

Systems and Methods for Optimizing Control Systems for a Process Environment

Field of the Invention

[001] The invention relates to the field of control systems including industrial or other process control systems. In particular the invention generates efficient control system and equipment (i.e. process control equipment and / or any other physical equipment) topologies based on heterogeneous control system data, and implements the generated topologies for the purposes of process environment control.

Background

[002] Control system engineering refers to a domain of engineering that deals with architectures, mechanisms and algorithms for maintaining output of a specific system or process within a desired range. Automated control systems are used extensively in industry and for example can be achieved using programmable logic controllers (PLC(s)), or in the case of more complex systems using distributed control systems (DCS) or supervisory control and data acquisition systems (SCADA).

[003] Automated control systems rely on one or more controllers communicatively coupled to one or more field devices. Field devices (e.g. sensors, valves, switches, receivers and transmitters) are located within the process environment corresponding to the control system (for example, but not limited to, an industrial plant or system) and may be configured to perform physical or process control functions to control one or more components, processes or variables under observation within the process environment. Process controllers may be located within the process environment and are configured to receive signals from field devices, make control decisions, generate control signals and communicate with field devices.

[004] Existing control systems rely on data received from field devices within the process environment and on archival of such data. Data generated by controllers or field devices within a process environment are stored in a plurality of specifically designated databases(e.g. data historians or data silos). These plurality of databases are independent and heterogeneous, in that they may differ from one another with respect to platform, or computer system in which they reside, data

model, storage, retrieval, language for implementation, interfaces and languages for querying and updating, schema, and data types. Among other reasons, the large number of heterogeneous field devices typically implemented within a control system results in data from the control system being stored in a wide variety of different data formats and at different frequencies.

[005] Data from heterogeneous databases within a control system may be extracted in an automated process, and thereafter consolidated and interpreted in a manner that identifies relationships between multiple data points within a process environment – and which enables modelling of the process environment, optimizing system operations, problem detection, problem analysis, remedial action and/or predictive modelling based on the identified relationships. However as a result of each data point within a control system having multiple relationships and associations with other data points, the resulting control system models represent all relationships and associations as being equally significant. The resulting control system models have been found to be overpopulated in terms of relationships and associations, and have also been found to be less effective in enabling a system, user or operator to discriminate between significant and insignificant relationships or associations within the control system models.

[006] There is accordingly a need for control system models that enable identification of significant relationships and / or associations within a control system model, and which enable elimination or pruning of insignificant relationships / associations (resulting in more efficient control system modelling), or which enable a system or system operator to select an event response based on significance of a relationship between entities within a control system model.

Summary

[007] The present invention enables methods, systems and computer program products for control system optimization.

[008] In a method embodiment, the invention comprises retrieving from a control system information repository, information corresponding to an implemented control system. Based on the retrieved information, the invention identifies (a) a plurality of function blocks corresponding to the implemented control system, and (b) equipment components related to the plurality of function

blocks. The plurality of function blocks are grouped into a plurality of function block groups, wherein grouping of function blocks within each function block group is based on identification of one or more attributes shared by each function block within said function block group. A plurality of equipment component groups are generated - wherein (c) each equipment component group corresponds uniquely to one function block group, and (d) each equipment component group includes one or more equipment components selected such that said one or more equipment components are related to one or more function blocks within a function block group that uniquely corresponds to said equipment component group. Within each equipment component group, the invention identifies interconnections between equipment components within said equipment component group. A control system topology may be generated based on the identified equipment components, and the identified interconnections between equipment components.

[009] The method may additionally comprise responding to detection of a first event within a process environment associated with the implemented control system by (i) identifying a first equipment component within the implemented control system, wherein the identified first equipment component is related to the detected first event, (ii) identifying a second equipment component within the implemented control system, wherein the identified second equipment component is related to the identified first equipment component and (iii) displaying one or more event notifications at a user interface, wherein the displayed one or more event notifications include information corresponding to both the first equipment component and the second equipment component. Identification of the second equipment component may be based on equipment component interconnection information retrieved from the control system topology.

[0010] Identification of interconnections between equipment components within an equipment component group may comprise analysing each possible pair of equipment components within said equipment group to determine existence of a relationship between said pair of equipment components.

[0011] In an embodiment, identification of interconnections between equipment components within an equipment component group may comprise applying association rule analysis to equipment parameter data corresponding to equipment components within said equipment component group. More specifically, identification of interconnections between equipment

components within an equipment component group may be based on one or more association scores resulting from the applied association rule analysis.

[0012] The control system topology may be generated based on a selected sub-set of the identified interconnections between equipment components. Selecting the sub-set of identified interconnections may comprise evaluating identified interconnections based on a predefined criteria.

[0013] In an embodiment, evaluating the identified interconnections based on a predefined criteria may include applying the predefined criteria to association scores resulting from the applied association analysis. In a particular embodiment, identified interconnections that do not satisfy the predefined criteria are omitted or eliminated from the generated control system topology.

[0014] In an invention embodiment, one or more association scores may comprise any of (i) a support score, (ii) a confidence score, (iii) a lift score, (iv) a chi square score, or (v) a unified score derived based on any of a support score, a confidence score, a lift score and a chi square score.

[0015] The method may additionally include identifying a plurality of clusters of equipment components within the generated control system topology. Identification of said clusters may be based on detection of community structure among equipment components within each cluster.

[0016] In an embodiment, information retrieved from the control system information repository may be retrieved from one or more of engineering documents, system specifications, control drawings, logic charts, sequence tables or interlock tables, flow diagrams, a control system engineering information data source, a control system classification information data source, a plant configuration information data source, or an asset management information data source.

[0017] For the purposes of the present invention, identification of one or more attributes shared by each function block within the identified group of function blocks may be based on classification identifiers assigned to each of the plurality of function blocks.

[0018] The one or more attributes shared by each function block within a function block group may comprise any one or more of (i) physical location, (ii) physical media relied on for operation, (iii) equipment type, (iv) an upstream or downstream data flow, (v) media flow or control flow

relationship, (vi) location within a specific area or plant site, (vii) being in network communication with other function blocks within the identified group of function blocks, and (viii) inclusion of each said function block within a single interface screen, display window or display wireframe corresponding to a user interface within the implemented control system.

[0019] In an invention embodiment, the detected first event may be independent of the identified second equipment component.

[0020] In another embodiment, displaying one or more event notifications at the user interface may include displaying an event notification corresponding to a detected second event, wherein the detected second event relates to the identified second equipment component. The invention may further comprise displaying information identifying one or more community structure based clusters of equipment components.

[0021] The invention additionally provides a system for control system optimization. The system may comprise one or more controllers, a plurality of field devices, and a processor. The processor may be configured to (i) retrieve from a control system information repository, information corresponding to an implemented control system, (ii) based on the retrieved information, identify: (a) a plurality of function blocks corresponding to the implemented control system, and (b) equipment components related to the plurality of function blocks, (iii) group the plurality of function blocks into a plurality of function block groups, wherein grouping of function blocks within each function block group is based on identification of one or more attributes shared by each function block within said function block group, (iv) generate a plurality of equipment component groups, wherein: (c) each equipment component group corresponds uniquely to one function block group, and (d) each equipment component group includes one or more equipment components selected such that said one or more equipment components are related to one or more function blocks within a function block group that uniquely corresponds to said equipment component group, (v) within each equipment component group, identify interconnections between equipment components within said equipment component group, and (vi) a topology generator configured to generate a control system topology based on the identified equipment components, and the identified interconnections between equipment components.

[0022] In an embodiment, the system may include a process monitor configured such that, responsive to detection of a first event within a process environment associated with the implemented control system, the process monitor (i) identifies a first equipment component within the implemented control system, wherein the identified first equipment component is related to the detected first event, (ii) identifies a second equipment component within the implemented control system, wherein the identified second equipment component is related to the identified first equipment component, and (iii) displays one or more event notifications at a user interface, wherein the displayed one or more event notifications include information corresponding to both the first equipment component and the second equipment component. The process monitor may be configured such that identification of the second equipment component is based on equipment component interconnection information retrieved from the control system topology.

[0023] In a system embodiment, identifying interconnections between equipment components within an equipment component group may include analysing each possible pair of equipment components within said equipment group to determine existence of a relationship between said pair of equipment components. Identifying interconnections between equipment components within an equipment component group may also comprise applying association rule analysis to equipment parameter data corresponding to equipment components within said equipment component group. In an embodiment, identifying interconnections between equipment components within an equipment component group may be based on one or more association scores resulting from the applied association rule analysis.

