Architecture of GIS Solutions for Detection and Development of Wildfire Database

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Case study

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Abstract: This research paper presents organization of the business environment for work with geographic information systems (GIS) which are based on open source. The solution is completely open source: operating system, working environment and supporting apps. The architecture consists of: server, workstations, mobile devices and sensors. Software packages for each architecture segment will be displayed. The goal is to achieve a complete business environment for work with open source GIS, thus minimizing the costs of system development and maintenance. The illustrated example shows the possibility of applying GIS within a forestry company, in the field of wildfire monitoring and data collection and registering the possibility of wildfire occurrence using IoT.

Keywords: GIS, open source, IoT, wildfires, wildfire detection.

Introduction

Open source software is being increasingly used in business environments, primarily due to its cost as well as cost of licenses. As the software itself is not license limited, it can be therefore installed and used on an unlimited number of workstations. Open source software is available free of charge, unlike commercial software, which are sold under strictly defined licensing terms. Also, open source software is distributed with a license, and the most commonly used license is the General Public License (GPL). The GPL license defines that we can use the program for any purpose [1]. Nowadays, open source software does not lag behind commercial software. In some cases, it is even more developed than commercial software, and has wider field of application. The advantages of commercial software are reflected in its user friendliness and its adaptation to the needs of end users. Due to this reason, we come to the question of whether it is smarter to invest in software or into education of users.

This work presents the GIS architecture, established as open source software, which is needed for the complete functioning of a business organization. The architecture consists of server and client system elements. Establishment of such system provides management of spatial data within various business spheres, both for those which use spatial data as primary inputs, but also for those which use different inputs, and all can use open source software without spending financial resources for software licensing. Concrete example of the application of GIS is from the field of forestry, which refers to the establishment and maintenance of wildfire records at the territory of Republic of Srpska.

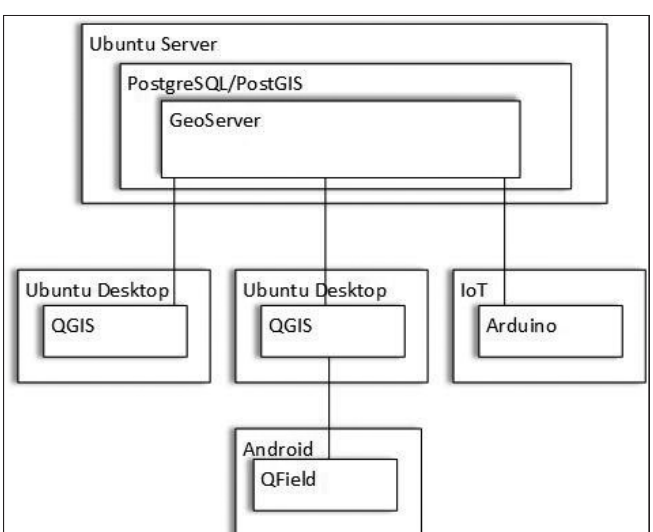
According to the Law on Forests of the Republic of Srpska [2], the beneficiary of forests and forest land owned by the Republic of Srpska is the Public Forest Enterprise "Forests of the Republic of Srpska" JSC Sokolac. The primary activity of the Public Company is the cultivation and protection of forests. Forest protection also includes protection against wildfires, and the obligation of the Public Company, in addition to the activities regarding fire protection, is to record and archive data on wildfires. The aim of this part of the research paper is to show the possibility of improving the current system of recording wildfires using GIS, on the example of this Public Forest Enterprise. In addition to the records of recent wildfires, the procedure of collecting and entering historical data on wildfires is also important.

GIS Development Methodology

The goal of this research paper is to present the development of GIS which is used in a business environment, and which is based on open source. This specific system was created by applying phase development, i.e. by applying incremental build model development. The structure of the GIS architecture is described in detail, which consists of servers, workstations, mobile devices and sensors for data collection including supporting software. Using the analysis methods, each individual element of the architecture will be analyzed and described. Using the synthesis methods, all elements of the architecture will be combined into one functional unit that enables work in a business environment.

