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A Novel Conceptual Fire Hazard Ranking Distribution System based on Multisensory Technology

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Abstract

Multisensory fire detection is widely accepted as the next generation of fire detection technology. A novel conceptual fire hazard ranking distribution system is proposed based on multisensory technology with the aim to assist building managers in fire emergency management, and fire brigades in fire rescue or fire fighting. The system is consisted of a fire node network representing fire hazard ranking of the divided control units in a building plan. Concept of fire information cloud is proposed inside the system to conduct most of the calculation and storage related to fire information. The system has the potential to provide space dimension in addition to traditional time and sensor type dimensions of a fire detection system. Fire location, fire situation assessment, and fire development intensity of a building in fire can be provided by the system for emergency management reference. Some long-term significances of the proposed conceptual system are also presented.

Keywords: fire hazard ranking, multisensory information fusion, fire information cloud, fire emergency management

1. Introduction

Fire detection system is the first barrier in protecting a building from all negative effects resulted from a fire accident. The purpose of a fire detection system is to detect a situation that is deemed to be a potential threat to residents [1], which can help to start early fire control and evacuation to reduce the relevant fire loss since both are powerful measures to mitigate all negative effects during a fire[2-4].

Tradeoff between failed alarm and false alarm has been a major problem in development of a new fire detection technology. Failed alarm can result in missing of the best fire control opportunity, while false alarm can lead to switching off of the fire detection system and expose a building to a dangerous situation with no fire detectionsystem [5,6].

Fire detection using a single sensor type can merely perceive limited partial fire signatures in a fire accident, and multiple fire sensors of different types are needed to provide sufficient local fire description from various aspects of a fire in an integrated manner. Repeated efforts have demonstrated the advantages of multisensor fire detection technology in increasing both fire detection sensitivity and reliability with advanced information fusion algorithm[7-10,1,11-13]. It is even deemed as the next generation of fire detection technology [14,15]. However, it can merely increase fire detection performance of
traditional fire detection systems. With the advancement of electronic engineering, pervasive calculation, and communication technology etc, it is now in urgent need that precise fire propagation progress can be provided other than merely signal a fire alarm and the entire system is abandoned after that. This can be of great significance in taking various emergency actions during a fire accident, such as different evacuation notification sequence of various areas inside a building, or various mobilization plans of fire forces.

One possible measure in solving this problem is to model the fire development process and predict the fire development process with the measured fire parameters. However, traditional fire plume relationships related to this issue may encounter great challenge due to complex structures of a building. Then application of CFD may be a better choice, but calculation cost of CFD is not acceptable in most real-time cases. Several days may typically be needed to conduct a CFD case calculation, which limits application of CFD mostly to fire safety design stage, such as the well-known performance-based fire design. It is then not be preferable in correcting the calculation results by CFD model with the measured fire parameters, and the prediction results sometimes even deviate the real fire process. Another possible measure is to send all the measured fire parameters outside the fire sites. However, increase of sensor node density and complexity may not be favorable in assisting fire emergency management and decision making but merely cause information overload problem[16].

Concept of intelligent building [17-20] or intelligent space [21-23] has been widely accepted as a powerful tool for scientific decision-making in building management in many aspects with distributed sensor nodes. Development of fire emergency management system can merge with the other intelligent systems to reduce cost and obtain synergistic observation effects. Some similar systems are already available [24,25], but these systems mainly concentrate on response time performance of communication protocols. Rare information is available about information fusion and application of acquired multisensor fire parameters currently. In fire emergency management and rescue process, it is typically difficult to make decision directly based on the original measured fire parameters. Information fusion is needed to make a final decision for fire rescue. In military field, different information fusion levels such as pixel-level, feature-level and decision-level can be found. Information fusion mode in constructing a fire emergency management system with multisensor technology can follow that structure.

The objective of this research is to construct a conceptual fire hazard ranking distribution system for intelligent fire emergency management and rescue based on multisensor fire technology. This system will use information fusion technology to make the best of multisensor fire detection and reduce information processing and communication cost with redundant information excluded. Four information fusion levels for the fire emergency management system will be incorporated, which includes multisensor fire detection level, fire hazard ranking level, fire hazard distribution level and system fire hazard ranking level (fire situation assessment). Based on the final system fire hazard ranking results, building managers and commanding officers can approach to the magnitude of the fire accident and the approximation of the fire location easily, and sensible emergency and rescue plan can be activated. Long term significance of the proposed system will also be projected.

