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(54) **Title**: A FIRE DETECTION SYSTEM USING A DRONE

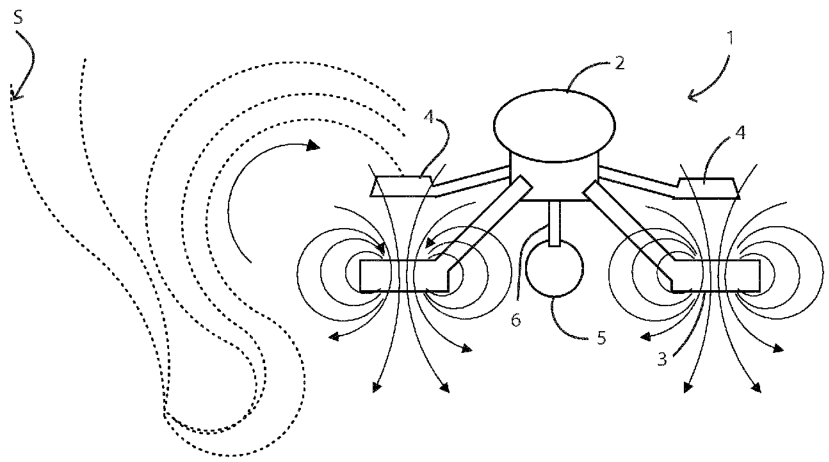

Fig.2

(57) Abstract: A fire detection system has a system controller (160) with a digital processor and a wireless interface for communicating in a local area within a building (156, 155), and at least one drone (150-152) having a body and at least one rotor (3), a controller, and a wireless interface for communicating with said system controller. Fire sensors (4, 5) are mounted on the drone, and it flies on a flight path within the building and to send fire alert data to the system controller upon sensing of a fire condition by said sensor. At least one smoke sensor (4) is located on a rotor axis on the upstream so that rising smoke (S) is drawn back downwardly past the smoke sensor. The flight path of a drone may be chosen for optimum detection, such as for validation of a fire event if potential incipient fire stage is detected.

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A FIRE DETECTION SYSTEM USING A DRONE

INTRODUCTION

Field of the Invention

The invention relates to detection of fire or potential fires internally in buildings such as warehouses.

Prior Art Discussion

It is known to provide fire control panels, both wired and wireless, and many detectors/sensors of different types. However, detecting fires in large buildings such as warehouses can still be very challenging. High ceilings and multi-level high density storage racks can mask fire sources from known point based smoke detectors. Beam detectors are used to overcome some of the issues, however, high ceilings and high density racking, pallet stacking and building flex make maintenance of beam detectors difficult and costly.

Current approaches include Aspirated Smoke Detection (ASD) systems, Video Image Detection (VID) systems, and linear heat detection (LHD) systems.

ASD systems employ sampling pipes to draw air through a network of pipes to the detectors. For example, in warehouse racks, sampling pipes can be run horizontally or vertically through the racks to sample air at all levels, overcoming smoke stratification problems. Aspirated smoke detection systems are effective in detecting fires where smoke is present; however, they will not detect heat sources. ASD systems are costly to install and maintain and sampling pipes can be prone to damage.

VID (Video Image Detection) systems employ imaging to detect smoke and flame signatures from a fire. However, densely packed warehouse structures, lighting and warehouse activities can create difficulties in achieving effective coverage.

Linear heat detection (LHD) systems employ a cable based detector that measures heat differentials along the length of the cable. This type of heat detection is good for warehouse applications because it can be run in storage racks. Limitations are that lower heat levels prior to rapid flame growth may not be detected.

For outdoor fire detection it is known to provide aerial surveillance as described in US6556981. In this system a combination of drones and aircraft perform surveillance, and expert system logic is used to analyse what is sensed. Aerial detection of outdoor fires is also described in EP2511888 and US2005189122.

YouTube, 2015, "Autonomous Drone Assists Firefighting Inside Naval Vessels", Youtube.com, [Online], Available from 'https://www.youtube.com/watch?v=g3dWQCECwlY' shows footage of an unmanned aerial vehicle under testing to locate fires within a ship.

There is a need for improved prevention of fires and early detection of fires in indoor locations such as warehouses and other industrial or retail buildings, for example.

The invention is directed towards achieving such detection.

SUMMARY OF INVENTION

We describe a fire detection system comprising:

a system controller comprising a digital processor and a wireless interface for communicating in a local area within a building,

at least one drone having a body and at least one rotor, a controller, and a wireless interface for communicating with said system controller, and

at least one fire sensor mounted on the drone,

wherein the drone controller is configured to direct flight of the drone on a flight path within said building and to send fire alert data to the system controller upon sensing of a fire condition by said sensor.

In one embodiment, the fire sensor includes at least one smoke sensor located at or adjacent a rotor. In one embodiment, said smoke sensor is located at or near a rotor axis. Preferably, said smoke sensor is located at or near an upstream side of the rotor.

In one embodiment, the drone comprises a plurality of rotors and there is a smoke sensor associated with each rotor.

In one embodiment, the fire sensor includes a thermal sensor, and the drone controller or the system controller are configured to detect a fire incipient stage according to the output of the thermal sensor. In one embodiment, the thermal sensor is located beneath the drone body. Preferably, the thermal sensor is mounted on an arm and is spaced apart from the drone body.

In one embodiment, the thermal sensor comprises a camera for IR imaging or video imaging.

In one embodiment, the system controller comprises a stored reference map of characteristic data associated with locations in a building, and the drone controller or the system controller are configured to determine a fire condition by performing processing including comparison of sensor outputs and said fire characteristic data.

In one embodiment, the fire characteristic data includes a reference temperature level for each location and the drone controller or the system controller are configured to generate an alert if temperature is sensed above a reference level at a particular location.

Preferably, the characteristic data is dynamically modified according to ambient temperature and weather conditions. In one embodiment, the characteristic data includes flammability and insulation data for material at each location.

In one embodiment, the system is configured to dynamically update the reference map as items are moved in and out of the building. In one embodiment, the system controller is linked with an inventory system to perform said dynamic updating.

In one embodiment, the system controller and/or the drone controller are configured to direct the drone to remain at, or return to, a location for which an alert has been determined, to capture additional sense data for validation of fire status for that location, and to communicate said sense data to the system controller.

Preferably, the system controller is configured to direct a drone flight path for more frequent flight past building locations which have greater fire risk than those with lower fire risk.

Preferably, the system controller comprises a stored reference map of characteristic data associated with locations in a building, and the drone controller or the system controller are configured to execute a fire potential algorithm using said reference map to determine desired location fly-by rates according to fire potential at locations.

In one embodiment, the characteristic data includes information from sources such as material safety data sheets (MSDS), material flammability, material burning rates such as heat release rates (HRR) and mass loss rate.

In one embodiment, the system controller is configured to automatically capture inventory data from transmitters located within the building, such as RFID tags.

Preferably, at least one fire sensor is mounted on a retractable arm, and the drone controller is configured to control position of said sensor.

In one embodiment, the system controller is configured to transmit a fire alarm communication to an external remote party such as a fire services system, said communication including fire location and material data derived from alert data from said drone.

Preferably, said communication includes an indication of fire stage derived from alert data from said drone. In one embodiment, the drone or drones include a plurality of fire sensors of different types and the system controller is configured to cause a subset of the fire sensors to be activated according to materials on a flight path.

In one embodiment, the system comprises a plurality of drones, at least some of which are mutually different in terms of their physical size, and/or fire sensing configurations, and the system controller is configured to select a preferred drone or drones for use on a particular flight path.

In another aspect, we describe a fire detecting drone comprising:

a body, at least one rotor, a controller, and a wireless communication interface; and

at least one fire sensor;

wherein the drone controller is configured to direct flight of the drone on a flight path within a building and to send fire alert data using said communication interface upon sensing by said sensor of a fire condition within said building.

In one embodiment, the fire sensor includes at least one smoke sensor located at or adjacent a rotor. In one embodiment, said smoke sensor is located at or near a rotor axis. Preferably, said smoke sensor is located at or near an upstream side of the rotor. In one embodiment, the drone comprises a plurality of rotors and there is a smoke sensor associated with each rotor. Preferably, the fire detector includes a thermal sensor. Preferably, the thermal sensor is located beneath the drone body.

In one embodiment, the thermal sensor is mounted on an arm and is spaced apart from the drone body. Preferably, the thermal sensor comprises a camera for IR imaging or video imaging.

In another aspect, we describe a fire detection method performed by a system of any embodiment, the method comprising:

the drone flying on a flight path within a building, and

the drone sending fire alert data to the system controller upon sensing of a fire condition by the sensor.

In one embodiment, the fire sensor includes a thermal sensor, and the drone controller or the system controller detect a fire incipient stage according to output of the thermal sensor.

Preferably, the system controller comprises a stored reference map of characteristic data associated with locations in a building, and the drone controller or the system controller determine a fire condition by performing processing including comparison of sensor outputs and said fire characteristic data.

In one embodiment, the fire characteristic data includes a reference temperature level for each location and the drone controller or the system controller generate an alert if temperature is sensed above a reference level at a particular location.

In one embodiment, the characteristic data is dynamically modified according to ambient temperature and weather conditions. In one embodiment, the system updates the reference map as items are moved in and out of the building.

Preferably, the drone remains at, or returns to, a location for which an alert has been determined, captures additional sense data for validation of fire status for that location, and communicates said sense data to the system controller.

In one embodiment, the drone flies more frequently past building locations which have greater fire risk than those with lower fire risk.

