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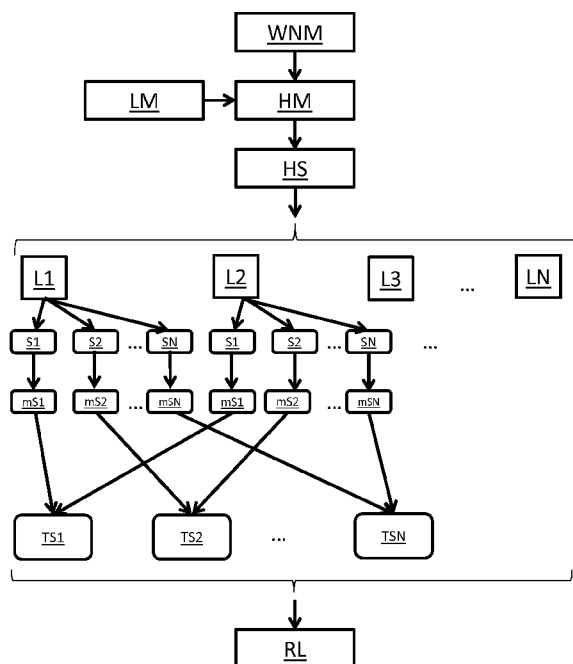
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(54) Title: COMPUTER-IMPLEMENTED METHOD AND APPARATUS FOR SENSOR POSITIONING FOR LEAK DETECTION IN A WATER NETWORK

Fig. 2



(57) Abstract: The invention relates to a computer-implemented method for sensor positioning for leak detection in a water network. Based on a hydraulic simulation (HS), total sensor sensitivities (TS1, TS2, ..., TSN) to modelled leaks (L1, L2, ..., LN) for modelled leak detection sensors are determined wherein for a respective modelled leak (L1, L2, ..., LN), sensor sensitivities (S1, S2, ..., SN) to said leak are determined, these sensor sensitivities are sorted and respective modified sensor sensitivities (mS1, mS2, ..., mSN) are generated based on the respective sorting index, and, for a respective leak detection sensor, a total sensor sensitivity (TS1, TS2, ..., TSN) is calculated by combining the respective modified sensor sensitivities (mS1, mS2, ..., mSN). Based on the respective total sensor sensitivity at least one modelled sensor is selected, and its respective sensor position is exported for positioning of a real leak detection sensor in the water network.

WO 2021/032294 A1

Description

Computer-implemented method and apparatus for sensor positioning for leak detection in a water network

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The present invention relates to a computer-implemented method, an apparatus and a computer program product for sensor positioning for leak detection in a water network.

10 Drinking water is one of the most important commodities. Considerable water losses due to leakage can occur in water distribution networks. Water losses can have a significant percentage even in developed countries. Therefore, it is a major challenge to detect leaks for avoiding and reducing wa-
15 ter losses. Efficient leakage detection requires sensors, e.g. flow meters, placed at favorable positions. For the sensor placement, topological as well as hydraulic consideration need to be considered in order to install sensors at relevant positions in the network. More sensors at relevant positions
20 increase the quality of the leakage detection, however, it is for example desired to avoid redundancies without decreasing the detection quality.

It is therefore an objective of the present invention to im-
25 prove the sensor positioning for leakage detection in a water distribution network.

The object is solved by the features of the independent
claims. The dependent claims contain further developments of
30 the invention.

The invention provides according to the first aspect a computer-implemented method for leak detection in a water network, comprising the steps:

- 35 (a) receiving a hydraulic model for the water network, wherein pipes and nodes of the water network are modelled based on a water network model,
(b) performing a hydraulic simulation for the water network using the hydraulic model,

(c) based on the hydraulic simulation, determining total sensor sensitivities to modelled leaks for modelled leak detection sensors wherein

- for a respective modelled leak, sensor sensitivities to said leak are determined, these sensor sensitivities are sorted and respective modified sensor sensitivities are generated based on the respective sorting index, and,

5 - for a respective leak detection sensor, a total sensor sensitivity is calculated by combining the respective modified sensor sensitivities, and

10 (d) selecting at least one modelled leak detection sensor based on the respective total sensor sensitivity and exporting its respective sensor position for positioning of a real leak detection sensor in the water network.

For executing the inventive method, a computer program product may be provided. The inventive method may be implemented by means of one or more processors.

