix B. In the equation, a subscript c represents a complementary tree and a subscript t represents a tree.

10 [0055]

[Math. 17]

$$\mathbf{A}^* \mathbf{B}^T = \begin{bmatrix} \mathbf{A}^*_c & \mathbf{A}^*_t \end{bmatrix} \begin{bmatrix} \mathbf{I} \\ \mathbf{B}_t^T \end{bmatrix}^T = \mathbf{A}^*_c + \mathbf{A}^*_t \mathbf{B}_t^T = \mathbf{0} \quad \dots \text{Equation (17)}$$

[0056]

The complementary tree is selected by, for example, a depth first search.

Specifically, the pipeline network model constructor 24 starts a search for an end point of a pipeline number from a start point node of a pipeline number 1. A state variable calculation unit 42 repeats this search until a pipeline number M, adds the start point and the end point to a stack, and sets a pipeline number at a time when a node number duplicated in the stack appears three times or more as a complementary tree.

20 [0057]

In a case of the model shown in Figs. 3 and 4, the basic closed loop matrix B can

be transformed into Equation (18) by rearranging columns so that columns corresponding to pipelines (3) and (5) which are complementary trees become front columns. Based on a definition of basic closed loop, a component related to a complementary tree is a unit matrix.

5 [0058]

[Math. 18]

$$\mathbf{B} = [\mathbf{I} \quad \mathbf{B}_t] = \begin{matrix} & \begin{matrix} (3) & (5) & (1) & (2) & (4) & (6) \end{matrix} \\ \begin{bmatrix} 1 & 0 & 0 & -1 & -1 & 0 \\ 0 & 1 & 0 & 0 & -1 & -1 \end{bmatrix} \\ \begin{matrix} \underbrace{\hspace{1.5cm}} & \underbrace{\hspace{2.5cm}} \\ \mathbf{I} & \mathbf{B}_t \end{matrix} \end{matrix} \quad \dots \text{Equation (18)}$$

[0059]

Based on this result, matrices A^*_c and A^*_t are obtained as shown in Equation
 10 (19) by rearranging columns in the same manner. Based on the theory described above, it is possible to calculate a flow rate of water flowing through each pipeline by performing an operation in accordance with the pipeline network model.

[0060]

[Math. 19]

$$\mathbf{A}^* = [\mathbf{A}^*_c \quad \mathbf{A}^*_t] = \begin{matrix} & \begin{matrix} (3) & (5) & (1) & (2) & (4) & (6) \end{matrix} \\ \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & -1 & 1 & 0 & 0 \\ 0 & 1 & 0 & -1 & 1 & 0 \\ -1 & 0 & 0 & 0 & -1 & 1 \\ 0 & -1 & 0 & 0 & 0 & -1 \end{bmatrix} \\ \underbrace{\hspace{1.5cm}} & \underbrace{\hspace{2.5cm}} \\ \mathbf{A}^*_c & \mathbf{A}^*_t \end{matrix} \quad \dots \text{Equation (19)}$$

[0061]

[Estimation of a water leakage amount]

As described above, components of the incidence matrix $\mathbf{A}$ are separated into a complementary tree and a tree, and thereby an operation according to estimation of a water leakage amount can be independently performed between the complementary tree and the tree. Equations (20), (21), (22), and (23) are obtained by dividing three equations of Equations (2), (3), and (9) which are governing equations into portions of a tree and a complementary tree of a graph, respectively.

10 [0062]

[Math. 20]

$$\mathbf{A}^*_c \mathbf{S}_c \mathbf{V}_c + \mathbf{A}^*_t \mathbf{S}_t \mathbf{V}_t = \mathbf{q} + \mathbf{l} \quad \dots \text{Equation (20)}$$

[0063]

[Math. 21]

$$\mathbf{dP}_c + \mathbf{B}_t \mathbf{dP}_t = \mathbf{0} \quad \dots \text{Equation (21)}$$

15

[0064]

[Math. 22]

$$\mathbf{dP_c} = \mathbf{R_c V_c} \cdot |\mathbf{V_c}| + \mathbf{L_c} \frac{d\mathbf{V_c}}{dt} - \mathbf{dE_c} \quad \dots \text{Equation (22)}$$

$$\mathbf{dP_t} = \mathbf{R_t V_t} \cdot |\mathbf{V_t}| + \mathbf{L_t} \frac{d\mathbf{V_t}}{dt} - \mathbf{dE_t} \quad \dots \text{Equation (23)}$$