Preferably, the system controller comprises a stored reference map of characteristic data associated with locations in a building, and the drone controller or the system controller execute a fire potential algorithm using said reference map to determine desired location fly-by rates according to fire potential at locations.

In one embodiment, the characteristic data includes information from sources such as material safety data sheets (MSDS), material flammability, material burning rates such as heat release rates (HRR) and mass loss rate. Preferably, the system controller automatically captures inventory data from transmitters located within the building, such as RFID tags.

In one embodiment, at least one fire sensor is mounted on a retractable arm, and the drone controller controls position of said sensor.

In one embodiment, the system controller transmits a fire alarm communication to an external remote party such as a fire services system, said communication including fire location and material data derived from alert data from said drone.

In one embodiment, said communication includes an indication of fire stage derived from alert data from said drone.

Preferably, the drone or drones include a plurality of fire sensors of different types and the system controller causes a subset of the fire sensors to be activated according to materials on a flight path.

In one embodiment, the system comprises a plurality of drones, at least some of which are mutually different in terms of their physical size, and/or fire sensing configurations, and the system controller selects a preferred drone or drones for use on a particular flight path.

In a further aspect, the invention provides a non-transitory computer readable medium comprising software code for performing a method of any embodiment when executed by a digital processor.

Additional Statements

According to the invention, there is provided a fire detection system comprising:

> a system controller comprising a digital processor and a wireless interface for communicating in a local area within a building,
>
> at least one drone having a body and at least one rotor, a controller, and a wireless interface for communicating with said system controller, and
>
> at least one fire sensor mounted on the drone,
>
> wherein the drone controller is configured fly on a flight path within said building and to send fire alert data to the system controller upon sensing of a fire condition by said sensor.

In one embodiment, the fire detector includes at least one smoke sensor located at or adjacent a rotor. Preferably, said smoke sensor is located at or near a rotor axis. In one embodiment, said smoke sensor is located at or near an upstream side of the rotor.

In one embodiment, the drone comprises a plurality of rotors and there is a smoke sensor associated with each rotor.

In one embodiment, the fire detector includes a thermal sensor. In one embodiment, the thermal sensor is located beneath the drone body. In one embodiment, the thermal sensor is mounted on an arm and is spaced apart from the drone body.

In one embodiment, the thermal sensor comprises a camera for IR imaging or video imaging.

In one embodiment, the system controller comprises a stored reference map of characteristic data associated with locations in a building, and the drone controller or the system controller are configured to determine a fire condition by performing processing including comparison of sensor outputs and said fire characteristic data.

In one embodiment, the fire characteristic data includes a reference temperature level for each location and the drone controller or the system controller are configured to generate an alert if temperature is sensed above a reference level at a particular location.

In one embodiment, the characteristic data is dynamically modified according to ambient temperature and weather conditions.

In one embodiment, the characteristic data includes flammability and insulation data for material at each location. In one embodiment, the system is configured to dynamically update the reference map as items are moved in and out of the building. Preferably, the system controller is linked with an inventory system to perform said dynamic updating.

In one embodiment, the system controller and/or the drone controller are configured to direct the drone to remain at, or return to, a location for which an alert has been determined, to capture additional sense data for validation of fire status for that location, and to communicate said sense data to the system controller.

In one embodiment, the system controller is configured to direct a drone flight path for more frequent flight past building locations which have greater fire risk than those with lower fire risk.

In one embodiment, the system controller is configured to automatically capture inventory data from transmitters located within the building, such as RFID tags.

In one embodiment, at least one fire sensor is mounted on a retractable arm, and the drone controller is configured to control position of said sensor.

In one embodiment, the system controller is configured to transmit a fire alarm communication to an external remote party such as a fire services system, said message including fire location and material data derived from alert data from said drone.

In one embodiment, said communication includes an indication of fire stage derived from alert data from said drone.

In another aspect, the invention provides a fire detecting drone comprising:

a body, at least one rotor, a controller, and a wireless communication interface; and

at least one fire sensor;

wherein the drone controller is configured to fly on a flight path within a building and to send fire alert data using said communication interface upon sensing by said sensor of a fire condition within said building.

The drone may have any of the features defined above of a drone of the fire detection system of any embodiment.

DETAILED DESCRIPTION OF THE INVENTION

Brief Description of the Drawings

The invention will be more clearly understood from the following description of some embodiments thereof, given by way of example only with reference to the accompanying drawings in which:

Fig. 1 is a front view of a drone of a fire detection system of the invention, and Fig. 2 shows air flows for optimum smoke detection in one embodiment;

Fig. 3 is a general plot showing the development of a fire from an initial incipient stage to a full fire stage, with a vertical axis of heat release rate ("HRR") versus time;

Fig. 4 is a flow diagram for the logic of the fire detection system processor;

Fig. 5 is an end view diagram showing fire-sensing drones in a warehouse and how they communicate with a control panel;

Fig. 6 shows an arrangement in which there is an integrated warehouse stock and drone management system communicating with drones;

Fig. 7 is a diagram showing priority monitoring by drones according to fire potential based on nature and location of items in the building;

Fig. 8 is a diagram illustrating movement of a drone to specific locations within racks for more accurate monitoring;

Fig. 9 illustrates a validation stage in which a drone moves close to a suspected item for validation of monitoring;

Fig. 10 illustrates updating of an alert, in which a controller processes location data for accurate pin-pointing of a fire location;

Figs. 11 and 12 illustrate drone movement to an inaccessible location to search for specific location of a fire and provide fire source material information; and

Figs. 13 to 15 are diagrams illustrating alternative drones of fire detection systems of the invention.

Description of the Embodiments

A fire detection system of the invention comprises a controller and at least one drone in wireless communication. The controller may comprise one or more hardware platforms, and platforms may be linked by a local area network or a wide area network.

The drones may for example have flying and navigation capabilities in principle of the type already known for use indoors, such as that described in US8989922. Warehouse drones are in use today, including drones that act independently of ground-based obstructions. Furthermore, they can move in any direction and see into hard-to-reach places, such as within tall storage shelves. The drones are robustly designed, lightweight flying robots that can reliably recognize their surroundings, and run intelligent software for their route planning and coordination. Collision-tolerant drones are in development today that remain stable after contact with solid objects and are safe to fly close to people.

Referring to Figs. 1 and 2 a drone 1 of the system has a body 2 with splayed arms supporting four rotors 3 beneath the body 2 at the same horizontal plane. At this level, the drone is conventional. However, additionally:

(a) the drone controller is configured to fly on a path for optimum early fire detection inside a building such as a warehouse, and

(b) it has smoke and thermal sensors for such detection.

The smoke detection is performed by optical smoke detectors 4, one located axially above each rotor 3. In the front elevation views of Figs. 1 and 2 only two rotors and associated detectors 4 are visible. Hence, as shown in Fig. 2 as the drone 1 laterally approaches rising smoke S, some smoke is drawn back downwards by the rotors, and hence past the detectors 4, *en route* to the rotors 3.

The rotors 3 therefore perform the dual purpose of providing lift for the drone and also drawing smoke promptly to the smoke detectors.

The drone in this embodiment also includes a thermal sensor 5, which is preferably mounted underneath the body, and more preferably on an arm 6 separating it from the body. This provides an excellent uninterrupted field of view beneath the drone. The sensor 5 is in this embodiment a thermal camera of the thermal imaging type.

In one embodiment, the smoke and heat detectors are Tyco detectors marketed as CWSI™ Model 301/302 Wireless Smoke Detectors and CWSI™ Model 320 Wireless Heat Detectors configured to provide digital values corresponding respectively to temperature and scattering smoke detected inside the smoke detector's measuring chamber. Such detectors are normally addressable.

In an embodiment, control software primarily resides in a wirelessly-linked controller (not shown) in a fire panel or warehouse management system. The software directs the drone on an optimum navigation path to cover a specified volume of the building. Also, it re-directs the drone 1 in real time if a possible alarm event is detected. Such re-direction is towards a possible fire site, preferably at an early stage of fire development. Such a possibility may be identified if a site has a higher temperature than expected on a reference map. When the drone is re-routed to such a site further monitoring is performed from a closer distance.

The reference map is a set of characteristic data related to locations in three-dimensional ("3D") space in the warehouse based on the materials stored at specific locations represented in the 3D space and the locations themselves. The characteristic data indicates the fire potential of that location in the warehouse based on the material and any packaging stored at that location, including their flammability. The characteristic data also includes the expected temperature of each location in a 3D space, based on elevation, proximity of doors, and side of the building (for example locations at the north side being expected to be colder than location on the south side). The characteristic data can be manually entered by an operator for each map location. Alternatively, it can be dynamically updated by the warehouse management system based on that systems knowledge of materials stored at each location. It is also changed either manually or automatically based on ambient temperature and other weather conditions. The reference map may in other embodiments only include one or other type of characteristic data.

Fig. 3 provides for illustration purposes the generally-recognized stages of fire development. An incipient stage is best detected by a thermal imaging camera such as the camera 5. The smoldering stage is best detected additionally by a smoke detector. Video image detectors are particularly effective for sensing flame and fire stages. The drones are equipped with a desired configuration of sensors according to the nature of the building and fire characteristics of the material within. One category is for materials which give a lot of smoke while burning at relatively low temperature, for example two relatively safe chemical elements that react chemically and corrosively on contact. Such materials give rise to emphasis on smoke detection. Heavily packaged material may require heat detection more so than smoke detection, requiring emphasis on IR/heat detection sensors (if visible to thermal a camera). Another category of material is heavily packaged material requiring heat detection more so than smoke detection, requiring emphasis on heat detection only if not visible to a thermal camera (heat radiation detection of unknown source).