It is an important advantage of the proposed computer-implemented method that sensitivities of leak detection sensors as well as the spatial distribution of leak detection sensors are considered for optimized sensor positioning. Hence, the method advantageously enables well-distributed positioning of leak detection sensors avoiding redundancies. Therefore, an improved leakage detection can be achieved. In particular, the optimized position for at least one sensor, e.g. a flow meter, is determined such that said sensor enables leak detection of multiple leaks distributed over the water network.

According to a preferred embodiment, a ranking list for the respective modelled leak detection sensors can be exported, wherein the ranking is based on the respective total sensor sensitivities, and wherein the ranking list can comprise the corresponding sensor positions.

Preferably, based on the provided information in the ranking list, real sensors can be placed at corresponding favorable positions and/or previously placed real sensors can be re-
placed or removed. Therefore, the ranking based on total sen-
5 sor sensitivities enables optimized and efficient sensor placement in a water network.

According to a preferred embodiment, a sensitivity threshold can be applied to the total sensor sensitivities listed in
10 the ranking list and at least one leak detection sensor can be selected from the ranking list based on the sensitivity threshold, and the sensor position of the selected leak de-
tection sensor can be provided by means of a user-interface for sensor positioning in the water network.

15

Preferably the ranking list can be sorted in a decreasing order and a sensitivity threshold is applied to select that at least one sensor which is sensitive enough to detect at least one leak of a specific size. The sensitivity threshold is
20 therefore preferably defined based on the size of the at least one leak which shall be detected. Hence, by introducing the sensitivity threshold to the ranking list, those sensors can be selected which are able to detect leaks of a defined size, resulting preferably in well-distributed sensor posi-
25 tions.

According to an advantageous embodiment, the at least one selected leak detection sensor can be removed from the ranking list and the ranking list can be updated by recalculating the
30 total sensor sensitivities.

By removing, blanking or hiding the respective entry of the selected sensors in the ranking list, the ranking can be up-
dated such that the next most sensitive sensor can be deter-
35 mined and positioned. Preferably, all leaks having a size above the sensitivity threshold and which may therefore be detected by the previously selected sensors are removed from the simulation and/or not further considered. This process

can be reiterated until enough modelled sensors are determined to detect the modelled leaks.

5 According to a further embodiment, the hydraulic model may be based on a load model for the water network, wherein the load model may comprise inflow and outflow rates of the water network.

10 The load model for the water network can comprise information about inflows and outflows, wherein outflows comprise throughput and consumption. The inflow and outflow rates can be deduced from flow measurements and/or estimated from annual flow quantities.

15 According to a further embodiment, the load model may be generated comprising the steps:
- calculating the distribution of inflow shares for a respective inlet pipe based on measured and/or estimated annual flow quantities for the water network,
20 - calculating the outflow rates for a respective node based on measured annual consumption of consumers,
and
- calculating the inflow rates based on the inflow shares and the outflow rates.

25 Usually, merely annual flow values for a water network are provided. Therefore, the load model can be generated as described in order to determine flow rates as input for the hydraulic simulation.

30 According to a preferred embodiment, the hydraulic model can be a steady state hydraulic model.

The calculation of a steady state hydraulic model is advantageously simple and/or fast.

According to a further embodiment, the hydraulic model may be simplified compared to the real water network by modelling

multiple pipes as single pipes and/or removing single taps and/or projecting a consumer load into a neighboring node.

5 According to a preferred embodiment, the water network model can be computer-readable and generated based on measured water network data and for at least a closed subnet of the water network.

10 According to a further embodiment, a real leak detection sensor can be positioned in a water network based on the exported position of the selected modelled leak detection sensor.

15 Preferably, the real leak detection sensor is positioned at or close to the exported position.

20 According to a second aspect, the invention provides an apparatus comprising a digital computer, configured to perform the computer-implemented method according to the invention.

25 According to an advantageous embodiment, the apparatus comprises a user-interface which is configured to provide the ranking list of the modelled leak detection sensors for sensor positioning in the water network.

30 The invention further comprises a computer program product directly loadable into the internal memory of a digital computer, comprising software code portions for performing the steps of the said method when said product is run on a computer.

35 A computer program product, such as a computer program means, may be embodied as a memory card, USB stick, CD-ROM, DVD or as a file which may be downloaded from a server. For example, such a file may be provided by transferring the file comprising the computer program product from a wireless communication network.