[0065]

5 [Selection of an placement position of water pressure sensors]

As described above, if a graph theory is applied, it is possible to classify the pipelines configuring a water distribution pipeline network into a complementary tree and a tree. As a result, it is possible to consider that a governing equation of the water distribution pipeline network is also divided into portions of a complementary tree and a tree. In other words, if a pressure loss dP_c can be measured with respect to the pipelines serving as a complementary tree, the water distribution pipeline network can be regarded as one pipeline composed of a pipeline serving as a tree. If the water distribution pipeline network is one pipeline, the water leakage amount at each node directly affects a total pressure loss, and thus this can be treated as one system. Therefore, if water pressure sensors are arranged at both ends of the pipelines serving as a complementary tree, it is possible to estimate a water leakage amount at all nodes. For this reason, the placement position selector 16 selects nodes at both ends of the pipelines extracted as a complementary tree as the placement position of water pressure sensors.

[0066]

20 Fig. 6 is a diagram which shows an example in which the water distribution pipeline network PN is regarded as one pipeline. An upper diagram of Fig. 6 shows that four pipelines indicated by black squares are extracted as a complementary tree with

respect to four loops of the water distribution pipeline network PN. In this case, the water distribution pipeline network PN is equivalent to one pipeline as shown in a lower diagram of Fig. 6. Then, nodes of black circles are selected as the placement position of water pressure sensors.

5 [0067]

For example, in a water distribution pipeline network having a graph structure in which the number of nodes is N , the number of pipelines is M , and the number of loops is F , a water pressure sensor is conventionally required at all nodes to calculate a water leakage amount at each node. That is, N water pressure sensors are needed. In contrast, the placement position selection device 1 of the first embodiment selects $2 \times F - \alpha + \beta$ nodes as positions at which water pressure sensors are arranged. The number of water pressure sensors required for water leakage diagnosis can be reduced by the selection of placement positions. α represents the number of duplicated nodes in the pipelines serving as a complementary tree, and β represents the number of nodes on a path configuring a loop. Specifically, in a case of an example of Fig. 6, a node 100 is a node corresponding to α . In addition, a node 101 is a node corresponding to β .

[0068]

The sensor placement position selection device 1 of the first embodiment configured in this manner extracts the pipelines serving as a complementary tree which configure a loop from the pipelines configuring the water distribution pipeline network 2 on the basis of an incidence matrix representing a connection configuration of the water distribution pipeline network 2 as a graph structure. Then, the sensor placement position selection device 1 selects both ends of the pipeline extracted as a complementary tree as an installation position of a water pressure sensor. By providing such a function, the sensor placement position selection device 1 can select an efficient placement

position of water pressure sensors from a plurality of pipeline nodes.

[0069]

Hereinafter, a modified example of the sensor placement position selection device 1 of the first embodiment will be described.

5 [0070]

The sensor placement position selection device 1 may include a graph structure aggregator 17 which aggregates graph structures of the water distribution pipeline network 2 on the basis of a configuration of a pipeline network. Fig. 7 is a functional block diagram which shows a functional configuration of a sensor placement position selection device 1a of a modified example. The graph structure aggregator 17 classifies each pipeline into a tree and a complementary tree in the same method as that of the complementary tree extractor 15 on the basis of the information stored in the water distribution pipeline network information storage 11. The graph structure aggregator 17 performs aggregation as shown below on a graph structure of the pipelines serving as a tree.

[0071]

Fig. 8 is a schematic diagram which shows an outline of a first method of aggregating graph structures.

Fig. 8 shows a method of classifying pipelines into a branch and a trunk on the basis of the graph structure of the pipelines serving as a tree and aggregating pipelines serving as a branch with pipelines serving as a trunk as a first method of aggregating graph structures. A left diagram of Fig. 8 is a diagram which shows an example of pipelines before aggregation. A right diagram of Fig. 8 is a diagram which shows an example of pipelines after aggregation. A size of each node in Fig. 8 represents an amount of water used at each node. In this case, for example, the graph structure

aggregator 17 may also aggregate four pipelines in the left diagram with one pipeline in the right diagram. The graph structure aggregator 17 reflects a result of the aggregation in the information stored in the water distribution pipeline network information storage 11.