It is of course possible that the system comprises multiple drones with different sensor configurations, so that it is versatile for catering for dynamically changing building contents.

The reference map may be static. It is however preferably dynamic; changing according to updating of an inventory system. The fire detection software is preferably configured to associate items of characteristic data with each inventory item, and to dynamically modify the thermal map as the inventory items are moved into or re-located in the building. The fire characteristic data is related to one or both of:

– insulation properties of the item, and
– flammability of the item.

In Fig. 4, the major steps of a method 100 of operation of the fire detection system shown in Fig. 5 are as follows:

101, Initiate the system controller ("fire panel") 160,

102, The panel establishes communication with the drones 150, 151, and 152 using a protocol such as the Frequency Hopping Spread Spectrum Technology (FHSS) protocol employed by the Tyco CWSI™ product line. These drones are similar to the drones 1.

103, The drones report to the panel their starting locations and their detector states.

104, The drones start to fly on their pre-configured flight paths, round and through warehouse racks 155 and 156 and. Alternatively, the routes may be randomly chosen. The drones have a default mode of constantly patrolling the building; including warehouse rack spaces and transmit their exact location to the fire control panel. When available, pre-configured flight paths are downloaded from the system controller. Flight paths may be manually entered by an operator by configuring the controller, or flight paths or may be dynamically calculated by a fire potential algorithm in cooperation with a warehouse management system, based on the reference map characteristic data such as heat values (fire potential) of warehouse materials. Generally, the system controller comprises a stored reference map of characteristic data associated with locations in a building, and the drone controller or the system controller are configured to execute a fire potential algorithm using said reference map to determine desired location fly-by rates according to fire potential at locations. Preferably, the characteristic data contains information from sources such as material safety data sheets (MSDS), material flammability, material burning rates such as heat release rates (HRR) and mass loss rate.

105, A drone thermal sensor detects a temperature level which is higher than a reference level for the location. The reference level may be a uniform ambient level for the full path or a specific level for that particular location on the path. A heat signature message is wirelessly transmitted to the controller 160. The heat signature is processed by the controller 160.

107, Additionally or alternatively, the drone sensors 4 and 5 detect smoke or fire.

108, A drone sends an alert message to the panel 160. This alert includes data defining what has been sensed and an associated location.

110, 111, The drone controller determines if communication of the alert is successful, and re-tries if not.

112, The drone remains at the alert location, or returns to it if it had moved away before generation of the alert. At this location, the drone continues to monitor data using all of its sensors, preferably smoke, heat and fire (thermal) sensors. Reports are continually transmitted to the panel. The drone remains at a safe distance to prevent heat damage. Preferably, the alert is generated at an early stage, before flames develop.

113, Back-up communication if the alert message cannot be safely communicated in the normal manner. For example, cellular (mobile network) communication may be used.

Referring to Fig. 6 a system of the invention has a controller 180 which is integrated with a warehouse inventory system to combine stock location and material information with drone fire detection information to more effectively patrol, locate and prepare to extinguish fires. The controller 180 communicates with devices in the warehouse including an RFID tag on an inventory item 182 and a fork-lift truck 181 in a warehouse having racks 183 and 184. Hence the controller 180 receives in real time inventory stock updates and so can generate navigation paths which prioritize the frequency of drone "fly-pass" to the most highly flammable stock. For example, if a flammable fuel is stored in the warehouse rack 184, a navigation path with a higher "fly-pass" rate of rack 184 is generated based on the fire potential algorithm, and for example if drinking water is stored at rack 183, a lower "fly-by" rate is generated

The data required by the fire risk assessment algorithm is stored in a database which contains information from sources such as material safety data sheets (MSDS), material flammability, material burning rates such as heat release rates (HRR) and mass loss rate. The fire risk assessment algorithm in some embodiments determines the optimum sensor or sensors to be used, based on the database information. By the algorithm taking into consideration the type of material being stored, how the material is packaged in storage, and the flammability of the material, an alert can be generated at an early stage, before flames develop.

It will be appreciated that different materials catch fire at different temperatures, with fires having different behaviours, in terms of duration to flame and development of smoke. The plot of Fig. 3 is typical but there can be large variations. Because of this, the fire risk assessment algorithm determines the most suitable sensor(s) to be used, according to the materials it is assigned to “fly-by”. For example, smoke or thermal sensors are suitable for the detection of a developing fire of a material that smolders for a long time. Heat or flame sensors are suited for materials which flame quickly.

The drone may comprise multiple sensors, which can be configured according to what the fire risk assessment algorithm determines is the most suitable combination for the earliest detection of potential fire. For example, it may be most suitable to activate multiple sensors to be used simultaneously. Likewise, it may be most suitable to activate only one sensor.

In other cases, sensor hardware may need to be changed or alternated in the drone in order to achieve the same optimal sensor configuration.

Alternatively, there may be a fleet of drones made up of individual drones or sub-groups of drones, each with individual sensor hardware and software pre-configured to suit an associated set of material, and/or flight paths (such as the extent to which the space is confined). Each drone or group of drones may be deployed to areas according to the location of the associated material to achieve optimal early fire detection. The fire risk assessment algorithm determines the optimal drone configuration for a particular set of materials. The system controller uses this information to calculate the optimal flight path for that drone configuration, for example the system controller deploys drone configuration “A” to “fly-by” materials of type “X” and drone configuration “B” to “fly-by” material of type “Y”.

When a fire is detected by one of its drones, the system matches the materials at the fire location to flammability and appropriate fire extinguishing procedures. For example, if vegetable oil is stored at the fire location, suitable extinguishing media such as CO_2, dry powder or foam is recommended by the material safety data sheet.

This information can then be used to alert and help firefighters prepare with the most effective counter-measures to extinguish the fire. Fig. 7 shows drones 190 flying in such paths in this warehouse.

Fig. 8 shows a drone 206 flying past an inventory item 205 in a warehouse rack 201 near another rack 202. This is because a heat signature detected by the thermal camera 5 indicates a possibility of fire at the incipient stage in or near the item 205. This “near” method of fire monitoring where the fire detectors are brought close to the potential fire hazard can rapidly improve detection speed as well as help to accurately locate the fire source. The use of a thermal sensor 5 aids in the early detection and prevention of fires, because for fires to take place heat has to be present first.

Fig. 9 shows this drone 206 remaining close to the inventory item 205 in order to validate fire detection before sending a further update. When the drone enters a heightened fire assessment mode to assess the validity of the detection to avoid false alarms, it attempts to maximize detector exposure to the fire signals such as smoke, heat, and flame to validate the alarm. If alarm validity is confirmed the drone will update the drone management system of the detection event including location co-ordinates. The drone management system then sends an alarm signal to the fire control panel indicating the zone of the alarm.

Referring to Fig. 10 a management server 300 is programmed to perform fire detection and inventory tracking operations in a warehouse having racks 304 and 305. It is programmed to convert drone co-ordinates to warehouse location identifiers and fire monitoring zones. The management server sends updates to a dedicated fire monitoring controller 301. In this illustrated example a drone 302 detects fire at a location 303 in the rack 304 and uploads its co-ordinates to the management server 300.

Fig. 11 shows priority drone flight paths in and around the warehouse rack 304, in which the drone 302 flies in a confined space over inventory items 323 and 324. This is based on fire risk assessment calculated from heat values (fire potential) of warehouse materials. Such a flight path allows sufficient data to be provided so that the nature of the fire and its stage can be determined. In the event that a fire has been detected and validated as a genuine fire, the drone enters a more focused search mode to find the source of the fire. Fig. 12 shows the drone in this mode performing more frequent and localised detection in warehouse rack 304. This allows the most accurate set of data to be transmitted in an alarm communication to the external fire departments. Hence, the fire department or remote monitoring centre system is provided with the correct type of fire-fighting equipment for the circumstances and location of the fire prior to arriving at the premises.

Communications method:

Wireless fire alarm panels are available and the communication method may use an existing Frequency Hopping Spread Spectrum Technology (FHSS), coupled with Bi-directional RF Communication such as used in the Tyco CWSI™ products for a secure and reliable alarm network between the panel and the addressable drones. The panel communications software receives building location co-ordinates from the drones. The communication interface of the drone behaves like an existing addressable fire detection initiating device to the panel; however the information communicated to the panel is enhanced to contain location information from the drone's navigation system.

Drone navigation and location information:

The system may use any or some of a number of methods to navigate and communicate location information. In one such method the drone includes a memory configured to store pre-defined location information from RFID tags located throughout the building. The drone contains an RFID reader configured to read information from the RFID tags and use the information to determine its location. The drone memory can also use its stored RFID database to determine pre-defined navigation paths. Another method uses barcode scanning to provide position and navigation information to the drone. Location information from the drone's navigation system is used to enhance the existing data communication between the sensor and the fire panel.

As well as containing location information the RFID tags can also contain information about the materials stored at a particular location. This information can include flammability and burning rate of the materials. Using this information, the system can increase the priority and frequency of drone "fly-pass" to the most highly flammable materials. The controller may consult its database to identify and assess the flammability of the material at the fire location and transmit this information to fire fighters. Fire fighters can then be well prepared when they arrive to the scene of the fire and employ the most effective fire suppression equipment for the materials on fire.

Backup communications method:

A drone may include on-board cellular communications interface to alert a remote monitoring center or Fire Department if sensor detects a fire and is unable to communicate its status and location via its primary RF communications interface.

