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(54) A SYSTEM AND METHOD FOR WILDFIRE DETECTION AND PREDICTION

(57) The subject of the invention is a system and method for detecting and predicting fires, in particular wildfires. The system for detecting and predicting fires comprises a set of local detection devices (100) and a central unit (200), the central unit (200) being configured to receive and analyse environmental parameter measurements from the set of local detection devices (100). The system is characterized in that the central unit (200) is further configured to receive an alarm signal indicative of fire detection risk from at least one detection device (100), and to verify the fire detection risk by checking the presence of predefined number of detection devices (100) sending the alarm signal within a common analysis time window, and if the fire detection risk is confirmed then to predict the fire probability and fire localization with the use of an heuristic prediction model (201b).

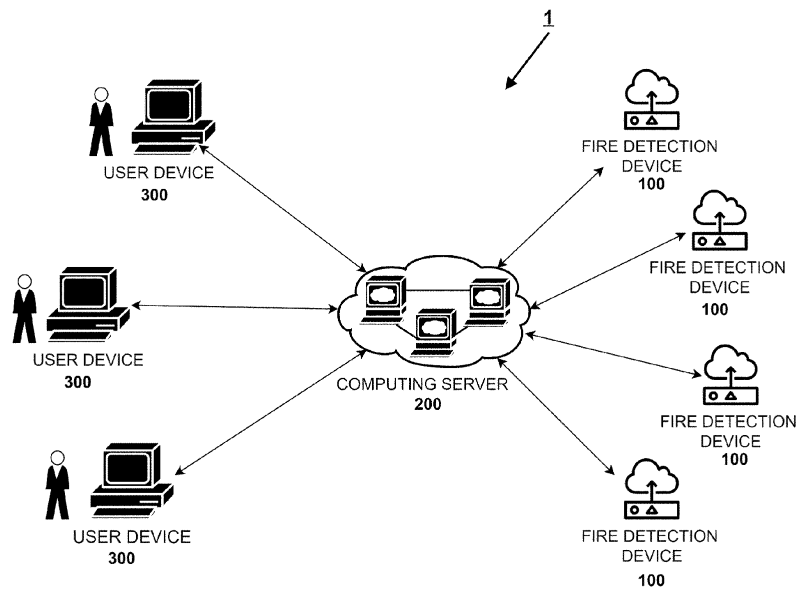

Fig. 1

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a system and method for wildfire detection and prediction.

BACKGROUND OF THE INVENTION

[0002] Recent advances in the field of wildfire detection have significantly changed the landscape of available means to monitor, sense and manage wild fires, in particular in forestry.

[0003] Most of the prior art approaches that are based on processing of image data gathered from the forest terrain are not sufficiently accurate. Even if costly image sensors are used, for example such a solution can still lead to blind spots that are beyond the reach of the cameras. This is due to, for example, the topography of the area. In addition, it is worth noting that camera-based systems are characterized by a certain delay caused by the time between the outbreak of fire and the release of smoke above the treetops, where it can be noticed by cameras. As a consequence these solutions often do not provide a sufficiently fast detection time, especially on windy days, when the smoke does not form a clearly visible pillar and is dispersed under the treetops for a long time. And such conditions, strong wind, are conducive to faster spreading of fire.

[0004] Some of the above-mentioned problems have been resolved by approaches that are based on collecting other fire-indicative environmental data, in particular relating to surrounding air composition in combination with for example weather markers .

[0005] Such a known device, system and method for wildfire detecting is disclosed in the patent US10762758. In particular it relates to a fire detection device and notification system configured for generating alerts based on detected environmental conditions (e.g., temperature, humidity, presence of flame or smoke or combustion gas). The disclosed fire detection device employs various sensor devices (e.g., temperature, humidity, flame, smoke, gas, and the like) to collect environmental data and determine whether the detected environmental conditions indicate the presence of or the increased possibility of a fire. In some embodiments, the invention further comprises a notification system for automatically generating and transmitting alerts to one or more computing devices (e.g., responder dispatch systems) based on the detection of hazardous conditions.

[0006] However, known devices, systems and methods based on collecting early detectable environmental data still have room for improvement as both the accuracy and efficiency of such methods can be further enhanced.

SUMMARY OF THE INVENTION

[0007] It is therefore desirable to provide a device, system and a method for wildfire detection, which addresses drawbacks of the prior art and provides better accuracy and enhanced efficiency, in particular more complex and accurate information on estimated fire range and fire development.

[0008] The present invention provides a system for detecting and predicting fires comprising a set of local detection devices and a central unit, the central unit being configured to receive and analyse environmental parameter measurements from the set of local detection devices, characterized in that the central unit is further configured to receive an alarm signal indicative of fire detection risk from at least one detection device, and to verify the fire detection risk by checking the presence of predefined number of detection devices sending the alarm signal within a common analysis time window and if the fire detection risk is confirmed then to predict the fire probability and fire localization with the use of an heuristic prediction model;

[0009] Advantageously, the heuristic prediction model is configured to calculate, for at least two detection devices, the maximum value of an alarm function, the alarm function taking as an input at least a concentration of volatile compounds, to convert calculated maximum values of the alarm function into the fire probability using the sigmoid function according to the following formula:

$$S(x) = \frac{1}{(1 - e^{-x})}$$

$$x = \frac{\sqrt[N]{\prod_a^{devices} a}}{tr_a} - tr_b$$

wherein a being pre-alert value of single detection device, tr_a and tr_b are adjustable threshold parameters.
to find a point that minimizes the sum over said all of at least two detection devices according to the following formula:

$$f(r, a) = \sum_a^{devices} r_a * a$$

so as to find the source of the emitted concentration of volatile compounds in such a way that the higher the reading of a particular detection device, the closer the source of the fire will be located to that detection device.

[0010] Advantageously, the fire probability and fire localization is predicted with additional use of a trained prediction model to be combined with said heuristic prediction model .

[0011] Advantageously, the predicted fire probability is a percentage probability of the occurrence of a fire calculated as an average of the output probability of the trained model and the heuristic model, while the predicted fire location is the fire location predicted by the trained model if the difference between the fire locations returned by the heuristic prediction model and the trained prediction module divided by the distance between the two most distant detection devices is less than a predefined maximal error.

[0012] Advantageously, the received alarm signal is generated upon calculating an alarm function value which exceeds a threshold value.

[0013] Advantageously, the alarm function is calculated based at least on measurements of concentration of volatile compounds.

[0014] Advantageously, the working mode management module of the detection device is configured to set frequency of measurements and frequency of sending out data at least depending on the low, medium or high fire risk determined based on environmental parameter measurements.

[0015] In another aspect the invention provides a method for detecting and predicting fires performed by a central unit, the method comprising receiving and analysing environmental parameter measurements from a set of local detection devices characterised in that it further comprises the following steps: receiving an alarm signal indicative of fire detection risk from at least one detection device, and verifying the fire detection risk by checking the presence of predefined number of detection devices that are sending the alarm signal within a common analysis time window and if the fire detection risk is confirmed then predicting the fire probability and fire localization with the use of an heuristic prediction model;

[0016] In another aspect, it is provided a computer-readable storage medium having instructions encoded thereon which when executed by a processor, cause the processor to perform the method according to the invention.

[0017] The system according to the invention is designed for the preventive detection of wildfires (with a focus on forest environments) and uses a dense network of sensors that constantly monitor environmental parameters (humidity, temperature, air particulate content, etc.) to detect even trace amounts of smoke. This allows for the detection of fires at a very early stage, which is crucial for successful firefighting operations. The detection devices according to the invention sensors constantly monitor air parameters in search of anomalies. In case of even trace amounts of smoke detected, a single detection device sends the information to the central server and triggers nearby detection devices to send measurements more frequently.

[0018] Moreover, advanced machine learning algorithms combine and analyze the data received from the sensor network in real time to eliminate false alarms and determine the exact location and direction of the fire's development. In case of danger, the local fire brigade is alerted automatically. The system sends information about the location of the fire, its predicted size, and additional forecasts regarding the direction and speed of the fire's spread. Thanks to the acquisition of precise data from the sensor network, foresters and firefighters can better adapt to the existing threat. In addition, the system according to the invention updates fire development data in real time, which allows for more efficient management of the firefighting operation.

[0019] By providing local pre-processing of data collected from sensors before sending it to the central unit, real-time monitoring of fires becomes possible.

[0020] By combining two fire verification and prediction algorithms the method for fire detecting is more accurate.

[0021] In particular, detection method is enhanced by hybrid, combined machine learning and heuristic algorithm. As a consequence, the method gain more robustness but also more stability.

[0022] Specific deep learning neural network structure allows processing data from many devices, where the algorithm can process data from a different number of sensors.

[0023] Moreover, by introducing the use of data from multiple sensors in the process of detecting wildfires the method can better eliminate false positives and enables a more accurate estimation of the location of the fire and predicts its spread which enhances the usefulness of the solution during the firefighting operation by providing valuable data and predictions in real time.

[0024] The method/system according to the invention has better efficiency also because of the use of controllable operating modes and an intelligent battery power supply system, the entire solution is much more energy-efficient, the capacity of the power source can be much smaller, which reduces the costs of implementing the invention.

[0025] Finally, the results of the method according to the invention are outputted in a complex manner, namely by providing appropriate emergency services with such information like the location of the fire, its predicted size, and additional forecasts regarding the direction and speed of the fire's spread. This results in comprehensive understanding of the real situation and enables the user of the system to act in the most optimal way as possible in order to counter the emergency situation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The following detailed description, given by way of example, but not intended to limit the invention solely to the specific embodiments described, may best be understood in conjunction with the accompanying drawings, wherein:

Fig. 1 shows a general diagram of the system according to the invention;
Fig. 2a-b show schematically details of the local fire detection device ;
Fig.3 shows details of communication of the local fire detection devices with other parts of the system according to the first embodiment of the invention ;
Fig. 4. shows details of communication of the local fire detection devices with other parts of the system according to the second embodiment of the invention;
Fig. 5a-b shows schematically cascade triggering of adjacent fire detection devices ;
Fig. 6 shows a general pipeline of the method according to the invention;
Fig.7a shows a schematic diagram of the method of fire detection run in the detection device according to the invention;
Fig.7b shows a schematic diagram of the algorithm of setting frequency of measurements and sending data;
Fig.8 shows a flowchart of the heuristic fire prediction method run in the central unit according to the invention;
Fig.9 shows a schematic diagram of the method of fire prediction with the use of artificial intelligence based run in the central unit according to the invention;
Fig.10 shows schematically the fire location prediction algorithm;
Fig. 11 shows a plot of reads from sensors embedded in the fire detection devices in time ;
Fig. 12 shows an exemplary layout of the user application with plotting the most important parameters in time;

DETAILED DESCRIPTION

[0027] The system and the method for fire detecting can be useful for ultra-early wildfire identifying in the forest. Moreover, the system and the method according to the invention can be of practical meaning also for wildfires in other non-urbanized areas, such as agricultural wastelands, grasses or bushes.

[0028] While various embodiments of the invention are shown and described herein, such embodiments are provided by way of example only. Numerous variations, changes, and substitutions may occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed.

[0029] Unless defined otherwise, all terms of art, notations and other technical and scientific terms or terminology used herein are intended to have the same meaning as is commonly understood by persons skilled in the art to which the claimed subject matter pertains. In some cases, terms with commonly understood meanings are defined herein for clarity and/or for ready reference, and the inclusion of such definitions herein should not necessarily be construed to represent a substantial difference over what is generally understood in the art.

[0030] The term "coupled" means a direct or indirect connection, such as a direct electrical, mechanical, or magnetic connection between the things that are connected or an indirect connection, through one or more passive or active intermediary devices.

[0031] The term "module" or "logic" or "unit" may refer to one or more passive and/or active components that are arranged to cooperate with one another to provide a desired function. The term "signal" may refer to at least one current signal, voltage signal, magnetic signal, or data/clock signal. The meaning of "a," "an," and "the" include plural references. The meaning of "in" includes "in" and "on." The terms "substantially," "close," "approximately," "near," and "about," generally refer to being within +/-10 percent of a target value.