[0024] The topology generator may be configured to generate the control system topology based on a selected sub-set of the identified interconnections between equipment components. Selecting the sub-set of identified interconnections may comprise evaluating identified interconnections based on a predefined criteria.

[0025] In a system embodiment, evaluating the identified interconnections based on a predefined criteria may comprise applying the predefined criteria to association scores resulting from the applied association analysis.

[0026] The topology generator may be configured to omit or eliminate from the generated control system topology, identified interconnections that do not satisfy the predefined criteria.

[0027] In an embodiment, the or more association scores comprise any of (i) a support score, (ii) a confidence score, (iii) a lift score, (iv) a chi square score, or (v) a unified score derived based on any of a support score, a confidence score, a lift score and a chi square score.

[0028] The processor may be configured to identify a plurality of clusters of equipment components within the generated control system topology, wherein identification of said clusters is based on detection of community structure among equipment components within each cluster.

[0029] In an embodiment of the system, information retrieved from the control system information repository may be retrieved from one or more of engineering documents, system specifications, control drawings, logic charts, sequence tables or interlock tables, flow diagrams, a control system engineering information data source, a control system classification information data source, a plant configuration information data source, or an asset management information data source.

[0030] The processor may be configured to identify one or more attributes shared by each function block within the identified group of function blocks, based on classification identifiers assigned to each of the plurality of function blocks. The one or more attributes shared by each function block within a function block group may comprise any one or more of (i) physical location, (ii) physical media relied on for operation, (iii) equipment type, (iv) an upstream or downstream data flow, (v) media flow or control flow relationship, (vi) location within a specific area or plant site, (vii) being in network communication with other function blocks within the identified group of function blocks, and (viii) inclusion of each said function block within a single interface screen, display window or display wireframe corresponding to a user interface within the implemented control system.

[0031] In an embodiment of the system, the detected first event is independent of the identified second equipment component.

[0032] In another system embodiment, displaying one or more event notifications at the user interface may include displaying an event notification corresponding to a detected second event, wherein the detected second event relates to the identified second equipment component.

[0033] The system may include a process monitor configured to display information identifying one or more community structure based clusters of equipment components.

[0034] The invention may additionally include a computer program product for control system optimization, comprising a computer usable medium having a computer readable program code embodied therein, the computer readable program code comprising instructions for implementing any of the method embodiments described above.

Brief Description of Accompanying Drawings

[0035] Figure 1A illustrates a process control system.

[0036] Figures 1B and 1C illustrate exemplary control system topologies.

[0037] Figure 2 illustrates an exemplary method for generating topologies.

[0038] Figure 3A provides an exemplary graphical representation of a control system topology.

[0039] Figure 3B shows an exemplary data structure for storing the control system topology of Figure 3A.

[0040] Figure 4 illustrates heterogeneous data sources that may be used to generate a control system topology.

[0041] Figures 5A and 6A to 6G illustrate a method for generating a control system topology.

[0042] Figure 7 illustrates an exemplary data structure capable of scoring relationships between equipment components, based on strength or significance of the respective relationships.

[0043] Figure 8 illustrates association rule analysis based scoring of relationships between equipment components.

[0044] Figure 9 illustrates a method for selecting relationships between equipment components, for inclusion within a control system topology.

[0045] Figure 10 illustrates a method of real-time system monitoring that relies on a control system topology developed in accordance with the present invention.

[0046] Figure 11 shows a process environment configured in accordance with the present invention.

[0047] Figure 12 illustrates an exemplary computing system in which various embodiments of the invention may be implemented.

Detailed Description

[0048] The present invention enables methods, systems and computer program products for control system optimization. The invention achieves the desired optimization through generation of an efficient topology for a control system (such as a process control system). The topology is generated based on identification of (i) function blocks within the control system, (ii) equipment related to the identified function blocks, (iii) relationships between the identified equipment and (iv) the relative significance of such relationships— which identification is in turn based on heterogeneous control system data corresponding to the control system or process environment.

[0049] For the purposes of this invention, the term “control system component(s)” shall mean any one or more devices or hardware components (such as controllers, actuators, sensors or other field devices) within a control system.

[0050] For the purposes of this invention, the term “control drawing” shall mean any drawing that represents interconnection or flow of control instructions within the control system and /or a process environment controlled thereby. A control drawing may include a plurality of function blocks interconnected in a manner that enables communication of a control action to a control system component and execution of the control action by the control system component. Another type of control drawing may include a plurality of control system components from within the

control system or the process environment (such as for example valves, thermocouples, pressure gauges, switches etc.) and may additionally delineate point connections between the plurality of control system components. Control drawings may include both drawings that represent part or whole of the control system and that are capable of being read by the control system, as well as graphical representations or drawings that are displayed on a graphical user interface.

[0051] For the purposes of this invention, the term “equipment component(s)” shall mean any hardware component or hardware entity within a process environment, and shall include without limitation, control system components.

[0052] For the purposes of the invention, the term “function block” shall mean a discrete or self contained block comprising code that defines and implements an input function (an input function block), an output function (an output function block), or a control function (a control function block) associated with a field device or any other part of a control system. A function block may include any discrete data point (analog or digital) that the control system may need to display or control – and represents, on the basis of corresponding algorithms which are executed in a processor or microprocessor, functions that are intended to be implemented or executed using one or more device or hardware components (such as controllers, actuators, sensors or other field devices) within a control system. Input or output function blocks may produce at least one process control input (such as a process variable from a process measurement device) or process control output (such as a valve position sent to an actuation device) while each control function block uses an algorithm to produce one or more outputs (such as for example, a process control output or an output at a user interface) from one or more inputs (such as for example, a process control input or an input received at a user interface). A function block may be capable of generating alarm or event indications based on predetermined criteria and may be capable of operating differently in different modes. Additionally, a function block may be configured to communicate with other blocks implemented within the same or different field devices – and combinations of function blocks (implemented in the same or different devices) may communicate with each other to produce one or more decentralized control loops.

[0053] Exemplary function blocks may include without limitation, components, component inputs, component outputs, set points, system or process variables, controller gains, module status,

calculation variables, logical actions, sequential operations, interlocks, control blocks, one or more specific wiring points on a digital or analog input or output card, logic charts, logic blocks, calculation blocks, comparison blocks, data inputs to or data outputs from a logic or calculation block, or any function block configured to implement a processing function (such as for example, calculation or comparison).

[0054] Function blocks have defined interfaces, and can therefore be interconnected for implementing complex control strategies. While the term “function blocks” is often understood in the context of the Fieldbus protocol, it will be apparent to the skilled person that control systems using other communication protocols will include process function modules analogous to the described function blocks. Thus, the term “function blocks” shall be understood as not being limited to control systems using the Fieldbus protocol, and as having application in networks using other communication protocols as well.

[0055] For the purposes of the present invention, “interlock table(s)” shall mean a table that documents process interlocks and / or safety interlocks implemented within a control system. Interlock tables are created by a process engineer by way of manual input during design or commissioning of a control system.

[0056] For the purposes of the present invention, “logical chart(s)” shall mean a chart or table that documents logical operations that may be performed in response to input signals to achieve a desired sequential control within a control system. Logical charts include logical operators which define logical operations to be performed on input received through input signals, a corresponding output signal to be generated in response to specific input, and a destination function block corresponding to the output signal.

[0057] For the purposes of the present invention, “sequence table” shall mean a chart or table that documents condition based actions that are performed sequentially. Sequence tables specify a sequence of actions for execution in response to occurrence of a conditional event.

[0058] For the purpose of the present invention, the term “tag” shall be understood as a unique identifier that is associated with or that can be used to access a particular function block. In control system such as DCS or SCADA, a tag simply comprises a unique name, variable or a memory

address which may be used to access or control a component or function block to which the tag has been assigned. Tags associated with physical components within a control system may be referred to as “physical tag(s)” while tags associated with data variables, calculations, or logical or sequential operations (and which do not identify a physical component) may be referred to as “virtual tag(s)”.

[0059] For the purpose of the present invention, the term “topology” shall be understood as a group of inter-linked entities. The interlinked entities may comprise entities within a control system or physical entities (such as components or equipment) within an industrial plant. Examples of entities within a control system include function blocks and tags. Examples of physical entities include components or equipment such reactors, compressors, filters, furnaces, boilers and blowers.

[0060] Figure 1A illustrates a generic process control system 100a. The process control system includes a plurality of controllers 102 and a plurality of field devices, such as for example actuators 104 and sensors 108. Controllers 102 control processes 106 through field devices within the process control system. By way of example, sensors 108 may communicate feedback to controllers 102 regarding state of one or more processes 106. Based on received feedback, controllers 102 may generate control signals and communicate them to actuators 104 to control processes under execution.