Advantages

It will be appreciated that the fire detection system uses the capability of drones to access inaccessible places in a warehouse to determine exactly the location of a fire incipient stage, a developing heat source, or fire. Locating such fire conditions has been proven to be difficult using existing systems. By communicating the exact location of the fire condition data to the fire panel, firefighters can quickly locate the fire and take steps to extinguish the fire in the fastest possible time.

The system enables rapid fire situation assessment and decision-making so that warehouse fires can be quickly and correctly eliminated before serious and costly damage is done to both warehouse and stored stock, especially large warehouses where the location and assessment of fire, its origin and its risk can take considerable time to achieve.

The airflow effect of the rotors may be advantageously used to draw smoke towards a smoke sensor mounted above or below the rotor blades of the drone.

The detection system can overcome limitations of existing systems to quickly detect and identify the exact location of a fire or heat source in a densely-packed warehouse environment. Advantageous features in various embodiments are:

- Integrate the drone sensors with proprietary or existing fire alarm control panels.
- Enhance data from the sensors with exact building location data.
- Perform a real-time fire risk assessment of warehouse stock
- Prioritize flight paths for drones for higher risk stock, and/or prioritize monitoring of data from drones on flight paths near high risk stock.

An advantage of the system is that it could be employed in older buildings without the disruption and cost associated with the installation of known fixed arrangements such as aspirated smoke detectors or linear heat induction systems.

Another advantage of the system is that it can be deployed quickly in event or temporary buildings, providing a high level of fire protection on a one-off or scheduled basis.

Alternatives

The invention is not limited to the embodiments described but may be varied in construction and detail. For example, the invention may be applied to any indoor environment, although it is especially suited to warehouse and industrial or large retail indoor environments. Examples of alternative environments are temporary event structures such as marquees or sea borne structures such as oil rigs or ships.

The drones may have any desired configuration of sensors. For example, a drone 400 shown in Fig. 13 has a smoke sensor 402 mounted on top of the main body, rotors 403, and a thermal camera 405 mounted directly on a body of the drone.

Referring to Fig. 14 a drone 450 has a body 451 and four rotors 452 each having a smoke sensor mounted on the rotor frame on the intake side. There are thermal cameras 456 mounted on top and underneath on the main body 451.

Referring to Fig. 15 a drone 470 has a main body 471 supporting rotors 472 above the body, and top and bottom thermal cameras 475. There are smoke sensors 473 mounted on retractable arms 474 for optimum control of location in relation to the rotors 472.

It is advantageous to locate a smoke sensor directly above or below the rotors to detect smoke in the air above the drone. Smoke sensor positioning is important to take best advantage of the air flow. The airflow is strongest directly above and below the rotors. Various drone designs can be employed to maximize air (and hence smoke) flow to the smoke sensor. The differential in signal strength between sensors on a drone can be measured to quantify the density and spread of the smoke plume. Video imaging detectors (VID) can additionally be mounted above and below the drone body to boost detection of smoke. By employing a variety of detectors each stage of a fire from the incipient to smoldering to flame stages can be most effectively detected.

The system controller may reside at any desired location, and indeed it may reside in one or more drones or indeed at a remote location. For example, there may be a master drone with system control software. Indeed, it is envisaged that there may not be a system controller as such within the building. The system may therefore comprise a set of one or more drones each having a communications interface for transmitting alert data to an external system such as a fire services system or a management server providing the system controller.

Claims

1. A fire detection system comprising:

a system controller comprising a digital processor and a wireless interface for communicating in a local area within a building,

at least one drone having a body and at least one rotor, a controller, and a wireless interface for communicating with said system controller, and

at least one fire sensor mounted on the drone,

wherein the drone controller is configured to direct flight of the drone on a flight path within said building and to send fire alert data to the system controller upon sensing of a fire condition by said sensor.

2. A fire detection system as claimed in claim 1, wherein the fire sensor includes at least one smoke sensor located at or adjacent a rotor.

3. A fire detection system as claimed in claim 2, wherein said smoke sensor is located at or near a rotor axis.

4. A fire detection system as claimed in claim 3, wherein said smoke sensor is located at or near an upstream side of the rotor.

5. A fire detection system as claimed in any of claims 2 to 4, wherein the drone comprises a plurality of rotors and there is a smoke sensor associated with each rotor.

6. A fire detection system as claimed in any preceding claim, wherein the fire sensor includes a thermal sensor, and the drone controller or the system controller are configured to detect a fire incipient stage according to the output of the thermal sensor.

7. A fire detection system as claimed in claim 6, wherein the thermal sensor is located beneath the drone body.

8. A fire detection system as claimed in claims 6 or 7, wherein the thermal sensor is mounted on an arm and is spaced apart from the drone body.

9. A fire detection system as claimed in any of claims 6 to 8, wherein the thermal sensor comprises a camera for IR imaging or video imaging.

10. A fire detection system as claimed in any preceding claim, wherein the system controller comprises a stored reference map of characteristic data associated with locations in a building, and the drone controller or the system controller are configured to determine a fire condition by performing processing including comparison of sensor outputs and said fire characteristic data.

11. A fire detection system as claimed in claim 10, wherein the fire characteristic data includes a reference temperature level for each location and the drone controller or the system controller are configured to generate an alert if temperature is sensed above a reference level at a particular location.

12. A fire detection system as claimed in claim 11, wherein the characteristic data is dynamically modified according to ambient temperature and weather conditions.

13. A fire detection system as claimed in claims 10 or 11 or 12, wherein the characteristic data includes flammability and insulation data for material at each location.

14. A fire detection system as claimed in any of claims 10 to 13, wherein the system is configured to dynamically update the reference map as items are moved in and out of the building.

15. A fire detection system as claimed in claim 14, wherein the system controller is linked with an inventory system to perform said dynamic updating.

16. A fire detection system as claimed in any preceding claim, wherein the system controller and/or the drone controller are configured to direct the drone to remain at, or return to, a location for which an alert has been determined, to capture additional sense data for validation of fire status for that location, and to communicate said sense data to the system controller.

17. A fire detection system as claimed in any preceding claim, wherein the system controller is configured to direct a drone flight path for more frequent flight past building locations which have greater fire risk than those with lower fire risk.

18. A fire detection system as claimed in claim 17, wherein the system controller comprises a stored reference map of characteristic data associated with locations in a building, and the drone controller or the system controller are configured to execute a fire potential algorithm using said reference map to determine desired location fly-by rates according to fire potential at locations.

19. A fire detection system as claimed in claim 18, wherein the characteristic data includes information from sources such as material safety data sheets (MSDS), material flammability, material burning rates such as heat release rates (HRR) and mass loss rate.

20. A fire detection system as claimed in any of claims 10 to 19, wherein the system controller is configured to automatically capture inventory data from transmitters located within the building, such as RFID tags.

21. A fire detection system as claimed in any preceding claim, wherein at least one fire sensor is mounted on a retractable arm, and the drone controller is configured to control position of said sensor.

22. A fire detection system as claimed in any preceding claim wherein the system controller is configured to transmit a fire alarm communication to an external remote party such as a fire services system, said communication including fire location and material data derived from alert data from said drone.

23. A fire detection system as claimed in claim 22, wherein said communication includes an indication of fire stage derived from alert data from said drone.

24. A fire detection system as claimed in any preceding claim, wherein the drone or drones include a plurality of fire sensors of different types and the system controller is configured to cause a subset of the fire sensors to be activated according to materials on a flight path.

25. A fire detection system as claimed in claim 24, wherein the system comprises a plurality of drones, at least some of which are mutually different in terms of their physical size, and/or fire sensing configurations, and the system controller is configured to select a preferred drone or drones for use on a particular flight path.

26. A fire detecting drone comprising:

a body, at least one rotor, a controller, and a wireless communication interface; and

at least one fire sensor;

wherein the drone controller is configured to direct flight of the drone on a flight path within a building and to send fire alert data using said communication interface upon sensing by said sensor of a fire condition within said building.

27. A fire detecting drone as claimed in claim 26, wherein the fire sensor includes at least one smoke sensor located at or adjacent a rotor.

28. A fire detecting drone as claimed in claim 27, wherein said smoke sensor is located at or near a rotor axis.

29. A fire detecting drone as claimed in claim 28, wherein said smoke sensor is located at or near an upstream side of the rotor.

30. A fire detecting drone as claimed in any of claims 26 to 29, wherein the drone comprises a plurality of rotors and there is a smoke sensor associated with each rotor.

31. A fire detecting drone as claimed in any of claims 26 to 30, wherein the fire detector includes a thermal sensor.

32. A fire detecting drone as claimed in claim 31, wherein the thermal sensor is located beneath the drone body.

33. A fire detecting drone as claimed in claims 31 or 32, wherein the thermal sensor is mounted on an arm and is spaced apart from the drone body.

34. A fire detecting drone as claimed in any of claims 31 to 33, wherein the thermal sensor comprises a camera for IR imaging or video imaging.

35. A fire detection method performed by a system of any of claims 1 to 25, the method comprising:

the drone flying on a flight path within a building, and

the drone sending fire alert data to the system controller upon sensing of a fire condition by the sensor.

36. A method as claimed in claim 35, wherein the fire sensor includes a thermal sensor, and the drone controller or the system controller detect a fire incipient stage according to output of the thermal sensor.

37. A method as claimed in claims 35 or 36, wherein the system controller comprises a stored reference map of characteristic data associated with locations in a building, and the drone controller or the system controller determine a fire condition by performing processing including comparison of sensor outputs and said fire characteristic data.