Embodiments of the invention will be explained in more detail by reference to the accompanying figures.

5 Fig. 1 shows a first flow chart including method steps involved in an embodiment of a method for sensor positioning for leak detection in a water network according to the invention;

10 Fig. 2 shows a second flow chart including method steps involved in an embodiment of a method for sensor positioning for leak detection in a water network according to the invention; and

15 Fig. 3 shows a schematic diagram of an embodiment of an apparatus for sensor positioning for leak detection in a water network according to the invention.

Equivalent parts in the different figures are labeled with the same reference signs.

20 Figure 1 shows a flow chart including method steps involved in an embodiment of a method for sensor positioning for leak detection in a water network according to the invention.

25 The first step 10 involves receiving a hydraulic model for the water network. The hydraulic model is based on a water network model, wherein the water network model comprises modelled pipes and nodes of the real water network. Preferably the water network model is computer-readable and generated
30 based on measured water network data such as topology information. Preferably the water network model and therefore the hydraulic model comprises information for at least a subnet of the real water network, wherein the subnet can be defined by calculable inflow and outflow shares for a closed net of
35 pipes. The advantage of modelling merely a closed subnet of the real water network lies in predictability of flows resulting in a higher leak detection accuracy.

The hydraulic model is preferably provided as a computer-readable data structure comprising parameters which specify the hydraulic properties of the modelled part of the water network. Preferably the hydraulic model is based on a load
5 model specifying the inflow and outflow rates of the real water network.

The next step 20 involves performing a hydraulic simulation for the water network based on the hydraulic model. Preferably the hydraulic simulation is executed at least twice,
10 wherein firstly the hydraulic simulation is executed without introducing leaks and secondly at least one leak is simulated. Leaks are preferably modelled at position of nodes, e.g., consumer nodes. The size or strength of a leak is preferably determined by a defined consumption. It is further
15 preferably assumed, that leak detection sensors, e.g. flow meters, can be positioned at positions of pipes. Therefore, by determining the effect of a leak on the flow through a pipe, the required sensor sensitivity of a sensor placed at the position of that pipe can be determined. The effect of a
20 leak on a pipe results in a difference of water flow through the pipe. Based on said difference in water flow, a required sensitivity of a potential sensor placed at the position of said pipe can be deduced.

25

The next step 30 involves the analysis of the hydraulic simulation. Based on the hydraulic simulation, total sensor sensitivities to modelled leaks are determined. For example, a comparison of the executed simulation without modelled leaks
30 to the executed simulation comprising modelled leaks, the effect of leaks on the water flows through pipes can be evaluated. The quotient, difference quotient or difference of such a flow through a pipe shows the effect of a leak on said pipe and can be considered for example as the potential sensitivity of a sensor to said leak. In other words, based on
35 the hydraulic simulation, the quotient, difference quotient or difference in water flow due to at least one leak on a respective pipe can be determined yielding a potential sensor sensitivity for a sensor placed at the position of that pipe.

Preferably, a number of potential leaks are modelled and included in the hydraulic simulation. For a respective modelled leak, sensor sensitivities for a number of pipes to the
5 respective leak are determine. Subsequently, the determined sensor sensitivities are sorted for example in a decreasing order and multiplied with their respective sorting index, generating modified sensor sensitivities. Hence, the modified
10 sensor sensitivities result from weighted sensor sensitivities. The weighting of the sensor sensitivity is based on the sorting index.

For a respective modelled leak detection sensor, a total sensor sensitivity is subsequently calculated by combining, e.g.
15 multiplying, the respective modified sensor sensitivities for that sensors.

In the next step 40 the total sensor sensitivities for all modelled sensors are provided and at least one modelled leak
20 detection sensor is selected based on its respective total sensor sensitivity. Preferably, a ranking list of the total sensitivities is generated, step 50, and the most sensitive sensor is selected from that ranking list based on a predefined sensitivity threshold, step 60. The position of that selected
25 sensor can further be provided, step 70, for sensor positioning in the real water network. The sensor position can for example be provided by means of a user-interface such that a real leak detection sensor with a corresponding sensitivity can be positioned in the real water network, step 80.

