



- (51) **International Patent Classification:**  
*G05B 19/00* (2006.01) *E03B 11/00* (2006.01)
- (21) **International Application Number:**  
PCT/AU2013/000355
- (22) **International Filing Date:**  
5 April 2013 (05.04.2013)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**  
2012901378 5 April 2012 (05.04.2012) AU
- (71) **Applicants:** RUBICON RESEARCH PTY LTD [AU/AU]; 1 Cato Street, Hawthorn, Victoria 3122 (AU). THE UNIVERSITY OF MELBOURNE [AU/AU]; 205-211 Grattan Street, Carlton, Victoria 3053 (AU).
- (72) **Inventors:** CHOY, Sumith; Unit 2, 25 Balmoral Avenue, Brunswick East, Victoria 3057 (AU). CANTONI, Michael William; 177 Edward Street, Brunswick, Victoria 3056 (AU). DOWER, Peter Maxwell; Unit 2, 140 Darebin Road, Northcote, Victoria 3070 (AU). KEARNEY, Michael Peter; 6 Copeland Street, Milton, Queensland 4064 (AU).
- (74) **Agents:** MACAULEY, Colin Douglas et al.; Callinans, 1193 Toorak Road, Camberwell, Victoria 3124 (AU).
- (81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

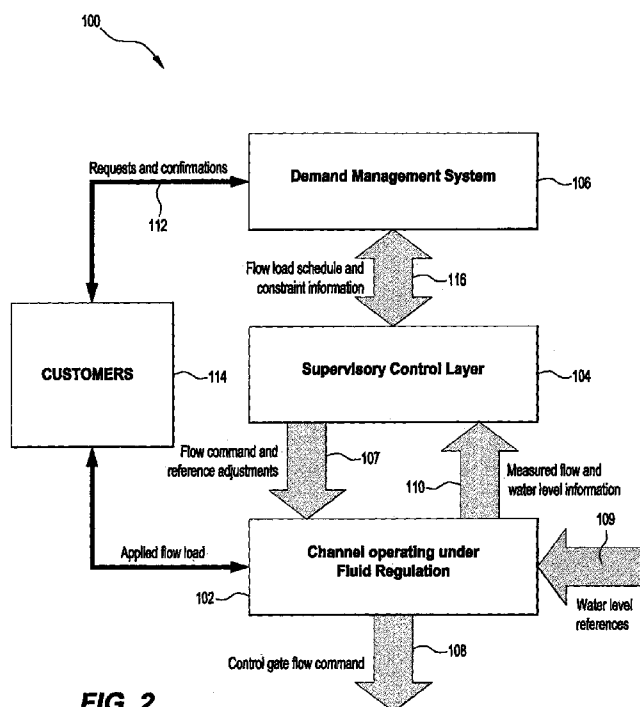
(54) **Title:** SUPERVISORY CONTROL OF AUTOMATED IRRIGATION CHANNELS

FIG. 2

(57) **Abstract:** The invention provides a method of delivery of fluid to at least one customer (114) through a computer controlled fluid network (100). The fluid network (100) has a plurality of regulators to control the flow of fluid along the fluid network (100) to deliver a predetermined amount of fluid to at least one customer (114). The network (100) includes a first control system (102) for opening and closing the regulators under computer control. The first control system (102) collects data based on timed measurements of fluid levels upstream and downstream of respective regulators and the opening positions of respective regulators, using data analysis to provide respective models for prediction of respective fluid levels between regulators. A second control system (104) that is a supervisory layer interacting with the first control system (102) to provide adjustments to the controlling of the regulators by the first control system (102) based on constraint and future flow load. A third control system interacting with the first (102) and second (104) control systems. The third control system (106) processing fluid delivery requests the at least one customer (114) to provide a flow load delivery schedule (118) based on the hydraulic capacity of the fluid network.



---

**Published:**

— with international search report (Art. 21(3))

— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

## SUPERVISORY CONTROL OF AUTOMATED IRRIGATION CHANNELS

### FIELD OF THE INVENTION

[0001] The present invention relates to a supervisory control system and method of supervisory control for fluid networks, and relates particularly, though not exclusively, to supervisory control systems for open conduits (channel networks) and closed conduits (pipelines).

### BACKGROUND OF THE INVENTION

[0002] In our US Patent No. 7,152,001, the entirety of which is herein incorporated, there is disclosed a computer based system for predicting the fluid level in a fluid flow network. The system has been very successful as it can use past and present measurements of parameters to predict and control fluid level and flow. The system gathers data from timed fluid levels and opening positions of regulators or valves to provide a model from which fluid levels and flow can be determined in real time. An irrigation channel is an open hydraulic system that serves to convey water from a source supply to end customers. Along the channel, flows and water levels are regulated via control gates situated at discrete points. Fig. 1 of US Patent No. 7,152,001 shows a side view of a typical channel regulated by overshot gates. The stretch of channel between gates 16, 18 is referred to as a pool. Water flows under the power of gravity, from a water source along the channel to farms. In view of this, the water levels along the channel correspond to the potential energy available to produce flow of water along the channel itself, into lateral distribution systems and onto land to be irrigated. It is therefore important to maintain the water levels above the levels required to meet flow demand.