[0061] Exemplary Figures 1B and 1C illustrate two alternative topologies 100b and 100c for a control system. While both topologies comprise identical equipment components (i.e. controllers 102a, 102b and 102c, actuators 104a, 104b and 104c, and sensors 108a, 108b and 108c) – their respective structures are different. Figure 1B illustrates a decentralized control system, where each of controllers 102a, 102b and 102c are responsible for controlling discrete groups of actuators and sensors. Figure 1C on the other hand illustrates a centralized control system, wherein controllers 102b and 102c are configured to control discrete groups of actuators and sensors, but are in turn controlled by a centralized controller 102a. While these illustrations are exemplary, they establish that in implementation, the control system 100a of Figure 1A may be configured in any topology that is suitable for controlling a specific process environment.

[0062] A topology of a control system may be represented as a set of interrelated function blocks or equipment components within the control system. Nodes of the topology correspond to represented

function blocks or equipment components within the control system, while interconnections and/or relationships between such nodes may be determined based on data flows, control flows or other attributes representative of function or hierarchy within the control system. For the purposes of the present invention, relationships between nodes may be understood to include any type of relationship, including by way of example, causal relationships or probabilistic relationships.

[0063] Figure 2 illustrates a prior method for generating a control system topology.

[0064] Step 202 comprises obtaining information corresponding to the control system. Information corresponding to a control system may be obtained from system designers or system operators, or may be extracted from engineering documents or specifications corresponding to the control system. The engineering documents or specifications may be parsed to extract information describing the control system.

[0065] Step 204 comprises identifying function blocks within the control system based on information extracted at step 202. Step 206 thereafter identifies interconnections or relationships between the identified function blocks within the control system, which identification is based on information extracted at step 202. Exemplary relationships between elements of a control system may include data, control or media flow dependencies, sequential relationships or interlock relationships between elements.

[0066] Based on function blocks and interconnections or relationships identified at steps 204 and 206, a topology of the control system is generated at step 208. The generated topology may be represented graphically, for example by way of tree structure 300A illustrated in Figure 3A, where function blocks X1 to X8 of a control system are represented as nodes, and relationships between the function blocks are represented by the connecting arrows as edges. Storage and retrieval of topology information, relies on a data structure or database schema configured to logically store information corresponding to function blocks and relationship information of the control system. Figure 3B illustrates an exemplary data structure for storing the topology of Figure 3A – and which data structure has been used to store information corresponding to nodes from Figure 3A. The illustrations of Figures 3A and 3B are exemplary, and it will be understood that any graphical representation and any appropriate data structures may be selected for display and storage / retrieval of topologies corresponding to a control system or a process environment.

[0067] Figure 4 illustrates exemplary heterogeneous data sources that may be used to generate or refine a control system topology in accordance with embodiments of the present invention. As shown, control system topology 410 corresponding to a control system may include information retrieved from discrete and heterogeneous data sources comprising (i) a control system engineering information data source 402 (also known as engineering information repository) (ii) a control system classification information data source 404 (iii) a plant configuration information data source 406 and (iv) an asset management information data source 408. While Figure 4 shows each data source as a distinct data repository (databases 402 to 408), some or all of these data sources may be stored together within a single database or data repository. The relevance of each of the heterogeneous data sources, and the manner in which information from these data sources may be used to generate a control system topology is described below.

[0068] Control system engineering information (as obtained from data source 402) comprises data and information created during the design phase of a control system, and may include (without limitation), engineering documents, or system specification resources such as control drawings, graphic displays windows or graphic display wireframes, logic charts, sequence tables and interlock tables. These documents or specification resources include information regarding function blocks and interconnections corresponding to a control system, which information can be parsed and used to generate a control system topology.

[0069] Control system classification information (as obtained from data source 404) comprises classification information corresponding to one or more entities within a control system under observation. Control system classification is based on a classification taxonomy and rules for classifying equipment components within the system. The objective of a classification taxonomy is to correlate or assign unique classification identifiers to equipment components and / or function blocks, which unique classification identifiers are generated and assigned in a manner that provides meaningful and accurate attribute information corresponding to the equipment component and / or function block. Classification taxonomies are well known within engineering disciplines, including planning, licensing, construction, operation and maintenance. Implementation of classification taxonomies within a control system or a process environment can convey attribute information corresponding to equipment components or function blocks, including equipment type or function, media required by the equipment component or function block for operation, types of

measurements input to or output from an equipment component or function block (e.g. temperature, pressure etc.) and identity of a plant or section of a plant within which the equipment component or function block has been implemented. In connection with Figure 4, it would be understood that control system classification information retrieved from data source 404 may include classification identifiers corresponding to equipment components or function blocks, as well as classification taxonomy rules for assigning or interpreting classification identifiers.

[0070] A classification taxonomy may be hierarchically structured or non-hierarchically structured. A hierarchically structured classification taxonomy provides classification identifiers corresponding to equipment components or function blocks that provide information regarding upstream or downstream relationships between said equipment components or function blocks. For example, in a hierarchically structured classification taxonomy, successively numbered classification identifiers may indicate that the equipment components or function blocks corresponding to two successively numbered identifiers are arranged successively in an upstream or downstream relationship. Likewise, equipment components or function blocks having the same identifier with a different alphabet prefix or suffix could indicate that the equipment components or function blocks are arranged and operating in parallel. In a non-hierarchically structured classification taxonomy, identifiers corresponding to equipment components or function blocks do not provide information regarding upstream or downstream relationships between components. In an embodiment of the present invention, the control system classification information retrieved from data source 404 may comprise classification information corresponding to equipment components or function blocks, wherein the classification is based on a hierarchically structured classification taxonomy, such as by way of example the Kraftwerk Kennzeichen System(KKS) or the Plant Numbering System (PNS).

[0071] Plant configuration information (as obtained from data source 406) comprises high level flow diagram information connecting major parts of a plant or process control environment in a series of parent-child relationships. Plant configuration information may be generated manually by a system designer at the time of plant design, or may be subsequently generated or refined by system engineers or operators based on run-time observations. Plant configuration information may be stored in plant configuration data source 406 in the form of flow diagrams or tables. Alternatively, information may be parsed from the flow diagrams and stored in an appropriately configured data structure or database that accurately reflects and facilitates retrieval of the parsed flow information.

[0072] Asset management information (as obtained from data source 408) comprises information regarding equipment components within a control system, including network information (for example, location, proximity or connectivity of a field control station within a plant communication network), equipment type or location related attributes of equipment components – which information may be used to group or hierarchically order equipment components or function blocks corresponding to such equipment components. In an embodiment of the invention, asset management information may additionally include attribute information that describe user requirements or functional results associated with an equipment component.

[0073] While Figure 4 illustrates a control system topology generated based on information from each of data sources 402 to 408, the topology may in various embodiments be generated based on information from any one or more of said data sources.

[0074] Figure 5 read with Figures 6A to 6F illustrate method steps associated with generating a control system topology based on information retrieved from one or more of the data sources (402, 404, 406 and 408) of Figure 4. Step 502 comprises parsing one or more of engineering documents, system specification documents, and any other documents or data repositories containing one or more of control system engineering information, control system classification information, plant configuration information and asset management information, documents and plant configuration documents specifications - to identify (i) discrete function blocks within the control system and (ii) equipment components that correspond to, or that are functionally related to the identified function blocks. Data and documents parsed at step 502 may in an embodiment include basic system specification documents such as control drawings, logic charts, sequence tables and interlock tables, which map components and functions of a system as well as the process flows between them.

[0075] Figure 6A provides an illustrative outcome of the first part of method step 502, wherein parsing of documents enables identification of discrete function blocks A1 to A5, B1 to B4, and C7 and C8. Figure 6B provides an illustrative outcome of the second part of method step 502, wherein parsing of documents enables identification of equipment components that are associated with, or that are functionally related to each of the identified function blocks i.e. As shown in Figure 6B, (i) within relationship set R1, equipment component E1 is functionally related to function blocks A1, A2 and C7; (ii) within relationship set R2, equipment component E2 is functionally related to

function blocks A3, A5 and B3; (iii) within relationship set R3, equipment component E3 is functionally related to function block A4; (iv) within relationship set R4, equipment component E4 is functionally related to function block C8; (v) within relationship set R5, equipment component E5 is functionally related to function blocks B1 and B2; and (vi) within relationship set R6, equipment component E6 is functionally related to function block B4.