[0032] Unless otherwise specified the use of the ordinal adjectives "first," "second," and "third," etc., to describe a common object, merely indicate that different instances of like objects are being referred to, and are not intended to imply that the objects so described must be in a given sequence, either temporally, spatially, in ranking or in any other manner.

[0033] The term "real-time" here generally refers to systems that respond under real-time or live constraints and generates a result within a time frame (e.g., in few or less microseconds).

[0034] The system 1 for wildfire detection according to the invention will be now described in reference to Fig.1. The system 1 for wildfire detection according to the invention can be divided into three main components: a) a set of single detection devices 100 b) a cloud based fire prediction software embedded in the central unit 200 c) plurality of user stations 300. The set of single detection devices is placed locally in the forest or other area of interest. The main part of the system, namely at least a managing module 202 and a fire predicting module 203 are embedded in the cloud based software 200 in the central unit 200. Detailed disclosure of the pipelines performed by the central unit 200 and appropriate modules are presented further in the description. The last part of the system are user stations 300 located stationary or being mobiles with the use of which fire alarms or monitoring information are delivered to the end users like fireman, forest inspectors, forest manager or other employee dealing with forest management and fire protection.

[0035] A single detecting device 100 according to the invention can be shown in Fig.2. Regarding its mechanical construction, it can be a waterproof box/case (not shown) with an appropriate sealing system, the outer box being made of plastic or metal. in which all electrical components are housed. Typically such a detection device is provided with attaching means configured to be complementary to attaching means appropriate for particular terrain type and allowing secure attachment in the predetermined location. For example, in the case of forests, it can be a strap made of plastic with an appropriate harness for mounting the sensor on a selected tree. The detection device100 according to the invention is a small device designed for long-term operation in outdoor environments.

[0036] As it can be seen in Fig.2 the detection device 100 has several components coupled to each other. It comprises a power generating module 101, power module 102, a processing unit 103, sensor module 104 and a transmission module 105.

[0037] The power generating module 101 can be a built-in small photovoltaic panel 101 (4.5 cm x 4.5cm), which allows to maintain continuous power supply. In other embodiments the power generating module 101 can be any other type of green energy converter appropriate for such use. The power module 102 of the detection device 100 supplies power to all electrical components of the detection device 100. The detection device 100 is advantageously powered by a small battery 102. In another embodiment the power module 102 can be a set of supercapacitors. The power module 102 is recharged by the power generating module 101, for example solar energy from the photovoltaic panel 101. In the power generating module 101 a special dynamic inverter (not shown) is used, which selects the charging voltage in such a way as to maximize the energy that can be obtained under given lighting conditions. Thanks to this approach it is possible to efficiently power the detection device 100 also in forest conditions where there is mostly shade and the access to direct light is rare.

[0038] Another important element of the detection device 100 according to the invention is a set of environmental sensors 106 comprised in the sensor module 104 that constantly monitor air parameters and are able to detect even trace amounts of smoke. The primary sensor 106a that is used is the commercially available BOSCH BME680 which is an air quality sensor. However, it works in such a way that it is a volatile compounds' sensor 106a that detects the concentration of volatile compounds. The volatile compounds sensor 106a accurately measures the resistance of the surrounding gases. The worse the air quality, understood by the concentration of volatile compounds, the higher the resistance. It turns out that this parameter is a very good indicator of fire, because the smoke from burning forest material, mulch, etc. contains a high concentration of volatile compounds.

[0039] Moreover, the sensor module 104 comprises, in addition, for calibration purposes, an independent temperature and humidity sensor 106b that monitors air temperature and humidity. Other sensors that can be present in the sensor module 103 of the detection device 100 according to the invention are atmospheric pressure sensor, radiance sensor, flame sensor, insolation sensor. The temperature and humidity sensor as well as an atmospheric pressure sensor are used, but they mainly perform correction functions. The main indicator of fire is the resistance of gases, which is read as raw data and already processed by the microcontroller of the already mentioned commercially available sensor itself as a parameter informing about air quality. When there are free volatile compounds in the air, the gas resistance parameter decreases and the air quality parameter (a non-linear inversely proportional function to the gas resistance) increases. Smoke resulting from the fire of litter and other organic fragments in the forest contains a high concentration of volatile compounds, which is why this method is highly effective. Generally, one can call the volatile compound sensor as an "artificial nose" because it detects similar substances. And this is supported by observations, when people smell smoke, the corresponding sensor readings increase significantly.

[0040] As shown in Fig. 2b, the detection device 100 also comprises a processing unit 103 that is responsible for several tasks and thus comprises several software implemented modules like: power managing module 103a, collected data pre-processing module 103b, working mode management module 103c, a data sending and receiving module 103d. Detailed information on operations performed by the local processing unit 103 is given in reference to Fig. 7a.

[0041] The power managing module 103a is responsible for selecting the appropriate working point, giving optimal efficiency of the photovoltaic panel at the available insolation. Said module is also involved in optimization in terms of power consumption. The power managing module 103a controls the operation of the detection device 100 using several deep sleep modes. This allows to remotely control the detection devices 100 and operate in different modes as needed, in particular energy-saving ones. In general, modes that measure more often use more energy, and energy-saving variants measure less often.

[0042] The data sending and receiving module 103d is responsible for aggregating data into packets, ordering their sending and handling data received from the server, which are then used to change the operating mode, the frequency of measurements or the frequency of data sending.

[0043] The collected data pre-processing module 103b is responsible for processing data collected by sensors 106. Operations that are performed over collected data are in particular averaging and calculating the value of the pre-alarm function in order to check if the initial fire detection condition is met. Pre-processing of the collected data by the local processing unit 103, namely by making processing data parallel, allows to monitor potential fires in real-time. In particular as a consequence of initial data pre-processing and filtering by the pre-processing module 103b not all readings collected by the detection device 100 are always sent. Advantageously, averaged readings are only sent. The working mode management module 103c deals with setting the appropriate frequency of measurements depending on the available battery charge level and the current level of fire risk.

[0044] The detection device 100 according to the invention comprises also a communication module 105. In one embodiment the communication module 105 allows to communicate in the LPWAN band (low-power wide-area network). Specifically, it can be the NB-IoT band which allows the detection devices 100 to communicate directly with telecommunications operators' BTS stations as shown in Fig.2. In another embodiment, the communication module 105 allows to operate on the basis of LORA-WAN technology. In said embodiment the gateway has to be run by a third party, in particular the operator of the detection devices 100. In said embodiment the gateway communicates with the detection devices 100 and then passes the signal on as shown in Fig.3.

[0045] As shown in Fig.1 single detection devices 100 are disposed in different locations so as to cover the area of interest to be monitored. The detection devices 100 are not directly connected to each other (it is not a mesh grid connection) however they can influence each other's operation as it will be further described in reference to Fig.6a and 6b. The detection devices 100 communicate directly with the central unit which can be a computing server 200. The central unit 200 communicates with at least one user station 300. Advantageously, the user station 300 can be a laptop or a mobile phone provided with an appropriate application or alternatively the access to the system according to the invention can be supplied via a browser run on said user station 300.

[0046] Now the method for wildfire detecting according to the invention will be described. The method for wildfire detection according to the invention can be divided into two main components: a) the operation of an individual detection device 100, b) aggregation and processing data from detection devices 100 by a cloud-based software embedded in the central unit 200. Both components of the method are run on different hardware entities.

[0047] Regarding the first component run on the detection device 100 the method according to the invention comprises the following steps: a) setting an initial first working mode; b) acquiring data from at least volatile compounds' sensor 106a then iteratively c) pre-processing collected data and checking a fire detection condition or checking the input data for request to change the working mode; d) if the fire detection condition is met then sending out a pre-alarm signal containing measurement values recorded by sensors and changing the working mode into the second working mode, or if the fire detection condition is not met but if the request to change the initial working mode is received then changing the working mode into the second working mode; then iteratively e) checking the input data for request to change the working mode, and f) if the request to change the initial working mode is not received, then pre-processing collected data and sending out pre-processed data collected from at least one sensor 106a according to the second working mode, or if the request to change the initial working mode is received changing the working mode to the first initial working mode.

[0048] As shown in Fig.7a, in the step of setting an initial first working mode, typically, a broadcasting mode is set. In the broadcasting mode the detection devices operates in the power saving mode, namely measurements are performed at fixed time, namely, depending on the amount of available energy and the level of fire risk, the frequency of taking and sending measurements is selected, moreover, pre-processed data sent to the central unit 200 with a selected frequency only. Depending on the set frequency of sending data, every period of time the data collected by the detection device

100 is sent regardless of the value of the alarm function calculated in another step.

[0049] The algorithm of setting measurement frequency comprises the following steps: first, information about the current state of charge of the detection device 100, the current level of fire risk and a short-term weather forecast are acquired. Short-term weather forecast is used to determine how much energy the solar panel will generate in the next few days. If the fire risk is low, the measurement frequency is selected to keep the battery at full charge. In the case of medium and high fire risk, measurements are made more frequently, ensuring that the device does not discharge completely. Moreover, the weather forecast is used to estimate how much the battery can be discharged, taking into account the charging intensity in future days, so as not to discharge the detection device 100. The greater the risk of fire, the battery level and the expected value of future charging, the more frequent the measurements. A detailed description of the algorithm for selecting the frequency of measurements and sending data is presented in the block diagram in Fig. 7b. The above-mentioned operations that result in outputting signals to other modules of the detection device 100 are performed by the working mode management module 103c.

[0050] In the step of acquiring data from at least volatile compounds' sensor 106a, sensors 106 measure at least parameters like volatile compounds concentration, which is measured by checking value of resistance of the gas surrounding the sensor and advantageously in addition parameters like temperature, humidity, atmospheric pressure or insolation.

[0051] In the step of pre-processing data collected from sensors 106 is averaged by using a moving average, with a time window of 30-300s if the current mode is the first working mode, namely broadcasting mode. If the current mode is the second working mode, namely an alarm mode then data collected from sensors 106 is averaged by using a moving average, with a time window of 10-30s.

[0052] In the step of checking a fire detection condition the collected data pre-procesing module 103b uses an algorithm that monitors the relative growth of the monitored environment parameter values over time. Absolute values would be a bad indicator of the appearance of anomalies because the sensors 106 may become calibrated, as well as the volatile compounds sensor 106a can register a steady increase in the concentration of particulate matter and volatile compounds being a result of smog which may occur in forest areas adjacent to urban areas. To the contrary, monitoring relative increases makes it possible to become independent of the above factors. The details of the calculation of the alarm function in the pre-processing module 103b are as follows: the maximum value of the alarm function from the analyzed time window is calculated. The alarm function depends on the readings recorded by the device. These may include volatile compound concentrations, temperature, humidity, and other monitored values. An exemplary alarm function can be:

$$f_{alarm} = \frac{vox^{0.33} * abs(vox_d)}{(abs(hum_{d5m})^{1.4})}$$

wherein, vox is the value of the concentration of volatile compounds, vox_d is the derivative of this concentration with a change count increment of 1 (next measurement minus previous measurement), hum_d_5m is the moving average of the derived air humidity values, where the width of the averaging window is 5. If the calculated maximum value of the alarm function exceeds a certain threshold value then the fire detection risk is confirmed in the detection device 100 and the alarm signal is generated and sent out to the computing server 200.

[0053] If the fire detection condition is not met then the detection device 100 further checks the input data for the request to change the working mode into the second working mode, namely an alarm mode. However, if there is no such a request the detection device 100 returns to the step of acquiring data in the first working mode as described earlier.

