Management of Forest Fires Using IoT Devices

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***Abstract*—Effectiveness and response time in emergency situations management are key factors that directly influence the number of victims. The analysis of environmental conditions in real time (such as weather events and polluting gases) could provide relevant data on the environment that could help prevent or detect an emergency situation. Nowadays, IoT (Internet of Things) devices and sensors allow the monitoring of different environmental variables, such as temperature, humidity, pressure and concentrations of pollutant gases, such as carbon monoxide and carbon dioxide. Radical changes and combinations of these variables could indicate the occurrence of adverse weather events that could cause a natural disaster, such as a forest fire. Thus, the developed system integrates IoT devices and sensors that can perform a real time control of different atmospheric variables and polluting gases, in order to activate alerts when pollution levels increase excessively or when detecting certain conditions that are considered to be possible factors for causing adverse climatic events. These events can favour the occurrence of fires and other emergency situations. Particular attention has been paid to the communication security among IoT devices, Web service and mobile devices. Moreover, a secure data transmission protocol, a block cipher algorithm and a secure authentication scheme have been implemented.**

Keywords–IoT; sensors; emergency situations management; weather events; forest fires; atmospheric pollutions.

I. INTRODUCTION

Nowadays, emergency situations involve huge losses, both material and personal. Adverse natural events and atmospheric pollution caused by human activities become disasters when they exceed a limit of normality and cause damages to the ecosystems and various diseases for the population. The effects of these events can be amplified due to poor planning of resources, such as lack of security or control steps, emergency plans and alert systems that can increase the options for predicting their occurrence or controlling their progress once they have occurred.

The existence and combination of certain atmospheric conditions in addition to unusual and excessive presence of pollutant gases (carbon monoxide and carbon dioxide) can anticipate the occurrence of an increasingly frequent natural disaster: forest fires. Generally, these kinds of events usually result in serious emergency situations that cause the need of mobilization of different emergency management agencies and services.

The land topography, different types of vegetation in the area and weather conditions are the main factors that affect forest fires generation and progress. The control and monitoring of atmospheric variables (temperature, relative humidity and atmospheric pressure) in addition to the concentration levels of certain pollutant gases (such as CO2 and CO) can favour the detection of fire generation and the monitoring of their progress.In this sense, some factors (excessive temperature increase, relative humidity decrease or dioxide and monoxide levels increase) could be important indicators to detect fire emergence or its proximity. It is important to name ”the rule of 30” [1], which is based on three relevant factors associated with the forest fires detection: temperature values above 30°C, humidity values below 30% and wind speed values above 30 Km/h in the same area. The use of this rule as forest fires prevention standard can contribute to determine which areas have a high probability of fires occurrence, in order to enable the deployment of preventive mechanisms and action protocols that could favour the environmental conservation.

Thus, an information system has been developed that integrates IoT devices and sensors which are able to register atmospheric variables, such as temperature, humidity and pressure in addition to pollutant gases, such as CO2 and CO (which are very important in the air quality measurement). These gases can affect people's health and are emitted during forest fires excessively as result of combustion of huge amounts of biomass. Furthermore, this system is responsible of realising a real time management of alerts that could be activated according to the latest events as well as realising the coordination of operations required between emergency teams situated in affected area and the emergency services platform.

In Section 2, we present the state of art and the preliminaries about the general topic that is addressed. Then, the proposed system is explained in Section 3. The developed system is explained in detail in Section 4 and the system security is detailed in Section 5. Finally, Section 6 contains some brief conclusions and future research lines.

II. PRELIMINARES

In the field of IoT applications for the control of forest fires, several kinds of systems can be used for the warning, prevention and monitoring of these natural disasters. For example, this is the case of the application Forest Fire Danger Meter [2] available for Android. It stands out mainly because it is a calculator to find the fire hazard according to the classification of McArthur Forest Fire Danger Index [3], taking as reference the following parameters: temperature, relative humidity, wind speed, dryness factor, vegetation and pending.

In the same field, Incendios CyL [4] beta application is under development. Although it currently only provides data for the province of Soria, this application has as its fundamental objective to realize a meteorological forecast which indicates in which recreational areas tourists are allowed to make a fire, prohibitions and recommendations of how to act in nature, etc.