5 [0072]

In addition, the aggregation of the pipelines may be performed to the extent that a selection result of the placement position selector 16 becomes the placement position of existing water pressure sensors. By performing the aggregation, it is possible to estimate a water leakage amount at each node even when an existing water pressure

10 sensor is used (even though a resolution of water leakage diagnosis is rough).

[0073]

Fig. 9 is a schematic diagram which shows an outline of a second method of aggregating graph structures.

Fig. 9 shows a method of aggregating pipelines with a small diameter as a

15 second method of aggregating graph structures. In the same manner as in Fig. 8, a left drawing of Fig. 9 shows an example of pipelines before aggregation and a right figure thereof shows an example of pipelines after aggregation. In this case, the graph structure aggregator 17 may aggregate a pipeline with a small diameter shown in a dashed line in the left figure with other pipelines. In this case, the graph structure

20 aggregator 17 can simply ignore the pipelines shown in a dashed line instead of aggregating the pipelines with other pipelines. The graph structure aggregator 17 reflects a result of the aggregation in the information stored in the water distribution pipeline network information storage 11.

[0074]

25 In addition, the placement positions selected by the sensor placement position

selection device 1a vary depending on a combination of extracted complementary trees.

Fig. 10 is a diagram which shows a specific example of a case when different placement

positions are selected. In Fig. 10, pipelines indicated by dashed lines are the pipelines

extracted as a complementary tree. Complementary trees are extracted in different

5 combinations in an upper diagram and a lower diagram of Fig. 10. At this time, the

number of water pressure sensors in the upper diagram is seven and the number of water

pressure sensors in the lower diagram is eight. Accordingly, selecting a combination of

the upper diagram is advantageous in terms of reducing the number of water pressure
sensors.

10 [0075]

The aggregation of graph structures and the selection of a combination of
complementary trees described above can reduce the number of water pressure sensors,

and can decrease an amount of information acquired by a water pressure sensor and

deteriorate a resolution of water leakage diagnosis. The resolution of water leakage

15 diagnosis denotes the fineness in a unit which can estimate water leakage. That is, there

is a trade-off relationship between reduction in the number of water pressure sensors and

the resolution of water leakage diagnosis. Therefore, the number of water pressure

sensors may be reduced so that the two sides are appropriately balanced.

[0076]

20 Moreover, the complementary tree extractor 15 may be configured to extract the

pipelines serving as a complementary tree so as to satisfy a target condition set in

advance for the nodes selected as placement positions of water pressure sensors. For

example, whether to install a water pressure sensor may also be set in the target

conditions. In this case, when the pipelines serving as complementary trees have nodes

25 at which a water pressure sensor can be installed, the complementary tree extractor 15

extracts the pipelines.

[0077]

Moreover, the selected placement position of water pressure sensors may also be set in the target condition. For example, the target condition may be set so that the selected placement position of water pressure sensors is the placement position of existing water pressure sensors. In this case, the placement position selector 16 may select a position of the existing water pressure sensor installed at a position close to nodes at both ends of the extracted pipelines serving as a complementary tree as a placement position.

[0078]

The sensor placement position selection device may be configured to prompt a user to update the water distribution pipeline network information stored in the water distribution pipeline network information storage 11. For example, the sensor placement position selection device may include an update notification unit which acquires information showing a presence of new water distribution pipeline network information from the outside and generates information for performing a notification to urge a user's update when there is water distribution pipeline network information newer than the water distribution pipeline network information currently stored,. In this case, water distribution pipeline network information includes information showing a time at which information is updated, and the placement position selection device determines the update time indicated by the water distribution pipeline network information and whether there is new water distribution pipeline network information updated after the update time. The update notification unit generates information which can be perceived by a human such as a sound or a character urging a user's update.

[0079]

(Second embodiment)

In a second embodiment, a water leakage amount estimation device 2 which diagnoses water leakage at each node using a water pressure sensor installed at the arrange position selected by the sensor placement position selection device 1 of the first
5 embodiment, a flowmeter which measures an amount of water supplied to the water distribution pipeline network PN, and a smart meter disposed at a node of each pipeline will be described.