[0076] Step 504 of Figure 5 comprises obtaining or extracting grouping information corresponding to the identified function blocks – wherein the grouping information defines a plurality of function block groups, and wherein each defined plurality of function blocks comprises a sub-set of function blocks identified at step 504. Grouping information may be obtained or extracted in a variety of ways and from multiple sources, including for example, by:

- parsing user interface screens, graphic display windows or display wireframes (or data files defining or describing the user interface screens, graphic display windows or display wireframes) and identifying function blocks or associated tags that are displayed within a single interface screen, display window or display wireframe. The function blocks or tags that are so identified may be treated as falling a single group or cluster of function blocks
- grouping function blocks or tags based on analysis of classification information corresponding to the identified function blocks or tags. Grouping of function blocks or tags based on classification information may be based on a predefined set of rules or criteria – which in an embodiment, may entail grouping of two or more function blocks or tags based on attributes common to the two or more function blocks or tags, which common attributes are identified in the course of the classification information based analysis of the function blocks or tags. In non-limiting examples of the method, function blocks or tags may be grouped together based on classification information that establishes at least one or more of (i) location within the same part of an industrial plant (ii) reliance on the same physical media (e.g. electricity, steam etc.) for operation (iii) common equipment type or (iv) sharing an upstream or downstream relationship, for example, in terms of one or more of data, media or control flow.

- grouping function blocks or tags based on asset management information corresponding to the identified function blocks or tags. Grouping based on asset management information may involve grouping based on a predefined set of rules or criteria for grouping – which in an embodiment may involve grouping of two or more function blocks or tags based on asset management attributes common to the two or more function blocks or tags. In non-limiting examples, function blocks or tags may be grouped together based on one or more of (i) being associated with the same equipment type (ii) being located within the same area or plant site or (iii) being in network communication with each other.

[0077] Step 504 results in grouping of the identified function blocks into a plurality of function block groups. Figure 6C provides an illustrative outcome of method step 504, wherein the identified function blocks A1 to A5, B1 to B4, C7 and C8 have been grouped into function block groups Grp1, Grp2, Grp3, Grp4 and Grp5. Function block group Grp1 comprises function blocks A1 to A5; Function block group Grp2 comprises function blocks A5, C7 and C8; Function block group Grp3 comprises function blocks A4, B1, B3 and C8; Function block group Grp4 comprises function blocks B1 and C8; and Function block group Grp5 comprises function block B4.

[0078] Step 506 of Figure 5 comprises generating a plurality of equipment component groups, wherein each equipment component group uniquely corresponds to one function block group generated at step 504. Each equipment component group comprises one or more equipment components, selected such that every equipment component within a specific equipment component group is functionally related to one or more function blocks within the function block group corresponding to said specific equipment component group.

[0079] In an embodiment of method step 506, a determination as to whether an equipment component is functionally related to one or more function blocks within a corresponding function block group, may be based on information parsed at step 502 (discussed previously).

[0080] Figure 6D presents an illustrative outcome of method step 506, wherein a plurality of equipment component groups (Grp1', Grp2', Grp3', Grp4' and Grp5' of Figure 6D) are generated – and wherein each equipment component group corresponds to a respective function block group (Grp1, Grp2, Grp3, Grp4 and Grp5 of Figure 6C) generated at step 504. Additionally:

- Equipment component group Grp1' comprises equipment components E1, E2 and E3, which have been selected for the reason that each of the selected equipment components is functionally related to one or more of function blocks A1 to A5 within the corresponding function block group Grp1 (reference to Figure 6B establishes that: equipment component E1 is functionally related to function blocks A1 and A2; equipment component E2 is functionally related to function blocks A3 and A5; and equipment component E3 is functionally related to function block A4).
- Equipment component group Grp2' comprises equipment components E1, E2 and E4, which have been selected for the reason that each equipment component is functionally related to one or more of function blocks A5, C7 and C8 within the corresponding function block group Grp2 (reference to Figure 6B establishes that: equipment component E2 is functionally related to function block A5; equipment component E1 is functionally related to function block C7; and equipment component E4 is functionally related to function block C8).
- Equipment component group Grp3' comprises equipment components E2, E3, E4 and E5, which have been selected for the reason that each equipment component is functionally related to one or more of function blocks A4, B1, B3 and C8 within the corresponding function block group Grp3 (reference to Figure 6B establishes that: equipment component E2 is functionally related to function block B3; equipment component E3 is functionally related to function block A4; equipment component E4 is functionally related to function block C8; and equipment component E5 is functionally related to function block B1).
- Equipment component group Grp4' comprises equipment components E4 and E5, which have been selected for the reason that each equipment component is functionally related to one or more of function blocks C8 and B1 within the corresponding function block group Grp4 (reference to Figure 6B establishes that: equipment component E4 is functionally related to function block C8; and equipment component E5 is functionally related to function block B1).

- Equipment component group Grp5' comprises equipment component E6, which has been selected for the reason that the equipment component E6 is functionally related to function block B4 within the corresponding function block group Grp5 (reference to Figure 6B establishes that: equipment component E6 is functionally related to function block B4).

[0081] For each equipment component group generated at step 506, step 508 of Figure 5 determines the existence of relationships between every possible pair of equipment components within said equipment component group. In an embodiment, step 508 may additionally include the step of determining the significance / weightage of each determined relationship relative to all other determined relationships. In an embodiment of the invention, the existence and / or significance of relationships between equipment components within an equipment component group may be determined based on association rule analysis. A more detailed explanation of association rule analysis based determination of relationships between equipment components is provided subsequently in this written description.

[0082] Figure 6E presents an illustrative outcome of method step 508, wherein determining the existence of relationships between every possible pair of equipment components within each equipment component group results in determinations that:

- Within equipment component group Grp1':
 - equipment component E1 is strongly related to equipment component E2
 - equipment component E1 is weakly related to equipment component E3
 - equipment component E2 is strongly related to equipment component E3
- Within equipment component group Grp2':
 - equipment component E1 is weakly related to equipment component E4
 - equipment component E1 is strongly related to equipment component E2
 - equipment component E2 is strongly related to equipment component E4

- Within equipment component group Grp3':
 - equipment component E2 is weakly related to equipment component E5
 - equipment component E2 is strongly related to equipment component E4
 - equipment component E2 is strongly related to equipment component E3
 - equipment component E4 is strongly related to equipment component E5
 - equipment component E3 is weakly related to equipment component E4
 - equipment component E3 is weakly related to equipment component E5
- Within equipment component group Grp4':
 - equipment component E4 is strongly related to equipment component E5
- Within equipment component group Grp5':
 - equipment component E6 is the only equipment component and is therefore not related to any other equipment component within the group

[0083] For the purposes of interpreting the above paragraphs and Figures 6E and 6G, solid lines may be understood as representing a strong relationship, while dashed lines may be understood as representing a weak relationship. The classification of relationships as strong or weak may be based on any predefined classification criteria. In an exemplary embodiment, all relationships having a relationship score above a predefined threshold may be classified (and represented) as strong relationships and all relationships having a relationship score below a predefined threshold may be classified (and represented) as weak relationships. It would be understood that the use of solid lines and dashed lines (to represent strong and weak relationships) is only exemplary, and any other

representation that is capable of conveying relative significance of relationships may be used (for example (i) increasing or decreasing the thickness of lines representing edges, based the significance of the corresponding relationships or (ii) color coding the lines representing edges, based on the significance of the corresponding relationships).

[0084] Step 510 of Figure 5 comprises generating a control system topology based on some or all of the equipment components identified in the preceding steps, and on some or all of the relationships (as determined at step 508) between said equipment components. In generating a control system topology, identified equipment components may be represented as nodes, while determined relationships between them may be represented as edges between nodes. In generating the topology, node attributes assigned to each node may be based on identified characteristics of the corresponding equipment component.

[0085] Figure 6F presents an illustrative outcome of method step 510, wherein the generated topology is based (i) on a selected sub-set (i.e. equipment components E1 to E6) of the entire set of equipment components (i.e. equipment components E1 to E6) that have been identified at step 506, and (ii) on relationships between said pairs of equipment components within said selected sub-set, which relationships have been determined at step 508. Specifically, the generated topology illustrated at Figure 6F includes functionally related equipment components E1 to E5, and the determined relationships between each of them, while also including equipment component E6 which has been found to be unrelated to the remaining equipment components (and which is therefore represented within the topology as being functionally unrelated to the remaining equipment components E1 to E5).