2. A Conceptual Fire Hazard Ranking Distribution System

A conceptual model of the proposed fire hazard ranking distribution system is shown in Fig 1. Five main modules, which include fire node subdivision module, fire detection model of a single sensor node, fire information cloud, fire hazard ranking module of a single sensor node, and fire hazard ranking distribution merge module, can be found in the model. The fire detection module of a single sensor node is a multisensor fire detection model proposed in our another research[26], which includes fire signature combination module, supervised training module, and fire detection module. The selected fire parameters in monitoring a fire can be determined by the fire signature combination module in the fire detection model. Descriptions of the other four modules will be presented in the following parts.
Fig. 1. Conceptual Model of the Proposed Fire Hazard Ranking Distribution System.
2.1. Running Procedures of the Proposed Fire Hazard Ranking Distribution System

A typical running procedure of the model is that a building plan is transformed to abstract control units, and there is a fire node inside each unit. On the one hand, algorithms of the multisensor fire detection model are embedded in each fire sensor node to detect a real fire. Detection results of each node can communicate with the fire information cloud. The fire information cloud can conduct storage of information of each node and calculate correction coefficients according to the stored fire information. The coefficients are delivered to the fire hazard ranking distribution merge module.

On the other hand, the measured fire parameters are delivered directly to the fire hazard ranking distribution merge module to produce an initial fire hazard ranking. The fire hazard ranking distribution merge module will generate the fire hazard ranking of a sensor node directly by combining the initial fire hazard ranking and the correction coefficients.

Similar process are conducted in all the divided fire nodes, and an abstract fire hazard ranking distribution map can be generated with fire ranking results of each node fused by the fire hazard ranking distribution merge module. The module can then transfer the abstract fire hazard ranking distribution of fire nodes to a real-site fire hazard ranking map. The real-site fire hazard ranking map can be copied to a remote site by remote communication measures such as TCP/IP, GSM, and GPRS. In the final process of remote information transformation, the communication efficiency will be considerably high since many information fusion processes have been completed to exclude redundant and detailed fire information.

2.2. Fire Node Subdivision Module

Function of fire node subdivision module is to divide structure of a building plan to a conceptual fire node network. Schematic of the major procedures of the fire node subdivision module is shown in Fig 2. The building plan is first divided into different conceptual areas according to structure, protection radius of the fire sensor nodes and expected detected fire size[26]. These areas are transferred to abstract control units, which are regularly aligned and each unit may represent areas of different shapes and dimensions. A conceptual fire node is proposed to represent the fire information and structural plan information of a control unit. In practice, the fire node may be embedded in the center control panel of a sensor node. In conceptual, a fire node is used to store information such as fire status of the control unit of a period, training fire detection patterns of the multisensor fire detection model, fire hazard ranking algorithm and fire hazard ranking results, and it can still store geographical information of a control unit or to communicate with the fire information cloud.

In traditional fire detection system sensor alignment mode, concepts of protection areas of the ground and protection radius are typically used to assure that there is no detection “blind area” of a building. Division of control units should not only ensure fire detection of all the protected areas, but ensure that information of a fire node can be reasonable to represent fire hazard ranking of the divided area.

In the proposed fire node subdivision module, three factors should be considered in the control unit division process. The first factor is expected detected fire size. As revealed in[26], expected detected fire size is a critical fire size that can cause potential negative fire effects and need to considered in the designing process of a fire detection system. Determination of expected fire size is relevant to building structures and locations of fire sensors. The second one is building plan. The control unit division process should be consistent with the building plan. For example, a control unit is not favorable to include areas both inside and outside a room. The third factor is protection radius of the selected sensors. Resolution or sensitivity of different sensors can vary dramatically. Even for the same sensor, measured fire signatures can be reduced from apparent to trivial with mounted location at elevated height. Then parameter of protection radius typically should be determined by both sensor resolution and structure of a building where the sensors are installed. Sensitivity of fire sensors can be quantified by RTI parameter[27].