30
The entry of the selected sensor is removed from the ranking list and the ranking list is updated, step 90, by repeating the steps 30 to 70, wherein preferably only remaining leaks which fall below the sensitivity threshold are modelled and
35 sensor sensitivities are determined only for these remaining sensors. In other words, preferably, all leaks having a size above the sensitivity threshold, and which may therefore be considered to be detected by the selected sensors, are remo-

ved from the simulation and/or not further considered when updating the ranking list.

5 Figure 2 shows a second flow chart including method steps involved in an embodiment of a method for sensor positioning for leak detection in a water network according to the invention.

10 First, a computer-readable water network model WNM is provided. The water network model WNM preferable represents the real water network or at least a subnet of the real water network. The water network model WNM is preferably simplified with respect to the real water network, wherein for example
15 pipes without intersections are modelled as one pipe and/or single tap offs are removed. Consumers and leaks can be modelled in nodes.

Further, a load model LM for the water network is provided. The load model LM can be generated based on measured and estimated annual flow quantities.
20

For example, the load model LM can be generated comprising the following steps. Firstly, based on measured annual flow quantities of the inflows of the water network the distribution, i.e. a percentage value, of the water inflow is calculated.
25 The percentage value is used as the mean value for a normal distribution of the inflow distribution. The according standard deviation can be decided depending on specific network situations, e.g. such that 1 sigma results to 5 percentage points. This formulates the distribution to calculate
30 the split of water inflow. If measured annual values are not available, a typical actual distribution can be used as a replacement for the mean value. Secondly, based on measured annual consumption values of all consumers, the actual water
35 outflow rate for each node is calculated in e.g. liter per second (l/s). This value is used in a further normal distribution, with the actual water outflow rate as a mean value. The standard deviation can be set depending of specific network situations, e.g. such that 1 sigma results to 5% of the

actual value. This setup formulates the distribution to calculate the water consumption.

5 The inflow rates are computed in liter/second by using the percentage values of the inflow and the total sum of all consumption values.

10 Based on the water network model WNM and the load model LM a steady state hydraulic model HM is generated, and as hydraulic simulation HS is executed based on the hydraulic model HM. Preferably, at least two hydraulic simulations are set up and executed, wherein one comprises modelled leaks and the other is modelled without leaks in order to determine water flow difference in the pipes due to a leak. In other words, 15 the different flow through a pipe due to a leak somewhere in the water network specifies the required sensitivity of a leak detection sensor at the position of that pipe for detecting that leak. Therefore, in order to determine a sensor sensitivity, the flow difference is determined based on the 20 hydraulic simulation.

The hydraulic simulation results are further evaluated to determine optimal positions for leak detection sensors. For each modelled leak L_1, L_2, \dots, L_N , sensor sensitivities S_1, S_2, \dots, S_N for respective sensors positioned at the position of a pipe are determined. For example, a larger effect, i.e. flow difference, is expected for pipes close to a leak than for pipes farther away, resulting in higher sensor sensitivities for sensors placed closer to the leak. The resulting 25 sensor sensitivities S_1, S_2, \dots, S_N for the respective leak L_1 are sorted in a decreasing order and subsequently weighted, e.g., multiplied, by the respective sorting index, generating modified sensor sensitivities mS_1, mS_2, \dots, mS_N . A corresponding procedure is performed for the other modelled leaks L_2, L_3, \dots, L_N . 35

The resulting modified sensor sensitivities mS_1, mS_2, \dots, mS_N are combined to total sensor sensitivities TS_1, TS_2, \dots, TS_N for each respective sensor. The total sensor sensitivity

therefore specifies the required sensitivity of a respective sensor to detect modelled leaks of a specific size. Preferably a ranking list RL is generated comprising the total sensor sensitivities TS1, TS2, ..., TN and respective positions of the sensors, i.e. the position of the respective evaluated pipe. The ranking list RL can for example be ordered in decreasing order based on the total sensor sensitivity values. Preferably, a real sensor can be placed at the position corresponding to the highest total sensitivity of a modelled sensor.

The ranking list RL can preferably be recalculated when at least one sensor is selected from the list based on a sensitivity threshold. The recalculation of the list comprises determining the sensor sensitivities by considering only leaks not well-detected by the sensors placed so far. Preferably this process is repeated until sensors are placed to detect all modelled leaks.