[0080]

Fig. 11 is a functional block diagram which shows a functional configuration of
10 the water leakage amount estimation device 2 according to the second embodiment.

The water leakage amount estimation device 2 includes a CPU, a memory, an auxiliary storage device, and the like connected by a bus, and executes a water leakage diagnosis program. The water leakage amount estimation device 2 functions as a device including an input unit 21, an output unit 22, a measurement data acquirer 23, a pipeline
15 network model constructor 24, a water leakage coefficient optimizer 25, and a water leakage amount estimator 26 by execution of the water leakage diagnosis program. All or some of respective functions of the water leakage amount estimation device 2 may also be realized by using hardware such as an ASIC, PLD, FPGA, and the like. The water leakage diagnosis program may also be recorded in a computer readable recording
20 medium. The computer readable recording medium is a portable medium such as a flexible disk, a magneto-optical disk, a ROM, or a CD-ROM, or a storage device such as a hard disk embedded in a computer system. The water leakage diagnosis program may also be transmitted via an electric communication line.

[0081]

25 The input unit 21 receives an input of user's operation configured by using an

input device such as a keyboard, a mouse, a touch panel, or a switch.

[0082]

The output unit 22 is configured to include a display device such as a liquid crystal display (LCD) or an organic electroluminescence (EL), a display control unit, a
5 printer, a speaker, and the like, and outputs information on the selected placement position of water pressure sensors.

[0083]

The measurement data acquirer 23 acquires measurement data acquired by a measurement from various types of measurement devices installed in the water
10 distribution pipeline network.

[0084]

The pipeline network model constructor 24 acquires water distribution pipeline network information from the sensor placement position selection device 1 of the first embodiment. The pipeline network model constructor 24 constructs a pipeline network
15 model of a water distribution pipeline network on the basis of the acquired water distribution pipeline network information. The construction of the pipeline network model is as described above. The pipeline network model constructor 24 outputs information on the constructed pipeline network model to the water leakage coefficient optimizer 22.

[0085]

The water leakage coefficient optimizer 25 determines a water leakage coefficient necessary for estimation of a water leakage amount at each node on the basis of the measurement data acquired by the measurement data acquirer 23. The water leakage coefficient optimizer 25 outputs the determined water leakage coefficient to the
25 water leakage amount estimator 26.

[0086]

The water leakage amount estimator 26 calculates a water leakage amount at each node on the basis of the water leakage coefficient determined by the water leakage coefficient optimizer 25. The water leakage amount estimator 26 outputs the calculated
5 water leakage amount at each node to the output unit 22 as an estimation value of water leakage amount.

[0087]

[Determination of a water leakage coefficient]

As described also in the first embodiment, if a water pressure at both ends of a
10 pipeline extracted as a complementary tree can be measured, the water distribution pipeline network 2 having N nodes is equivalent to one pipeline (hereinafter, referred to as "virtual pipeline") from which water is drawn from a node N-1. Thus, a relationship between an effective water pressure difference dP in the virtual pipeline at a certain time and a differential pressure dP_j of each pipeline is expressed as in a specific example of
15 Fig. 12. As shown in Fig. 12, if there is one virtual pipeline, a relationship between a water leakage amount and a water pressure difference at each node is uniquely determined, and thus the estimation of a water leakage amount at each node of the water distribution pipeline network can be formulated as a constrained non-linear optimization problem. In the following, a method of formulating the constrained non-linear
20 optimization problem will be shown using two specific examples.

[0088]

[First method]

A first method is a method of constraining that a total water leakage amount is expressed as a sum of water leakage amounts at each node and optimizing a water
25 leakage coefficient k_i so that a differential pressure from a start point to an end point of a

virtual pipeline gradually approaches an actual measurement value on the basis of measurement data measured at each time. The water leakage coefficient k_i is a coefficient which determines an estimation value of the water leakage amount at each node, and is represented by Equation (24) on the assumption that it is proportional to a

5 water pressure of the power of 1.15.

[0089]

[Math. 23]

$$l_i = \mathbf{k}_i (P_i)^{1.15} = \mathbf{k}_i \left(A_t^{T-1} (R_t \mathbf{V}_t |\mathbf{V}_t| - dE_t) \right)^{1.15} \quad \dots \text{Equation}$$

(24)

10 [0090]

In this case, estimation of water leakage amount at each node is formulated as in Equation (25) in the first method.