After subdivision of the building plan combining the three factors, a regular abstract control unit map can be formed as is shown in Fig 2. A conceptual fire node is located in each control unit. By indexing the fire nodes, a network model of all the fire nodes is generated, which is convenient for geographical information searching. Many attributes including fire detection status, fire hazard ranking, geographical information etc can be involved in the fire node.
2.3. Fire Information Cloud

Hazard ranking of a fire node needs different correction coefficients that should be calculated based on fire hazard ranking distribution of the whole building. It is then not cost-effective to store all the relevant data and perform all the large quantity of calculation in a sensor node. Meanwhile, further application of the fire hazard ranking distribution map will still need a large amount of storage and calculation that are typically beyond capacity of a single fire node with common pervasive calculation devices such as Micro Control Unit.

Concept of fire information cloud is then proposed in the fire hazard ranking distribution model as a media center for large amount of fire information storage and calculation. Geographical information of all fire nodes is stored in the fire information cloud. The fire detection results and fire hazard ranking of all fire nodes in time sequence of a certain period are also saved in the fire information cloud. However, storage of the measured raw data from different sensors is not preferred in the system, and information fusion is needed to reduce calculation and communication cost with pervasive calculation performed in individual fire nodes.

Fire information cloud should have bidirectional communication capacity with each individual fire node to receive fire hazard ranking and fire detection information and respond to requirement of each node. Characteristics of the fire
information cloud should include parallel calculation, mass storage media etc., and can be conducted using distributed computer network according to application need of various buildings.

Three fire hazard ranking correction coefficients should be provided by fire information cloud for all the fire nodes. These include fire status correction coefficient, fire source distance correction coefficient and multiple detected fire spots coefficient. When receiving communication requirement from a fire node, fire information cloud will compare the index of the node with the stored information and perform relevant calculation. All the calculations are based on the fire hazard distribution map of the last time point.

Measured real-time fire parameters are used as inputs of the multisensor fire detection model, the model has the advantage of combining fire parameter trend of a certain period using a dynamic observation window. The fire detection results of time sequence can be provided and transmitted to fire information cloud continuously. After receiving the first fire status, fire information cloud will calculate the continuous next few fire status results and determine whether a real fire happens, which can exclude influence of nuisance sources to a large extent. After confirmation of a fire in a node is recognized, fire status correction coefficient of the node can be set to a value larger than 1, such 1.2. Otherwise, the coefficient should be less than 1, for example 0.8. This correction coefficient is meant to confirm fire status and reduce influence of zero-drift or destroyed sensors.

Fire source distance correction coefficient is proposed to combine time factor of fire development process between a fire node and fire location in fire hazard ranking. Fire location inside the fire information cloud can be determined where the first detected fire status is signaled. In practical application, some confirmation can be conducted by monitoring fire status of several fire nodes geographically near the first fire status node. This location can be used as the approximation fire position, and can be of great significance in further fire control activities. For fire information cloud, the fire position is used to determine fire source distance correction coefficient. A range of fire source distance correction coefficient should be predetermined such as between 0.5 and 1.5. Then geographical distance between each node and the fire location should be calculated by fire information cloud. After that, a function type which can transfer function output within a certain range with distance as inputs should be used to determine the according fire source distance correction coefficient of each node. Many function types such as sigmoid function can meet the requirements. The output range should be scaled to be the same as the predetermined correction coefficient range.

Multiple detected fire spots coefficients is proposed to combine influence of instantaneous fire size inside a building. This coefficient is actually a system coefficient which is used to describe system performance and is exactly the same for all fire nodes. Areas with fire status or fire hazard ranking over certain levels are determined by fire information cloud combing geographical information of the nodes. Summation of all the areas can be used to assess fire intensity. Multiple detected fire spots coefficient is then determined. Application of fuzzy rules is recommended in calculation this coefficient by separating dimensions of the areas to several ranges.