System Architecture

This system consists of four primary elements: *server* which is the central unit for all data contained in the GIS and which enables a large number of users to mutually work and exchange spatial data; *client element* which enables the client workstation to access the central geo-base through appropriate software; *mobile application* for field data collection which can be used for data editing and data storing at client stations and also for data saving at central storage location, as well as the use of IoT for automatic data collection using sensors which are delivered to a central storage location for further data processing.



Picture 1: *GIS architecture*

Picture 1 shows architecture of above mentioned system including separate graphic elements with supporting links. Further, each software package shall be separately described of which the architecture is composed.

Table 1: *Software packages and its components*

Server	Workstations	Mobile device	IoT
Ubuntu Server	Ubuntu Desktop	Android	Arduino
PostgresSQL/PostGIS	QGIS	QField	Sensor
GeoServer			

Server

The operating system used for the server architecture is the **Ubuntu server** developed by Canonical, which was founded in 2004, and the current version of the server is 20.04 LTS, which has guaranteed updates and upgrades until 2032 [3]. It is a Linux operating system, based on the Debian distribution. A Server is a device that provides services to other software or devices called clients. This type of server architecture is called the client-server model, and this concept is based on distributed data processing whereas the programs and data are located in the most efficient places, so such systems are usually located in the local network [4].

Geo-base data used in this system is **PostgreSQL**. It is free and open source and is published under the PostgreSQL license [5]. It is visible on its official website that there are no plans to change the licensing conditions of the mentioned software, so it is to be expected that it will remain free forever. PostgreSQL, also known as Postgres, is a relational database system that uses the SQL language. The aforementioned software comes with many integrated features whose primary goal is to enable the creation of applications, protection and data integrity that help users manage their data regardless of their quantity. PostgreSQL is dated September 14th 2021 and is harmonized with at least 170 of the 179 mandatory functions with SQL: 2016 Core standard. It is important to be emphasized that no relational database is fully compliant with this standard [6].

The **PostGIS** software package is also open source, which provides support for spatial data management in the PostgrSQL database. This extension allows you to run SQL queries over spatial data [7].

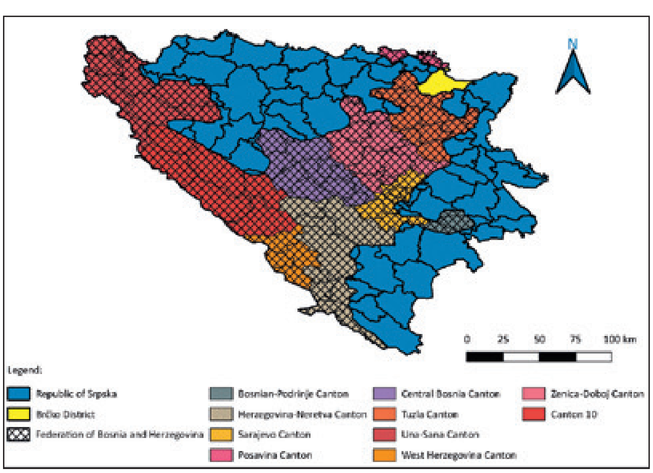
GeoServer is an open source server based on the Java programming language, which enables users to view and edit spatial data. This software package uses the Open Geospatial Consortium (OGC) standard, which allows great flexibility in creating maps and exchanging data with other systems. GeoServer has the ability to work according to the standards of Web Feature Service (WFS) and Web Coverage Services (WCS), which enables data sharing and data processing [8]. In addition to the above mentioned, it also includes certified high performance Web Map Service (WMS). With the help of these services, it is possible to embed data into other systems and websites. GeoServer is a fundamental component of the business GIS environment.

Workstations

After installation of server, which provides storage and distribution of data for further processing and editing by users, next step are client workstations. These workstations also use open source software and consist of an operating system, GIS and supporting software.