[0091]

[Math. 24]

$$\begin{aligned} \min. \quad & \sum_{t=1}^T \{dP(t) - \sum (R_t \mathbf{V}_t(t) |\mathbf{V}_t(t)| - dE_t)\}^2 \\ s.t. \quad & L_{total}(t) = \sum \mathbf{k}_i \left((A_t^T)^{-1} (R_t \mathbf{V}_t(t) |\mathbf{V}_t(t)| - dE_t) \right)^{1.15} \\ & P_i = (A_t^T)^{-1} (R_t \mathbf{V}_t |\mathbf{V}_t| - dE_t) \geq 0 \\ & k_i \geq 0 \end{aligned}$$

15

... Equation (25)

[0092]

It is known that a differential pressure $dP(t)$ from a start point to an end point of

the virtual pipeline and a total amount L_{total} of water leakage are measurable. The total amount L_{total} of water leakage is represented by Equation (26).

[0093]

[Math. 25]

$$L_{total} = \sum_{i=1}^N l_i \quad \dots \text{Equation (26)}$$

[0094]

The water leakage coefficient k_i is obtained by solving the optimization problem. If the water leakage coefficient k_i is determined, V_t is obtained by solving a non-linear simultaneous equation of Equation (27) using convergent calculation.

[0095]

[Math. 26]

$$A_c S_c V_c + q - f + A_t S_t V_t + \mathbf{k}_i \left(A_t^{T-1} (R_t V_t |V_t| - dE_t) \right)^{1.15} = 0$$

... Equation (27)

[0096]

[Second method]

A second method is a method of optimizing the water leakage coefficient k_i by partially relaxing a constraint on the total water leakage amount in the first method. In this case, in the second method, the estimation of the water leakage amount at each node is formulated as in, for example, Equation (28).

[0097]

[Math. 27]

$$\min. \quad f_1 + f_2$$

$$f_1 = \sum_{t=1}^T \left\{ dP(t) - \sum (R_t \mathbf{V}_t(t) |\mathbf{V}_t(t)| - dE_t) \right\}^2$$

$$f_2 = \sum_{t=1}^T \left\{ L_{total}(t) - \sum \mathbf{k}_i \left((A_t^T)^{-1} (R_t \mathbf{V}_t(t) |\mathbf{V}_t(t)| - dE_t) \right)^{1.15} \right\}$$

$$s.t. \quad P_i = (A_t^T)^{-1} (R_t \mathbf{V}_t(t) |\mathbf{V}_t(t)| - dE_t) \geq 0$$

$$k_i \geq 0$$

... Equation (28)

[0098]

Here, an objective function to be optimized is set as a sum of f_1 and f_2 , but the
 5 objective function may be formulated by another equation like a product of f_1 and f_2 .

[0099]

The method of formulation described above is represented by a block diagram as shown in Fig. 13. In addition, an arbitrary method may be used as a method of solving the optimization problem formulated as described above.

10 For example, the optimization problem may also be solved by a search using a Newton method shown in the following Equation (29). In Equation (29), F is a matrix expression of the objective function, and J is a Jacobian matrix.

[0100]

[Math. 28]

$$J(x_k)d_k = -F(x_k)$$

$$x_{k+1} = x_k + d_k$$

$$J(x_k) = \begin{bmatrix} \nabla F_1(x_k)^T \\ \nabla F_2(x_k)^T \\ \vdots \\ \nabla F_n(x_k)^T \end{bmatrix} \quad \dots \text{Equation (29)}$$

[0101]

The water leakage amount estimation device 2 of the second embodiment configured in this manner includes a water leakage coefficient optimizer configured to

5 determine a water leakage coefficient at each node by solving an optimization problem in which the water leakage coefficient at each node is set as a decision variable on the basis of a water pressure measured by a water pressure sensor arranged at a node selected by the sensor placement position selection device 1 of the first embodiment, a differential pressure from a start point to an end point of an open pipeline passing through each node

10 of a water distribution pipeline network, a total amount of water leakage in the water distribution pipeline network, an inflow rate at each node, and an amount of water used at each node, and a water leakage amount estimator configured to estimate a water leakage amount at each node on the basis of the determined water leakage coefficient and a fluid motion equation in which a connection relationship between nodes in the water

15 distribution pipeline network is reflected. Accordingly, the water leakage amount estimation device 2 can estimate a water leakage amount at each node with fewer water pressure sensors.