Another important parameter inside the fire information cloud is system fire status. When the first fire node detected a fire, the system fire status can be set to be fire. However, as aforementioned, a more preferable measure is to set system fire status to be a fire when several geographical nearby fire nodes signal fire status. Fire detection using a single sensor with a threshold detection algorithm can be deemed to be zero-dimensional fire detection technology, while that with time sequence information such as trend algorithm can be deemed as one-dimensional detection technology. Similarly, multisensor fire detection technology can be one or two dimensional fire detection technology depending on whether the time sequence information is considered. Inside the fire information cloud, the system has the advantage to provide the third fire detection dimension, which is the space dimension in addition to time dimension and sensor dimension. The system can then have the best flexibility between fire detection sensitivity and reliability.

2.4. Fire Hazard Ranking Module

Fire hazard ranking module is conducted inside each fire node. As is shown in Fig. 1, two main information flow routine can be found from the initial inputs of the module. Both routines merge inside the module by fire hazard ranking correction algorithm. One routine is to generate initial fire hazard ranking of a fire node, while the other is to produce fire hazard ranking correction coefficient to incorporate the aforementioned influences in a fire accident.

On the one hand, measured fire parameters are provided to the fire hazard ranking module directly. A fire hazard ranking algorithm will be performed to produce the initial fire hazard ranking score according to the measured raw fire parameters. Fuzzy rules will be needed in the algorithm to separate the range of the selected fire parameters to several parts and assign a certain score for each part. The range of each selected fire parameter should be determined by considering the harmful effect on pedestrian’s height such as 1.8m and the location of the mounted fire sensor node related to the structure of the building. CFD simulation may be a possible measure to determine the flexible range. All the fire hazard ranking scores of each fire
parameters will then be merged by the algorithm to produce initial fire hazard ranking score.

On the other hand, fire hazard ranking module communicates with the fire information cloud to obtain the according three correction coefficients, namely fire status correction coefficient, fire source distance correction coefficient, and multiple detected fire spots correction coefficient. These coefficients are merged by correction coefficient fusion algorithm to produce a final fire hazard ranking correction coefficient of a single fire node. The algorithm can be a simple function of multiplying all the three coefficients together, or be a function to obtain mean value of the three coefficients.

The initial fire hazard ranking score is then corrected by multiplying the final fire hazard ranking correction coefficient by the fire hazard ranking correction algorithm. Output of the algorithm will be fire hazard ranking of the node. Five fire hazard ranking levels are recommend in the system, which includes safe level, minor danger level, danger level, major danger level and destroy level. Fuzzy rules can be adopted to determine the fire hazard ranking according to the corrected fire hazard ranking score. With all the corrections performed, the system will make the best of advantages of the distribution network, and can minimize influence of problems in a single sensor node such as zero-drift or destroyed sensor.

2.5. Fire Hazard Ranking Distribution Merge Module

Function of fire hazard ranking distribution merge module is to transfer fire hazard ranking results of all fire nodes to a colorful fire hazard ranking distribution map in the real-site building plan. Most of the calculations should be conducted by the fire information cloud. Areas with safe fire hazard ranking level can be blue-colored, while areas with destroy level can be red colored. Then some transition colors can be used for the other three fire hazard ranking levels.

Fire hazard ranking results of all fire nodes are delivered to the module and the conceptual fire node network can have different fire hazard ranking of each node. Then a reference hazard ranking to color transformation matrix as mentioned above is used to produce a control unit hazard ranking distribution map with the fire hazard ranking of each fire node to represent the hazard ranking of the according fire control unit.

Combining control unit geographical information which is generated by the fire node subdivision module initially and stored in the fire information cloud, the control unit anti-transformation sub-module can transfer the control unit hazard ranking distribution map to a real-site fire hazard ranking distribution map. Relevant real-time fire hazard ranking of different areas will be represented by the central fire node and iterated with time step. However, it should be emphasized there are initially safe level status for all fire nodes related to the entire building for the first application of the system. Then the real-site fire hazard distribution map can be updated with the real-time measured fire information. Many possible applications can be conducted inside the fire information cloud based on the map and will be discussed in the following sections.