38. A method as claimed in claim 37, wherein the fire characteristic data includes a reference temperature level for each location and the drone controller or the system controller generate an alert if temperature is sensed above a reference level at a particular location.

39. A method as claimed in claim 38, the characteristic data is dynamically modified according to ambient temperature and weather conditions.

40. A method as claimed in any of claims 37 to 39, wherein the system updates the reference map as items are moved in and out of the building.

41. A method as claimed in any of claims 35 to 40, wherein the drone remains at, or returns to, a location for which an alert has been determined, captures additional sense data for validation of fire status for that location, and communicates said sense data to the system controller.

42. A method as claimed in any of claims 35 to 41, wherein the drone flies more frequently past building locations which have greater fire risk than those with lower fire risk.

43. A method as claimed in any of claims 35 to 42, wherein the system controller comprises a stored reference map of characteristic data associated with locations in a building, and the drone controller or the system controller execute a fire potential algorithm using said reference map to determine desired location fly-by rates according to fire potential at locations.

44. A method as claimed in claim 43, wherein the characteristic data includes information from sources such as material safety data sheets (MSDS), material flammability, material burning rates such as heat release rates (HRR) and mass loss rate.

45. A method as claimed in any of claims 35 to 44, wherein the system controller automatically captures inventory data from transmitters located within the building, such as RFID tags.

46. A method as claimed in any of claims 35 to 45, wherein at least one fire sensor is mounted on a retractable arm, and the drone controller controls position of said sensor.

47. A method as claimed in any of claims 35 to 46, wherein the system controller transmits a fire alarm communication to an external remote party such as a fire services system, said communication including fire location and material data derived from alert data from said drone.

48. A method as claimed in claim 47, wherein said communication includes an indication of fire stage derived from alert data from said drone.

49. A method as claimed in any of claims 35 to 48, wherein the drone or drones include a plurality of fire sensors of different types and the system controller causes a subset of the fire sensors to be activated according to materials on a flight path.

50. A method as claimed in claim 49, wherein the system comprises a plurality of drones, at least some of which are mutually different in terms of their physical size, and/or fire

sensing configurations, and the system controller selects a preferred drone or drones for use on a particular flight path.

51. A non-transitory computer readable medium comprising software code for performing a method of any of claims 35 to 50 when executed by a digital processor.

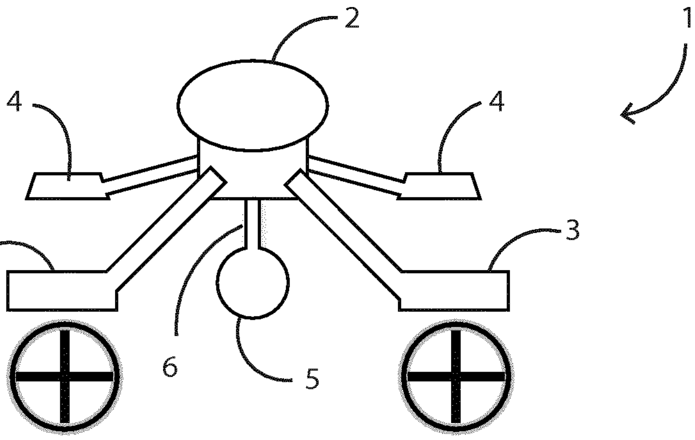

Fig.1

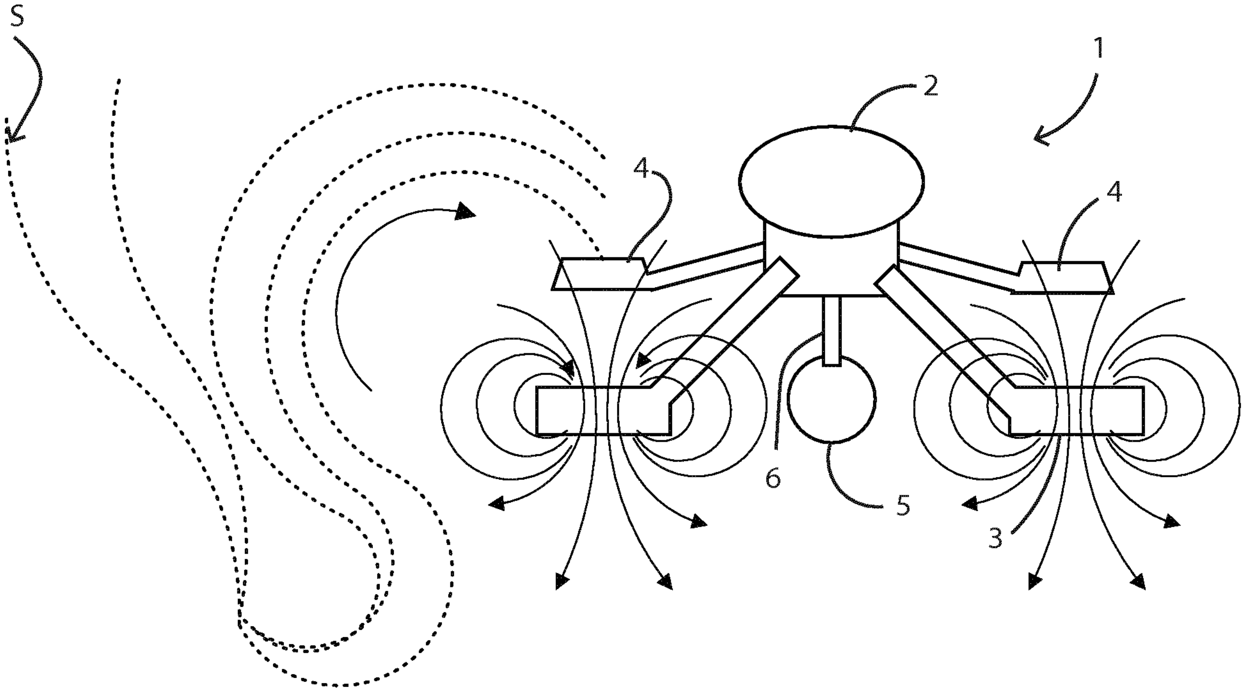

Fig.2

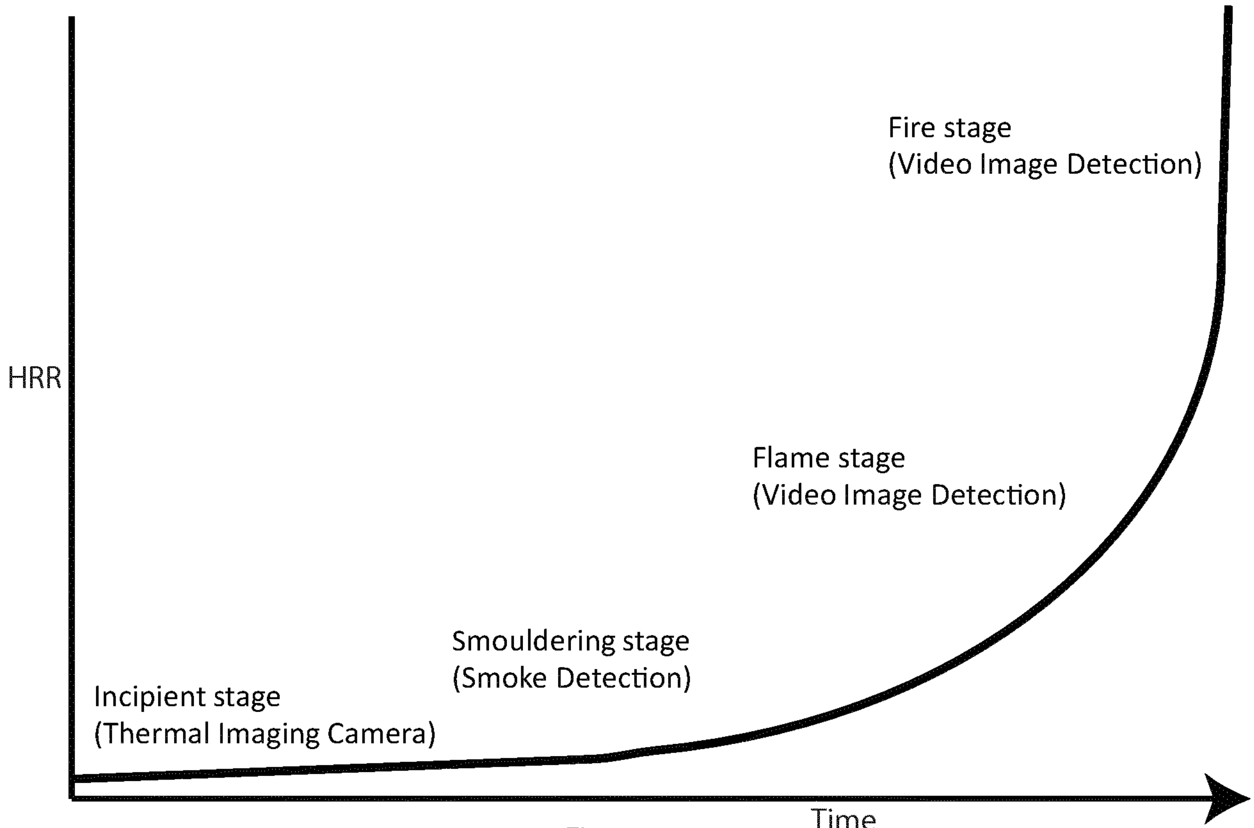
Fire stage
(Video Image Detection)
HRR
Flame stage
(Video Image Detection)
Smouldering stage
(Smoke Detection)
Incipient stage
(Thermal Imaging Camera)
Time

