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Description of HVAC System and Identification of Flow Rates and Pressures in HVAC Based on Collective Intelligence System

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Description of HVAC System and Identification of Flow Rates and Pressures in HVAC Based on Collective Intelligence System

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Abstract. The efficient control of the HVAC system is important for the reduction of energy consumption in buildings. The water and air distribution network of HVAC system not only consume energy but also determine whether the cold and heat are delivered properly in the building according to the cooling and heating loads. The optimal control of the HVAC distribution system is complex due to the scale of the network and the coupling effects between HVAC devices. This paper proposes a novel distributed control system using standard computing process nodes, which is called the Collective Intelligence System (CIS). The proposed method is validated using a typical HVAC system in a real office building. The description of the HVAC system and the identification of flow rates and pressures of the distribution network is demonstrated using the decentralized identification algorithm.
Keywords. topology description, Collective Intelligent System (CIS), identification, distribution network.

1. Introduction

The Building Automation System (BAS) is an intelligent system to automatically control HVAC equipment to create comfort and healthy indoor environment, reduce labour requirement, and increase building energy efficiency. The building automation system has become a standard configuration in modern public buildings in recent years [1]. Current BAS structure and technology are originated from industrial automation [2]. However, due to the lack of experienced and capable engineering team and the lower level of maintenance of the automation system in buildings, the general performance and the completeness of BAS in the building sector are far from satisfactory. China Academy of Building Research carried out a three-year survey on the application of BAS in China and the results show that the majority of the current BAS could not meet the designed requirements. After the installation of controllers, actuators, and sensors, the control system needs a lot of effort to finish the necessary configuration and programming. Although the required resources could generally be met during the commissioning of assembly lines in factories, similar expertise is often in shortage for the BAS applications. The architecture of BAS that inherited from the industrial automation may not be suitable for buildings.

A novel distributed control system using standard computing process nodes was proposed for the control application in buildings as the Collective Intelligence System (CIS) system [3]. The CIS system is based on standard distributed smart nodes (Computing Process Nodes, CPNs) as the basic unit of the control system. Each smart node stands for a subspace or a piece of equipment in the controlled building. The smart nodes have the same hardware, same data structure, and run the same algorithm. A smart node only exchanges information with its neighbours through a direct cable connection. The smart node automatically finds the HVAC equipment, sensors, and actuators within the controlled subspace and generates standard programs according to the detected configurations and scenarios. The subspace controllers also can automatically coordinate with each other to achieve a higher level of intelligence because the subspace controllers have information about the geometric relationships between each other. By using the above mechanism, the CIS system (figure 1) does not need supervisory coordinators like the traditional BAS system. Therefore, the BAS can be decentralized into a distributed structured system and enable the automatic set-up and operation.