Another important element in the area of emergency situations and forest fires management is how Geographic Information Systems (GIS) [5] have become very relevant in the forest fires prevention and control. GIS allows real time access to data in the area, creating strategies to evacuate affected people, performing simulations, establishing health care points and redefining transport routes depending on the affected areas among other aspects. In fact, this system has been used recently by organizations such as the Civil Guard during the work of extinguishing the last fire in La Palma Island in 2016 and in other cases, such as a Portugal forest fire in 2017 [6].

Similarly, Senticnel [7] fire detection system (NTForest company) uses sensors and IoT technology to collect information on humidity, temperature and other environmental factors that could allow to predict the evolution of this type of natural disasters and encourage their extinction.

Due to the importance of natural disasters and emergency situations management, multiple projects and IoT applications exist. The system Find&Rescue [8] offers a global online vision of emergency teams through a specific device carried by each emergency team member. Several IoT applications are based on the deployment from helicopters [9] of different kinds of sensors, which could register environmental data: temperature, gases, etc. In the MERIS project, a real time application allows accessing the information of the status of recoverable victims through devices and sensors that control vital signs [10]. The management of emergency tactics is done using sensor technologies, such as liDAR and the Esphera platform: helicopter tracking through a 3D environment, integration of video from different resources and others aspects [11]. iSafety is a comprehensive emergency management system, which allows the integration of smart sensors and other applications to realize a real time emergency situation control [12].

Taking into account the previous applications, the proposed system in this paper offers new improvements, such as the use of innovative IoT technologies and a data treatment focused on the prevention, detection, activation of alarms and management of operations for the extinction of fires. A system with secure communications has been configured that allows the monitoring of different variables of the environment and the processing and visualization of the information registered in real time guaranteeing the access for all users through diverse platforms.

III. PROPOSED SYSTEM

The developed system is based on a sensor network and distributed wireless IoT devices able to obtain data from the environment and process it in real time. The main goal is to provide information to the systems responsible for the management and strategic planning in emergency situations generated mainly due to forest fires. In this sense, the system consists of gathering data of magnitudes and atmospheric variables that determine the meteorological conditions and the presence of polluting gases in each zone to transform it into useful information that could be visualized through interactive elements (maps, graphs, statistics and gauges) (Figure 1).

Atmospheric variables and pollutant gases control and monitoring can favour forest fires prevention in different ways. Firstly, it helps to prevent and determine possible risk areas for forest fires. Taking into account values collected by IoT devices and ”the rule of 30”, temperature measurements that exceed 30°C and humidity values below 30% in a same zone could implicate a preventive management process through alerts activation. The main reason is the existence of meteorological conditions that are favorable to forest fires generation. In addition to these factors, the pressure value is relevant in the field of early detection of periods of storms or anticyclones that can improve or aggravate the weather conditions in case of fire. Secondly, the control and monitoring of atmospheric variables and pollutant gases can also favour the early forest fires detection (when values and measurements provided by the IoT devices imply unusual meteorological conditions in the area, such as an abrupt rise of temperature values, decrease of humidity in the area or periods of anticyclone). In addition, an excessive increase of the CO2 and CO concentrations could indicate an evidence of biomass combustion. Thirdly, the control and monitoring of atmospheric variables and pollutant gases can also favour the control of the forest fires progress. The monitoring of the commented variables in the surroundings of the burned zone allows to control the fire progress through detection of progressive increases of temperature, humidity, and CO2 or CO concentrations. In this way, it is possible to realize a real time management of the area occupied by forest fire.

The developed information system is composed of three important parts: IoT devices, Web services and mobile application.