[0102]

Fig. 14 is a diagram which shows an example of simulation results of water leakage amount estimation.

A lower diagram in Fig. 14 is a diagram which shows simulation results. In addition, an upper diagram of Fig. 14 is a diagram which shows actual measurement values in an environment assumed by simulation. In both diagrams, a horizontal axis represents each node and a vertical axis represents a water leakage amount at each node. As seen from the diagrams, it is known that a water leakage amount at each node can be estimated with high accuracy by the method described above. In this manner, the water leakage amount estimation device 2 of the embodiment can estimate the water leakage amount at each node even when a water leakage amount varies depending on a pressure.

[0103]

Hereinafter, a modified example of the water leakage amount estimation device 2 of the second embodiment will be described.

[0104]

The water leakage amount estimation device 2 may cause the output unit 22 to display the water leakage amount at each node estimated in this manner, for example, on a screen (image) shown in Fig. 15. Fig. 15 is a diagram which shows an example of a screen displayed by the output unit 22 of the embodiment. For example, a display control unit of the output unit 22 may cause the water leakage amount at each node to be displayed on a display device in a form of a bar graph or the like. In addition, the display control unit of the output unit 22 may change a color of a symbol indicating a node depending on a size of a water leakage amount and display the symbol in this color on the display device.

[0105]

Moreover, when there is a node to which no smart meter is attached in a water

distribution pipeline network, the water leakage amount estimation device 2 may use meter reading data acquired by a water meter as information showing an amount of water used at the node.

[0106]

5 The water leakage amount estimation device 2 may be configured to calculate a priority for an update of pipeline based on water leakage in accordance with conditions such as the number of years after burial of a pipeline, a material of a pipeline, and the soil. In this case, the water leakage amount estimation device 2 includes a burial conditions information storage configured to store burial conditions information showing burial
10 conditions including conditions such as the number of years since burial of a pipeline, a material of a pipeline, the soil, and the like, and an update priority calculation unit configured to calculate a priority for an update of pipeline on the basis of the water leakage amount estimated by the water leakage amount estimator 11 and the burial condition.

15 [0107]

 According to at least one of the embodiments described above, it is possible to select an efficient placement position of water pressure sensors by including an incidence matrix generator, configured to generate an incidence matrix representing a graph structure of a water distribution pipeline network on the basis of information showing a
20 connection configuration of pipelines configuring the water distribution pipeline network, a complementary tree extractor configured to classify the pipelines configuring the water distribution pipeline network into pipelines serving as a tree configuring an open pipeline and pipelines serving as a complementary tree configuring a closed pipeline along with a tree in the water distribution pipeline network and to extract the pipelines serving as a
25 complementary tree, and a selector configured to select nodes at both ends of the

extracted pipelines serving as a complementary tree as the placement position of water pressure sensors.

[0108]

Several embodiments of the present invention are described, but these

5 embodiments are presented as examples and are not intended to limit a scope of the invention. These embodiments can be implemented in various other forms, and various omissions, substitutions, and changes can be performed within a range not departing from a gist of the invention. These embodiments and modifications thereof are included in the invention described in the claims and an equivalent scope thereof as well as in the

10 scope or the gist of the invention.

[CLAIMS]

[Claim 1]

A sensor placement position selection device comprising:

an incidence matrix generator, configured to generate an incidence matrix

5 representing a graph structure of a water distribution pipeline network on the basis of information showing a connection configuration of pipelines configuring the water distribution pipeline network;

a complementary tree extractor configured to classify the pipelines configuring the water distribution pipeline network into pipelines serving as a tree configuring an
10 open pipeline and pipelines serving as a complementary tree configuring a closed pipeline along with the tree in the water distribution pipeline network on the basis of the incidence matrix, and to extract the pipelines serving as a complementary tree; and

a selector configured to select nodes at both ends of the extracted pipelines serving as a complementary tree as placement positions of water pressure sensors.