[0003] The goal of automating an irrigation channel is to improve distribution efficiency in terms of the water taken from the supply and the water delivered to end customers. This is achieved by employing advanced instrumentation and control systems of the type shown in US Patent No. 7,152,001, which provide for a closer match between the water ordered by the farmers and the volume of the water moving through or flowing

into the channel system, while maintaining the water levels along the channel system within operational limits dictated by quality of service and safety concerns.

[0004] US Patent No. 7,152,001 includes sensors 24, 26, 28, 29 and actuators linked through a Supervisory Control and Data Acquisition (SCADA) communication network 44 and advanced control practices that work in conjunction with each other to achieve high distribution efficiency, reduce transmission losses and provide high level of service to the customer/farmer thereby yielding high productivity from water which is a limited resource. When a channel is fully automated, the channel control gates 16, 18 are operated in such a manner so as to meet the demand for water downstream of the control gates 16, 18 and to maintain the water level upstream of the gate or regulator in every pool. A certain level of water must be exceeded in each pool to provide the potential energy needed to propel water further downstream, into secondary channels and onto the adjacent farms. The volume of water flowing into the channel system is controlled at the upstream or top end. The volume of water flowing into the channel is increased if a drop in the water level is sensed in a given pool or is reduced if the water level rises ensuring a constant water level is maintained.

[0005] A reactive control strategy is employed to maintain the water level in pools at their set points, i.e. control action is taken only when the controlled variable (water level in a pool) deviates from its set point. This is often referred to as feedback control. Measured flow information at the downstream regulator 18 in a pool and at the lateral off takes and at the farm outlets (if available) can be exploited to augment the feedback controller and make the control system more responsive. Often referred to as feed forward control, the upstream gate 16 sends a percentage of the measured outflows immediately rather than waiting for the flows to affect the water level in the pool and the feedback controller to take action.

[0006] The reactive control architecture described above confines the propagation of transients to upstream of changes in flow load (i.e. an out flow starting or stopping). This has merit in terms of the corresponding demand driven release of water from the upstream source; i.e. water is released from the top only when there is an out flow due to an off take downstream and this is cut off when the off take stops. However, the achievable

transient performance is fundamentally limited by inherent transport delays, particularly in terms of transient peaking of control gate flow commands and deviation in water levels in response to an increase in flow load and similar undesirable effects when flow load is reduced.

[0007] Fig. 1 of the drawings shows a graph of a flow peak amplification along a channel operated using US Patent No. 7,152,001 for a 55 Megalitre/day step up 20 in flow from bottom control gate in the channel. The first and main limitation of the control strategy depicted in Fig. 1 is the limited transient flow characteristic. The peaks in the transient flows commands for the control gates 16 are amplified as the effect of a load change propagates upstream. Transient behaviour as depicted in Fig. 1 can result in actuator (i.e. control gate) saturation, thereby triggering undesired behaviour. This is the second limitation of the existing strategy used in US Patent No. 7,152,001. The mechanism to counter saturation, often called anti-windup in the control industry, is designed as an afterthought in US Patent No. 7,152,001 and this may not be very effective. In the case of long pools e.g. greater than 5 km that have limited storage volume, the flow transient may result in unacceptable water level deviations that may affect service to customers/farmers or it may violate safe operational limits. This is the third limitation of the existing strategy. The third limitation means that the existing control strategy cannot be applied to open irrigation channels with very limited freeboards. This is the fourth limitation. "Freeboard" is the height of the channel bank above the highest water level anticipated.

#### OBJECTS OF THE INVENTION

[0008] It is an object of the present invention to provide a method and system to accurately deliver water through an irrigation network to customers.

[0009] A further object of the invention is to provide a method or system where overheads to the delivery of water through an irrigation network are reduced.

## SUMMARY OF THE INVENTION

[0010] The present invention in one aspect provides a method of delivery of fluid to at least one customer through a computer controlled fluid network, said fluid network having a plurality of regulators to control the flow of fluid along said fluid network to deliver a predetermined amount of fluid to said at least one customer, said network including a first control system for opening and closing said regulators under computer control, said first control system collecting data based on timed measurements of fluid levels upstream and downstream of respective regulators and the opening positions of respective regulators, using data analysis to provide respective models for prediction of respective fluid levels between regulators, a second control system that is a supervisory layer interacting with said first control system to provide adjustments to the controlling of said regulators by said first control system based on constraint and future flow load, and a third control system interacting with said first and second control systems, said third control system processing fluid delivery requests from said at least one customer to provide a flow load delivery schedule based on the hydraulic capacity of said fluid network.