[0086] Specific methods for (i) determining the existence and / or significance of relationships between equipment components within an equipment component group (within step 508) and (ii) for generating a topology based on selected equipment components and determined relationships between equipment component pairs (step 510) are now described in more detail.

[0087] In accordance with the present invention, methods for determining the existence and / or significance of relationships between pairs of equipment components within an equipment component group rely on identifying relationships between each pair of equipment components –

which relationships are identified based on application of data mining and association rule analysis algorithms (for example, association rule induction methods that are well known in the domain of data mining). The association rule analysis comprises analysis of data sets comprising monitored equipment state parameters or equipment performance parameters corresponding to each equipment component within each pair of equipment components under consideration. The data sets of monitored equipment state parameters or equipment performance parameters may comprise parameter values monitored by appropriate component monitoring schemes housed within a control system, and may be retrieved from one or more historical databases.

[0088] Based on data sets corresponding to equipment components within each pair of equipment components, and based on association rule analysis algorithms, the invention identifies relationships that may be inferred between equipment components within each pair of equipment components under consideration. Each inferred relationship (or “association rule”) may be expressed in the general form:

Equipment Component A $\leftrightarrow$ Equipment Component B

which may be understood to mean that state / performance of Equipment Component B is dependent on state / performance of Equipment Component A or vice versa. Additionally, the relative significance of each inferred relationship may be expressed in terms of one or more scores, including one or more of:

- Support score – the percentage of cases within the total data set for which the relationship is found to be true.
- Confidence score – the probability that the consequent is true, given that the antecedent is true.
- Lift score – the confidence score of the relationship divided by the expected confidence assuming that the item sets corresponding to the antecedent and consequent were independent.

- Chi square score – the measure of how much a pair-wise pattern deviates from the situation where state changes in either of Equipment Component A and Equipment Component B are random or occur independent of a state change in the other of Equipment Component A and Equipment Component B.
- Unified Score – a unified score generated based on any two or more of support score, confidence score, lift score and chi square score. For example, a unified score may be generated by normalizing any two or more of the support scores, confidence scores, lift scores and chi square scores – and calculating an average score based on the normalized scores.

[0089] Figure 7 illustrates an exemplary data structure capable of scoring relationships between intra-group pairs of equipment components, in terms of support score, confidence score, lift score, chi-square score generated from association rule analysis, and a unified relationship score. For the purposes of illustration, the data structure in Figure 7 has been populated with exemplary support scores, confidence scores, lift scores, chi-square scores and unified relationship scores corresponding to the various intra-group pairs of equipment components E1 to E6 as grouped in Figure 6E. The scores in Figure 7 are only exemplary, and it would be understood that these may be based on any of the scoring metrics illustrated in Figure 7, or in fact any other scoring metric that is representative of relationships between equipment components.

[0090] It would be understood from the above that identification of a relationship at step 508 of Figure 5, between equipment components corresponding to any intra-group pair of equipment components, may be based on whether a relationship is inferred between said equipment components.

[0091] Figure 8 illustrates a table representing exemplary unified relationship scores corresponding to intra-group pairs of equipment components illustrated in Figure 6E. The table classifies relationships between said intra-group pairs of equipment components as strong relationships or weak relationships. As explained previously, the classification of relationships as strong or weak may be based on any predefined classification criteria. The unified relationship scores and relationship classifications in Figure 8 are only exemplary, and it would be understood that these may be based

on any of the scoring metrics illustrated in Figure 7 or in fact any other scoring or classification metrics that are representative of relationships between equipment components. In the embodiment illustrated in Figure 8, the existence of a relationship between any intra-group pair of equipment components (such as relationships between equipment component pairs E1 and E2; E2 and E3; E2 and E4; and E4 and E5) may be inferred in case of a positive unified relationship score or a unified relationship score that is higher than a defined threshold value. Likewise, referring to the illustration of Figure 7, the lack of a relationship between any intra-group pair of equipment components (such as between equipment component pairs E2 and E6; or between E5 and E6) may be inferred from a relationship score having a zero value, or a score lower than any defined threshold value.

[0092] In understanding the nature of relationship classifications illustrated in Figure 8, it would be appreciated that a threshold unified score value may be optionally and / or dynamically defined to enable classification of relationships between intra-group equipment component pairs as strong or weak relationships. For example, in Figure 8, the threshold unified score value is set to 0.3. In this illustration, relationships having unified score values of 0.3 or above are classified as strong relationships and relationships having unified score values of less than 0.3 are classified as weak relationships.

[0093] Accordingly at step 508, a relationship (or functional dependence) may be identified for every pair of equipment components having a positive relationship score (or a relationship score that is higher than an optionally defined threshold) – resulting in identified relationships within equipment component pairs E1 and E2, E2 and E3; E2 and E4; and E4 and E5. Conversely, it may be determined that a relationship (or functional dependence) does not exist within any pair of equipment components having a zero value for a determined relationship score (or having a score lower than that a dynamically defined threshold).

[0094] Accordingly it would be understood that at step 510 of Figure 5 (and as illustrated in Figure 6F), the generated control system topology may represent relationships between nodes, based on the relationships between corresponding equipment components that are determined at step 508.

[0095] It would also be understood that in addition to determining the existence of relationships, the relative significance of determined relationships between intra-group pairs of equipment

components may optionally be determined at step 508 – which determination may be based on the determined values of relationship scores. In an embodiment, a higher relationship score may be interpreted as a stronger or more closely bound functional dependence or linkage between equipment components, whereas a lower relationship score may be interpreted or displayed as a weaker or less closely bound functional dependence or linkage between equipment components.

[0096] In an embodiment of the invention, in displaying the control system topology generated at step 510 or in displaying interconnections between equipment components, the invention may vary the display attributes of edges (or interconnections) between equipment components, based on the relative significance of the underlying relationship between said equipment components. By way of non-limiting example, thickness of edges between each pair of equipment components may increase or decrease according to the relative significance of the determined relationships between said pairs of equipment components. Alternatively, strong relationships may be illustrated by solid line edges while weak relationships may be illustrated by dashed line edges (see for example, Figure 6F).

[0097] In an embodiment of the method discussed in connection with Figure 5, step 510 may comprise generating a control system topology which includes all grouped equipment components and all relationships that are identified therebetween. It has however been found that often enough, the number of discoverable functional relationships or links that each equipment component may have with other equipment components is significantly large (and in certain cases can be ten or more relationships or links per equipment component). Further, of the total number of discoverable relationships or links associated with each equipment component, it is typically found that only a small sub-set of such relationships (typically between 1 and 3) are significant. Accordingly, in an embodiment of the method of Figure 5, step 510 may comprise generating a control system topology, wherein represented relationships between equipment components (i.e. edges between nodes of the control system topology) are restricted to relationships that satisfy a predetermined criteria for significance. For example, a possible predetermined criteria for significance can be a threshold unified relationship score value, which value can be optionally or dynamically defined (referring to the illustration in Figure 8,, the threshold unified relationship score value is set to 0.3.) – and only such relationships that meet or exceed the threshold value would be included and represented within the control system topology.

[0098] Figures 6F and 6G illustrate the manner in which a control system topology can be restricted to relationships that meet a predetermined criteria for significance. In the illustration of Figure 6F, certain equipment component pairs are strongly connected or strongly dependent (as exhibited by solid line edges), while others are weakly connected or weakly dependent (as exhibited by dashed line edges), while yet other equipment components are entirely unconnected or entirely independent of the others. Figure 6G illustrates a modified control system topology that has been generated based on a smaller sub-set of equipment components – which modified control system topology comprises only those equipment component pairs (from Figure 6F) that are strongly related or interconnected with each other, while eliminating the equipment component pairs that are weakly related or that are entirely unrelated.

[0099] Figure 9 illustrates method steps for selecting equipment component relationships within a control system topology based on a predetermined criteria for evaluating significance of relationships.

[00100] Step 902 comprises applying association rule analysis to monitored equipment state parameters or equipment performance parameters corresponding to a plurality of pairs of equipment components– resulting in determination of one or more association scores corresponding to each pair of equipment components. In an embodiment, these one or more association scores may comprise any one or more of a support score, confidence score, lift score, chi square score, or unified score, of the kind described previously.

[00101] Thereafter step 904 comprises selecting (for inclusion within a control system topology) relationships between pairs of equipment components – based on one or more of the determined association scores. In an alternative embodiment, step 904 may comprise identification of relationships between pairs of equipment components that are not sufficiently significant and which are therefore discarded when generating a control system topology or which are eliminated from an existing control system topology – wherein the determination regarding insufficient significance is based on one or more of the determined association scores.