Fig.3

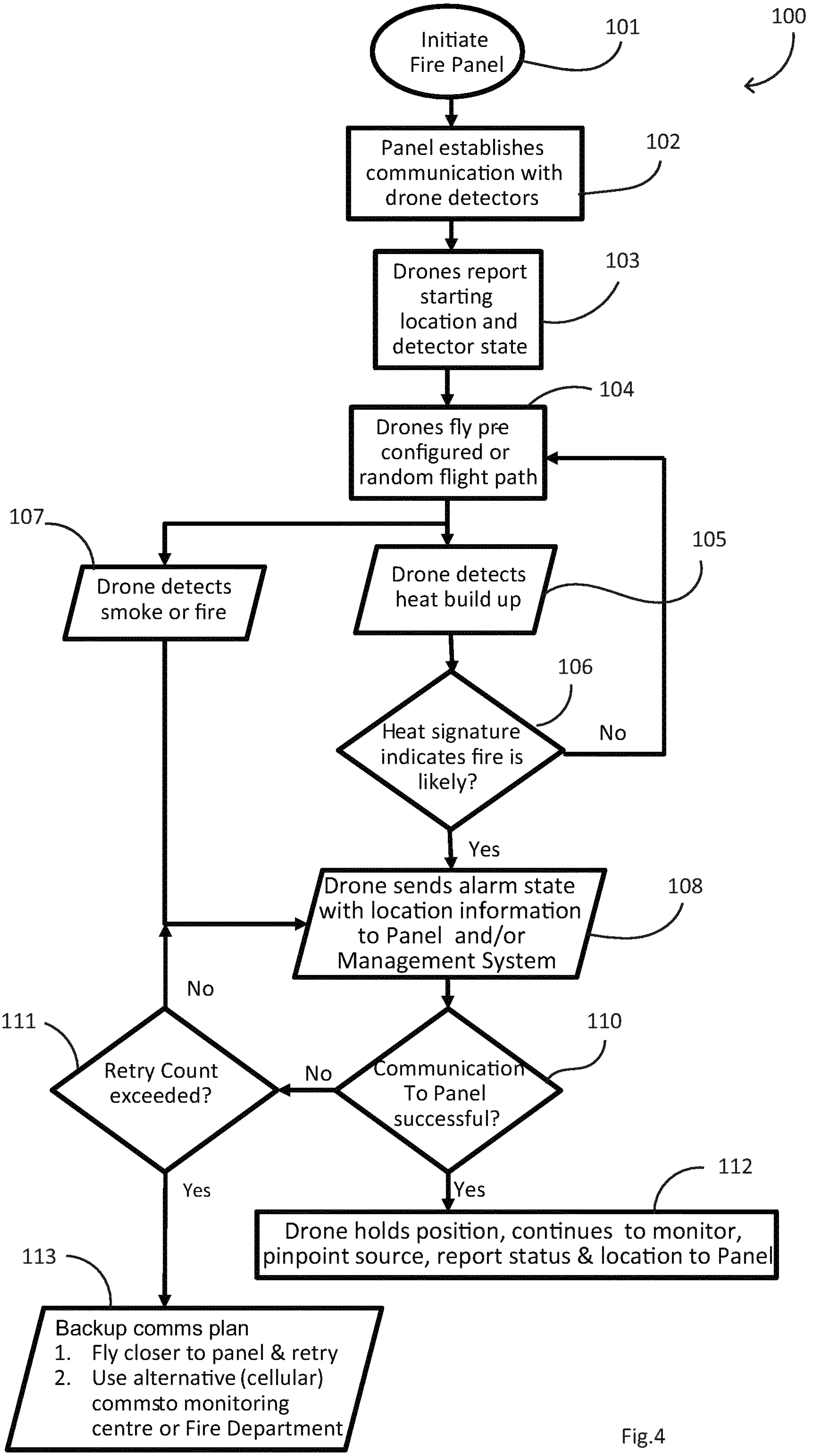
100
Initiate Fire Panel
101
Panel establishes communication with drone detectors
102
Drones report starting location and detector state
103
Drones fly pre configured or random flight path
104
107
Drone detects smoke or fire
Drone detects heat build up
105
106
Heat signature indicates fire is likely?
No
Yes
Drone sends alarm state with location information to Panel and/or Management System
108
No
111
Retry Count exceeded?
No
Communication To Panel successful?
110
Yes
Yes
112
Drone holds position, continues to monitor, pinpoint source, report status & location to Panel
113
Backup comms plan
1. Fly closer to panel & retry
2. Use alternative (cellular) commsto monitoring centre or Fire Department