[0011] The invention also provides a delivery system for the delivery of fluid to at least one customer through a computer controlled fluid network, said fluid network having a plurality of regulators to control the flow of fluid along said fluid network to deliver a predetermined amount of fluid to said at least one customer, said network including a first control system for opening and closing said regulators under computer control, said first control system collecting data based on timed measurements of fluid levels upstream and downstream of respective regulators and the opening positions of respective regulators, said first control system adapted to use data analysis to provide respective models for prediction of respective fluid levels between regulators, a second control system that is a supervisory layer interacting with said first control system to provide adjustments to the controlling of said regulators by said first control system based on constraint and future flow load, and a third control system interacting with said first and second control systems, said third control system processing fluid delivery requests from said at least one customer to provide a flow load delivery schedule based on the hydraulic capacity of said fluid network.

[0012] In a preferred embodiment said second control system uses model predictive control to provide pre-emptive control.

[0013] Preferably data from a SCADA interface is used to calibrate and continually fine tune the computer controlled fluid network using a model of the pipe network based on system identification techniques.

[0014] The invention may also provide a method of delivery of fluid to at least one customer through a computer controlled fluid network, said fluid network having a plurality of regulators to control the flow of fluid along said fluid network to deliver a predetermined amount of fluid to said at least one customer, said network including a first control system for opening and closing said regulators under computer control, said first control system collecting data based on timed measurements of fluid levels upstream and downstream of respective regulators and the opening positions of respective regulators, using data analysis to provide respective models for prediction of respective fluid levels between regulators, and a second control system that is a supervisory layer interacting with said first control system to provide adjustments to the controlling of said regulators by said first control system based on constraint and future flow load.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The structure and functional features of a preferred embodiment of the present invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings, in which: -

[0016] Fig. 1 shows a graph of a flow peak amplification along a channel operated using the system described in US Patent No. 7,152,001 for a 55 Megalitre per day step up in flow from the bottom most regulator;

[0017] Fig. 2 is a schematic flow chart of a computer controlled fluid network in accordance with the concepts of the present invention; and

[0018] Fig. 3 is a similar view to that of Fig. 3 of US Patent No. 7,152,001 including features in accordance with the concepts of the present invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

[0019] The preferred embodiment is an enhancement of the inventions disclosed in US Patent No. 7,152,001 and Australian Patent Application No. 2011903084, now International Patent Application No. PCT/AU2012/000907 and any patent applications based on International Patent Application No. PCT/AU2012/000907. In order to reduce repetition of description, the whole contents of US Patent No. 7,152,001 and International Patent Application No. PCT/AU2012/000907 are herein incorporated into this specification.

[0020] Fig. 2 is a schematic flow chart of a computer controlled fluid network system 100 for open conduits, i.e. channel networks, especially for irrigation. The system has three (3) sub-systems, namely a first control system 102, a second control system 104 and a third control system 106. The first control system 102 is a fluid regulator system preferably of the type disclosed in US Patent No. 7,152,001 which is more fully disclosed and incorporated into this description from US Patent No. 7,152,001. The third control system 106 is a demand management system preferably of the type disclosed in International Patent Application No. PCT/AU2012/000907 which is more fully disclosed and incorporated into this description from International Patent Application No. PCT/AU2012/000907. The second control system 104 is a supervisory control system to be discussed shortly. The first control system 102 provides a control scheme and allows movement of a plurality of control gates (not shown) to set flow locally after a disturbance in the form of water level deviation or a measured outflow in the pool is observed. This operation is discussed in the preferred embodiment of US Patent No. 7,152,001. First control system 102 has control gate flow commands 108 for the opening of control gates (not shown). An approach to mitigating the limitations of reactive control architecture of this kind is to exploit available information about future flow demand. Allowing the control gate flow commands 108 produced by first control system 102 and the water level references 109 used in determining these commands to be adjusted by second control system 104, provides scope for systematically exploiting both measure off-take flows and a schedule of such flows into the future. Accordingly, the second control system 104 makes adjustments 107 to the control gate flow commands 108 and/or water-level references 109 in order to improve transient performance by ensuring the satisfaction of constraints, based

on measured information and a model of the automated channel, including a representation of future flow load, such as a schedule. The second control system 104 is the middle layer in a three-tier hierarchy, with the channel operating under first control system 102 at the lowest layer and the third control system 106, the demand management system, at the highest layer. The third control system 106 processes orders 112 from customers or farmers 114 to build up a flow load schedule 116.

[0021] A preferred embodiment of the supervisory control scheme that can achieve the objectives specified above, involves the use of a receding horizon optimal control technique often called Model Predictive Control (MPC) in the open literature for the third control system 106. It is particularly well suited to supervisory control problems of the kind mentioned above. Specifically, the MPC technique can directly incorporate predictions or a schedule of the flow load (demand) over a future horizon, as well as constraints on how the water level and references may vary across time. These features are ideally suited to providing quality-of-service guarantees at supply points, flood-free operation and the avoidance of actuator saturation, which can lead to very undesirable dynamic behaviour. That is, the features are ideally suited to mitigating the four limitations of the existing first control system 102 i.e. the fluid regulator system disclosed in US Patent No. 7,152,001.