[0054] As mentioned earlier, if in a short period of time there is a significant percentage increase in the monitored environment parameter value, the detection device 100 considers such a condition as the occurrence of a suspected alarm and sends notifications to the central server 200, which then wakes up neighboring devices 100. In parallel said detection device 100 itself changes the working mode into the second working mode, namely the alarm mode. Then the detection device 100 collects and preprocess data in the second working mode and iteratively checks input data for the request to change the mode into the first working mode. Such a request is sent back to all detection devices 100 after a while if the alarm is negative and the fire detection risk is not confirmed at the computing server 200 level.

[0055] Once the central unit 200 receives the information that the first detection device 100 of the plurality of detection devices 100 detected some anomalies in the environment parameter values over time allowing to determine that there was a fire, the central unit 200 sends to at least a second detection device 100 a request to change the working mode into the second working mode, namely the alarm working mode. Said at least one second detection device 100 is located in the predefined distance from the first detection device 100.

[0056] In the substep of changing the working mode to the second working mode, in response to a request for changing the working mode into the second working mode, the processing unit 103, namely the working mode management module 103c sends a setting signal to the sensors 106 in the sensor module 104 in order to set appropriate measurement which means that from now data are sent with a higher frequency as well as sends a setting signal to the data sending and receiving module 103d in order to set appropriate data sending frequencies.

[0057] Once the threat is detected, in the step of sending pre-processed data collected from at least one sensor 106a according to the alert working mode, all available pre-processed data are sent to the central unit 200. In parallel, the input data is checked for the request to change the current working mode (namely the alarm mode) into the first initial working mode if the risk of fire has not been confirmed.

[0058] As it can be seen in Fig. 6a and Fig.6b, a special cascade triggering routine is provided for the plurality of detection devices 100 according to the invention. Once the fire is detected by one of the plurality of detection devices 100 (see Fig.6a), other adjacent detection devices 100 are remotely forced by the central unit 200 to enter the same alert mode as the first detection device 100 (see Fig.6b). The number of neighbouring detection devices 100 that has to be triggered in such a case depends on the number of devices that are in the vicinity, the vicinity being defined by a threshold vicinity distance, usually it is a distance of 500-1000m.

[0059] In other words, a mechanism to excite neighboring devices for faster alarm verification and fire location estimation is provided. When one detection device 100 makes an initial detection of an anomaly, it sends this information to the central unit 200 (computing server 200) in order to forward the alarm to another detection device(s) 100 and request the change of their working modes. Moreover, said first detection devices 100, in parallel, itself goes into the alarm mode of taking measurements at a higher frequency and sending these measurements more frequently.

[0060] As mentioned earlier, in addition, when the computing server 200 receives information about the initial alarm detection (information sent by a single first detection device 100) it remotely changes the operation mode of neighbouring detection devices 100, waking them up from sleep modes.

[0061] When the neighbouring detection devices 100 of an alarming detection device 100 receive a signal from the computing server 200 about the mode change, they wake up (see Fig. 5b) and increase the frequency of measurements and the frequency of sending the collected data.

[0062] As a result of these actions, in the step e) of sending data according to alarm mode by selected detection devices100, the computing server 200 receives denser data from multiple sensors 106 of the plurality of awaken detection devices 100. The use of this data leads to verification of an alarm detected by a single detection device 100. The detailed process run in the central unit 200 is presented further in the description in reference to Fig.8 and Fig.9.

[0063] In a situation where the alarm is eliminated, the detection devices 100 remain in the alarm mode for some time after which they return to their default mode of operation, namely the broadcasting mode. Namely in the step f) of changing the working mode to the initial broadcasting mode in response to a request for changing the working mode into the initial first working mode appropriate detection devices 100 are requested by the central unit 200 to change their working mode to the initial one, namely to the broadcasting mode.

[0064] Now the component of the method for wildfire detecting which is run on the computing server will be described in reference to Fig.8 and Fig.9. In the first step the central unit 200 receives from a first detection device 100 an alarm signal along with a set of data collected by its sensor module 104. In the second step, the central unit 200 sends request to other selected detection devices 100 in the predefined vicinity to change their working mode into the alarm mode Once the cascade triggering step is performed by the central unit 200 the method passes to a step of fire verification and prediction. In this step of fire verification and prediction dense data from a plurality of detection devices 100 are received and processed. In particular, the step of fire verification and prediction comprises several substeps.

[0065] First in the substep of fire verification it is checked whether other detection devices 100 also sent a pre-alarm in the predefined analyzed time window. In other words, the alarm signal received from one single detection device 100 is only indicative of fire detection risk and the central unit 200 has to verify fire detection risk by checking further appropriate conditions.

[0066] This concept is related to the fact that it is not desirable to combine pre-alarm from unrelated events. An alarm from a single sensor 106a may be false, e.g. caused by a car passing nearby. However, when the smoke spreads through the forest, and activates several sensors 106a, it is much more sure that a real fire has been detected. Since the smoke spreads relatively slowly, it cannot be expected that several detection devices 100 will register a pre-alarm at exactly the same time, hence a common analysis time window was introduced with a selectable parameter, for example fixed at 15 minutes. If no more detection devices 100 send pre-alarm to the central unit 200 within said common analysis time window then after a certain configurable time, such as one hour, the central unit 200 sends back a request to change the working mode into the frist working mode, namely broadcasting mode. As a consequence, the detection devices 100 exit the alarm mode and switch to the standard, more energy-saving mode.If at least two neighbouring detection devices 100 send pre-alarms within said time window then it means that the fire detection risk has been confirmed and the method pass to another substep of fire prediction. In other words, if the fire detection risk is confirmed then the computing server 200 has to predict the fire localization and fire development advantageously with the use of combination of an heuristic prediction model and a trained prediction model. However, in one embodiment the fire prediction is performed only with the use of heuristic prediction model 201b. The mentioned heuristic prediction model used for prediction is shown in Fig. 8. This algorithm can be described as follows.

[0067] First N detection devices 100 are selected that also registered an alarm in the analyzed time window, usually N=2 or N=3. Secondly, for each device, the maximum value of the alarm function from the analyzed time window is calculated. The alarm function depends on the readings recorded by the detection devices 100. These may include volatile compound concentrations, temperature, humidity, and other monitored values. The alarm function can by any function taking into account said input data in such a way that changes of input data in time are considered. An exemplary alarm function can be:

$$f_{alarm} = \frac{vox^{0.33} * abs(vox_d)}{(abs(hum_{d5m})^{1.4})}$$

wherein, vox is the value of the concentration of volatile compounds, vox_d is the derivative of this concentration with a change count increment of 1 (next measurement minus previous measurement), hum_d_5m is the moving average of the derived air humidity values, where the width of the averaging window is 5.

[0068] Next, conversion of pre-alarm values into fire probability using the sigmoid function is performed according to the following formula:

$$S(x) = \frac{1}{(1 - e^{-x})}$$

$$x = \frac{\sqrt[N]{\prod_a^{devices} a}}{tr_a} - tr_b$$

where, a is pre-alert value of single detection device 100, tr_a and tr_b are adjustable threshold parameters.

[0069] Then a point that minimizes the sum over all alarming devices is found. It can be an increasing function f(r,a) whose arguments r are the distance of the point from the detection device 100, and a is the value of the device's alarm function. An example of a minimized function can be:

$$f(r, a) = \sum_a^{devices} r_a * a$$

Using an increasing function with respect to r and a causes the fire to be located closer to detection devices 100 with higher readings. In other words, the heuristic algorithm finds the source of the emission in such a way that the higher the reading of a particular sensor 106a , the closer the source of the fire will be located to that sensor 106.

[0070] Further, a correction that takes into account the strength and direction of the wind is applied. At the end the heuristic algorithm returns the estimated location and probability of fire.

[0071] In particular, in another embodiment an approach combining aspects of a heuristic algorithm with machine learning is used. For that purpose a trained fire verification and prediction model 201 is used as well as heuristic prediction model 202 in the substep of fire prediction. The trained fire prediction model 201 is a deep neural network (DNN) and was trained in a typical manner with the use of input data in the form of time series representing the values measured by each detection device 100, along with appropriate labels, namely assigned locations of the detection devices 100.

[0072] As background studies a fuel model that simulates the spread of fire in a forest environment was developed to better understand how derived products from fire are transported in the atmosphere. Using such a model, virtual versions of equipment were judged in a simulated forest environment, in which d fire formation and spread was simulated. In this way, a synthetic dataset containing pairs: the indications returned by the detection devices 100 - the known location of the simulated fire were generated. The synthetic dataset created in this way allowed to train a deep learning model 201 performing the inverse task: based on sensors 106 readings, the model 201 determined the location of fire occurrence.

[0073] As it can be seen in Fig. 9 the deep neural network used in the trained prediction model 201 is of particular structure in which several inputs are grouped together. In the first phase, data from individual devices are analysed independently (however, parameter sharing is used, so data from all devices are processed through layers with identical weight values). Data from devices that are processed by the deep learning model are sensor indications in the form of a time series. The following values are used: concentration of volatile compounds, temperature, humidity, however additional parameters monitored by the device may be used, such as, for example, atmospheric pressure or insolation. Then, the representations obtained in the first phase are combined, the meteorological data vector is added and the feature vector combined in this way is subject to further processing, which results in the output in the form of fire location estimation and the probability of its occurrence.

[0074] During the real-world tests, the parameters of the trained prediction model 201 can be tuned so that the prediction of the situation better reflects the situation in the real environment.

[0075] In the substep of fire prediction the input data for the trained model 201 is also a time series representing the values measured by sensors 106 of each detection device 100, in particular from at least volatile compounds sensors 106a, along with the assigned locations of the devices. At least data from the same three selected detection devices 100 are sent to the trained fire prediction model 201 and in parallel to the heuristic prediction model 202.

[0076] Also additional data input used by the heuristic model 201b which are information about the current weather condition (wind speed and direction, atmospheric pressure, cloud cover, sunshine, air temperature and humidity) to better analyze the state of the atmosphere are sent to the trained model 201. The output of the trained prediction model 201a is also a probability of fire detection as well as its location. At the end both predictions are combined. It should be noted that the deep learning model often returns more accurate predictions, but sometimes they are burdened with a very large error. On the other hand, the heuristic model is characterized by a lower tendency to generate very large errors. Therefore, a methodology was adopted (in the context of fire location estimation) that the machine learning result is acceptable if it differs from the result of the heuristic algorithm less than a certain threshold value (25% was assumed). Said difference is counted as the difference between the fire locations returned by the heuristic and machine learning algorithms divided by the distance between the two most distant devices whose data was used in the data analysis process. In the context of calculating the percentage probability of the occurrence of a fire, the average of the machine learning and heuristic algorithm is taken. Said methodology for choosing location prediction can be presented as follows:

$$location = \begin{cases} DNN_{location} & \frac{|DNN_{location} - Heuristic_{location}|}{max\ distance} \leq max\ error \\ Heuristic_{location} & \frac{|DNN_{location} - Heuristic_{location}|}{max\ distance} > max\ error \end{cases}$$

[0077] Like in the first embodiment, further in the step of fire verification and prediction, the central server 200 determines the displacement vector of the fire location using location estimations, calculated by an appropriate algorithm for different moments. For this purpose, a simple linear regression is used to estimate the location of the fire source in the future. This mechanism is shown in Fig. 10

[0078] The output of the substep of fire prediction in the second embodiment is also the probability of detecting a fire and its estimated location. The two variants of the algorithm (a less accurate but predictable heuristics, and a more accurate machine learning algorithm, which sometimes returns large errors) combined together give a solution more convenient and accurate than their components.

[0079] If the alarm is confirmed in this step of fire verification and prediction, the method passes to the next step of sending notifications. Said notifications are immediately sent by the central unit 200 to the relevant services via end user stations 300. The alarm can be in the form of an alarm on the web application or its mobile version, SMS alarm, alarm by automated telephone connection to the indicated list of numbers, alarm on the indicated list of e-mails, alarm on the indicated contact list using the indicated chat platform (e.g. telegram, whatsapp, messenger, etc.), sending information to a device (for example dedicated device) located at the headquarters of the forest inspectorate, forest guard and/or fire brigade, which produces a sound signal after receiving the alarm signal. Notification solutions can be freely combined. Exemplary layouts available via the user stations 300 are presented in Fig. 11 and Fig.12.