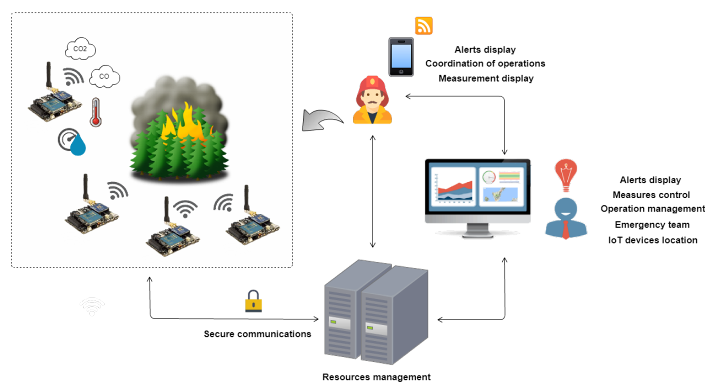

Figure 1. Operation of the system

A. IoT devices

Every IoT device distributed in the environment communicates wirelessly through 4G with the Web service, which is the responsible for storing and processing all data. So, these devices have integrated 3 different sensors that are able to interact with the environment and collect multiple variables: temperature, humidity, atmospheric pressure and pollutant gases, such as carbon monoxide and carbon dioxide (indicators of air quality). In addition, they are based on Arduino and are composed of a motherboard that is assembled with a 4G module to send the collected data. Other hardware elements are also necessary to integrate the multiple sensors that allow to register the atmospheric variables. The use of a 4G module allows registering the location of each distributed device guaranteeing their visualization and representation through interactive maps.

Once the IoT device is in the environment, the atmospheric variables and the pollutant gases of the area where it is located are captured. Besides, it is necessary to add some other device parameters: battery level, latitude and longitude (to manage their locations from the Web service) and International Mobile station Equipment Identity (IMEI) parameter that allows them to be uniquely identified in the system (Figure 2).

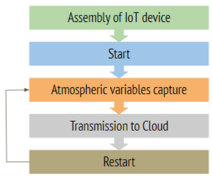

Figure 2. IoT devices functions

Temperature, humidity and pressure measurements have been registered by a same digital sensor. Regarding the temperature, the operational range is situated between -40°C and +85°C. In the case of humidity, the measurement range of relative humidity is 0 - 100%, taking into account the temperature values. Regarding atmospheric pressure, measures are situated between 30 - 110 kPa, based on the sensor sensing capacity. Furthermore, $CO2$ and CO data have been collected using 2 other different sensors. In the case of carbon monoxide gas, the measurement range limits the registration of data between 30 - 1000 particles per million (ppm) every second. Finally, the CO2 sensor can register values from 350 ppm to 10000 ppm.

Overall, measurement values change depending on each monitored zone and other factors, such as altitude, typical climate or the presence of human activities (car pollution, industries, etc.). For example, taking into account CO2 and CO gases, some tests developed have evidenced that measurements are decreaser at outdoor areas than at indoor areas or cities. While in forests the sensors register values around 8 ppm (CO) and 350 ppm (CO2), these results are usually higher in cities or indoor areas (CO2 and CO concentrations above 400 ppm and 10 ppm, respectively). The increase of the concentrations of these gases is much more evident from the burning of biomass in forest fires.

B. Web service

Once all the required data is available, the information is sent to the Web service that manages the resources. In this sense, it is responsible for database management of the entire information system: new measurements, users and active IoT devices. In addition, the Web service stores measures and manages their visualization through graphs and other interactive elements (graphs, indicators, gauges, etc.) that allow the interpretation of meteorological conditions and contamination levels of each registered area by users.

Other functionalities of the Web service could be to synchronize all system information among all users in real time by connecting IoT devices, mobile devices and the Web application. However, the data synchronization process needs information that system obtains by a continuous monitoring of new measurements. This aspect allows to activate alerts depending on whether registered values represent a potential hazard for forest fire generation or other emergency situations. In this case, notifications will be sent to the active users through the mobile application. In addition to these notifications, new information about activated alerts and the state of variables (temperature, humidity, etc.) will be updated in the Web application.

The Web service has been configured to allow bidirectional real time communication based on events through any platform or browser. Websockets [13] are used in order to satisfy this requirement. So, the server will send data to the connected users without the need of making client requests. When new data is processed (new measurements, activation of alerts, new IoT devices, etc.), the server transmits it to all listening sockets, so the information accessed by users is updated automatically. This advantage offered by this technology avoids the need to manually update the application to see new changes. Continuous availability of updated information is an essential requirement for prevention, detection and extinction of forest fires or other emergency situations.

The system configuration is exposed to users through automatic updating of graphs and gauges, interactive maps or updating information that is associated with the state of each monitored environmental variable.

Every security failure or unusual system event is stored in database for future security audits. This data is sent in real time thanks to the use of sockets to the system administrator who can display this information through a special management interface. In addition to having access to registered failures, the administrator can also add new IoT devices, changes their configuration parameters and changes variable atmospheric limits depending on the weather conditions of each zone. Only the role of the administrator has the specific privileges to perform these operations and to see this type of information.