[0022] As can be seen in Fig. 2, second control system 104 has knowledge of the future flow load schedule 116 and it obtains an estimate of the state of the first control system 102, via measured water level and flow information 110. This provides scope for taking pre-emptive control action in anticipation of future load (demand) in order to achieve improved transient performance, with quality of service guarantees via the satisfaction of constraints on water levels and flows.

[0023] The control scheme of the first control system 102 provides a degree of robustness against uncertainties such as model and instrumentation inaccuracies, transportation losses and customer/farmer non-compliance with the agreed flow load schedule via feedback based control action. The second control system 104 also employs feedback in decision making via the measured water level and flow information 110.

[0024] The hierarchical architecture of the three control systems 102,104,106 provides scope for exploiting the advantages of both worlds; pre-emptive control via second control system 104 that is a supervisory control layer that exploits the knowledge of future flow demand schedule using the preferred control implemented via MPC, for example, and reactive control via first control system 102. This is a first unique aspect of the solution. The additional supervisory control layer of the second control system 104 in the hierarchy will enable further exploitation of the capability of the fluid network system by the use of available storage to surcharge the network in anticipation of a future load change, via adjustment of water-level references 109 and by varying the flow commands 108 of first control system 102.

[0025] The use of MPC techniques to implement a supervisory control layer in second control system 104 for a lower-level reactive water-level regulation controller of the first control system, with a view to exploit information regarding the load schedule agreed between the customers 114 and a demand management system in the third control system 106 so as to improve transient performance, is a second unique aspect of the solution.

[0026] As previously discussed MPC is a receding horizon optimal control technique. Within the context of Fig. 2, this means that before each update time, the adjustment to the flow command or water-level reference 107 is determined by solving a constrained optimization problem. This occurs each time the flow commands and reference water levels 107 are to be updated. The optimization problem solved at each time step involves a model for the channel operating under the first control system 102, which includes the effect of the schedule load over a prediction horizon into the future. The model is initialized using observer-based estimates of the state, derived via measurements of the water levels and flows along the channel. The optimization problem solved for each update time involves a cost function to steer the solution to desirable transient characteristics and constraints on water-levels and flows, which avoid the performance degrading effects of actuator saturation and which lead to quality of service and safe operation guarantees. The ability to make such guarantees is a third unique aspect of the solution.

[0027] The building blocks of the MPC are the channel models and controller models that underpin the design of the first control system as described in US Patent No. 7,152,001. The channel models are grey box (part physics based part data based) models with good predictive capabilities. The usage of grey box models is fourth unique aspect of the solution. A common practice in the automation industry is to use black box models based on a step response. All the abilities of the invention discussed in columns 8 and 9 of US Patent No. 7,152,001 are applicable to MPC as well since MPC is built using the models and controllers described in US Patent No. 7,152,001.

[0028] The preferred Model Predictive Controller of second control system 104 will seamlessly integrate with the SCADA and computer environment discussed at column 6 of US Patent No. 7,152,001. A copy of "Fig. 3" from US Patent No. 7,152,001, augmented to include an MPC implementation of the supervisory control layer of second control system 104, is shown as Fig. 3 of the present application. The architecture of deploying MPC as a supervisory control layer as shown in Fig. 3 is a fifth unique aspect of the solution. Fig. 3 uses the identical reference numerals used in Fig. 3 of US Patent No. 7,152,001 and discussion of reference numerals 42 to 54 are fully described in US Patent No. 7,152,001 and do not require further repetition of description. As can be seen second control system 104 is linked to pool construction module 54, LQR controller software module, the SCADA module 44, main database 46 and third control system 106. Similarly, third control system 106 is linked to network topology software 52, second control system 102, main database 46 and user interface 48. This integration of second and third control systems provides a complete irrigation control system as opposed to the fluid regulation system of US Patent No. 7,152,001.

#### Glossary of terms

[0029] "Black box model" – Model based on pure input and output behaviour of the system without any knowledge of actual physics

[0030] "Demand" – Flow load on the fluid network system

[0031] “Grey box model” – Model based on physics of the system and experimental data

[0032] “Off-take” – A channel for taking away water. An off-take can be a farmer outlet or a secondary irrigation channel taking water off the main irrigation channel

[0033] “Transient response” – behavior of a control system for a change in its load or set point

[0034] “Set point” – Desired level/band at/within which the controlled variable should be maintained

[0035] “Step response”- Step response is the time behavior of the outputs of a system when its inputs change from zero to a non-zero value in a very short time

[0036] The invention will be understood to embrace many further modifications as will be readily apparent to persons skilled in the art and which will be deemed to reside within the broad scope and ambit of the invention, there having been set forth herein only the broad nature of the invention and certain specific embodiments by way of example.