[0080] Provided herein is also a non-transitory computer readable medium comprising machine-executable code that, upon execution by one or more computer processors, implements a method for wildfire detecting run on the detection device 100 and/or on the central unit 200.

[0081] The code can be pre-compiled and configured for use with a machine having a processor adapted to execute the code, or it can be compiled during runtime. The code can be supplied in a programming language that can be selected to enable the code to execute in a pre-compiled or as-compiled fashion.

[0082] Hence, a machine readable medium, such as computer-executable code, may take many forms, including but not limited to, a tangible storage medium, a carrier wave medium or physical transmission medium. Non-volatile storage media include, for example, optical or magnetic disks, such as any of the storage devices in any computer(s) or the like, such as may be used to implement the databases, etc. shown in the drawings. Volatile storage media include dynamic memory, such as the main memory of such a computer platform. Tangible transmission media include coaxial cables; copper wire and fiber optics, including the wires that comprise a bus within a computer system. Carrier-wave transmission media may take the form of electric or electromagnetic signals, or acoustic or light waves such as those generated during radio frequency (RF) and infrared (IR) data communications. Common forms of computer-readable media therefore include for example: a floppy disk, a flexible disk, hard disk, magnetic tape, any other magnetic medium, a CD-ROM, DVD or DVD-ROM, any other optical medium, punch cards paper tape, any other physical storage medium with patterns of holes, a RAM, a ROM, a PROM and EPROM, a FLASH-EPROM, any other memory chip or cartridge, a carrier wave transporting data or instructions, cables or links transporting such a carrier wave, or any other medium from which a computer may read programming code and/or data. Many of these forms of computer readable media may be involved in carrying one or more sequences of one or more instructions to a processor for execution.

Claims

1. A system for detecting and predicting fires comprising a set of local detection devices (100) and a central unit (200), the central unit (200) being configured to receive and analyse environmental parameter measurements from the set of local detection devices (100) **characterized in that** the central unit (200) is further configured to

   - receive an alarm signal indicative of fire detection risk from at least one detection device (100), and to
   - verify the fire detection risk by checking the presence of predefined number of detection devices (100) that are sending the alarm signal within a common analysis time window
   - and if the fire detection risk is confirmed then to predict the fire probability and fire localization with the use of an heuristic prediction model (201b);

2. The system according to claim 1, wherein the heuristic prediction model (201b) is configured to

   - calculate, for at least two detection devices (100), the maximum value of an alarm function, the alarm function taking as an input at least a concentration of volatile compounds
   - to convert calculated maximum values of the alarm function into the fire probability using the sigmoid function according to the following formula:

$$S(x) = \frac{1}{(1 - e^{-x})}$$

$$x = \frac{\sqrt[N]{\prod_{a}^{devices} a}}{tr_a} - tr_b$$

   wherein a being pre-alert value of single detection device (100), tr_a and tr_b are adjustable threshold parameters.
   - to find a point that minimizes the sum over said all of at least two detection devices (100) according to the following formula:

$$f(r,a) = \sum_{a}^{devices} r_a * a$$

so as to find the source of the emitted concentration of volatile compounds in such a way that the higher the reading of a particular detection device (100) , the closer the source of the fire will be located to that detection device (100).

3. The system according to claim 1 or 2, wherein the fire probability and fire localization is predicted with additional use of a trained prediction model (201a) to be combined with said heuristic prediction model (201b).

4. The system according to claim 3, wherein the predicted fire probability is a percentage probability of the occurrence of a fire calculated as an average of the output probability of the trained model (201a) and the heuristic model (201b), while the predicted fire location is the fire location predicted by the trained model (201a) if the difference between the fire locations returned by the heuristic prediction model and the trained prediction module divided by the distance between the two most distant detection devices is less than a predefined maximal error.

5. The system according to any preceding claim, wherein the received alarm signal is generated upon calculating an alarm function value which exceeds a threshold value.

6. The system according to any preceding claim, wherein the alarm function is calculated based at least on measurements of concentration of volatile compounds.

7. The system according to claim 3, wherein the working mode management module (103c) of the detection device (100) is configured to set frequency of measurements and frequency of sending out data at least depending on the low, medium or high fire risk determined based on environmental parameter measurements.

8. A method for detecting and predicting fires performed by a central unit (200), the method comprising receiving and analysing environmental parameter measurements from a set of local detection devices (100) **characterised in that** it further comprises the following steps:

- receiving an alarm signal indicative of fire detection risk from at least one detection device (100), and to
- verifying the fire detection risk by checking the presence of predefined number of detection devices (100) that are sending the alarm signal within a common analysis time window
and if the fire detection risk is confirmed then
- predicting the fire probability and fire localization with the use of an heuristic prediction model (201b);

9. The method according to claim 1, wherein the heuristic prediction model (201b) is configured to

- calculate, for at least two detection devices (100), the maximum value of an alarm function, the alarm function taking as an input at least a concentration of volatile compounds
- to convert calculated maximum values of the alarm function into the fire probability using the sigmoid function according to the following formula:

$$S(x) = \frac{1}{(1 - e^{-x})}$$

$$x = \frac{\sqrt[N]{\prod_{a}^{devices} a}}{tr_a} - tr_b$$

wherein *a* being pre-alert value of single detection device (100), tr_a and tr_b are adjustable threshold parameters.
- to find a point that minimizes the sum over said all of at least two detection devices (100) according to the following formula:

$$f(r,a) = \sum_{a}^{devices} r_a * a$$

so as to find the source of the emitted concentration of volatile compounds in such a way that the higher the reading of a particular detection device (100), the closer the source of the fire will be located to that detection device (100).

10. The method according to claim 8 or 9, wherein predicting fire probability and fire localization is performed with additional use of a trained prediction model (201a) to be combined with said heuristic prediction model (201b).

11. The method according to claim 10, wherein the predicted fire probability is a percentage probability of the occurrence of a fire calculated as an average of the output probability of the trained model (201a) and the heuristic model (201b), while the predicted fire location is the fire location predicted by the trained model if the difference between the fire locations returned by the heuristic prediction model and the trained prediction module divided by the distance between the two most distant detection devices is less than a predefined maximal error.

12. The method according to any of preceding claims, wherein the received alarm signal is generated upon calculating an alarm function value which exceeds a threshold value.

13. The method according to any of preceding claims, wherein the alarm function is calculated based at least on measurements of concentration of volatile compounds.

14. The method according to claim 10, wherein the trained prediction model (201a) is a deep learning neural network.

15. A computer-readable storage medium having instructions encoded thereon which when executed by a processor, cause the processor to perform the method according to claim 8 to 14.

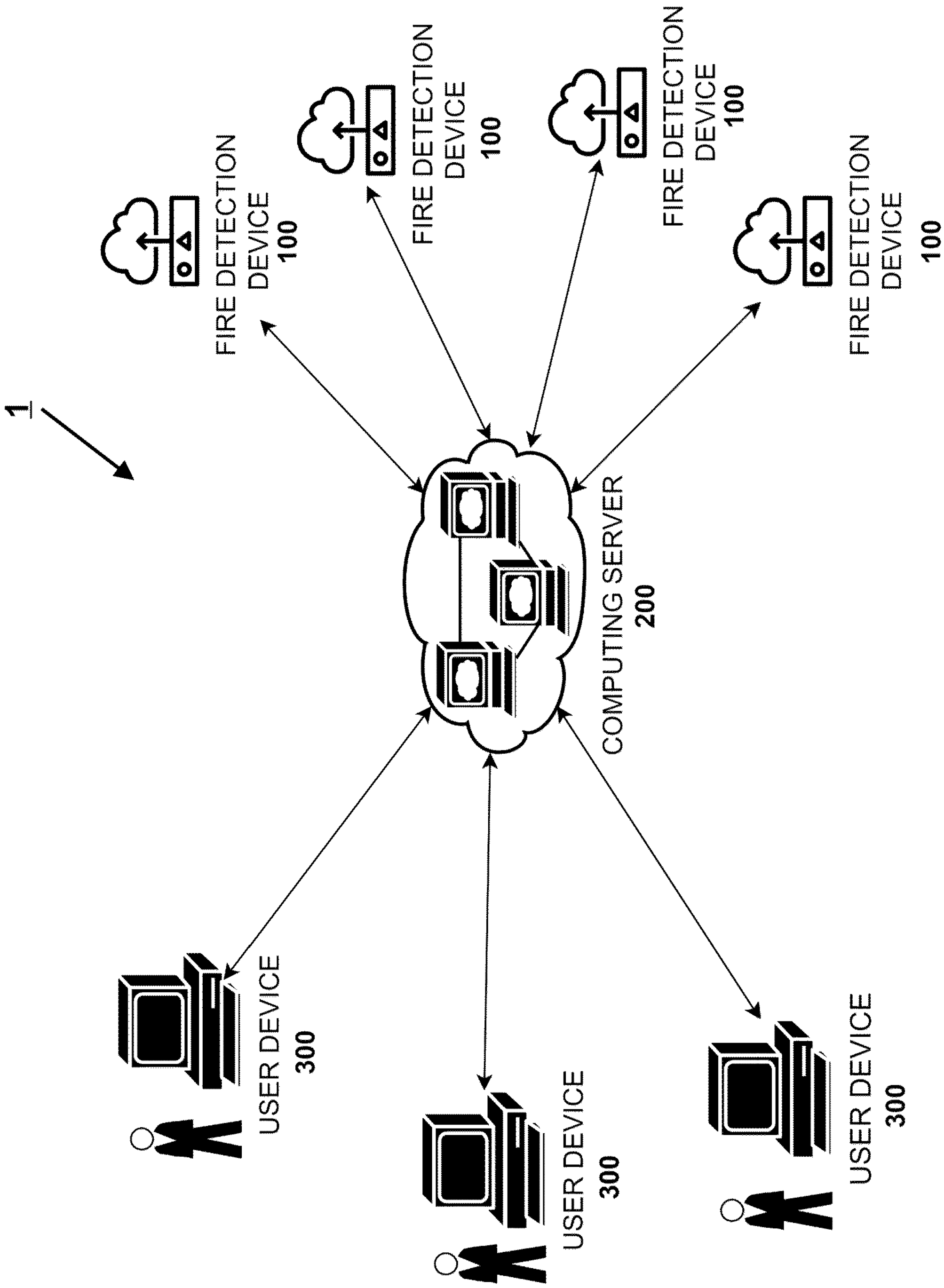
1
FIRE DETECTION DEVICE 100
FIRE DETECTION DEVICE 100
FIRE DETECTION DEVICE 100
FIRE DETECTION DEVICE 100
COMPUTING SERVER 200
USER DEVICE 300
USER DEVICE 300
USER DEVICE 300