[00102] In an embodiment of step 904, selection of relationships between pairs of equipment components for representation within a control system topology is based on a determination whether one or more of the association scores meets a predefined threshold of significance.

Assuming a non-limiting illustrative example, where the determined association scores include a unified score on a scale of between 0 and 1, and where the predefined threshold of significance may be a unified score of 0.3 (i) any relationship between a pair of equipment components having a unified score of 0.3 or greater may be selected for inclusion within a control system topology, and (ii) any relationship having a unified score of less than 0.3 may be discarded. It would be understood that the predefined threshold of significance, as well as the association rule metric(s) that may be used for scoring, may be defined by a system operator, system administrator or system designer. Additionally, it would be understood that the predefined threshold of significance may be expressed in terms of any association rule metric, including without limitation any one of support score, confidence score, lift score, chi square score or unified score. In a preferred embodiment, data within a data structure for storing relationship scores corresponding to equipment component pairs may be sorted in ascending or descending order based on values of any association score metric (such as for example, any one of support score, confidence score, lift score, chi-square score or unified relationships score).

[00103] In one embodiment of the invention, step 904 may include selection of all relationships that have non-zero scores on a selected association rule metric, for inclusion within a control system topology (while simultaneously eliminating all relationships that have a zero score on the selected association rule metric).

[00104] In another embodiment of step 904 of Figure 9, the determined relationships between pairs of equipment components may be sorted in a descending order based on corresponding association scores. Thereafter, the invention may select a predefined number (or a predefined percentage) of the most significant relationships (i.e. the relationships having the highest association scores) for inclusion within a control system topology. The predefined number or predefined percentage of relationships intended for selection, as well as the relevant association rule metric used for sorting in descending order, may be defined by a system operator, system administrator or system designer. In an embodiment, the association rule metric used for sorting the relationships may include without limitation, any one of support score, confidence score, lift score, chi square score or unified score.

[00105] In an embodiment of the invention, the sorting of equipment component relationships in descending order according to an association score, may occur within each equipment component group (as determined at step 506 of Figure 5). Thereafter the step of selecting a predefined number or percentage of relationships for inclusion within a control system topology may also be executed on a per-group basis. By way of illustrative example, assuming that the predefined number of relationships intended for selection from each equipment component group is five, and the relevant association rule metric is the confidence score, the step of selection may involve selecting from each equipment component group, five relationships that have the highest confidence scores within said equipment component group, and which selected relationships may thereafter be represented within the generated control system topology.

[00106] In a particular embodiment of step 904, the step of sorting relationships in descending order according to corresponding association rule scores, may rely on scores generated on at least two separate metrics. In this embodiment, relationships are first sorted in descending order according to scores on a first metric, whereafter relationships that have scores of identical value on the first metric are inter-se sorted based on their corresponding scores according to a second metric. It would be understood that in case of further ties between scores according to a second metric, the method may rely on scores according to third, fourth or any appropriate number of subsequent metrics to break the ties and to achieve a set of relationships that are fully sorted according in descending order of magnitude (i.e. magnitude of association rule scores).

[00107] In a specific embodiment of step 904:

- (i) relationships between pairs of equipment components within each equipment component group are first sorted in descending order of magnitude based on their corresponding chi square scores
- (ii) in case of a tie between two or more chi square scores, the corresponding relationships are sorted in descending order of magnitude based on their corresponding lift scores

- (iii) in case of a tie between two or more lift scores, the corresponding relationships are sorted in descending order of magnitude based on their corresponding support scores
- (iv) in case of a tie between two or more support scores, the corresponding relationships are sorted in descending order of magnitude based on their corresponding confidence scores

[00108] It would be understood that step 902 as described above relates to a specific embodiment of step 508 of Figure 5. Further, step 904 as described above may relate to a specific embodiment of step 508 or of step 510, or in an embodiment may comprise an intermediate step between step 508 and 510 of Figure 5.

[00109] It would additionally be understood that the method steps discussed specifically in connection with Figure 9 may be used either (i) for selecting equipment components and relationships between equipment components for inclusion within a new control system topology or (ii) when modifying an existing control system topology by identifying equipment components and relationships for addition to the topology, or equipment components or relationships that may be eliminated or discarded from the existing control system topology.

[00110] One or more of the method steps and method embodiments described in connection with Figures 5 to 9 above may be applied to generate a topology for an industrial process control system (such as for example a DCS or SCADA based control system) used in any industrial process environment, e.g. within a chemical plant, power plant, or oil and gas rig.

[00111] In a further embodiment of the present invention, equipment components and/or identified relationships between equipment components within a control system topology that has been generated or modified in accordance with the teachings above, may be further grouped into a plurality of clusters using algorithms for detection of community structure (community detection algorithms) that are known within the domain of data mining and clustering. The community detection algorithms may detect community structure (or a lack thereof) between two or more equipment components, based on the density of interconnections between equipment components. The clusters of equipment components arising out of application of community detection

algorithms are typically found to represent or correspond to discrete functional areas, units sub-plants within an industrial plant.

[00112] The community detection algorithm based grouping of equipment components into a plurality of clusters can provide meaningful information to an operator, for example by presenting a control system operator with display information clearly identifying (i) a sub-groups or clusters of equipment components that are densely or sufficiently inter-related with a specific equipment component, and which are therefore more likely to affect or be affected by a state of the specific equipment component under consideration, or conversely (ii) a sub-group or cluster of equipment components that are sparsely or insufficiently inter-related with a specific equipment component, and which are therefore less likely to affect or be affected by a state of the specific equipment component under consideration. The grouping or clustering information derived based on community detection methods or algorithms may be added to the control system topologies resulting from the methods discussed in connection with Figures 5 to 9 above. In an embodiment of the invention, information defining clusters that have been identified using community detection algorithms may be added to the control system topology way of attribute information associated with nodes within each identified cluster.

[00113] The control system topologies resulting from the methods described above offer multiple advantages. A first advantage is that these topologies present information regarding relationships and interconnections between equipment components function blocks within a process environment. This information can be used for the purposes of root cause analysis – for example to correlate events (such as changes in process environment conditions) with subsequent system changes (such as alarms). Additionally, in view that the control system topologies generated in accordance with the present invention enable the relative significance of relationships to be factored, immediate improvements are observable in system monitoring and event response time, by enabling meaningful real time correlation between causative events and alarm notifications or system interruptions, allowing personnel to identify and address causative factors quickly and accurately. The improved system topology information also enables efficient predictive modelling of equipment component behaviour – which in turn improves predictive maintenance and reduces system downtime. The improved topology information also has relevance for personnel training purposes, for improving knowledge transfer from existing operators, and for advancing system design in

response to previously undeciphered relationship or interconnection information. By enabling elimination of insignificant relationships between equipment components, and providing meaningful clustering information corresponding to equipment components, control system topologies in accordance with the present invention further improve monitoring and predictive modelling within process control systems.

[00114] Figure 10 illustrates an exemplary method of real-time system monitoring that relies on and implements a control system topology developed in accordance with the methods described above.

[00115] Step 1002 comprises receiving a plurality of event notifications or alarm notifications related to the control system. At step 1004, a sub-set of event notifications or alarm notifications are selected from among the received plurality of event notifications or alarm notifications, wherein selection of the sub-set of event notifications or alarm notifications is based on equipment component interconnection information extracted from the control system topology corresponding to the control system – such that the selected sub-set of event notifications or alarm notifications corresponds to an interconnected set of equipment components within the control system topology. It would be understood that selection of a sub-set of event notifications or alarm notifications based on extracted interconnection information may rely on one or more predefined or operator defined rules for selection.

[00116] Step 1006 comprises presenting or displaying the selected sub-set of event notifications or alarm notifications to a system operator. In an embodiment of the invention, the control system eliminates or does not display or present event notifications or alarm notifications other than the selected sub-set of alarm notifications to the system operator. In another embodiment, the selected sub-set of event notifications or alarm notifications are presented to a user in real time or with an indication that they require high priority, while all other event notifications or alarm notifications received from the control system are either not displayed, or displayed in a time phased manner or with a delay, or displayed with an indication of lower priority. The selection, prioritization or exclusion of event notifications or alarm notifications at step 1006 may be based on predefined or operator defined rules for selection, prioritization or exclusion of event notifications or alarm notifications.

[00117] In an embodiment that enables predictive modelling, subsequent to step 1006, the control system may optionally notify a system operator regarding equipment components that are operating normally but which are interconnected with equipment components for which event notifications or alarm notifications have been received – thereby enabling the system operator to monitor these equipment components for any potential failure or alarm notifications, or for initiation of preventive maintenance.