## CLAIMS

1. A method of delivery of fluid to at least one customer through a computer controlled fluid network, said fluid network having a plurality of regulators to control the flow of fluid along said fluid network to deliver a predetermined amount of fluid to said at least one customer, said network including a first control system for opening and closing said regulators under computer control, said first control system collecting data based on timed measurements of fluid levels upstream and downstream of respective regulators and the opening positions of respective regulators, using data analysis to provide respective models for prediction of respective fluid levels between regulators, a second control system that is a supervisory layer interacting with said first control system to provide adjustments to the controlling of said regulators by said first control system based on constraint and future flow load, and a third control system interacting with said first and second control systems, said third control system processing fluid delivery requests from said at least one customer to provide a flow load delivery schedule based on the hydraulic capacity of said fluid network.
2. The method of claim 1, wherein said second control system uses model predictive control to provide pre-emptive control.
3. The method of any one of the preceding claims, wherein said first control system includes a SCADA interface that collects said data used to calibrate and continually fine tune the computer controlled fluid network using a model of the pipe network based on system identification techniques.
4. A delivery system for the delivery of fluid to at least one customer through a computer controlled fluid network, said fluid network having a plurality of regulators to control the flow of fluid along said fluid network to deliver a predetermined amount of fluid to said at least one customer, said network including a first control system for opening and closing said regulators under computer control, said first control system collecting data based on timed measurements of fluid levels upstream and downstream of respective regulators and the opening positions of respective regulators, said first control system adapted to use data analysis to provide respective models for prediction of

respective fluid levels between regulators, a second control system that is a supervisory layer interacting with said first control system to provide adjustments to the controlling of said regulators by said first control system based on constraint and future flow load, and a third control system interacting with said first and second control systems, said third control system processing fluid delivery requests from said at least one customer to provide a flow load delivery schedule based on the hydraulic capacity of said fluid network.

5. The delivery system of claim 4, wherein said second control system uses model predictive control to provide pre-emptive control.

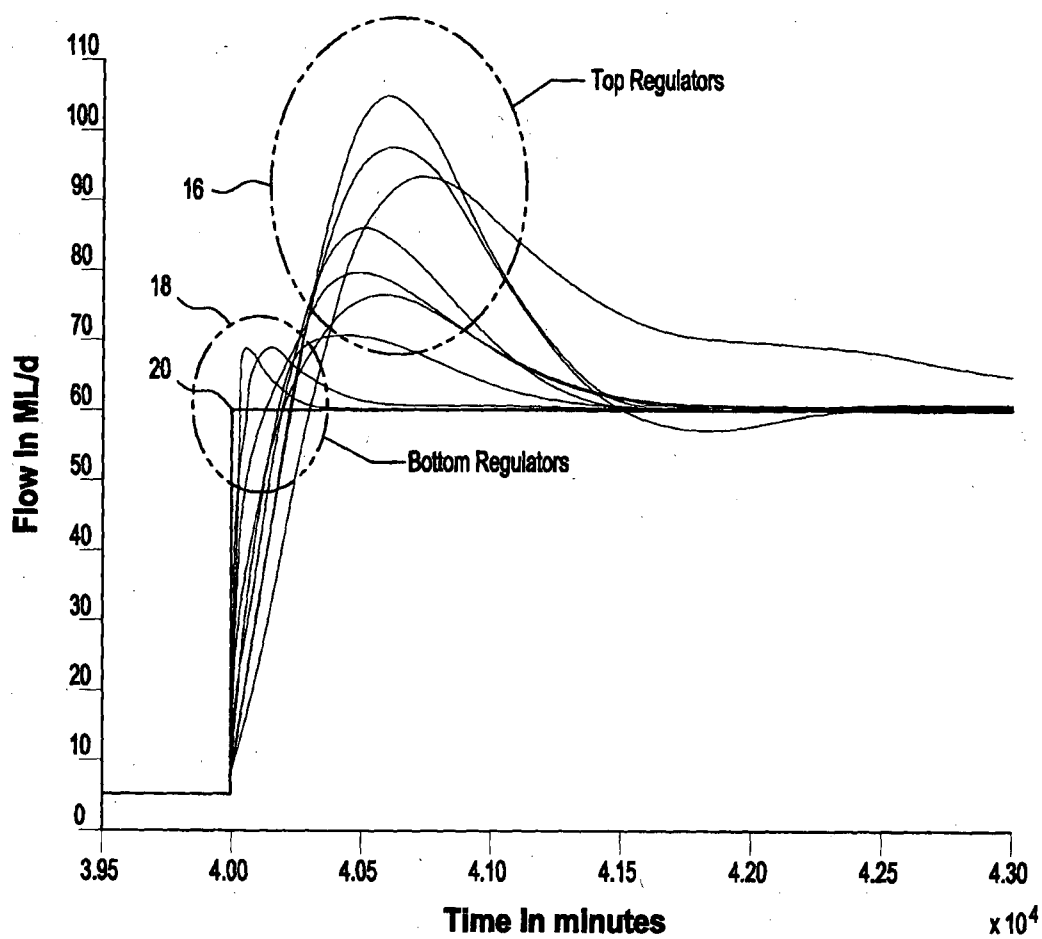
6. The delivery system of claims 4 or 5, wherein said first control system includes a SCADA interface that collects said data used to calibrate and continually fine tune the computer controlled fluid network using a model of the pipe network based on system identification techniques.