C. Mobile application

Finally, an Android mobile application has been developed with the objective of representing locations of IoT devices, measures and averages for each variable monitored through graphs that users could interpret easily. Moreover, this application is responsible for synchronizing notifications and activated alerts that have been sent from the server (when a measure registered recently represented a potential hazard for the generation of an emergency situation). In the application, the authenticated users can interact with a map that represents locations of IoT devices through latitude and longitude parameters and markers. When one of them clicks on a marker, a new interface will be displayed showing all available information about the device selected: location, description, level of the battery in addition to all registered measures of each monitored variable in that day (Figure 3). Users can also access a bar chart that represents the real time averages of measurements for each atmospheric variable or pollutant gases.

However, another important element is the alert control panel. This section is used for representing all notifications and alerts activated from the server when a measurement involves a danger for forest fires generation. Each notification received informs the users about the exact zone associated with the danger, the variable and a description to identify which alert level has been increased. This functionality has been configured through the cloud messaging Firebase services and an identification token that the server needs to identify each mobile device when it's necessary to notify and synchronize a new alert. Only notifications or alerts that are associated

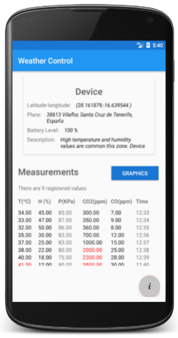

Figure 3. Mobile application view

with the mobile device location can be received. In addition, notifications are controlled by a time period. In this sense, a same alert that repeats constantly will not be sent from the server to the same mobile device until 10 minutes have passed since last notification was sent. This rule was set to avoid overloading the application.

Finally, this mobile application has been considered especially useful for emergency teams located in affected areas when forest fires or emergency situations are active. For that, it has also an operational panel integrated to show all actions and required operations for fire extinction.

D. Alerts management

One of the features of the developed information system is the introduction of an alarm management component that is activated every time when a new measurement arrives at the server. To this end, the system verifies if the value associated with each monitored variable (temperature, humidity, CO2, etc.) represents a potential danger that indicates the proximity of an adverse weather event that could favour the occurrence of a forest fire or another type of emergency situation.

For this reason, some reference limits and ranges have been defined for each atmospheric variable and pollutant gas. So, when a new measurement does not increase these limits, the value is considered as normal or stable, in addition to the fact that it does not indicate any danger or the need to activate any alerts. There are three main alert levels associated with these ranges or limits (Table I).

TABLE I. VARIABLE ALERTS MANAGEMENT

Variable	*Alert: level 3*	*Alert: level 2*	*Alert: level 1*
Temperature	>= 30°C	>= 37°C	>= 40°C
Humidity	<= 30 %	<= 20 %	<= 10 %
CO2	>= 350 ppm	>= 2000 ppm	>= 5000 ppm
CO	>= 10 ppm	>= 25 ppm	>= 50 ppm

In the case of temperatures, all values above 30°C have been considered as reference to activate a level 3 alert taking into account "the rule of 30" that considers zones characterized by temperatures above 30°C and humidity values below 30 % as risk areas for forest fires. Temperatures below this limit are situated in a normal range and are not considered a risk factor to activate any type of alert. An increase of the registered measurements above 37°C means that environmental conditions have aggravated, so a level 2 alert is established. Finally, temperatures above 40°C imply potentially dangerous meteorological values for the activation of forest fires. In these cases, a level 1 alert is activated.

Humidity values considered normal and beneficial to the health of people are between 40 % and 60 %. Taking into account "the rule of 30" again, measures below 30 % involves the activation of a level 3 alert. Most radical values below 20 % and 30 % imply the generation of a level 2 and level 1 alerts, respectively. Atmospheric conditions favour forest fires generation when relative humidity percent is lower especially if temperature alerts have been established in the same area at the same time. Values close to 0 % and 100 % are harmful to the health of people, because they can complicate physiological processes, such as sweating or elimination of fluids. For these reasons, activation of level 3, 2 and 1 alert has been considered in the same way when the server receives measures of 70 %, 80 % and 90 % relative humidity, respectively.