Figure 3 shows a schematic diagram of an embodiment of an apparatus 100 for sensor positioning for leak detection in a water network according to the invention. The apparatus comprises a digital computer P which is configured to perform a computer-implemented method according to the invention. The apparatus 100 preferably comprises an interface IF configured to receive for example a hydraulic model for a water network. The apparatus further comprises preferably a storage unit S configured to store and provide for example a hydraulic model for a water network. The apparatus 100 comprises preferably a user-interface UI configured to provide the sensor positioning information, e.g., a ranking list for the leak detection sensors for positioning real sensors in a water network.

Although the present invention has been described in detail with reference to the preferred embodiment, it is to be understood that the present invention is not limited by the disclosed examples, and that numerous additional modifications and variations could be made thereto by a person skill-

led in the art without departing from the scope of the invention.

Patent claims

1. Computer-implemented method for sensor positioning for leak detection in a water network, comprising the steps:

- 5 (a) receiving (10) a hydraulic model (HM) for the water network, wherein pipes and nodes of the water network are modelled based on a water network model (WNM),
- (b) performing (20) a hydraulic simulation (HS) for the water network using the hydraulic model (HM),
- 10 (c) based on the hydraulic simulation (HS), determining (30) total sensor sensitivities (TS1, TS2, ..., TSN) to modelled leaks (L1, L2, ..., LN) for modelled leak detection sensors wherein
- for a respective modelled leak (L1, L2, ..., LN), sensor sensitivities (S1, S2, ..., SN) to said leak are determined, these
- 15 sensor sensitivities are sorted and respective modified sensor sensitivities (mS1, mS2, ..., mSN) are generated based on the respective sorting index,
- and,
- for a respective leak detection sensor, a total sensor sensitivity (TS1, TS2, ..., TSN) is calculated by combining the
- 20 respective modified sensor sensitivities (mS1, mS2, ..., mSN),
- and
- (d) selecting (40) at least one modelled leak detection sensor based on the respective total sensor sensitivity (TS1,
- 25 TS2, ..., TSN) and exporting its respective sensor position for positioning of a real leak detection sensor in the water network.

- 30 2. Computer-implemented method according to claim 1 wherein a ranking list (RL) for the respective modelled leak detection sensors is exported, wherein the ranking is based on the respective total sensor sensitivities (TS1, TS2, ..., TSN), and wherein the ranking list (RL) comprises the corresponding
- 35 sensor positions.

3. Computer-implemented method according to one of the preceding claims wherein a sensitivity threshold is applied (60) to the total sensor sensitivities (TS1, TS2, ..., TSN) listed

in the ranking list (RL) and at least one leak detection sensor is selected (70) from the ranking list (RL) based on the sensitivity threshold, and the sensor position of the selected leak detection sensor is provided by means of a user-
5 interface for sensor positioning in the water network.

4. Computer-implemented method according to claim 3, wherein the at least one selected leak detection sensor is removed from the ranking list and the ranking list (RL) is updated by
10 recalculating (90) the total sensor sensitivities.

5. Computer-implemented method according to claim 1, wherein the hydraulic model (HM) is based on a load model (LM) for the water network, wherein the load model (LM) comprises in-
15 flow and outflow rates of the water network.

6. Computer-implemented method according to claim 5, wherein the load model (LM) is generated comprising the steps:
- calculating the distribution of inflow shares for a respective inlet pipe based on measured and/or estimated annual
20 flow quantities for the water network,
- calculating the outflow rates for a respective node based on measured annual consumption of consumers,
and
25 - calculating the inflow rates based on the inflow shares and the outflow rates.

7. Computer-implemented method according to claim 1 or 5 wherein the hydraulic model (HM) is a steady state hydraulic
30 model.

8. Computer-implemented method according to one of the preceding claims wherein the hydraulic model (HM) is simplified compared to the real water network by modelling multiple
35 pipes as single pipes and/or removing single taps and/or projecting a consumer load into a neighboring node.

9. Computer-implemented method according to claim 1, wherein the water network model (WNM) is computer-readable and gene-

rated based on measured water network data and for at least a closed subnet of the water network.

5 10. Computer-implemented method according to one of the preceding claims wherein a real leak detection sensor is positioned in a water network based on the exported position of the selected modelled leak detection sensor.

10 11. Apparatus (100) comprising a digital computer (P), configured to perform the computer-implemented method according to at least one of the claims 1 to 10.