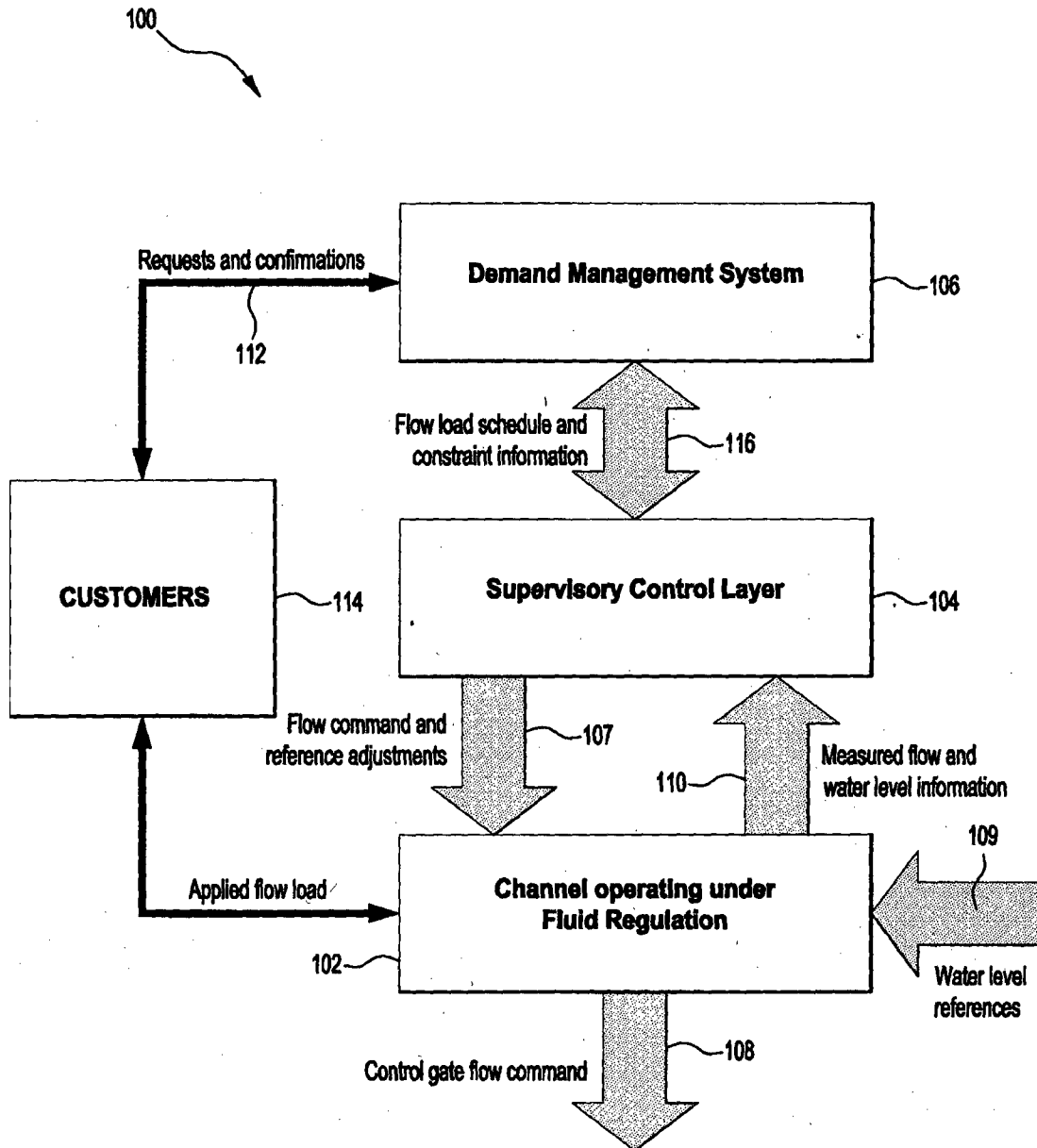
7. A method of delivery of fluid to at least one customer through a computer controlled fluid network, said fluid network having a plurality of regulators to control the flow of fluid along said fluid network to deliver a predetermined amount of fluid to said at least one customer, said network including a first control system for opening and closing said regulators under computer control, said first control system collecting data based on timed measurements of fluid levels upstream and downstream of respective regulators and the opening positions of respective regulators, using data analysis to provide respective models for prediction of respective fluid levels between regulators, and a second control system that is a supervisory layer interacting with said first control system to provide adjustments to the controlling of said regulators by said first control system based on constraint and future flow load.

8. The method of claim 7 further including a third control system interacting with said first and second control systems, said third control system processing fluid delivery requests from said at least one customer to provide a flow load delivery schedule based on the hydraulic capacity of said fluid network.