In the case of atmospheric pressure, control of its variations is so relevant for detecting of storms and anticyclones that could improve or aggravate forest fires generation conditions and their advance. Activation of alerts for this variable has been configured taking into account the occurrence of abrupt pressure changes [14]: excessive rises of 1 mb/h in a period of 6 hours (evidence of the proximity of strong winds) and excessive drops of 1 mb/h in a period of 6 hours too (evidence of the storm generation).

Other very important elements for early forest fire detection are the air pollutant gases, such as CO2 and CO. These chemicals are emitted during forest fire disasters and they can cause serious health issues for people. In this sense, excessive rises of their concentrations are relevant factors at the time of considering forest fire activation in a certain zone.

Carbon monoxide is fixed in the hemoglobin of blood and impedes the transport of oxygen. It can cause death in people when its value is too high. The limit value considered in a time of 8 hours is around 10 ppm [15], so it is the reference for activating a level 3 alert. Taking into account IoT devices are distributed in forest areas mainly (where air quality is better) and some studies of CO measures emitted in forest fires [16], level 2 alert is activated since 25 ppm values and level 1 alert for CO concentrations above 50 ppm.

Regarding CO2, the activation of level 3 alert has been considered at 350 ppm, taking into account multiple results that establish this value as the limit to be considered to prevent the worsening of the climate change [17]. From this value, other studies propose the establishment of 2000 ppm as reference for level 2 alert activation and CO2 measures over 5000 ppm for level 1 alert. With level 2, some health problems could be experimented (headaches, drowsiness, nausea, tachycardias, etc.). Besides, oxygen privation could occur for level 1 alert [18].

Each new measurement of each atmospheric variable or pollutant gas is analyzed taking into account thresholds associated with these alert levels. Depending on each monitored zone, these limits can change because of the weather conditions and environment. For these reasons, an interface of system management has been configured in the Web service to manage alert levels and their graphical representation.

In agreement with common European criteria [19], each level of alert is associated with a specific color. The color code is used to indicate visually the state and range of values in which each registered measurement is situated. This code in addition to the graphic interface components allow for a quick interpretation when a measurement value of an atmospheric variable or pollutant gas is normal or dangerous.

- Green color indicates all measurements that do not favour certain dangerous weather conditions for forest fires generation. So, alerts are not activated.
- Yellow color. There is no meteorological risk for the general population. However, measurements could mean that there is some danger for some specific activities or locations. It is associated with a level 3 alert.
- Orange color. It includes important and unusual meteorological risks. These weather conditions may be dangerous for common activities. It is associated with a level 2 alert.
- Red color. Extreme weather risks. All unusual and very intense meteorological events that usually involve dangerous situations for population. It is the riskiest alert, so this color refers to level 1 alert.

Since the server checks if an alert has been detected, the next step is to register it in the system and to transmit in real time the new data to all connected users through notifications (for the mobile app) or update special information panels (for the Web application). The creation of a new alert implies the declaration of some attributes, such as alert level (3, 2 or 1), IoT device, variable values that have activated the alert, a description, and the alert activation date.

E. Data visualization

In the Web service, the visualization of information and resources are mainly focused on four aspects: geolocation of IoT devices that are available, new registered measurements, atmospheric variables and pollution levels (through the devices on each zone), activated alarms in the server (when some of the processed values are out of the normal range for each monitored variable) and the management of emergency teams that are situated in the zone affected by the forest fire. Every new registered measurement by an IoT device can be represented in the Web service through different types of graphics and gauges. Furthermore, there are two different modules to represent them depending on the registration time.

To represent these values from the environment, some elements, such as charts and gauges, have been configured. Firstly, the Web service interface shows to users independent line graphs to represent (through dotted lines) variable values registered by devices for each atmospheric variable or pollutant gas. In addition, bar diagrams are used to make real time comparisons between different magnitude groups: a group for atmospheric variables (temperature, humidity and atmospheric pressure) and another group for pollution gases (CO2 and CO). Other important graphic element are gauges. They are used to represent only the latest value available from each variable monitored from the environment. Line graphs and gauges are organized together in a way to show all data associated with magnitude measurements. Finally, there is an alert control panel that indicates to users the real time state of each magnitude or variable registered in the monitored environment. Every time that new values are collected by the server from IoT devices, this panel updates and changes its information.