15 [Claim 2]

The sensor placement position selection device according to claim 1,

wherein the complementary tree extractor extracts the pipelines serving as a complementary tree to satisfy a target condition set in advance for the nodes selected as the placement position of water pressure sensors.

20 [Claim 3]

The sensor placement position selection device according to claim 2,

wherein the target conditions are conditions which show whether or not a water pressure sensor can be installed in each node, and the complementary tree extractor extracts a pipeline having a node in which a water pressure sensor can be installed as a
25 complementary tree.

[Claim 4]

The sensor placement position selection device according to claim 1, further comprising:

an aggregator configured to classify open pipelines into pipelines serving as a
5 trunk and pipelines serving as a branch on the basis of a graph structure of the open
pipeline configured from the pipelines serving as a tree, and to aggregate the pipelines
serving as a branch with the pipelines serving as a trunk if there are the pipelines serving
as a branch.

[Claim 5]

10 The sensor placement position selection device according to claim 4,
wherein the aggregator aggregates a pipeline with a smaller diameter with other
pipelines.

[Claim 6]

The sensor placement position selection device according to claim 4,
15 wherein the aggregator performs the aggregation of pipelines to the extent that
an placement position selected by the placement position selector is an placement
position of existing water pressure sensors.

[Claim 7]

The sensor placement position selection device according to claim 1,
20 wherein the complementary tree extractor acquires a plurality of combinations
of the pipelines serving as a complementary tree, and extracts the pipelines serving as a
complementary tree by selecting a combination with the least number of pipelines
serving as a complementary tree among the plurality of combinations.

[Claim 8]

25 The sensor placement position selection device according to claim 1,

wherein the selector selects nodes with distances from the placement positions of existing water pressure sensors less than a threshold value or nodes which are at the placement positions of existing water pressure sensors as placement positions among the nodes at both ends of the pipelines serving as a complementary tree.

5 [Claim 9]

The sensor placement position selection device according to claim 1, further comprising:

a water distribution pipeline network information storage configured to store water distribution pipeline network information including a connection relationship
10 between nodes in the water distribution pipeline network; and

an update notification unit configured to notify information to the effect that the water distribution pipeline network information needs to be updated when information showing that there is information newer than the water distribution pipeline network information stored by the water distribution pipeline network information storage is
15 acquired.

[Claim 10]

A non-transitory storage medium which stores a computer program to cause a computer to function as a sensor placement position selection device, the sensor placement position selection device includes

20 an incidence matrix generator, configured to generate an incidence matrix representing a graph structure of a water distribution pipeline network on the basis of information showing a connection configuration of pipelines configuring the water distribution pipeline network;

a complementary tree extractor configured to classify the pipelines configuring
25 the water distribution pipeline network into pipelines serving as a tree configuring an

open pipeline and pipelines serving as a complementary tree configuring a closed pipeline along with the tree in the water distribution pipeline network on the basis of the incidence matrix, and extracts the pipelines serving as a complementary tree; and

a selector configured to select nodes at both ends of the extracted pipelines

5 serving as a complementary tree as placement positions of water pressure sensors.

[Claim 11]

A water leakage amount estimation device comprising:

a water leakage coefficient optimizer configured to determine a water leakage

coefficient at each node by solving an optimization problem in which the water leakage

10 coefficient at each node is set as a decision variable on the basis of information showing

water pressures of the pipelines serving as a complementary tree in a water distribution

pipeline network, which are measured by water pressure sensors installed in the

placement position selected by the sensor placement position selection device described

in one of claims 1 to 9, a differential pressure between a start point and an end point of an

15 open pipeline passing through each node of the water distribution pipeline network, a

total amount of water leakage in the water distribution pipeline network, an inflow rate at

each node, and an amount of water used at each node; and

a water leakage amount estimator configured to estimate a water leakage amount

at each node on the basis of a fluid motion equation that reflects the determined water

20 leakage coefficient and a connection relationship between nodes in the water distribution

pipeline network.

[Claim 12]

The water leakage amount estimation device according to claim 11, further

comprising:

25 a display unit configured to display images based on a water leakage amount

estimated by the water leakage amount estimator.

[Claim 13]

The water leakage amount estimation device according to claim 11,
wherein the display unit displays an image in which a symbol representing the
5 node is drawn with a color corresponding to a water leakage amount estimated by the
water leakage amount estimator.