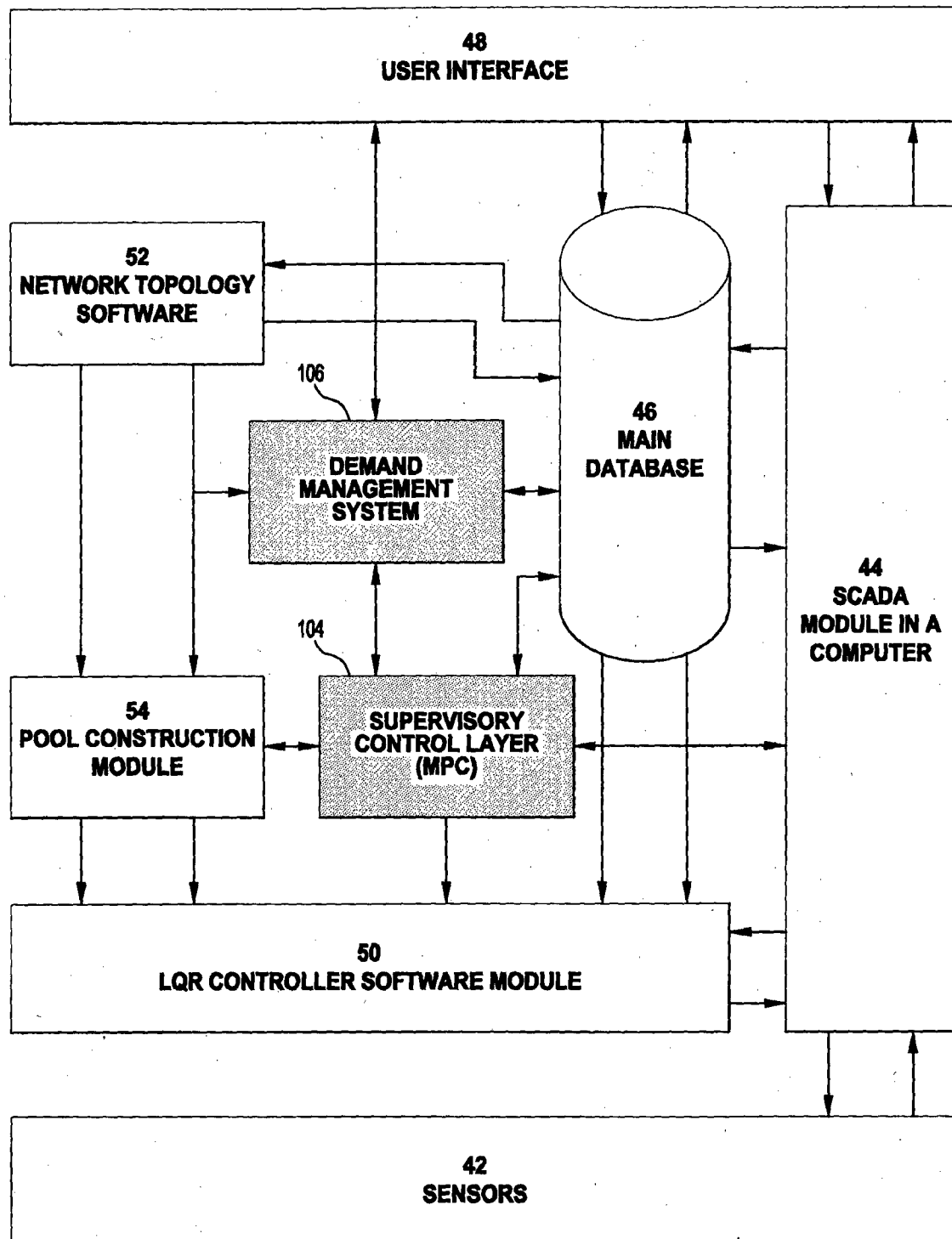
9. A delivery system for the delivery of fluid to at least one customer through a computer controlled fluid network, said fluid network having a plurality of regulators to control the flow of fluid along said fluid network to deliver a predetermined amount of fluid to said at least one customer, said network including a first control system for opening and closing said regulators under computer control, said first control system collecting data based on timed measurements of fluid levels upstream and downstream of respective regulators and the opening positions of respective regulators, said first control system adapted to use data analysis to provide respective models for prediction of respective fluid levels between regulators, and a second control system that is a supervisory layer interacting with said first control system to provide adjustments to the controlling of said regulators by said first control system based on constraint and future flow load.

10. The delivery system of claim 9, further including a third control system interacting with said first and second control systems, said third control system processing fluid delivery requests from said at least one customer to provide a flow load delivery schedule based on the hydraulic capacity of said fluid network.

**FIG. 1**

**FIG. 2**

3/3

**FIG. 3**

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/AU2013/000355**

## A. CLASSIFICATION OF SUBJECT MATTER

**G05B 19/00 (2006.01) E03B 11/00 (2006.01)**

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)

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)

WPI, EPODOC, INSPEC: control, regulate, valve, fluid, demand, system, feedback, feed forward, compensation and similar keywords.