Fig. 1

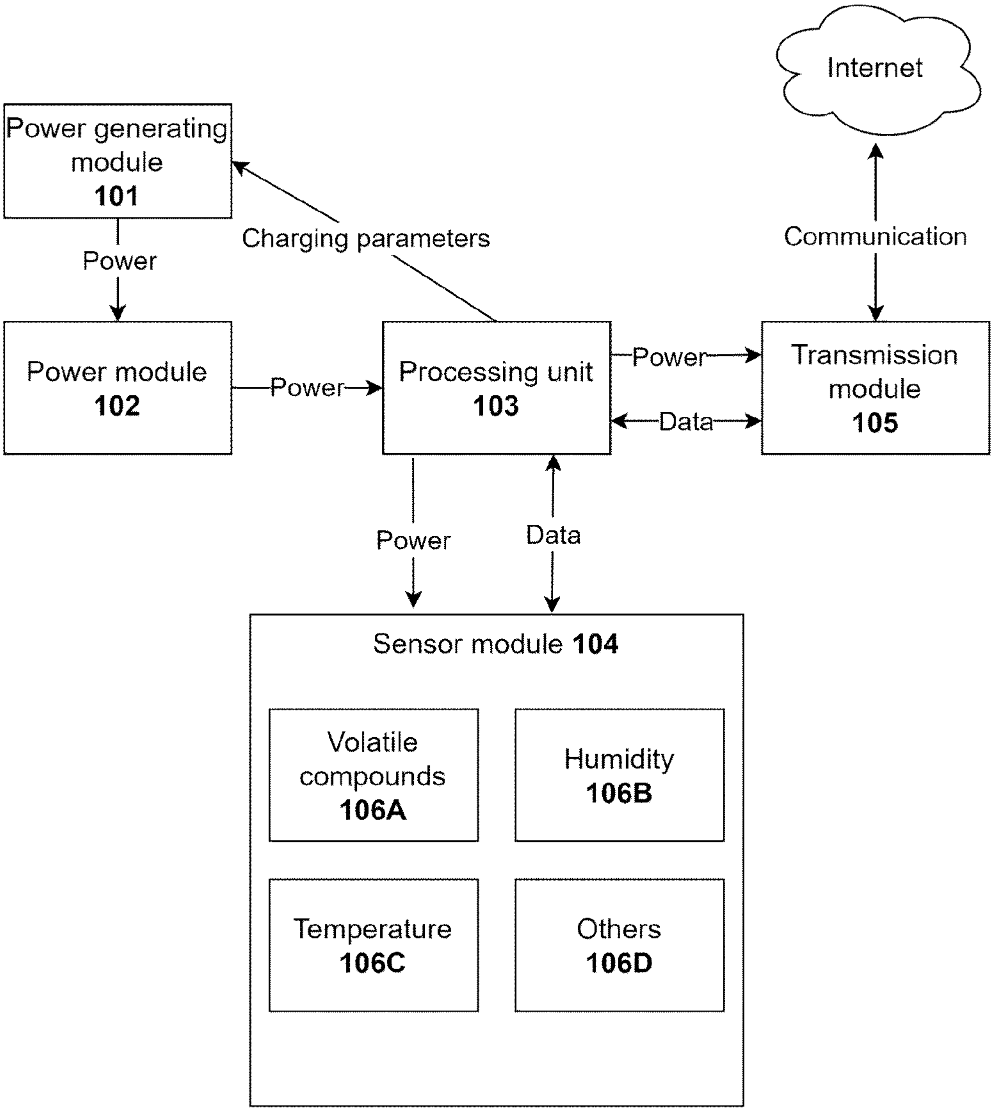
Internet
Power generating module 101
Charging parameters
Communication
Power
Power module 102
Power
Processing unit 103
Power
Data
Transmission module 105
Power
Data
Sensor module 104
Volatile compounds 106A
Humidity 106B
Temperature 106C
Others 106D

Fig. 2A

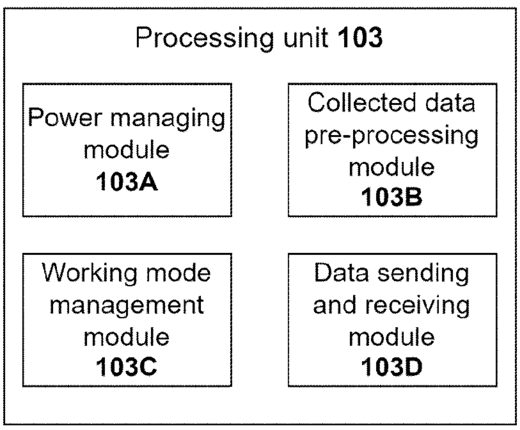
Processing unit 103
Power managing module 103A
Collected data pre-processing module 103B
Working mode management module 103C
Data sending and receiving module 103D

Fig. 2B

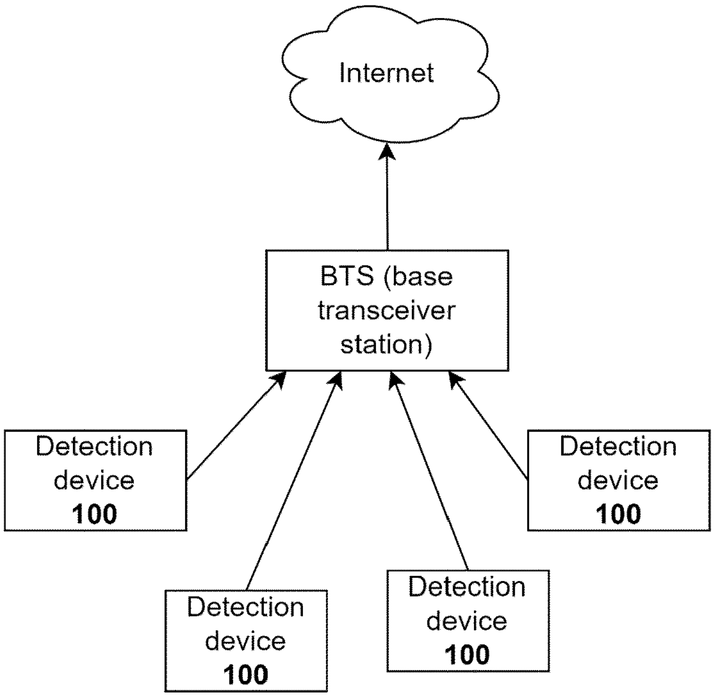
Internet
BTS (base transceiver station)
Detection device 100
Detection device 100
Detection device 100
Detection device 100

Fig. 3

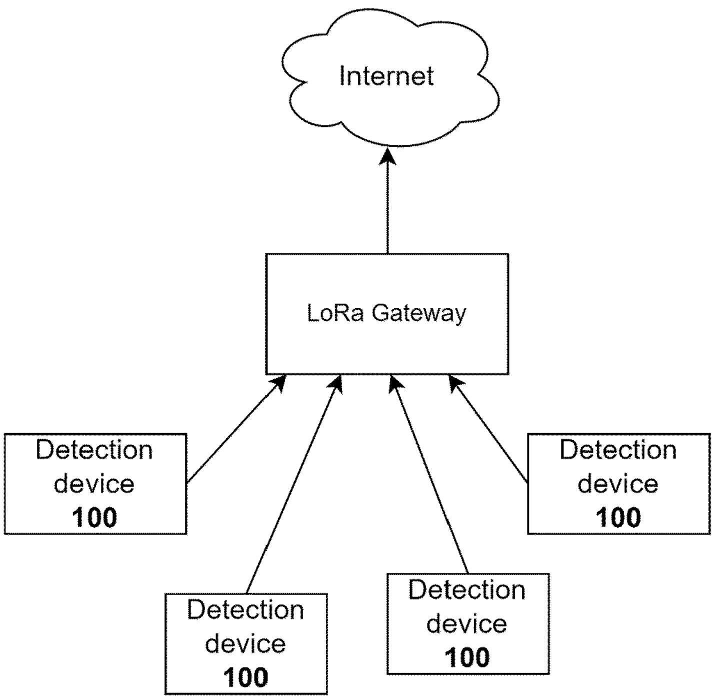
Internet
LoRa Gateway
Detection device 100
Detection device 100
Detection device 100
Detection device 100