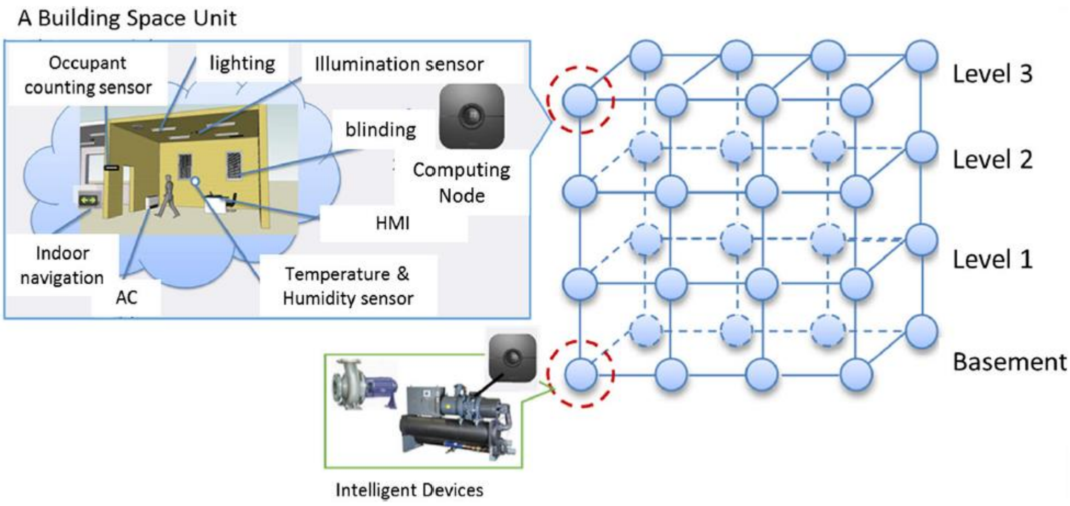

Figure 1. Structure of CIS [3].

2. Mechanism of the CIS System and Traditional BAS

The distributed nature of the proposed CIS requires the smart nodes in the CIS system to work simultaneously to achieve system-level goals. One of the major differences between the traditional BAS system and the CIS system is the control targets. The traditional BAS concept comes from industry and the control target is the equipment or process. While in buildings, the control targets are air handling units, chillers, room units, etc. The CIS system aims to deal with spaces or zones in buildings. Each CPN stands for a space or zone of the building and the related devices, sensors, and actuators within the zones. The inner logic between the contained elements is therefore identified and configured automatically. The basic principles for the description and control of the building system using CIS are:

- CPNs represent zones and subspaces. Rooms, corridors, and atriums are usually recognized as building zones or subspaces.
- The HVAC system is mapped to building zones.
- Connection relation between neighbouring CPNs implicates the geometric directions in the physical world.
- Name of HVAC space, HVAC element type, and linkage of ventilation subspace are stored in CPNs.
- One CPN knows its neighbour only. Global information about the system is stored in the network.
- The information exchange is local. Only the neighbouring information can be acquired by each CPN.
- All CPNs have the same program and run the same algorithm.

3. Description of Building Spaces

Several applications using the CIS concept in building automation system**s** are reported in recent publications [4-8]. A typical water distribution network of the HVAC system controlled by the CIS

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system is provided in the following section. The method to identify the flow rates and pressures of the water distribution system is proposed and validated using a case study.

The building spaces can be classified into zones according to the functions and spaces [9]. The CIS system is based on smart zones represented by CPNs. In figure 2, a typical office building is chosen to demonstrate the feasibility of the CIS concept. The building is located in Qingdao City, China. The building is a 10350m^2, 6-floor office building designed to accommodate 450 occupants. The layout of the standard floor as shown in figure 2 indicates that the building has an open atrium surrounded by corridors and office rooms.

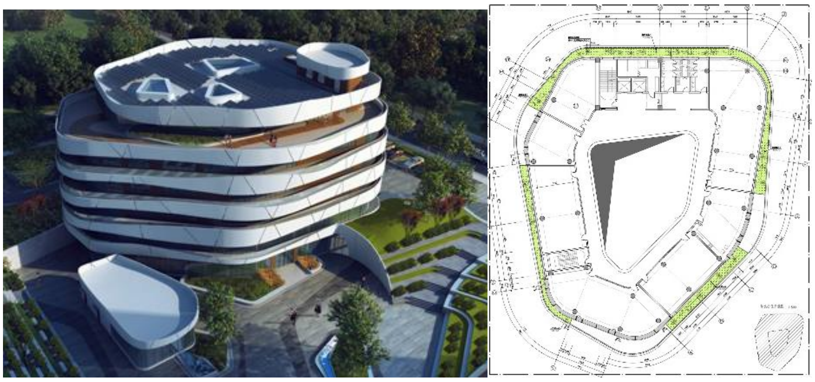

Figure 2. A typical office building and the layout of a standard floor.

CPNs are assigned to building subspaces, as shown in figure 3. CPNs represent building atrium, corridors, and working spaces according to their locations in the building. Different CPNs are connected by communication cables. There are two kinds of relations between building spaces: adjacent or connected. "Adjacent" means that two spaces are side-by-side but there is no physical path linking them. "Connected" means that there are certain connections between the spaces.