[00118] In an implementation related embodiment of the real time system monitoring method described above, the method responds to detection of a first event within the process environment by identifying a first equipment component within the process control system, which identified first equipment component is related to the detected event. The method thereafter identifies a second equipment component within the process control system, which identified second equipment component is related to the identified first equipment component. Identification of the second equipment component may be based on information identifying interconnections between a plurality of equipment components, that is retrieved from the control system topology. One or more event notifications may thereafter be displayed at a user interface, which displayed one or more event notifications include information corresponding to both the first equipment component and the second equipment component.

[00119] In a more specific embodiment, the detected event within the process environment may be independent of or only indirectly related to the identified second equipment component. However, based on (i) the detected first event being related to the first equipment component and (ii) interconnection information that establishes a relationship involving the first and second equipment components– the method associates the detected first event with both of the first and second equipment components and displays one or more event notifications with information corresponding to both of the first and second equipment components. In a specific instance of the above embodiment, the displayed one or more event notifications with information corresponding to both of the first and second equipment components includes (i) at least a first event notification corresponding to the detected first event that is related to the first equipment component, and (ii) optionally includes at least a second event notification corresponding to a detected second event that is related to the second equipment component. The detected first event may in certain embodiments be indirectly related to, independent of or unrelated to the second equipment

component. Likewise, the detected second event may in certain embodiments be indirectly related to, independent of or unrelated to the first equipment component.

[00120] In an embodiment, the method assigns a first priority to the detected first event and assigns a second priority to a detected second event – wherein, responsive to determining that the second event is either independent of, or only indirectly related to the first and second equipment components, the assigned second priority is lower than the assigned first priority.

[00121] It would be understood that by controlling presentation of alarm or event notifications based on topology information regarding interconnected events or entities, the invention significantly improves (i) root cause analysis (ii) the likelihood of associative or connected problems being prevented, detected and resolved and (iii) response time or timelines for remedial action. As a result of the invention, in addition to real time notification of a detected event, a system operator can now receive in real time, contextually relevant information regarding associated or causative upstream events, as well as associated downstream events that may have been caused or are likely to be caused by the detected event. The additional contextual information improves accuracy of root cause analysis, and also reduces response time involved in isolating a root cause and identifying and delivering a remedial or preventive maintenance solution. Likewise, reducing the urgency or priority assigned to unconnected or isolated event notifications or alarm notifications, the invention (i) reduces the likelihood of incorrect associations between isolated or unconnected event notifications or alarm notifications, and (ii) enables a system operator to realistically ascertain the magnitude and effect of a detected problem or failure, and to prioritize simultaneously occurring events, alarms or failures in order of importance.

[00122] Figure 11 illustrates an exemplary process environment 1100 configured to implement the methods of the present invention. Controller 1102 is connected to a plurality of repositories 1106a to 1106c, which repositories may contain one or more heterogeneous data sources (of the kind that have been described in connection with Figure 4) that may be used to generate and / or refine a control system topology in accordance with embodiments of the present invention. Controller 1102 is also communicably coupled to one or more field devices 1104 (which field devices may include sensors and actuators for effecting control of process environment 1000). Both controller 1102 and repositories 1106a to 1106c are communicably coupled to topology

generator 1108 – which in an embodiment of the invention, is configured to generate a control system topology in accordance with one or more of the methods discussed above in connection with of Figures 5 to 9. The process environment 1100 additionally includes process monitor 1110 that is communicably coupled to controller 1102 and topology generator 1108 for monitoring the process environment, and generating, displaying and prioritising notifications or alarms in accordance with one or more of the method steps discussed above in connection with Figure 10.

[00123] Figure 12 illustrates an exemplary computing system in which various embodiments of the invention may be implemented.

[00124] The system 1202 comprises at least one processor 1204 and at least one memory 1206. The processor 1204 executes program instructions and may be a real processor. The processor 1204 may also be a virtual processor. The computer system 1202 is not intended to suggest any limitation as to scope of use or functionality of described embodiments. For example, the computer system 1202 may include, but not be limited to, one or more of a general-purpose computer, a programmed microprocessor, a micro-controller, an integrated circuit, and other devices or arrangements of devices that are capable of implementing the steps that constitute the method of the present invention. Exemplary embodiments of a system 1202 in accordance with the present invention may include one or more servers, desktops, laptops, tablets, smart phones, mobile phones, mobile communication devices, tablets, phablets and personal digital assistants. In an embodiment of the present invention, the memory 1206 may store software for implementing various embodiments of the present invention. The computer system 1202 may have additional components. For example, the computer system 1202 includes one or more communication channels 1208, one or more input devices 1210, one or more output devices 1212, and storage 1214. An interconnection mechanism (not shown) such as a bus, controller, or network, interconnects the components of the computer system 1202. In various embodiments of the present invention, operating system software (not shown) provides an operating environment for various softwares executing in the computer system 1202 using processor 1204, and manages different functionalities of the components of computer system 1202.

[00125] The communication channel(s) 1208 allow communication over a communication medium to various other computing entities. The communication medium provides information

such as program instructions, or other data in a communication media. The communication media includes, but not limited to, wired or wireless methodologies implemented with an electrical, optical, RF, infrared, acoustic, microwave, Bluetooth or other transmission media.

[00126] The input device(s) 1210 may include, but is not limited to, a touch screen, a keyboard, mouse, pen, joystick, trackball, a voice device, a scanning device, or any another device that is capable of providing input to the computer system 1202. In an embodiment of the present invention, the input device(s) 1210 may be a sound card or similar device that accepts audio input in analog or digital form. The output device(s) 1212 may include, but not limited to, a user interface on CRT, LCD, LED display, or any other display associated with any of servers, desktops, laptops, tablets, smart phones, mobile phones, mobile communication devices, phablets, personal digital assistants, printer, speaker, CD/DVD writer, or any other device that provides output from the computer system 1202.

[00127] The storage 1214 may include, but is not limited to, magnetic disks, magnetic tapes, CD-ROMs, CD-RWs, DVDs, any types of computer memory, magnetic stripes, smart cards, printed barcodes or any other transitory or non-transitory medium which can be used to store information and can be accessed by the computer system 1202. In various embodiments of the present invention, the storage 1214 contains program instructions for implementing the described embodiments.

[00128] In an embodiment of the present invention, the computer system 1202 is part of a distributed network.

[00129] The present invention may be implemented in numerous ways including as a system, a method, or a computer program product such as a computer readable storage medium or a computer network wherein programming instructions are communicated from a remote location.

[00130] The present invention may suitably be embodied as a computer program product for use with the computer system 1202. The method described herein is typically implemented as a computer program product, comprising a set of program instructions which is executed by the computer system 1202 or any other similar device. The set of program instructions may be a series of computer readable codes stored on a tangible medium, such as a computer readable storage

medium, for example, diskette, CD-ROM, ROM, flash drives or hard disk, or transmittable to the computer system 1202, via a modem or other interface device, over either a tangible medium, including but not limited to optical or analogue communications channel(s) 1208. The implementation of the invention as a computer program product may be in an intangible form using wireless techniques, including but not limited to microwave, infrared, bluetooth or other transmission techniques. These instructions can be preloaded into a system or recorded on a storage medium such as a CD-ROM, or made available for downloading over a network such as the Internet or a mobile telephone network. The series of computer readable instructions may embody all or part of the functionality previously described herein.

[00131] While the exemplary embodiments of the present invention are described and illustrated herein, it will be appreciated that they are merely illustrative. It will be understood by those skilled in the art that various modifications in form and detail may be made therein without departing from or offending the spirit and scope of the invention as defined by the appended claims.

Claims:

1. A method for control system optimization, the method comprising:
retrieving from a control system information repository, information corresponding to an implemented control system;
based on the retrieved information, identifying:
a plurality of function blocks corresponding to the implemented control system; and
equipment components related to the plurality of function blocks;
grouping the plurality of function blocks into a plurality of function block groups, wherein grouping of function blocks within each function block group is based on identification of one or more attributes shared by each function block within said function block group;
generating a plurality of equipment component groups, wherein:
each equipment component group corresponds uniquely to one function block group; and
each equipment component group includes one or more equipment components selected such that said one or more equipment components are related to one or more function blocks within a function block group that uniquely corresponds to said equipment component group;
within each equipment component group, identify interconnections between equipment components within said equipment component group;
and
generate a control system topology based on the identified equipment components, and the identified interconnections between equipment components.
2. The method as claimed in claim 1, comprising responding to detection of a first event within a process environment associated with the implemented control system by:
identifying a first equipment component within the implemented control system, wherein the identified first equipment component is related to the detected first event;
identifying a second equipment component within the implemented control system, wherein the identified second equipment component is related to the identified first equipment component; and

displaying one or more event notifications at a user interface, wherein the displayed one or more event notifications include information corresponding to both the first equipment component and the second equipment component;
wherein identification of the second equipment component is based on equipment component interconnection information retrieved from the control system topology.