Fig. 4

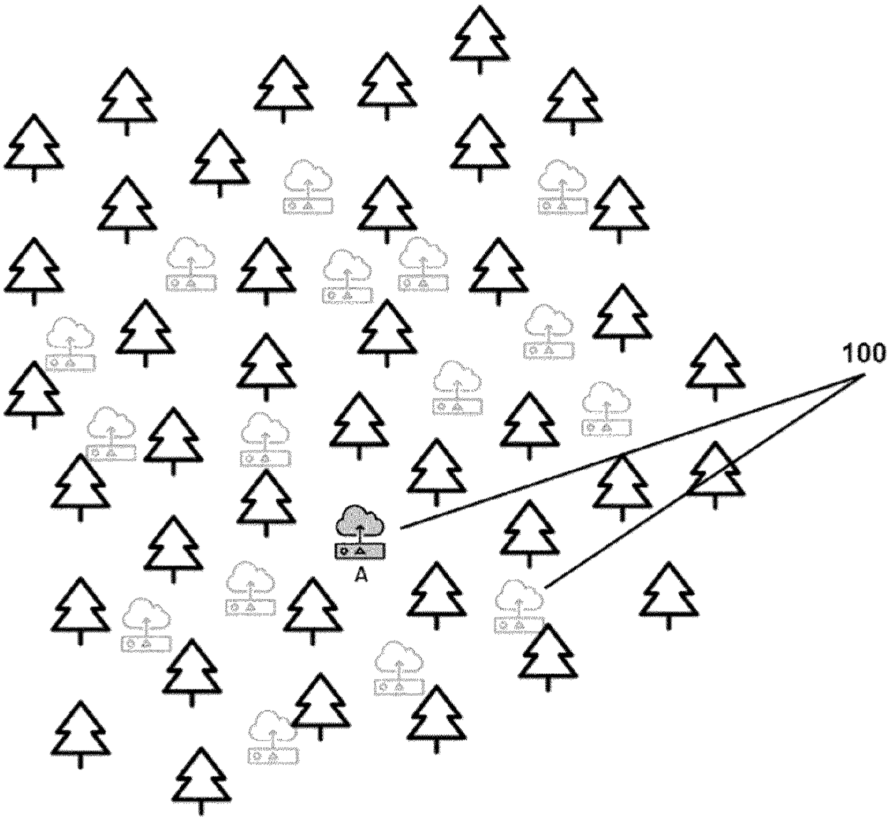

Fig. 5A

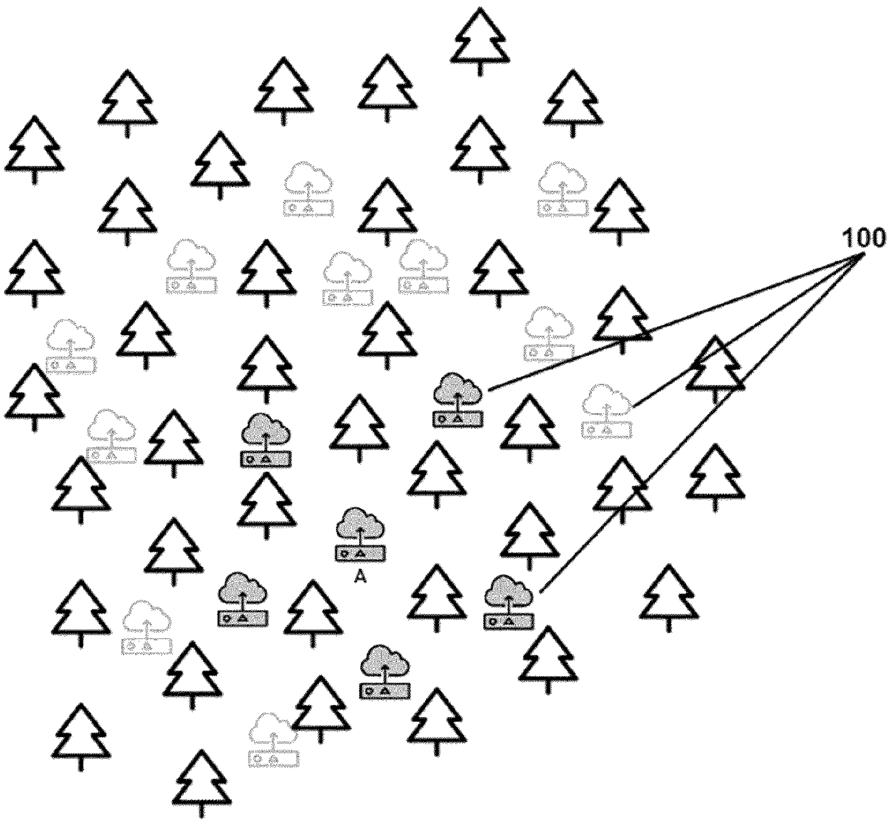

Fig. 5B

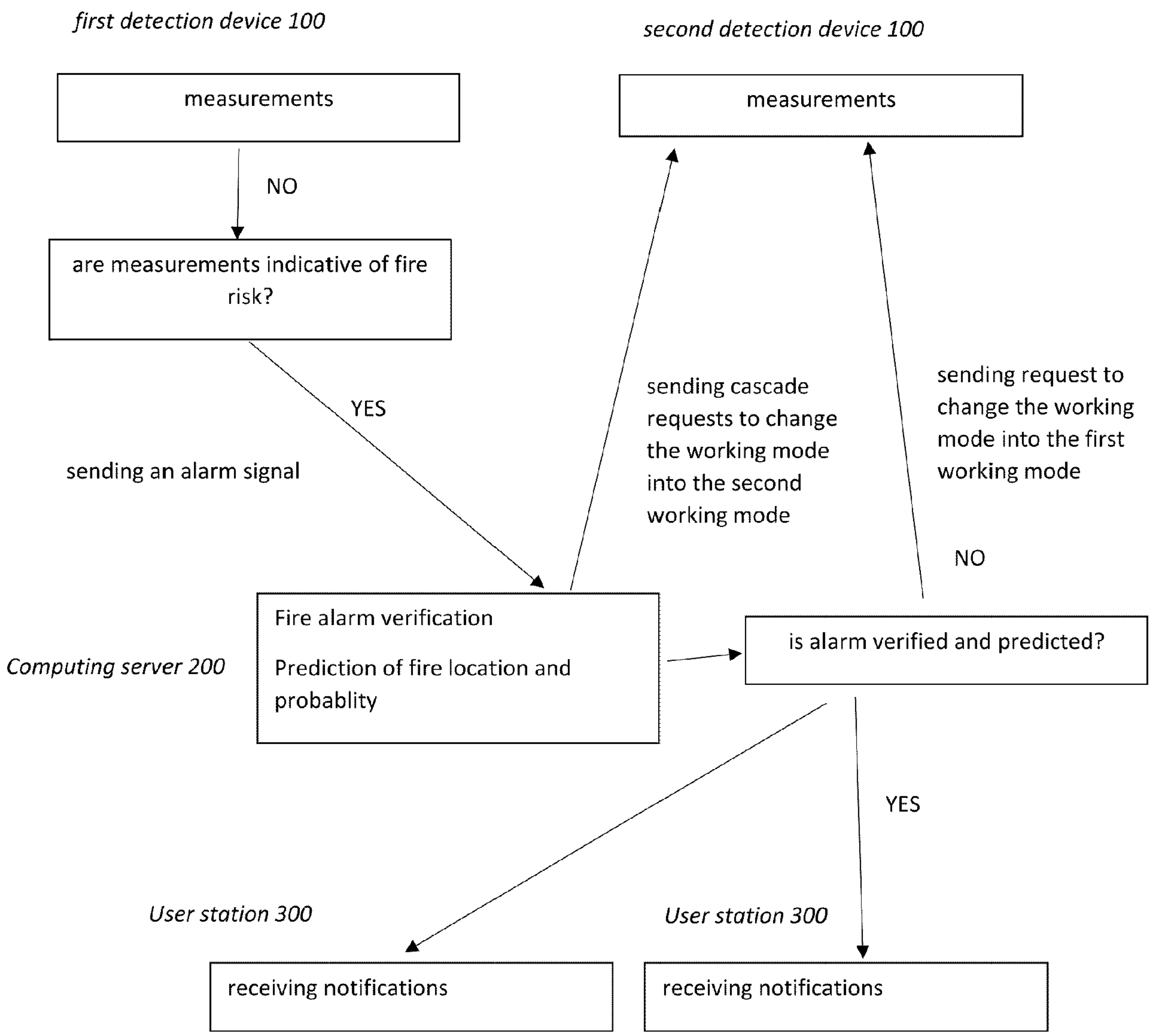
first detection device 100
second detection device 100
measurements
measurements
NO
are measurements indicative of fire risk?
YES
sending an alarm signal
sending cascade requests to change the working mode into the second working mode
sending request to change the working mode into the first working mode
NO
Computing server 200
Fire alarm verification
Prediction of fire location and probablity
is alarm verified and predicted?
YES
User station 300
User station 300
receiving notifications
receiving notifications

Fig. 6

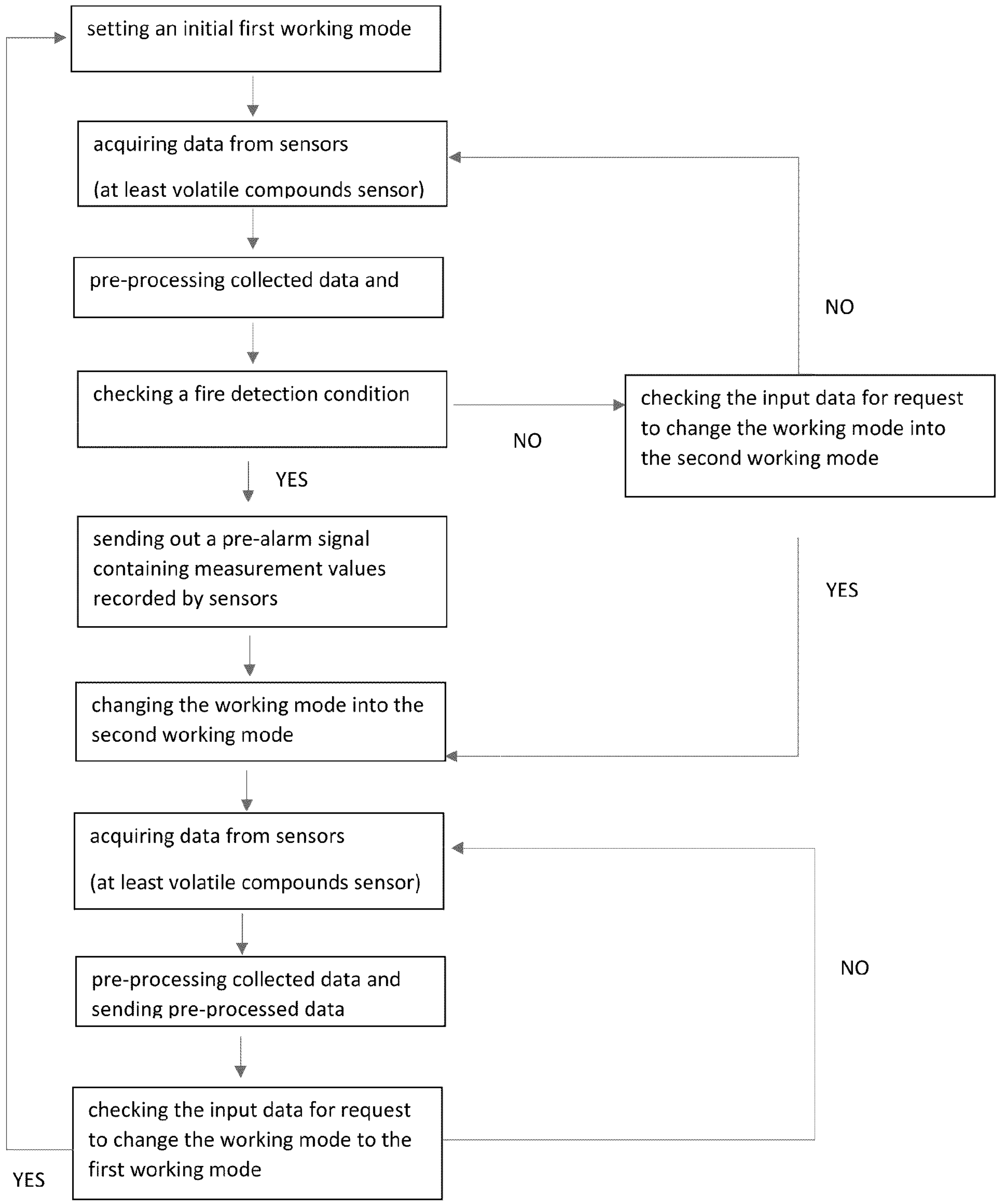
setting an initial first working mode
acquiring data from sensors
(at least volatile compounds sensor)
pre-processing collected data and
checking a fire detection condition
NO
checking the input data for request to change the working mode into the second working mode
NO
YES
sending out a pre-alarm signal containing measurement values recorded by sensors
YES
changing the working mode into the second working mode
acquiring data from sensors
(at least volatile compounds sensor)
pre-processing collected data and sending pre-processed data
NO
checking the input data for request to change the working mode to the first working mode
YES

Fig. 7A

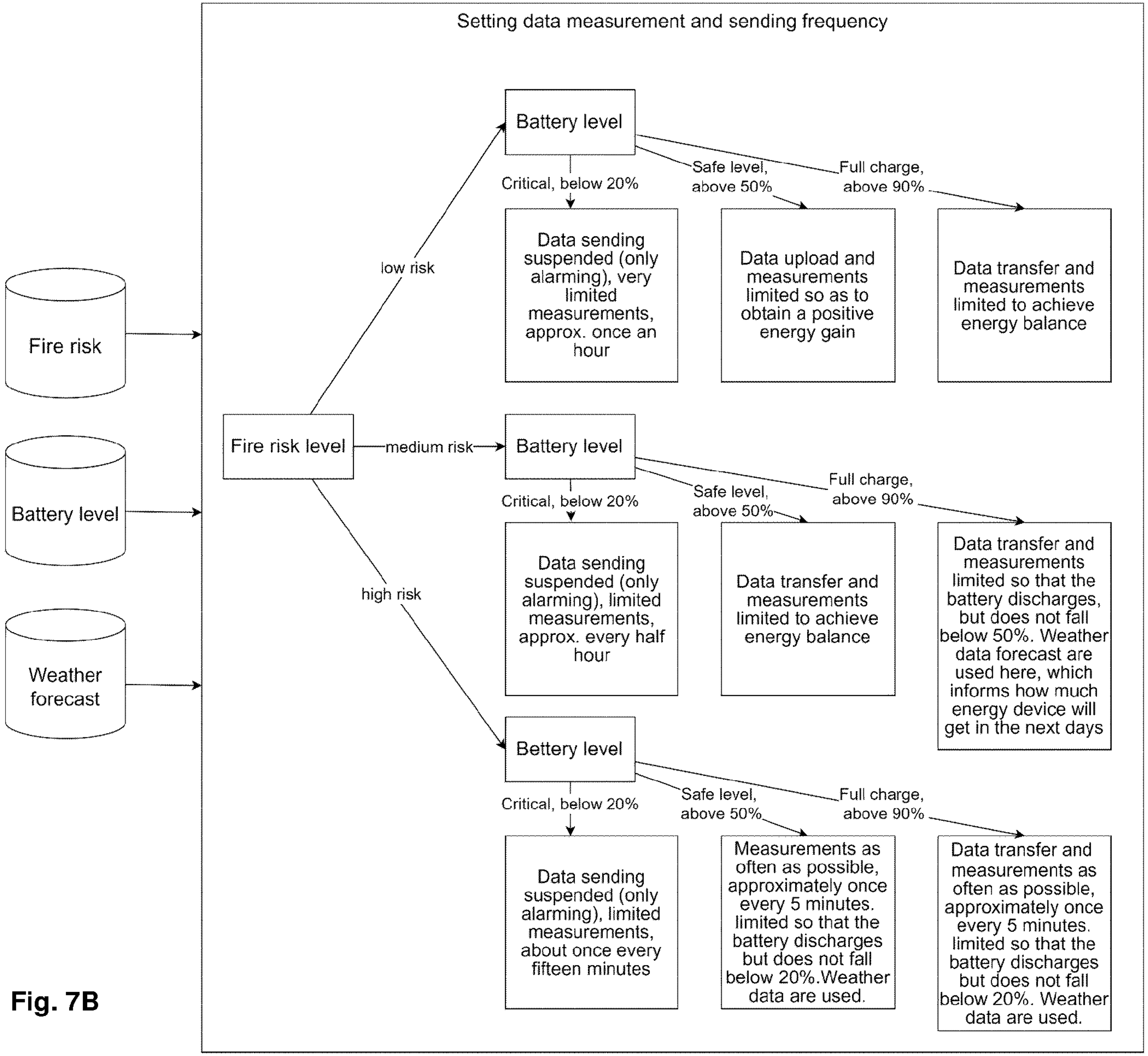
Fire risk
Battery level
Weather forecast
Setting data measurement and sending frequency
Fire risk level
low risk
medium risk
high risk
Battery level
Critical, below 20%
Safe level, above 50%
Full charge, above 90%
Data sending suspended (only alarming), very limited measurements, approx. once an hour
Data upload and measurements limited so as to obtain a positive energy gain
Data transfer and measurements limited to achieve energy balance
Battery level
Critical, below 20%
Safe level, above 50%
Full charge, above 90%
Data sending suspended (only alarming), limited measurements, approx. every half hour
Data transfer and measurements limited to achieve energy balance
Data transfer and measurements limited so that the battery discharges, but does not fall below 50%. Weather data forecast are used here, which informs how much energy device will get in the next days
Bettery level
Critical, below 20%
Safe level, above 50%
Full charge, above 90%
Data sending suspended (only alarming), limited measurements, about once every fifteen minutes
Measurements as often as possible, approximately once every 5 minutes. limited so that the battery discharges but does not fall below 20%.Weather data are used.
Data transfer and measurements as often as possible, approximately once every 5 minutes. limited so that the battery discharges but does not fall below 20%. Weather data are used.