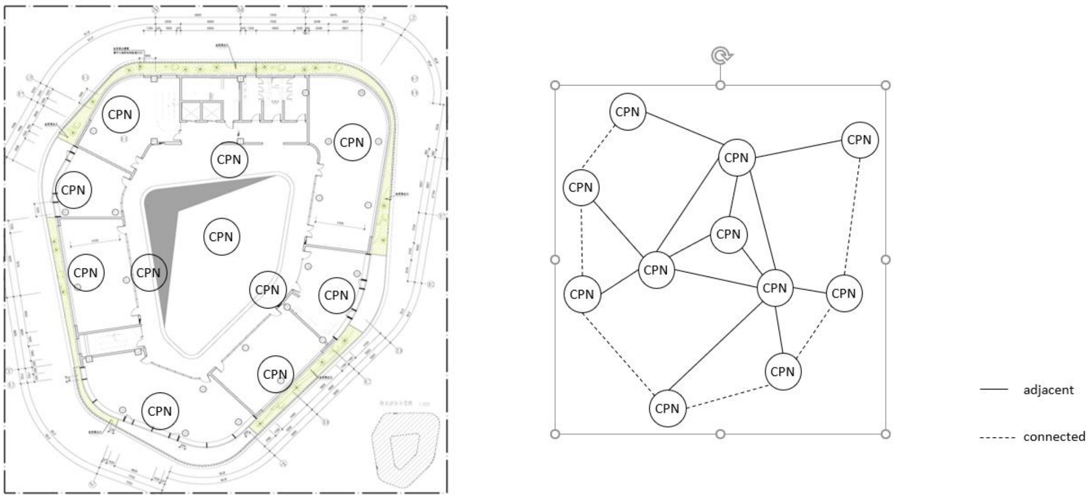

Figure 3. Space description of the standard floor using CIS.

4. Description of HVAC System

The HVAC distribution network and equipment are installed in building spaces. Therefore, the description of the building mechanical system in the CIS is based on the description of the building spaces or attached to the building spaces. The HVAC system of the selected building is shown in figure 4. The HVAC system can be considered as a distribution network that connects terminal devices. The

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description of the HVAC system based on the CIS is also provided in figure 4. Specific information is assigned to each CPN to reflect the HVAC system element installed in building subspaces. “AC” means that the HVAC terminal devices are installed in the space. “S” represents the flow resistance of the device. “P” and “G” are the pressure and flow rates of the HVAC water distribution network at the given building space. The CPN labelled as “Pipe Joint” represents the junction where the distribution network of this floor is connected to the main network. The solid and dotted lines represent the main water pipes and the pipe branches.