Google Patents, Google Scholar & [Esp@cenet](http://Esp@cenet) were also searched with similar keywords as above.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|------------------------------------------------------------------------------------|-----------------------|
|           | Documents are listed in the continuation of Box C                                  |                       |



Further documents are listed in the continuation of Box C



See patent family annex

|          |                                                                                                                                                                     |     |                                                                                                                                                                                                                                              |
|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| *<br>"A" | Special categories of cited documents:<br>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                                                                     |
| "L"      | document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) | "Y" | document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art |
| "O"      | document referring to an oral disclosure, use, exhibition or other means                                                                                            | "&" | document member of the same patent family                                                                                                                                                                                                    |
| "P"      | document published prior to the international filing date but later than the priority date claimed                                                                  |     |                                                                                                                                                                                                                                              |

Date of the actual completion of the international search  
22 August 2013

Date of mailing of the international search report  
22 August 2013

## Name and mailing address of the ISA/AU

AUSTRALIAN PATENT OFFICE  
PO BOX 200, WODEN ACT 2606, AUSTRALIA  
Email address: [pct@ipaustalia.gov.au](mailto:pct@ipaustalia.gov.au)  
Facsimile No.: +61 2 6283 7999

## Authorised officer

Riju Jacob  
AUSTRALIAN PATENT OFFICE  
(ISO 9001 Quality Certified Service)  
Telephone No. 0262832220

| INTERNATIONAL SEARCH REPORT                           |                                                                                                                                                 | International application No. |
|-------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|
| C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                 | PCT/AU2013/000355             |
| Category*                                             | Citation of document, with indication, where appropriate, of the relevant passages                                                              | Relevant to claim No.         |
| A                                                     | EP 2175332 A2 (EMERSON PROCESS MANAGEMENT POWER & WATER SOLUTIONS, INC.) 14 April 2010<br>Abstract, paras 0008-0031, 0034-0056 and figures 2-9. | 1-10                          |
| A                                                     | JP S5968415 A (FUJI ELECTRIC CO. LTD et al.) 18 April 1984<br>Whole document                                                                    | 1-10                          |
| A                                                     | US 2010/0204808 A1 (THIELE) 12 August 2010<br>Whole document                                                                                    | 1-10                          |
| A                                                     | US 5472312 A (TAKEDA et al.) 05 December 1995<br>Whole document                                                                                 | 1-10                          |
|                                                       |                                                                                                                                                 |                               |

Form PCT/ISA/210 (fifth sheet) (July 2009)

| <b>INTERNATIONAL SEARCH REPORT</b><br>Information on patent family members                                                                                                                                                                                            |                  | International application No.<br><b>PCT/AU2013/000355</b> |                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-----------------------------------------------------------|------------------|
| This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information. |                  |                                                           |                  |
| Patent Document/s Cited in Search Report                                                                                                                                                                                                                              |                  | Patent Family Member/s                                    |                  |
| Publication Number                                                                                                                                                                                                                                                    | Publication Date | Publication Number                                        | Publication Date |
| EP 2175332 A2                                                                                                                                                                                                                                                         | 14 Apr 2010      | CN 101713988 A                                            | 26 May 2010      |
|                                                                                                                                                                                                                                                                       |                  | EP 2175332 A2                                             | 14 Apr 2010      |
|                                                                                                                                                                                                                                                                       |                  | GB 2464181 A                                              | 14 Apr 2010      |
|                                                                                                                                                                                                                                                                       |                  | US 2010087933 A1                                          | 08 Apr 2010      |
|                                                                                                                                                                                                                                                                       |                  | US 7930045 B2                                             | 19 Apr 2011      |
| JP S5968415 A                                                                                                                                                                                                                                                         | 18 Apr 1984      | JP S6216283 B2                                            | 11 Apr 1987      |
| US 2010/0204808 A1                                                                                                                                                                                                                                                    | 12 Aug 2010      | GB 2479315 A                                              | 05 Oct 2011      |
|                                                                                                                                                                                                                                                                       |                  | JP 2012517052 A                                           | 26 Jul 2012      |
|                                                                                                                                                                                                                                                                       |                  | US 2010204808 A1                                          | 12 Aug 2010      |
|                                                                                                                                                                                                                                                                       |                  | US 8200346 B2                                             | 12 Jun 2012      |
|                                                                                                                                                                                                                                                                       |                  | WO 2010088693 A1                                          | 05 Aug 2010      |
| US 5472312 A                                                                                                                                                                                                                                                          | 05 Dec 1995      | EP 0616277 B1                                             | 01 Oct 1997      |
|                                                                                                                                                                                                                                                                       |                  | JP H06149306 A                                            | 27 May 1994      |
|                                                                                                                                                                                                                                                                       |                  | JP 2988163 B2                                             | 06 Dec 1999      |
|                                                                                                                                                                                                                                                                       |                  | NO 933901 A                                               | 02 May 1994      |
|                                                                                                                                                                                                                                                                       |                  | US 5375969 A                                              | 27 Dec 1994      |
|                                                                                                                                                                                                                                                                       |                  | US 5472312 A                                              | 05 Dec 1995      |
| <b>End of Annex</b>                                                                                                                                                                                                                                                   |                  |                                                           |                  |
|                                                                                                                                                                                                                                                                       |                  |                                                           |                  |
| Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.<br>Form PCT/ISA/210 (Family Annex)(July 2009)                                                                                               |                  |                                                           |                  |