3. Long-term Significance of the Proposed Fire Hazard Ranking Distribution System

Based on the proposed multisensor fire hazard ranking distribution system, many potential applications can be conducted with assistance of the current emerging electronic and communication technology. In this section, several possible applications are constructed to illustrate the application prospective of the proposed system.

3.1 Intelligent Fire Detection and Control

As described above, the system has the potential to provide three dimensional fire detection capacities with fire detection dimensions of time, sensor type and space. Fire information cloud can conduct the possible detection based on the fire hazard ranking distribution map related to different fire hazard areas and hazard levels.

Fire control is important to protect a building from fire accident loss and provide more available egress time for residents inside a building in fire. Fire control measures inside a building can be sprinkler, smoke ventilation, fire extinguisher, and fire nozzle etc. However, traditional fire detection system can merely provide a fire alarm and will be abandoned during all the following fire protection process.

Based on the fire hazard ranking distribution system, an ambiguous fire location can be provided as discussed above, which can be used as targets for fire control. Release of fire extinguishing agent can be more precise according to different fire hazard ranking inside a control unit. This can help to obtain the maximum fire control efficiency with the minimum cost.

Most of casualties in a fire accident are due to toxic smoke inhalation. Smoke exhaust efficiency is one of the major concerns in fire protection design of a building. Smoke control mode can determine smoke exhaust efficiency to a large extent. Areas near fire should use ventilation mode, while the vicinity places may be suitable to use supply mode. Currently, application of efficient smoke control mode related to various fire situations is limited due to lack of fire development
information in a fire accident. With the proposed fire hazard ranking distribution system, smoke control areas can be linked to control units, and different smoke control mode is easy to be implemented with dynamic fire hazard ranking of the control units. Fire information cloud can help to conduct complex decision-making algorithms in the selection of smoke control modes.

3.2 Intelligent Evacuation Guidance System

Evacuation modeling is a powerful measure in designing or assessing of a fire protection system of a building. One popular application of evacuation model is in the performance-based fire design, in which evacuation model is typically used to calculate required egress time for residents to evacuate outside a building. The counterpart is available egress time that is calculated with CFD simulation tools to determine the period between initiation of a fire and an unacceptable dangerous situation. A criterion is usually conducted to compare the two times to assess a fire protection system of a building. However, application of evacuation models mostly cease in the designing or assessing process of a fire protection system. Meanwhile, the mostly adopted evacuation criterion is to search for the shortest routine for all pedestrians. In practical application, a more favorable measure may be search for the safest routine related to fire location and evacuation efficiency.

In practice, some intelligent evacuation indication system can be found with bi-directional allows indicating an evacuation direction deviate from fire location in a fire accident. However, efficiency of the system is restricted dramatically due to limited number of arrow indicators and the direction choices. It is preferable that an indication system can provide guidance for individual persons.

With the fire hazard ranking system, it is possible that a search algorithm can be performed for each individual person to find a routine that has the best balance between summation of encountered fire hazard ranking for each step size and the evacuation time.

Detailed guidance for individual pedestrian can be provided by electronic map of a building using smart phone. It is very possible that WiFi signals can be provided in most important buildings in the near future. A possible measure is that software in the smart phone can automatically download the according building plan when entering a new building and location of the individual can be determined by signal strength of different WiFi spots, or by additional communication with GPS module which is already prevalent in smart phones. Another possible measure is that mobile network operator can provide building plan information and location of individual persons. However, in the above process, privacy and information safety should always be a major concern in application. With the proposed system, a suggested routine can be provided for each individual inside the building in a fire accident.

3.3 Real-time Fire Situation Assessment

In a fire situation, it is important to assess the fire intensity and possible development to evaluate the possible fire loss and take effective measures to minimize fire accident loss. However, traditional fire detection system merely signals a fire alarm and no further information will be provided. Evaluation of fire situation mainly depends on observation and empirical experience of building managers and on-site fire commanding officers.

With the proposed fire hazard ranking system, it is practical to implement fire situation assessment timely in a fire accident. Information fusion algorithms can be constructed related to fire hazard ranking distribution and the relevant areas of the control units. Some fuzzy rules can then be conducted to provide an overall level of the fire situation for the building in fire. Further algorithm concerning time iteration of fire hazard ranking distribution, distribution changes between continuous time points can be used to characterize fire development speed.