Fig. 7B

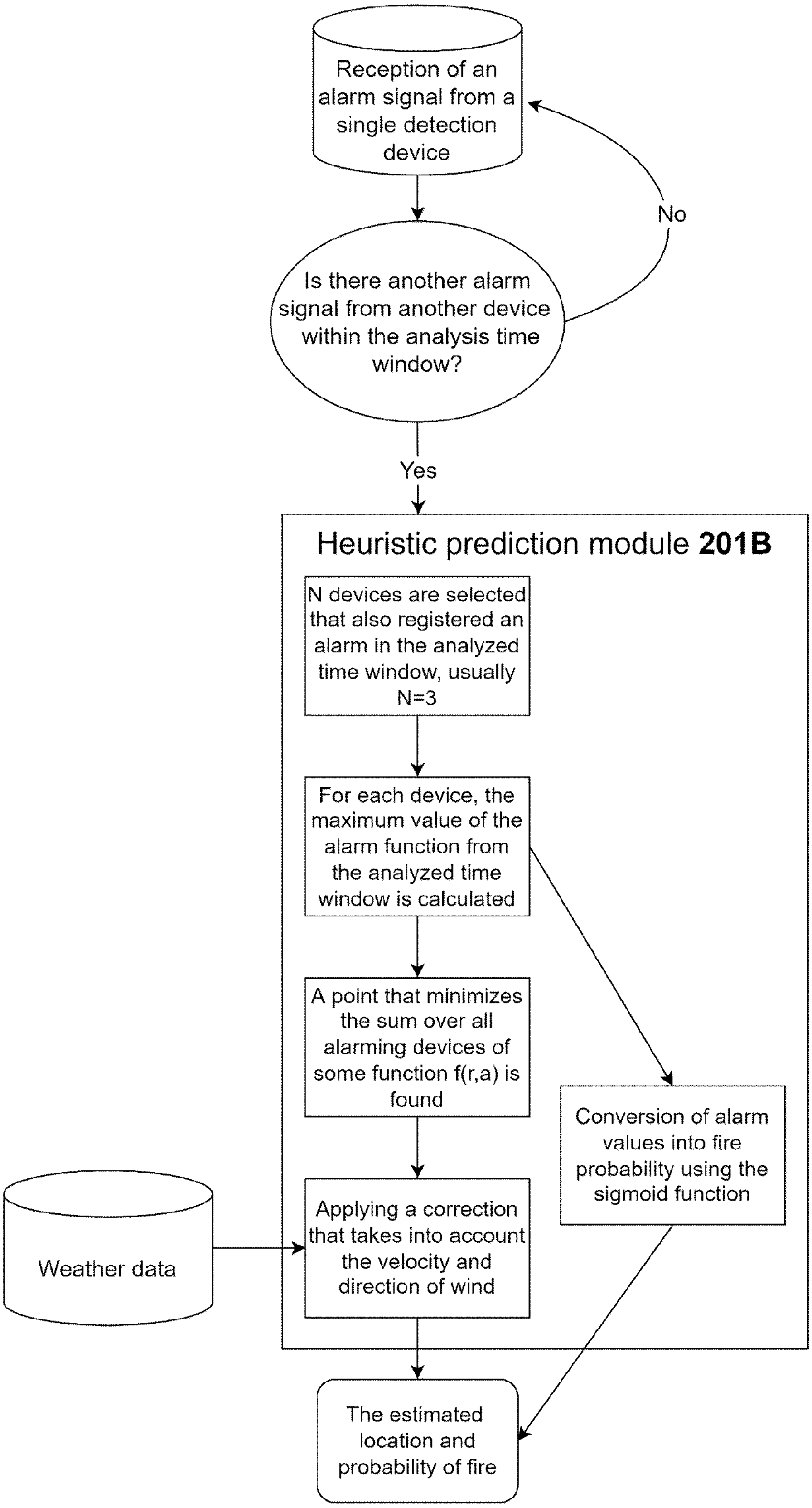
Reception of an alarm signal from a single detection device
No
Is there another alarm signal from another device within the analysis time window?
Yes
Heuristic prediction module **201B**
N devices are selected that also registered an alarm in the analyzed time window, usually N=3
For each device, the maximum value of the alarm function from the analyzed time window is calculated
A point that minimizes the sum over all alarming devices of some function f(r,a) is found
Conversion of alarm values into fire probability using the sigmoid function
Weather data
Applying a correction that takes into account the velocity and direction of wind
The estimated location and probability of fire

Fig. 8

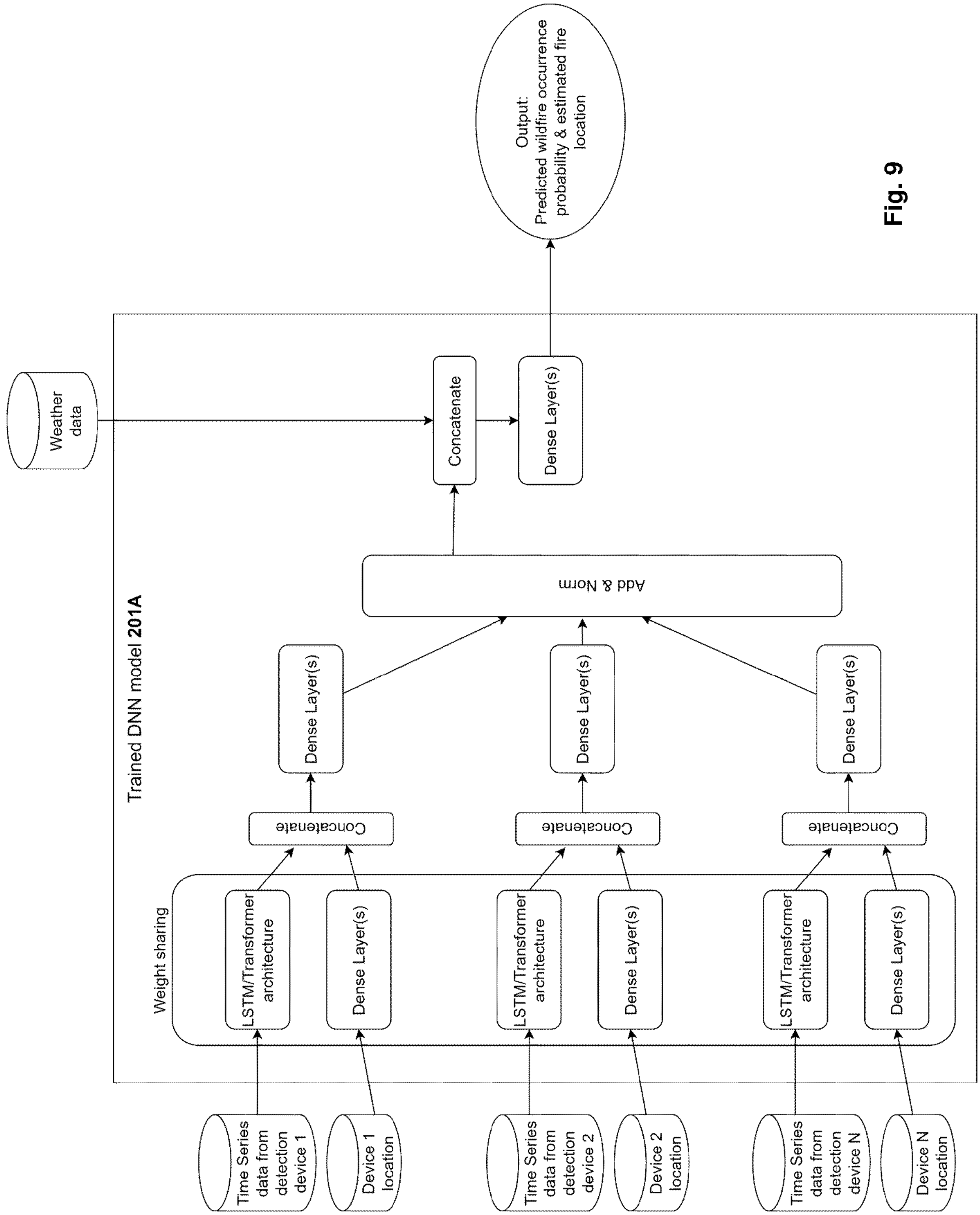
Trained DNN model 201A
Weight sharing
Time Series data from detection device 1
Device 1 location
Time Series data from detection device 2
Device 2 location
Time Series data from detection device N
Device N location
LSTM/Transformer architecture
Dense Layer(s)
Concatenate
Add & Norm
Weather data
Output: Predicted wildfire occurrence probability & estimated fire location