Fig.4

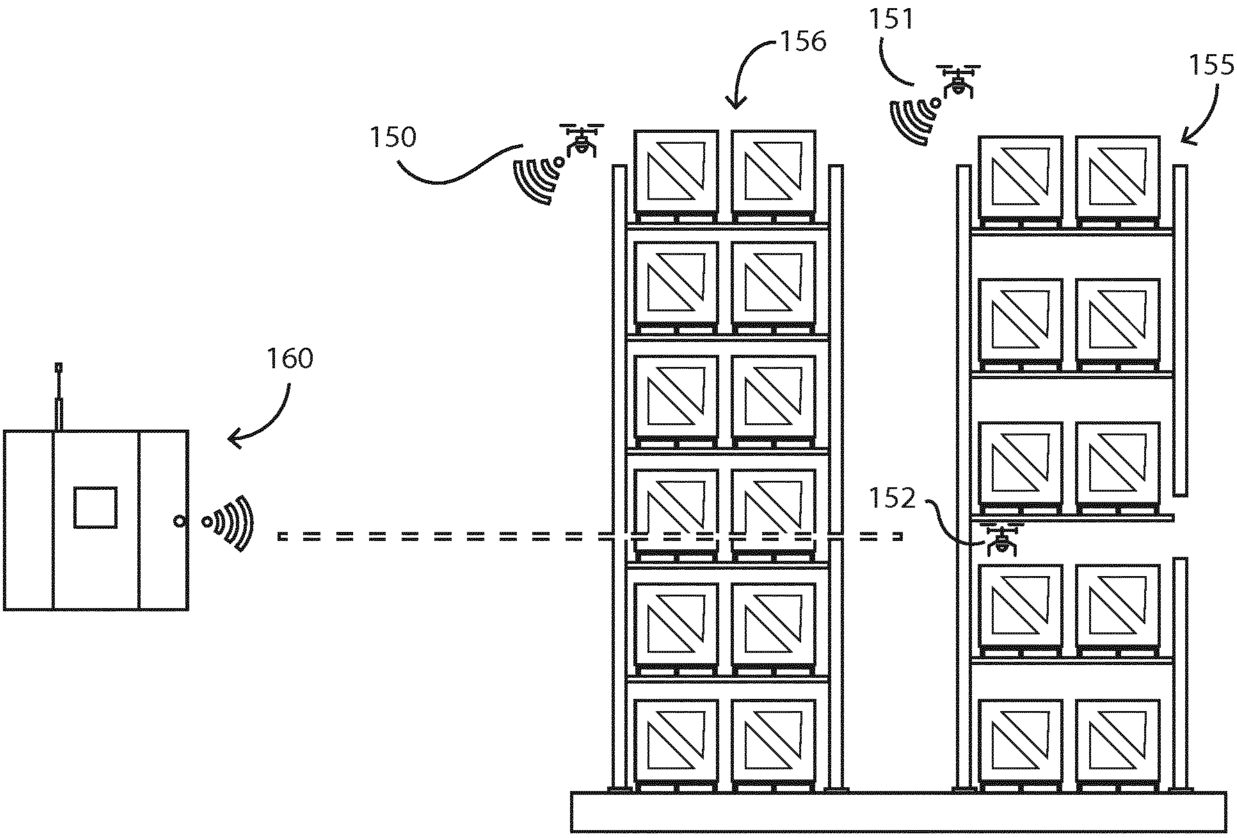

Fig.5

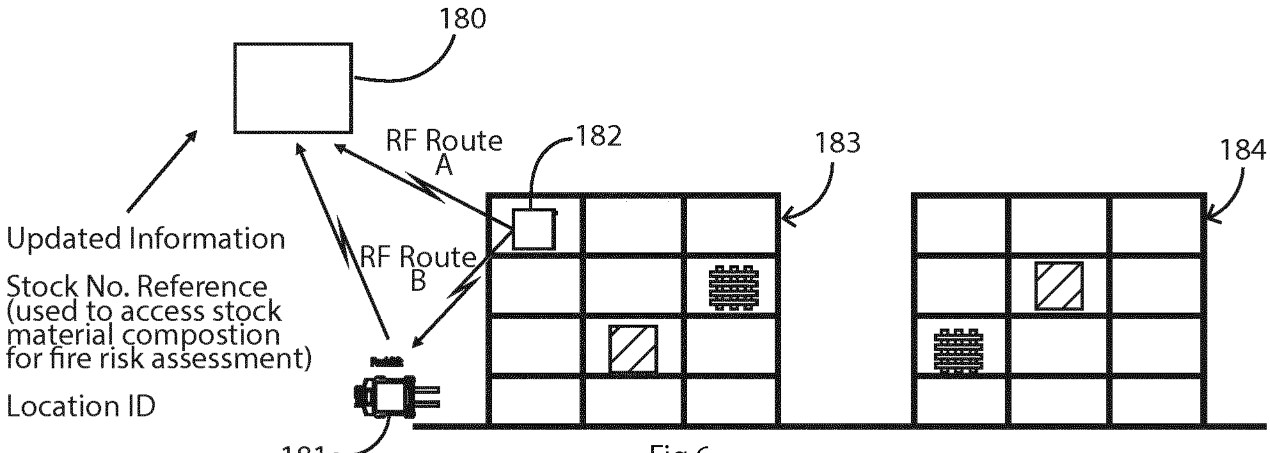

Fig.6

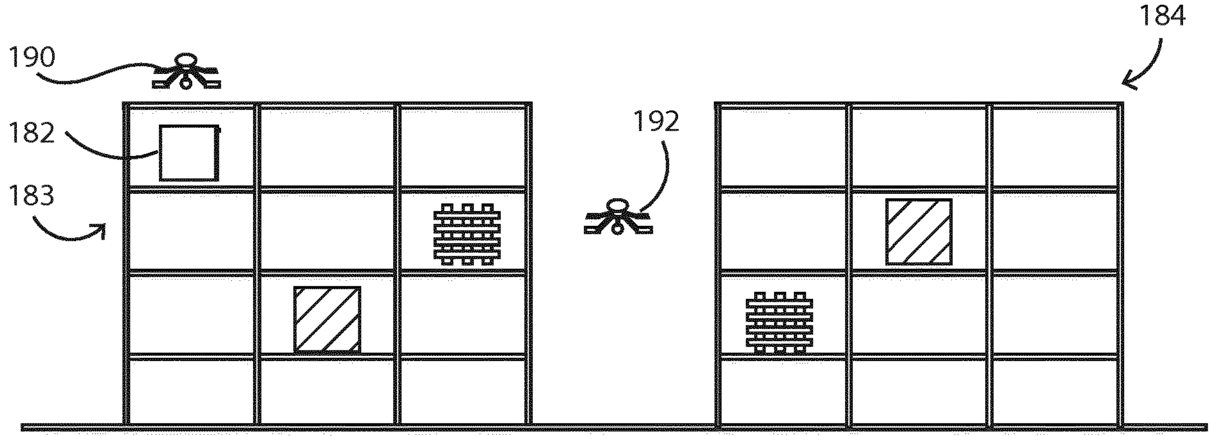

Fig.7

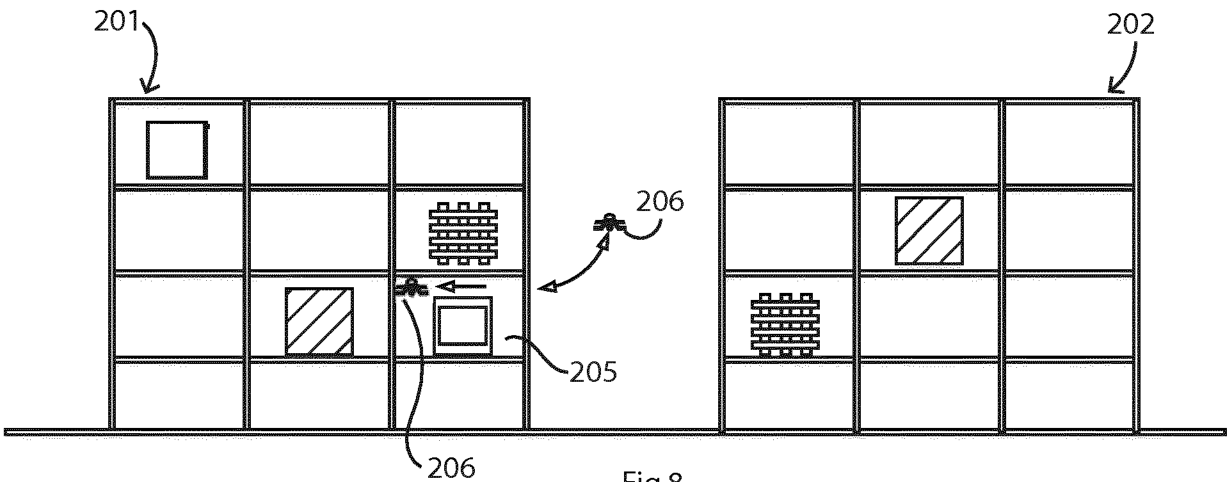

Fig.8

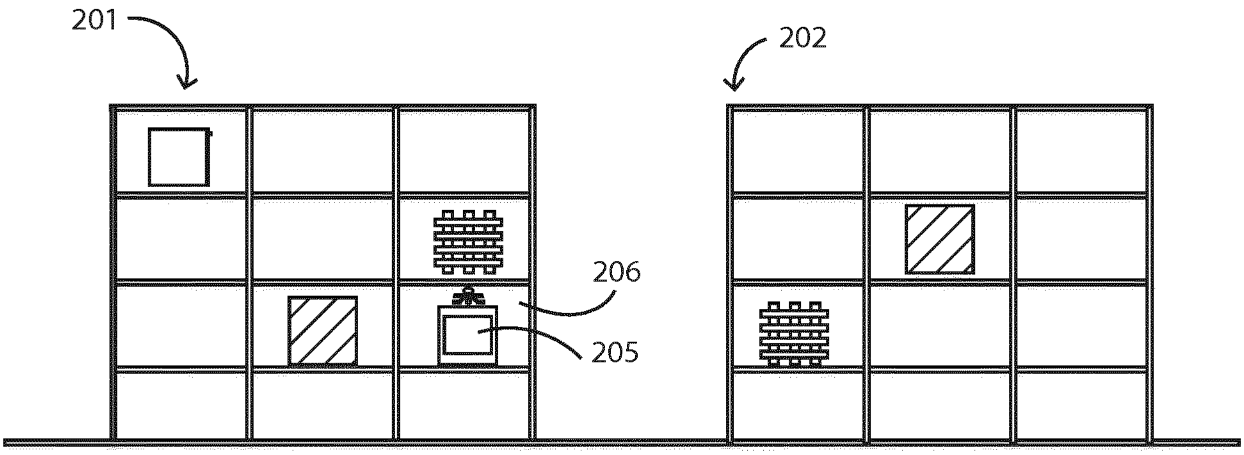
201
202
206
205

Fig.9

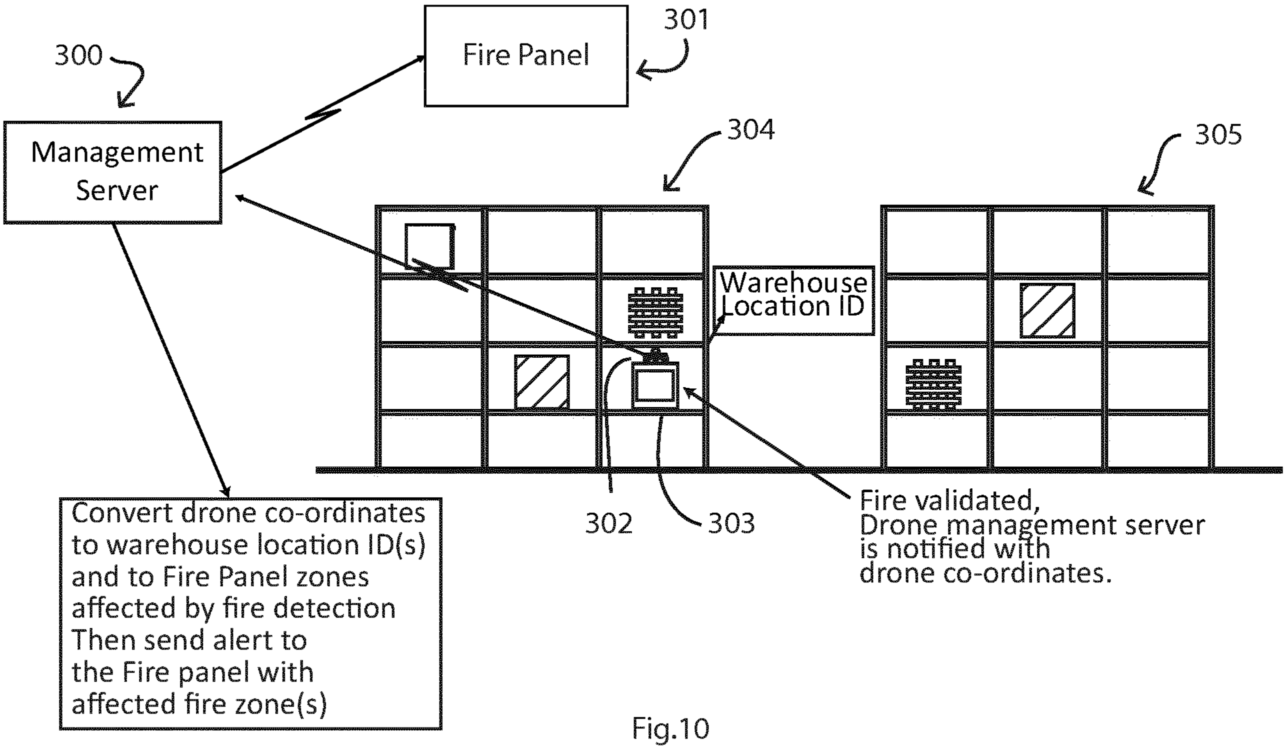
300
Management Server
Fire Panel
301
304
305
Warehouse Location ID
302
303
Fire validated, Drone management server is notified with drone co-ordinates.
Convert drone co-ordinates to warehouse location ID(s) and to Fire Panel zones affected by fire detection Then send alert to the Fire panel with affected fire zone(s)