15 12. Apparatus according to claim 11, wherein the apparatus comprises a user-interface (UI) which is configured to provide the ranking list of the modelled leak detection sensors for sensor positioning in the water network.

20 13. Computer program product directly loadable into the internal memory of a digital computer, comprising software code portions for performing the steps of at least one of the claims 1 to 10 when said computer program product is run on a computer.

Fig. 1

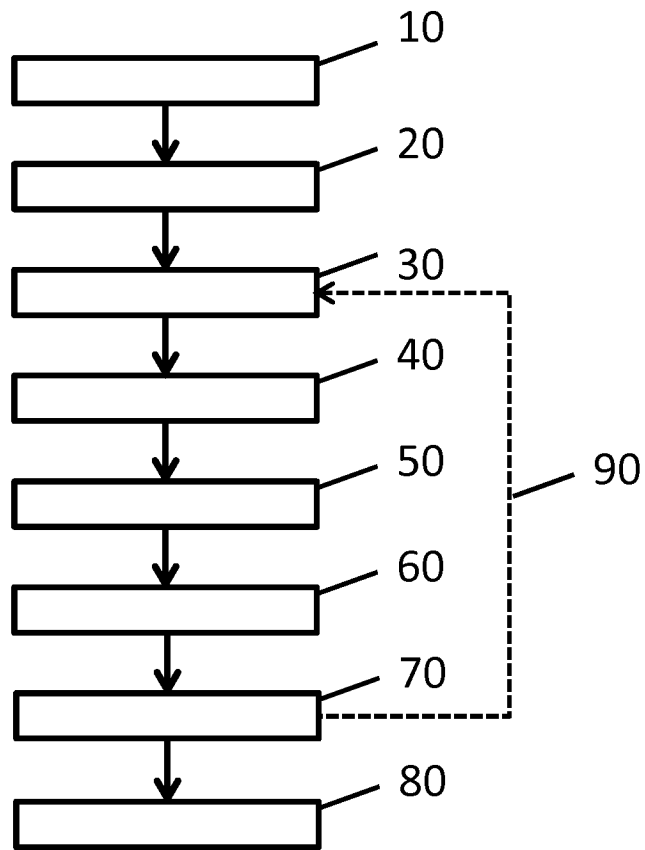


Fig. 2

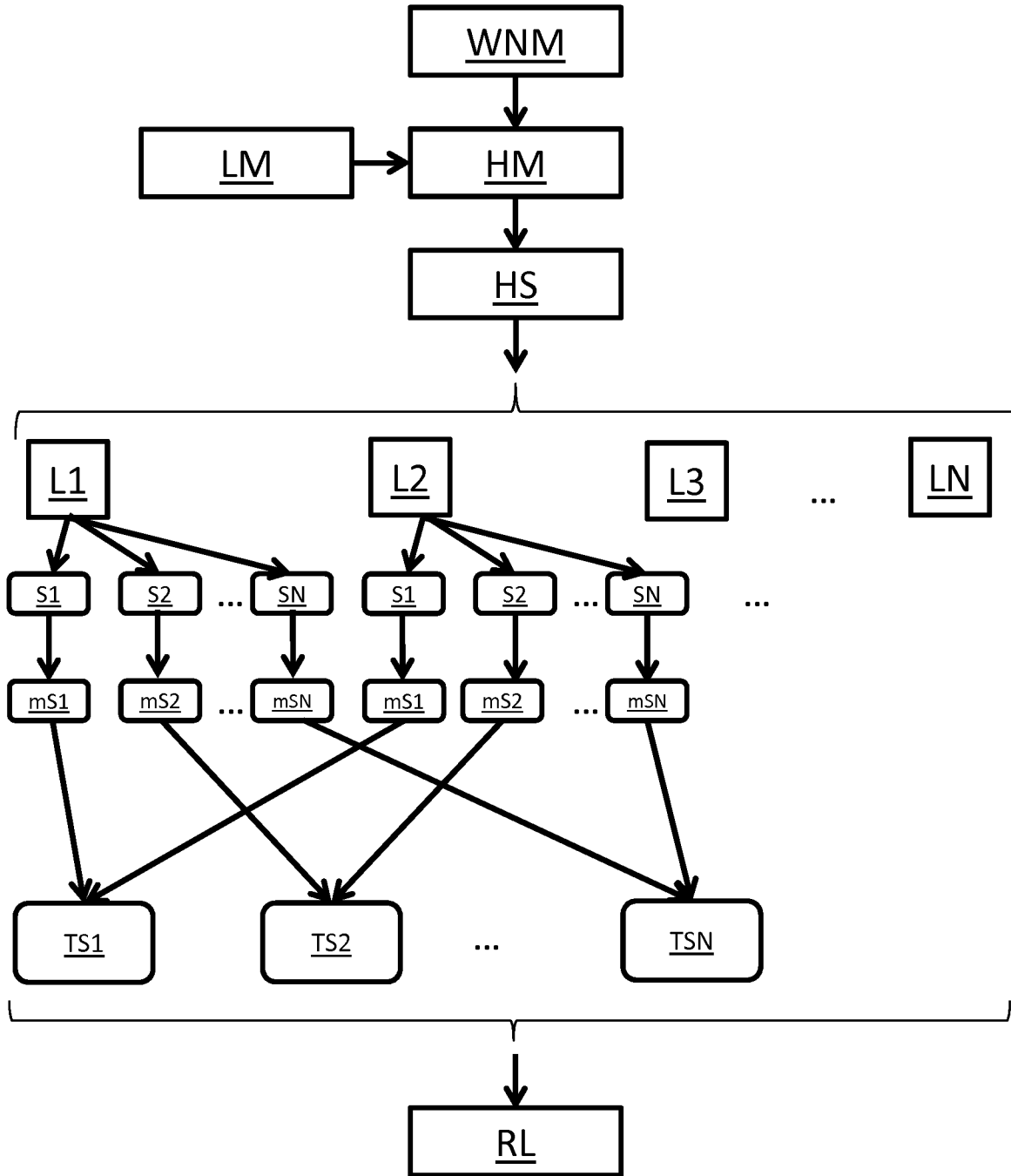
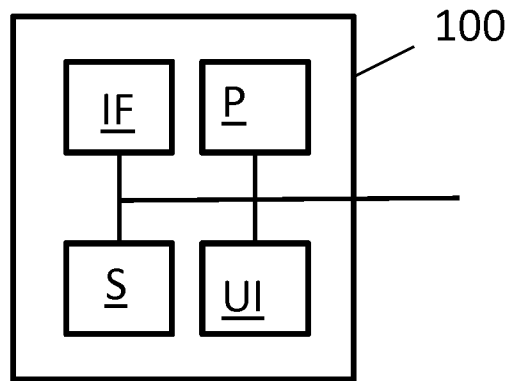


Fig. 3



INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. G01M3/28 G06F30/13 G06Q50/06
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
G01M G06F G06Q
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/262068 A1 (ISRAELI EITAN [IL] ET AL) 3 October 2013 (2013-10-03) paragraph [0025] - paragraph [0055]; figures 1-3	1-13
X	US 2014/163916 A1 (BA AMADOU [IE] ET AL) 12 June 2014 (2014-06-12) paragraph [0024] - paragraph [0059]; figures 1-3	1-13

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
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Date of the actual completion of the international search 30 April 2020	Date of mailing of the international search report 12/05/2020
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Gruss, Christian
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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/072346

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>RAMON PÃ REZ ET AL: "Methodology for leakage isolation using pressure sensitivity analysis in water distribution networks", CONTROL ENGINEERING PRACTICE, PERGAMON PRESS, OXFORD, GB, vol. 19, no. 10, 2 June 2011 (2011-06-02), pages 1157-1167, XP028274795, ISSN: 0967-0661, DOI: 10.1016/J.CONENGPRAC.2011.06.004 [retrieved on 2011-06-21] page 2, paragraph 2 - page 9, paragraph 7; figures 1-12</p> <p style="text-align: center;">-----</p>	1-13
X	<p>SARRATE RAMON ET AL: "Clustering techniques applied to sensor placement for leak detection and location in water distribution networks", 22ND MEDITERRANEAN CONFERENCE ON CONTROL AND AUTOMATION, IEEE, 16 June 2014 (2014-06-16), pages 109-114, XP032687045, DOI: 10.1109/MED.2014.6961356 ISBN: 978-1-4799-5900-6 [retrieved on 2014-11-18] page 1, paragraph 2 - page 5, paragraph 5; figures 1-5</p> <p style="text-align: center;">-----</p>	1-13
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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