3. The method as claimed in claim 1, wherein identification of interconnections between equipment components within an equipment component group comprises analysing each possible pair of equipment components within said equipment group to determine existence of a relationship between said pair of equipment components.

4. The method as claimed in claim 1, wherein identification of interconnections between equipment components within an equipment component group comprises applying association rule analysis to equipment parameter data corresponding to equipment components within said equipment component group.

5. The method as claimed in claim 4, wherein identification of interconnections between equipment components within an equipment component group is based on one or more association scores resulting from the applied association rule analysis.

6. The method as claimed in any one of claims 4 or 5, wherein the control system topology is generated based on a selected sub-set of the identified interconnections between equipment components, and wherein selecting the sub-set of identified interconnections comprises evaluating identified interconnections based on a predefined criteria.

7. The method as claimed in claim 6, wherein evaluating the identified interconnections based on a predefined criteria comprises applying the predefined criteria to association scores resulting from the applied association analysis.

8. The method as claimed in claim 6, wherein identified interconnections that do not satisfy the predefined criteria are omitted or eliminated from the generated control system topology.

9. The method as claimed in claim 5, wherein the one or more association scores comprise any of (i) a support score, (ii) a confidence score, (iii) a lift score, (iv) a chi square score, or (v) a unified score derived based on any of a support score, a confidence score, a lift score and a chi square score.

10. The method as claimed in claim 1, further comprising identifying a plurality of clusters of equipment components within the generated control system topology, and wherein identification of said clusters is based on detection of community structure among equipment components within each cluster.

11. The method as claimed in claim 1, wherein the information retrieved from the control system information repository is retrieved from one or more of engineering documents, system specifications, control drawings, logic charts, sequence tables or interlock tables, flow diagrams, a control system engineering information data source, a control system classification information data source, a plant configuration information data source, or an asset management information data source.

12. The method as claimed in claim 1, wherein identification of one or more attributes shared by each function block within the identified group of function blocks is based on classification identifiers assigned to each of the plurality of function blocks.

13. The method as claimed in claim 1, wherein the one or more attributes shared by each function block within a function block group comprises any one or more of (i) physical location, (ii) physical media relied on for operation, (iii) equipment type, (iv) an upstream or downstream data flow, (v) media flow or control flow relationship, (vi) location within a specific area or plant site, (vii) being in network communication with other function blocks within the identified group of function blocks, and (viii) inclusion of each said function block within a single interface screen, display window or display wireframe corresponding to a user interface within the implemented control system.

14. The method as claimed in claim 2, wherein the detected first event is independent of the identified second equipment component.

15. The method as claimed in claim 2, wherein displaying one or more event notifications at the user interface includes displaying an event notification corresponding to a detected second event, wherein the detected second event relates to the identified second equipment component.

16. The method as claimed in claim 10, further comprising displaying information identifying one or more community structure based clusters of equipment components.

17. A system for control system optimization, the system comprising:

one or more controllers;

a plurality of field devices;

a processor configured to:

retrieve from a control system information repository, information corresponding to an implemented control system;

based on the retrieved information, identify:

a plurality of function blocks corresponding to the implemented control system; and

equipment components related to the plurality of function blocks;

group the plurality of function blocks into a plurality of function block groups, wherein grouping of function blocks within each function block group is based on identification of one or more attributes shared by each function block within said function block group;

generate a plurality of equipment component groups, wherein:

each equipment component group corresponds uniquely to one function block group; and

each equipment component group includes one or more equipment components selected such that said one or more equipment components are related to one or more function blocks within a function block group that uniquely corresponds to said equipment component group;

within each equipment component group, identify interconnections between equipment components within said equipment component group;

and

a topology generator configured to generate a control system topology based on the identified equipment components, and the identified interconnections between equipment components.

18. The system as claimed in claim 17, further comprising a process monitor configured such that, responsive to detection of a first event within a process environment associated with the implemented control system, the process monitor:

identifies a first equipment component within the implemented control system, wherein the identified first equipment component is related to the detected first event;

identifies a second equipment component within the implemented control system, wherein the identified second equipment component is related to the identified first equipment component; and

displays one or more event notifications at a user interface, wherein the displayed one or more event notifications include information corresponding to both the first equipment component and the second equipment component;

wherein identification of the second equipment component is based on equipment component interconnection information retrieved from the control system topology.

19. The system as claimed in claim 17, wherein identifying interconnections between equipment components within an equipment component group comprises analysing each possible pair of equipment components within said equipment group to determine existence of a relationship between said pair of equipment components.

20. The system as claimed in claim 17, wherein identifying interconnections between equipment components within an equipment component group comprises applying association rule analysis to equipment parameter data corresponding to equipment components within said equipment component group.

21. The system as claimed in claim 20, wherein identifying interconnections between equipment components within an equipment component group is based on one or more association scores resulting from the applied association rule analysis.

22. The system as claimed in any one of claims 20 or 21, wherein the topology generator is configured to generate the control system topology based on a selected sub-set of the identified interconnections between equipment components, and wherein selecting the sub-set of identified interconnections comprises evaluating identified interconnections based on a predefined criteria.
23. The system as claimed in claim 22, wherein evaluating the identified interconnections based on a predefined criteria comprises applying the predefined criteria to association scores resulting from the applied association analysis.
24. The system as claimed in claim 22, wherein the topology generator is configured to omit or eliminate from the generated control system topology, identified interconnections that do not satisfy the predefined criteria.
25. The system as claimed in claim 21, wherein the one or more association scores comprise any of (i) a support score, (ii) a confidence score, (iii) a lift score, (iv) a chi square score, or (v) a unified score derived based on any of a support score, a confidence score, a lift score and a chi square score.
26. The system as claimed in claim 17, wherein the processor is configured to identify a plurality of clusters of equipment components within the generated control system topology, and wherein identification of said clusters is based on detection of community structure among equipment components within each cluster.
27. The system as claimed in claim 17, wherein the information retrieved from the control system information repository is retrieved from one or more of engineering documents, system specifications, control drawings, logic charts, sequence tables or interlock tables, flow diagrams, a control system engineering information data source, a control system classification information data source, a plant configuration information data source, or an asset management information data source.
28. The system as claimed in claim 17, wherein the processor is configured to identify one or more attributes shared by each function block within the identified group of function blocks, based on classification identifiers assigned to each of the plurality of function blocks.

29. The system as claimed in claim 17, wherein the one or more attributes shared by each function block within a function block group comprises any one or more of (i) physical location, (ii) physical media relied on for operation, (iii) equipment type, (iv) an upstream or downstream data flow, (v) media flow or control flow relationship, (vi) location within a specific area or plant site, (vii) being in network communication with other function blocks within the identified group of function blocks, and (viii) inclusion of each said function block within a single interface screen, display window or display wireframe corresponding to a user interface within the implemented control system.

30. The system as claimed in claim 18, wherein the detected first event is independent of the identified second equipment component.

31. The system as claimed in claim 18, wherein displaying one or more event notifications at the user interface includes displaying an event notification corresponding to a detected second event, wherein the detected second event relates to the identified second equipment component.

32. The system as claimed in claim 26, wherein a process monitor is configured to display information identifying one or more community structure based clusters of equipment components.

33. A computer program product for control system optimization, comprising a non-transitory computer usable medium having a computer readable program code embodied therein, the computer readable program code comprising instructions for:

retrieving from a control system information repository, information corresponding to an implemented control system;

based on the retrieved information, identifying:

a plurality of function blocks corresponding to the implemented control system; and

equipment components related to the plurality of function blocks;

grouping the plurality of function blocks into a plurality of function block groups, wherein grouping of function blocks within each function block group is based on identification of one or more attributes shared by each function block within said function block group;

generating a plurality of equipment component groups, wherein:

each equipment component group corresponds uniquely to one function block group; and

each equipment component group includes one or more equipment components selected such that said one or more equipment components are related to one or more function blocks within a function block group that uniquely corresponds to said equipment component group;

within each equipment component group, identify interconnections between equipment components within said equipment component group;

and

generate a control system topology based on the identified equipment components, and the identified interconnections between equipment components.

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