[Claim 14]

The water leakage amount estimation device according to claim 11, further
comprising:

10 a burial condition information storage configured to store burial condition
information including burial conditions for each pipeline; and

an update priority calculation unit configured to calculate a priority when
pipelines are updated on the basis of the water leakage amount at each node estimated by
the water leakage amount estimator and the burial condition information.

15 [Claim 15]

The water leakage amount estimation device according to claim 11,
wherein meter reading data acquired by a water meter are used for information
indicating an amount of water used in some or all of nodes.

[Claim 16]

20 A non-transitory storage medium which stores a computer program to cause a
computer to function as a water leakage amount estimation device, the water leakage
amount estimation device includes

a water leakage coefficient optimizer configured to determine a water leakage
coefficient at each node by solving an optimization program in which a water leakage
25 coefficient at each node is set as a decision variable on the basis of information showing

water pressures of pipelines serving as a complementary tree in a water distribution pipeline network which are measured by water pressure sensors installed in an placement position selected by the sensor placement position selection device described in one of claims 1 to 9, a differential pressure between a start point and an end point of an open pipeline passing through each node of the water distribution pipeline network, a total amount of water leakage in the water distribution pipeline network, an inflow rate at each node, and an amount of water used at each node; and

a water leakage amount estimator configured to estimate a water leakage amount at each node on the basis of a fluid motion equation that reflects the determined water leakage coefficient and a connection relationship between nodes in the water distribution pipeline network.

[Claim 17]

A water leakage diagnostic system comprising:

an incidence matrix generator, configured to generate an incidence matrix representing a graph structure of a water distribution pipeline network on the basis of information showing a connection configuration of pipelines configuring the water distribution pipeline network;

a complementary tree extractor configured to classify the pipelines configuring the water distribution pipeline network into pipelines serving as a tree configuring an open pipeline and pipelines serving as a complementary tree configuring a closed pipeline along with the tree in the water distribution pipeline network and to extract the pipelines serving as a complementary tree on the basis of the incidence matrix;

a selector configured to select nodes at both ends of the extracted pipelines serving as a complementary tree as an placement position of water pressure sensors;

a water leakage coefficient optimizer configured to determine a water leakage

coefficient at each node by solving an optimization problem in which the water leakage coefficient at each node is set as a decision variable on the basis of information showing water pressures of the pipelines serving as a complementary tree in the water distribution pipeline network which is measured by a water sensor installed at the placement position
5 selected by the selector, a differential pressure between a start point and an end point of an open pipeline passing through each node of the water distribution pipeline network, a total amount of water leakage in the water distribution pipeline network, an inflow rate at each node, and an amount of water used at each node; and

a water leakage amount estimator configured to estimate a water leakage amount
10 at each node on the basis of a fluid motion equation that reflects the determined water leakage coefficient and a connection relationship between nodes in the water distribution pipeline network.

[Claim 18]

A water leakage diagnosis method comprising:

15 an incidence matrix generation step of generating an incidence matrix representing a graph structure of a water distribution pipeline network on the basis of information showing a connection configuration of pipelines configuring the water distribution pipeline network;

a complementary tree extraction step of classifying the pipelines configuring the
20 water distribution pipeline network into pipelines serving as a tree configuring an open pipeline and pipelines serving as a complementary tree configuring a closed pipeline along with the tree in the water distribution pipeline network on the basis of the incidence matrix, and extracting the pipelines serving as a complementary tree;

a selection step of selecting nodes at both ends of the extracted pipelines serving
25 as a complementary tree as an placement position of water pressure sensors;

a water leakage coefficient optimization step of determining a water leakage coefficient at each node by solving an optimization problem in which the water leakage coefficient at each node is set as a decision variable on the basis of information showing water pressures of the pipelines serving as a complementary tree in a water distribution pipeline network, which are measured by water pressure sensors installed in the placement position selected in the selection step, a differential pressure between a start point and an end point of an open pipeline passing through each node of the water distribution pipeline network, a total amount of water leakage in the water distribution pipeline network, an inflow rate into each node, and an amount of water used at each node; and

a water leakage amount estimation step of estimating a water leakage amount at each node on the basis of a fluid motion equation that reflects the determined water leakage coefficient and a connection relationship between nodes in the water distribution pipeline network.