Fig.10

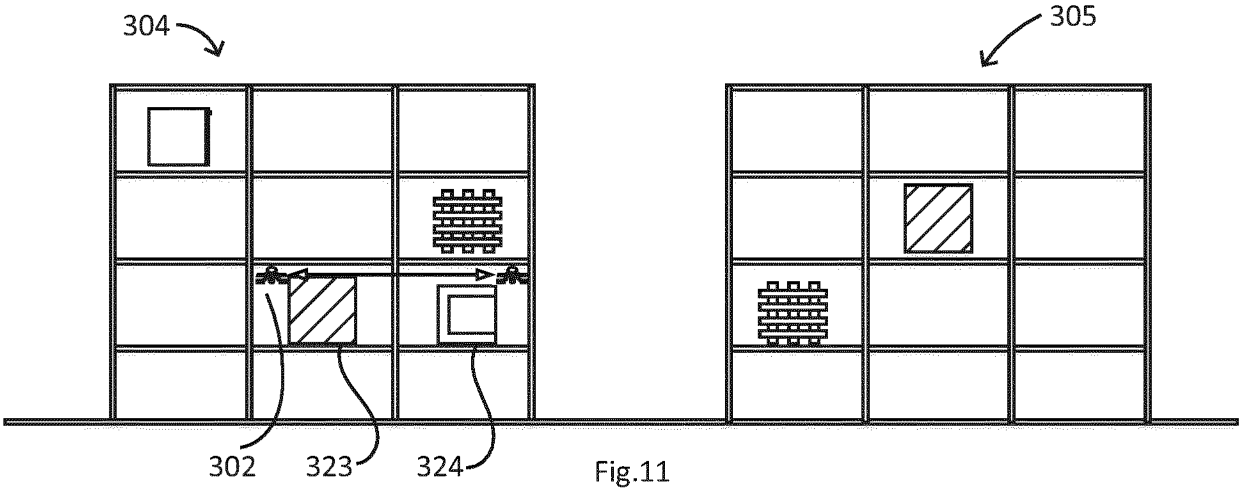
304
305
302
323
324

Fig.11

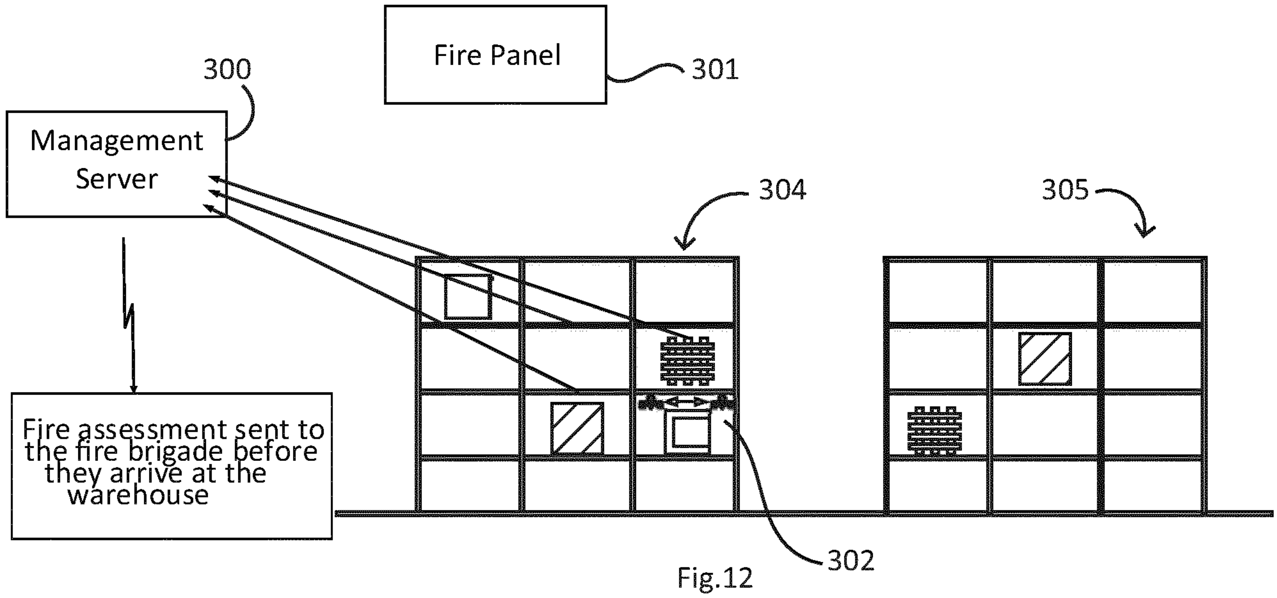
Fire Panel
301
300
Management Server
304
305
Fire assessment sent to the fire brigade before they arrive at the warehouse
302

Fig.12

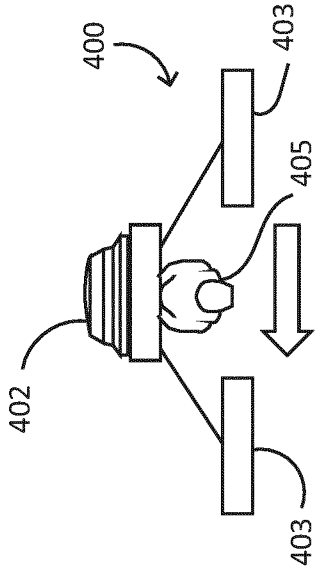

Fig.13

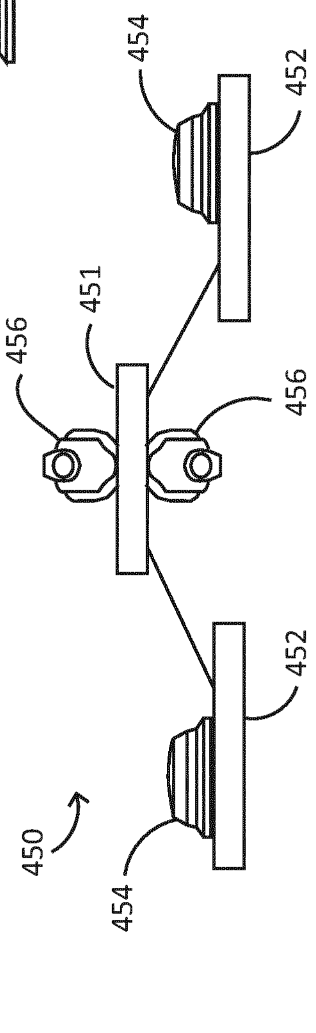

Fig.14

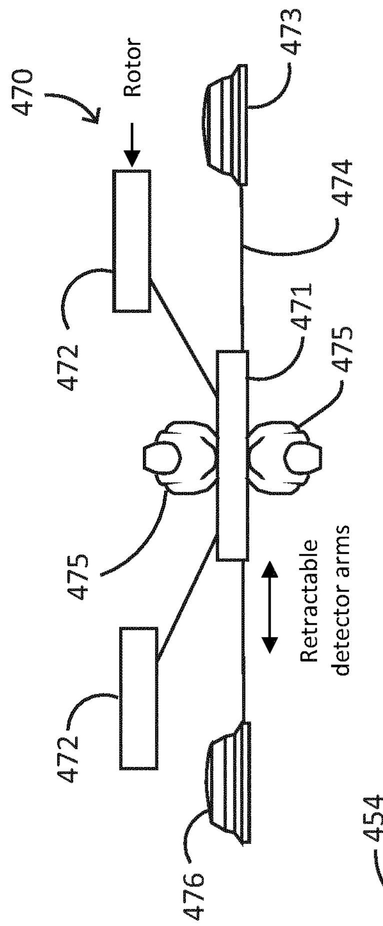

Fig.15

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/052638

A. CLASSIFICATION OF SUBJECT MATTER
INV. G08B17/10 G08B17/113 G08B17/12
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G08B A62C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Byron Spice: "Autonomous Drone Flies in Dark, Tight Quarters To Assist Firefighting Inside Naval Vessels", , 4 February 2015 (2015-02-04), XP002769377, Retrieved from the Internet: URL:https://www.cmu.edu/news/stories/archives/2015/february/firefighting-drone.html [retrieved on 2017-04-19]	1-3,6-9, 21, 24-28, 31-36, 46,49-51
A	the whole document	4,5,29, 30
X	WO 2015/029007 A1 (GABBAY RONEN IZIDOR [IL]) 5 March 2015 (2015-03-05) abstract page 33, line 7 - line 12	1,26,35, 51

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 June 2017	03/07/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Wagner, Ulrich

3

International application No
PCT/EP2017/052638

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2008/144884 A1 (HABIBI BABAK [CA]) 19 June 2008 (2008-06-19) abstract; figures 1,2,7 paragraph [0023] - paragraph [0024] paragraph [0028] - paragraph [0030] paragraph [0047] - paragraph [0059] paragraph [0066] - paragraph [0067] paragraph [0091] paragraph [0096] - paragraph [0102] -----	16-20, 41-45 10-15, 37-40

3

INTERNATIONAL SEARCH REPORT

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☒ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

1-21, 24-46, 49-51

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-9, 21, 24-36, 46, 49-51

   A fire detection system employing a drone, defining various sensors on the drone;

   ---

2. claims: 10-20, 37-45

   A fire detection system employing a drone, comprising a stored reference map and directing the drone;

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3. claims: 22, 23, 47, 48

   A fire detection system employing a drone, transmitting an alarm to an external party.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/052638

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2015029007 A1	05-03-2015	NONE	
US 2008144884 A1	19-06-2008	NONE	