Building managers can make reasonable emergency management decision rapidly based on the fire situation assessment results of the proposed fire hazard ranking distribution system, and the relevant fire accident loss can be minimized. Fire rescue commanding officer on-site can formulate effective fire fighting strategy according to the assessed fire situation. The fire situation results can also be transferred to the remote fire fighting command center for further rescue strategy making and allocation of fire rescue resources which will be discussed later. In the implementation process of the application, issues of destroyed fire sensor nodes should be considered to increase reliability of fire situation assessment.

3.4 Fire Rescue Resource Allocation Optimization

One of the major issues in fire fighting process is proper fire rescue resource allocation in accordance with the fire situation. In practical application, many fire rescues are sponsored with descriptions in a fire telephone. Accuracy of fire rescue resource allocation decision will then mainly depend on empirical knowledge of the caller. This situation can be changed with application of the proposed fire hazard ranking system as mentioned above.
Fire situation assessment results can be transformed to the remote command center and can be connected to a more systematic fire rescue resource allocation system that has the entire available fire rescue sources incorporated, including status and location of fire fighters, fire fighting vehicles, and other fire rescue resources. All these resources should be integrated to the fire rescue resource allocation system with the measures of internet of things.

Based on the obtained fire situation from the proposed fire hazard ranking distribution system, some search algorithms can be conducted to optimize fire rescue resource allocation related to routine, transportation time etc. This implies that the fire rescue resource allocation system should combine with geographic information system and global positioning system. Some reservation fire fighting resources should be spared for some other possible fire emergency situations. The obtained fire rescue resource allocation plan can be sensible, automatic and effective.

3.5 Mobile Fire Rescue Information Platform

Fire development in practice can be swift and violent. It is important that fire fighting strategy can be established at the first time. With the proposed fire hazard ranking distribution system, it is possible that the map and the assessed fire situation can be copied to a mobile fire rescue information platform that is carried by a bus, which is actually popular in many occasions.

When receiving fire alarms, the on-site commanding officer can communicate with the command center to perceive the fire development progress and the allocated fire rescue resources. Structure of the building in fire, assessed possible fire location and intensity can all be provided to the commanding officer as discussed above. Preliminary fire fighting strategy can be determined on the road, and the implemented strategy can be settled quickly after approaching the fire site. The communication process can be conducted via satellite or mobile communication platform such as 3G or GPRS. Advantage of information fusion of the proposed system will be apparent in limiting communication data load.

4. Conclusions

A novel conceptual fire hazard ranking distribution system based on multisensortechnology is proposed in this research. The system has the potential to provide possible fire location, fire development intensity and fire situation of an entire building in fire, which are all important references for fire emergency management, fire rescue and fire fighting for building managers or fire brigade officers. Structure and information fusion algorithms of the proposed system are brief and effective.

Concept of fire detection dimension is proposed to characterize the potential flexibility of a fire detection system. Traditional fire detection systems are mainly one or two dimensional with time dimension or sensor type dimension. The proposed fire hazard ranking system has another space dimension for application. The involved multisensor fire detection model of the proposed system can detect a fire with fire development information of a period. Then the system has the advantage to describe fire development with limited data load by reflecting possible influence of fire development in terms of time and space.

Concept of fire information cloud is proposed to reduce calculation and storage cost of the distributed sensor node. With development of pervasive calculation, distributed central panel of each sensor node can conduct most calculation. However, it is still not cost-effective to perform large amount of repeated calculation and storage or conduct complex algorithms in each panel. Fire information cloud has the advantage to solve these problems in the proposed system.

Three correction coefficients including fire status, fire source distance and multiple detected fire spots can be obtained for each control unit via communication with fire information cloud. With all the coefficients, the system has the advantage to minimize unstable status influence of a single sensor node by making the best of the distributed sensor network. Meanwhile, influence of fire development intensity is also reflected by multiple detected fire spot correction coefficient.

It is probable that the proposed fire hazard ranking distribution system can be applied in practice within or beyond the above mentioned framework of the aforementioned long term significance with advancement of electronic engineering, communication technology, and computer science.

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