Fig. 9

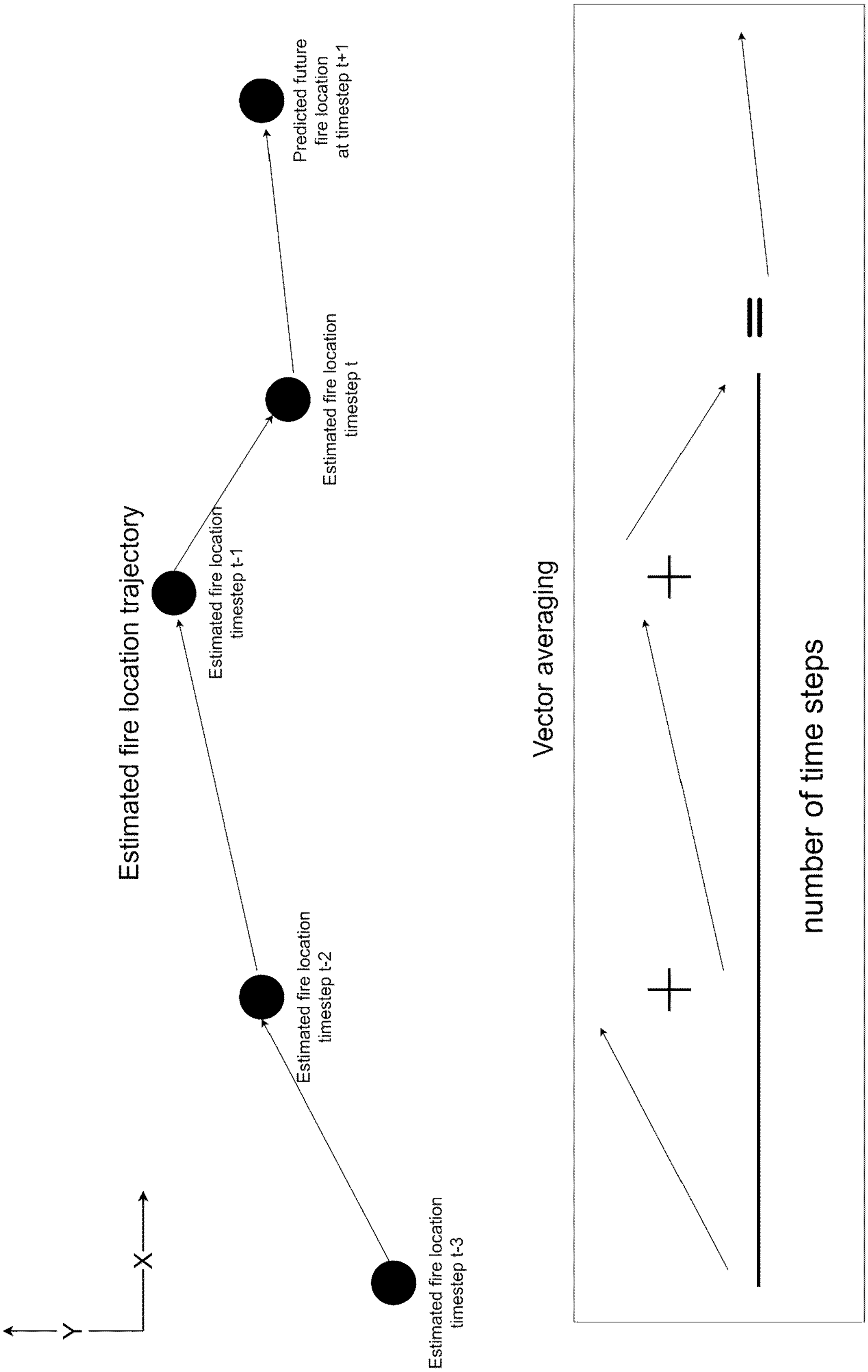
Estimated fire location trajectory
X
Y
Estimated fire location timestep t-3
Estimated fire location timestep t-2
Estimated fire location timestep t-1
Estimated fire location timestep t
Predicted future fire location at timestep t+1
Vector averaging
+
+
=
number of time steps

Fig. 10

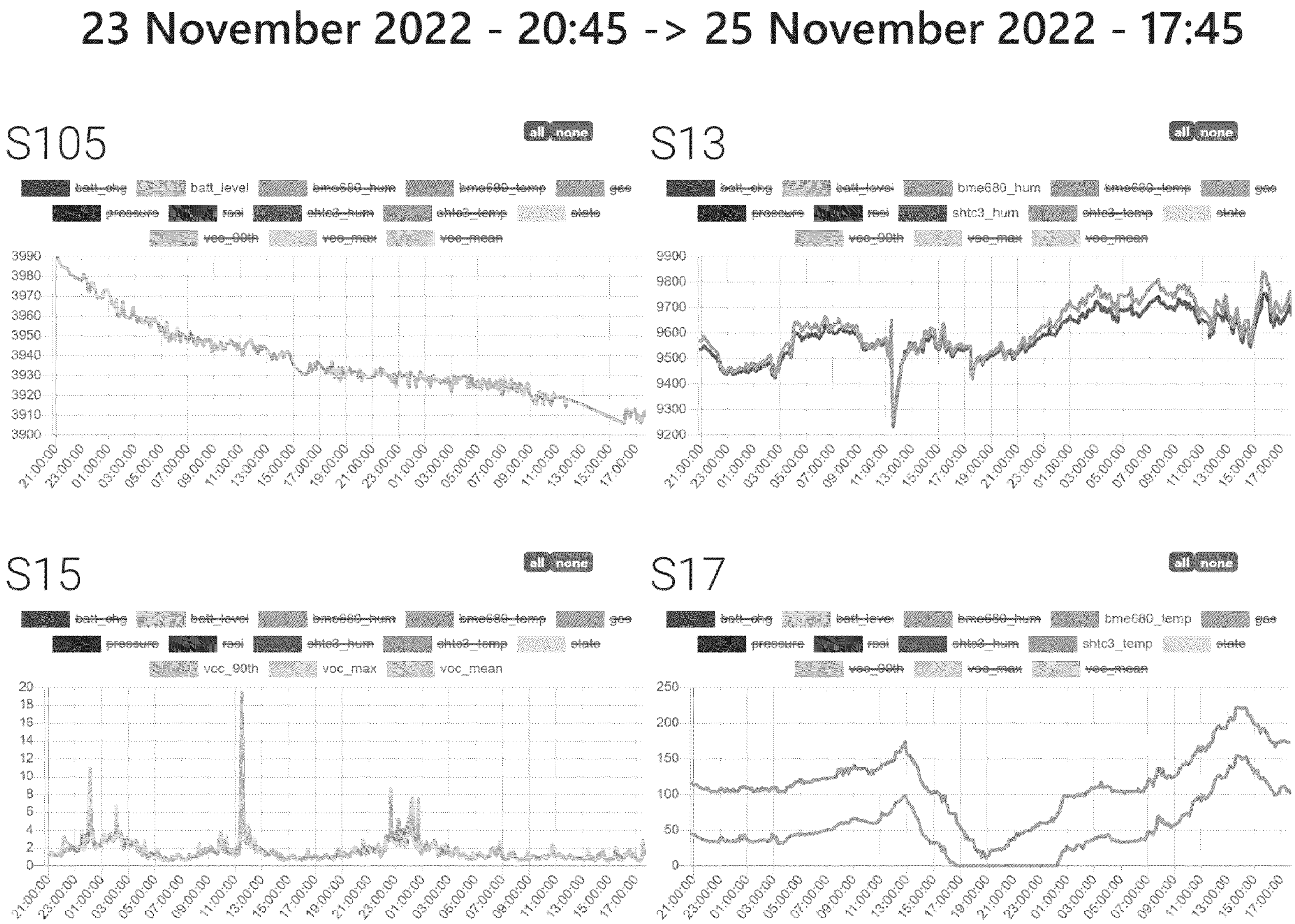
23 November 2022 - 20:45 -> 25 November 2022 - 17:45
S105
all none
batt_chg
batt_level
bme680_hum
bme680_temp
gas
pressure
rssi
shtc3_hum
shtc3_temp
state
voc_90th
voc_max
voc_mean
3990 3980 3970 3960 3950 3940 3930 3920 3910 3900
21:00:00 23:00:00 01:00:00 03:00:00 05:00:00 07:00:00 09:00:00 11:00:00 13:00:00 15:00:00 17:00:00 19:00:00 21:00:00 23:00:00 01:00:00 03:00:00 05:00:00 07:00:00 09:00:00 11:00:00 13:00:00 15:00:00 17:00:00
S13
all none
batt_chg
batt_level
bme680_hum
bme680_temp
gas
pressure
rssi
shtc3_hum
shtc3_temp
state
voc_90th
voc_max
voc_mean
9900 9800 9700 9600 9500 9400 9300 9200
21:00:00 23:00:00 01:00:00 03:00:00 05:00:00 07:00:00 09:00:00 11:00:00 13:00:00 15:00:00 17:00:00 19:00:00 21:00:00 23:00:00 01:00:00 03:00:00 05:00:00 07:00:00 09:00:00 11:00:00 13:00:00 15:00:00 17:00:00
S15
all none
batt_chg
batt_level
bme680_hum
bme680_temp
gas
pressure
rssi
shtc3_hum
shtc3_temp
state
voc_90th
voc_max
voc_mean
20 18 16 14 12 10 8 6 4 2 0
21:00:00 23:00:00 01:00:00 03:00:00 05:00:00 07:00:00 09:00:00 11:00:00 13:00:00 15:00:00 17:00:00 19:00:00 21:00:00 23:00:00 01:00:00 03:00:00 05:00:00 07:00:00 09:00:00 11:00:00 13:00:00 15:00:00 17:00:00
S17
all none
batt_chg
batt_level
bme680_hum
bme680_temp
gas
pressure
rssi
shtc3_hum
shtc3_temp
state
voc_90th
voc_max
voc_mean
250 200 150 100 50 0
21:00:00 23:00:00 01:00:00 03:00:00 05:00:00 07:00:00 09:00:00 11:00:00 13:00:00 15:00:00 17:00:00 19:00:00 21:00:00 23:00:00 01:00:00 03:00:00 05:00:00 07:00:00 09:00:00 11:00:00 13:00:00 15:00:00 17:00:00

Fig. 11

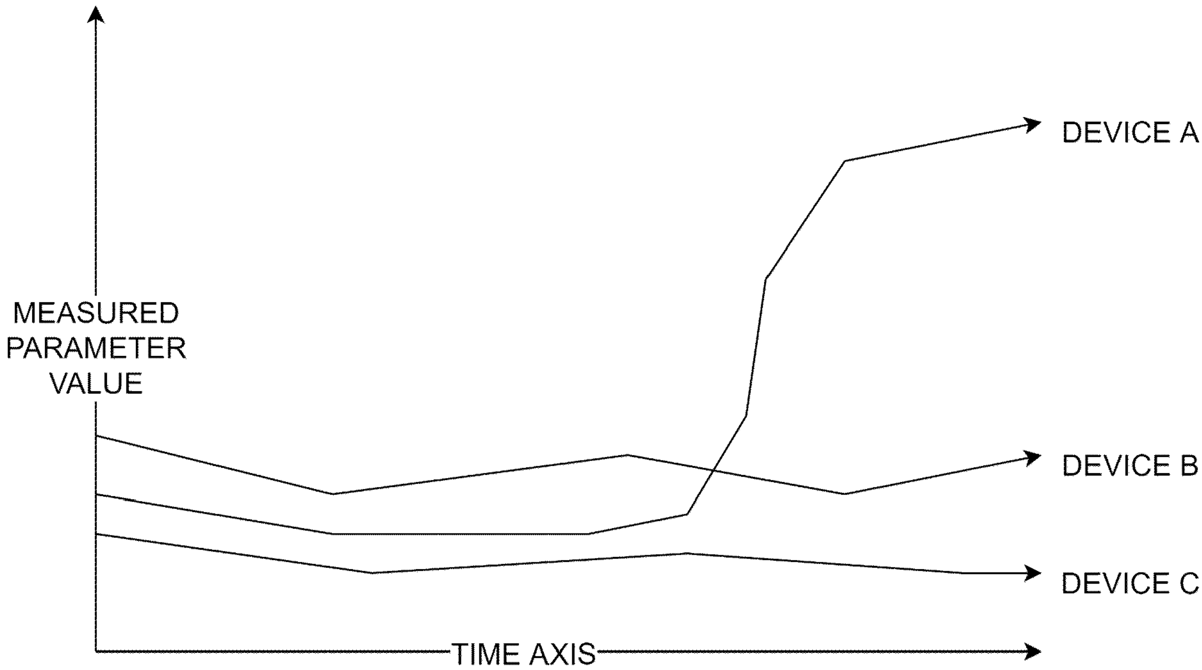
DEVICE A
MEASURED
PARAMETER
VALUE
DEVICE B
DEVICE C
TIME AXIS

Fig. 12

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 22 46 1659

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2021/350691 A1 (SHAH ABHI UMESHKUMAR [US] ET AL) 11 November 2021 (2021-11-11) * paragraph [0019] - paragraph [0020] * * paragraph [0027] * * paragraph [0031] - paragraph [0041] * * paragraph [0046] - paragraph [0047] * * paragraph [0051] * * paragraph [0062] - paragraph [0063] * * paragraph [0065] - paragraph [0066] * * figures * -----	1,3,5-8, 10,13-15	INV. G08B17/00
X	US 2017/169683 A1 (RYDER NOAH LAEL [US]) 15 June 2017 (2017-06-15) * paragraph [0014] - paragraph [0020] * * paragraph [0027] - paragraph [0028] * * paragraph [0051] * * paragraph [0059] * * paragraph [0067] - paragraph [0071] * * figures * -----	1,3,5-8, 10,12-15	
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