Each linear graph is formed by a dotted line that shows each measurement of the corresponding atmospheric variable, so users can interpret their variations visually. Updating these graphs occurs automatically each time a new value is registered in the system. Moreover, users can group measurements taking into account different time periods through a control button panel at the top left of the graph. In addition to these aspects, each graph has got colored bands as background to represent different ranges of values and limits that are defined depending on each atmospheric variable. Colours have been used taking into account the same color code that was explained in the previous section: green color (normal values), yellow color (level 3 alert), orange color (level 2 alert) and red color (level 1 alert). So, users have access to the exact value of the measurement (through the dotted line), the time that measure was registered and the range of values in which it was situated, in addition to which level alert was activated (Figure 4).

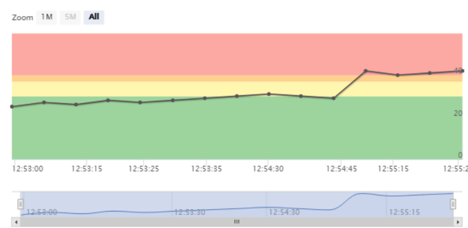

Figure 4. Temperature linear graphic

Other graph components have been developed, as follows:

- A special and interactive map that changes typical markers to colored circles depending on the average of all registered measurements on each zone, taking into account the same color codes and the defined limits or alert levels for each atmospheric variable.
- Another interactive map that manages the emergency teams location when a forest fire has been activated.
- A graph comparison module that allows to make comparisons and simultaneous reviews of the measurements registered by different IoT devices.

IV. SECURITY

System security has been divided in two different fields: IoT devices confidentiality and secure authentication.

Firstly, before sending each measurement registered through 4G by the sensors of distributed devices, data values (temperature, humidity, latitude, longitude, IMEI, etc.) are ciphered through the use of AES 128 key bits algorithm [20]. Moreover, Cipher Block Chaining (CBC) mode has been used so each block of plaintext is XORed with the previous ciphertext block before being cyphered. In this way, each ciphered block depends on all plaintext blocks processed up to that point. In addition to CBC mode, Zero padding has been used so the padding system is based on null characters. When data reaches the cloud server, it is deciphered using the same algorithm. Then, IoT device identification is verified by IMEI parameter and data measurements are processed and stored in the database if verification is correct.

Secondly, secure authentication has been developed through Open Web Application Security Project (OWASP) guidelines verification [21] in order to protect the system against different attacks.

In this sense, each specified standard guideline has been verified in order to guarantee a secure authentication process. In particular, the following aspects have been considered. It is a requirement that all authentication processes are to be performed exclusively on the server. Besides, authentication tokens have been used, avoiding the use of cookies to save user information. In this way, users are authenticated and each HTTP request is accompanied by a token in the header from that moment. This token is configured through a ciphered signature only available in the server. This technique allows adding more security to the authentication system and avoiding Cross-Site Request Forgery (CSFR) [22] attacks. Also HTTPS has been used for the transport of credentials. The encryption of authentication keys allows to use external services to the application as Google Maps API. Finally, we have included the registration of possible attacks to the system and the addition of metadata for future security audits.

V. Conclusion

The proposal presented in this paper describes a new information system that has been developed taking into account innovative technologies, IoT devices and the use of sensors with the aim of helping to improve the management of emergencies. Specifically, devices based on Arduino have been used. During the development of this solution, multiple challenges, such as the use of data transmission protocols (4G), interaction with hardware devices, integration of sensors and the transformation of registered data into useful information for the visualization of users have been solved. Furthermore, the integration of different technologies (mobile devices, Web service and IoT devices), the synchronization of all system data among different platforms (new alerts, measurements, etc.) and more considerations have been done.

Given the importance of confidentiality and authenticity, the system has been provided with security services. Specifically, OWASP guidelines and AES CBC encryption have been applied. This proposal is a work in progress, so several lines of work are still open. First, we will try to incorporate new sensors in the system that allow to control new environment variables, in order to improve prevention, detection and management of emergency situations. Secondly, we will try to increase interaction possibilities with emergency teams and workforce that are situated in the zone affected by forest fire, in order to gather more data as multimedia real time information. Finally, we will try to introduce and combine more layers and content types in the system for improving development of action protocols and forest fires extinction.

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