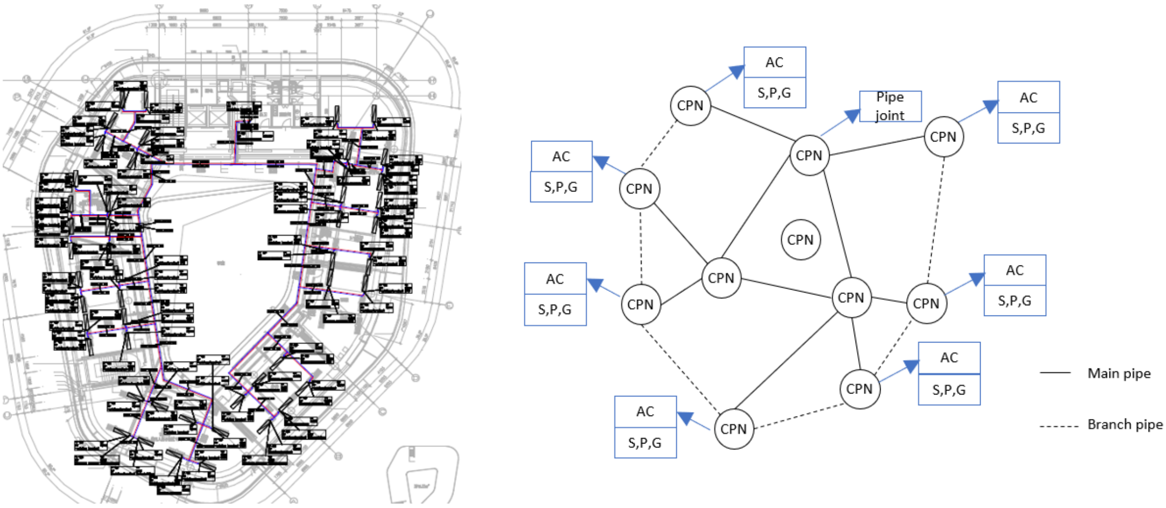

Figure 4. The HVAC water system and its description in CIS.

To maintain appropriate indoor thermal comfort without wasting energy, the chilled water should be distributed proportionally to the places where the cooling load is demanded. The identification of the pressures and flow rates of the distribution network of the chilled water will effectively help improve the control of the HVAC system. In the traditional system, only regional level heating systems covering millions of square meters can afford the pressure and flow rate identification procedure because of the complexity of the work and the lack of sufficient expertise. With the CIS concept, the identification of the distribution network can be implemented at a much lower cost.

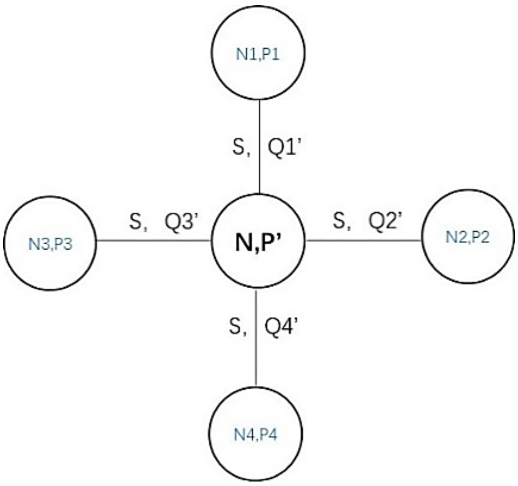

Figure 5. Standard unit in CIS representing the water distribution network.

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For the identification process, the governing equations follow the same basic physical laws. The same calculation functions are stored in each CPN. The governing functions of node N in figure 5 are:

$$\sum_{i=1}^{n} Q_i = Q_N \tag{1}$$

$$\mathrm{P_i} - \mathrm{P_N} = \mathrm{s_i Q_i^2},\ \mathrm{i} = 1 \ldots \mathrm{n} \tag{2}$$

Equation (1) describes the flow balance at node N. Q_N is the flow intake or outlet flow rate to the ambient environment of node N; Q_i is the flow rate from node N_i to node N; n is the number of neighbouring nodes of node N.

Equation (2) describes the energy balance at node N. P_N is the pressure of node N; P_i is the pressure of node N_i; s_i is the resistance of the branch between node N_i and node N.

$$\mathrm{Q(n+1) = Q(n) + \lambda\Delta Q} \tag{3}$$

Information is exchanged between each CPN and its neighbours. Each node refreshes its previous information according to the information from its neighbours. A learning factor λ is employed to determine how much of the new information is used to update the previous knowledge. The iteration continues until the maximum ΔQ of all the CPNs is less than a given threshold value.

The identification process starts simultaneously at each node with initial values of P, Q, and S. When the process begins, different nodes solve equations (1) and (2) locally and exchange information with their neighbours. When the new P and Q values at each node updated, the ΔQ and ΔP were examined whether the difference between each iteration is less than the given threshold. The process stops when all the CPNs have balanced flow rates and the difference between each iteration is small enough.

5. Simulation Results

A 6-node water distribution system is used to demonstrate the feasibility of the proposed identification method (figure 6). The node n1, n4, n5, and n6 are nodes that their pressures and flow rates are measured. The node n3 and n4 are nodes where the pressure and flow rate information need to be identified without direct measurement. The pressure at node n1 is set to be 100 MPa and the pressures at nodes 4, 5, and 6 are 0 Pa. The flow resistance at each node and branch are known (This information can be found from design drawings or construction documents).

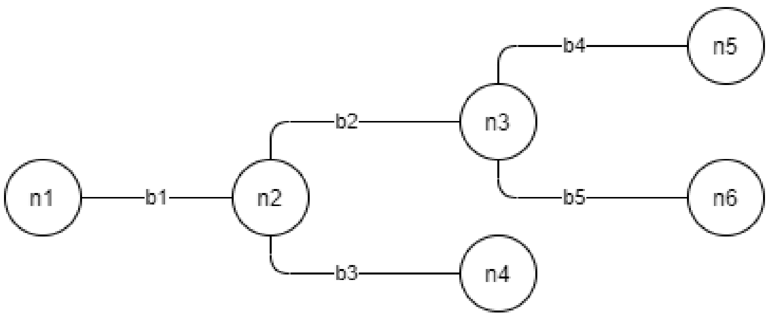

Figure 6. The topology of a simplified water distribution network of the HVAC system.

The proposed algorithm was carried out in a simulation environment developed by Python 3.5. The identified results of pressure at node n2 and n3 are shown in figures 7 and 8, respectively. For both nodes, the calculation achieved a good convergence after about 10 iterations. The pressure (P) of node n2 reached steady around 19.3 MPa, and the pressure of node n3 remained unfluctuating at 1.9 MPa. As the calculation became converged, the updated pressures between each iteration decreased gradually. The unknown pressures at node n2 and n3 were successfully found.

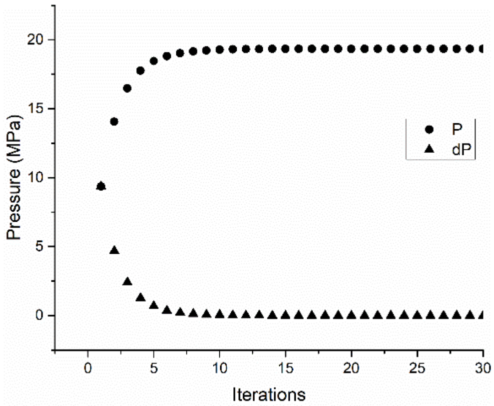

Figure 7. Values of pressure and difference of pressures of each iteration at node n2.

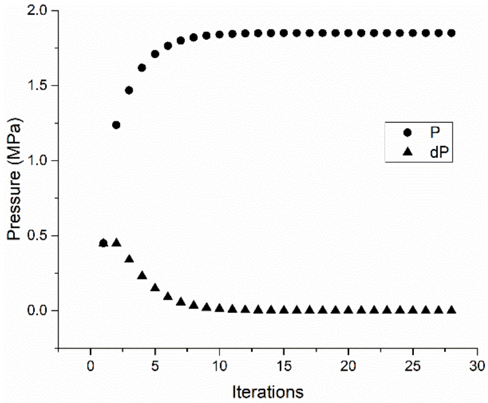

Figure 8. Values of pressure and difference of pressures of each iteration at node n3.

6. Conclusion

The proper control of the HVAC system is complex due to the scale of the network and the coupling effects between HVAC devices. A novel distributed control system using standard computing process nodes to achieve system-level goals, which is called the Collective Intelligence System, is proposed in this paper. The proposed method is described using a typical HVAC system in a real office building. The description of the building space, HVAC system, and the identification of flow rates and pressures of the distribution network are demonstrated using the distributed identification algorithm.

Compared with traditional BAS, the proposed system uses standard and pre-programmed algorithms running at each standard smart node to achieve system-level optimality. The decentralized nature of the proposed method enables simpler configuration and identification of the system without global knowledge.

Acknowledgments

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