The workstation operating system is **Ubuntu Desktop** which comes from the same manufacturer as Ubuntu Server, which has been at the very top of popularity on DistroWatch [9] in recent years. Ubuntu desktop is based on Debian, which is created as a Linux desktop which is user-friendly [3].

After initial preparation of the operating system, it is necessary to install GIS on the workstation, and in this case it is **QGIS**. QGIS is one of the most popular GIS software solutions for open source desktops. With QGIS it is possible to create, modify, analyze and visualize spatial data. This software package supports numerous vector file types, raster file formats, as well as various databases [10].



Picture 2. *Map created by QGIS*

In addition to a large number of built-in features, QGIS can be upgraded by a large number of add-ons that are available in the integrated repository. In addition to the operating system and GIS software, other supporting and needed software such as SAGA, GRASS and LibreOffice can be installed on workstations and thus have all applications needed for working in a business environment.

Mobile device

In order for GIS in a business environment to be completely functional, it is needed to enable data collection via mobile devices. The most important issue for all systems dealing with spatial data processing is field data collection. There are numerous open source software to perform this task. In our area, the most popular operating system for mobile devices is Linux based **Android**, which is open source, so the specified operating system for mobile devices will be the default and the system architecture will be built on it.

One of the most popular apps for fieldwork and open source data collection is **QField**. QField enables efficient work with outdoor spatial data, which is based on QGIS. Field work is not similar to the office work, because the work is executed on a smaller screen and the tasks are different. The primary goal of the QField application is to enable the user to perform field tasks within minimal working conditions. This means that only those functions that are essential for performing tasks in the field are available to the user on home screen [11].

IoT Sensor

IoTs represent the next generation of IT devices. IoT represents the use of different sensors and devices with unique identifiers that can send information about objects and people through the Internet, without requiring human-human or human-machine interaction, or is a communication network of physical objects with a unique IP address [12]. The purpose of the Internet of Things is to continuously monitor, detect and eliminate any possible irregularity and enable an alternative mode of operation of any process [4].

In this example, an Arduino microcontroller was used, which is a suitable device for prototyping general-purpose IoT devices. Arduino is an open source microcontroller platform for designing projects from the field of electronics. Its open source basis and its user friendliness have made the Arduino a functional choice for those looking to develop a variety of electronic projects [13].

Application of GIS System

Geographic information system can be applied in various areas of business, and in this example a review will be given regarding wildfire data collection. The need for such system exists in forestry companies. The application of GIS in the field of forestry is obvious, especially if we take into account that most of the business in forestry is related to the specific location, i.e. forest, regardless of activity type (forest inventory, forest restoration, forest protection, forest exploitation or any other related activity).

After implementation the GIS system, it is necessary to obtain a basic set of geo-spatial data. The data that represent the set of basic needed graphic images are: topographic map; digital terrain model (DEM); map of forests and forest land; map of forest management areas; road infrastructure map; watercourse identification map; administrative boundaries; map of mined and mine suspected areas; meteorological weather stations data (temperature and precipitation data) and similar. There is no limit of graphic images and survey data imported to GIS and all graphic images and survey data that can be obtained or designed are useful by creating new possibilities for future analyses.

After the completion of the preparatory phase related to the obtainment of graphic images and survey data, it is necessary to start developing GIS. Special attention in the process of developing GIS project should be paid to the selection of the reference coordinate system. For the purposes of this project, the Gauss-Krüger coordinate system (projection with 6 degrees wide zones) was used. In addition to the above, it is very important to define set of certain rules related to the organization of the GIS project, primarily for its easier handling afterwards, and especially regarding the possibility of future upgrades or integration of this GIS system into different system.

Each GIS project, including this one, is organized through sets of different data that are displayed through layers, in order to separate different categories of data through different layers. All data contained in a GIS include spatial component and associated attribute data. The spatial component is visually displayed on one of the layers, while the attribute data are located in the background data geobase. Spatial data can be a point feature, a line data, and a spatial polygon data.

Regarding the database and its content, it is necessary to clearly define the organizational structure of the Public Forest Company with the corresponding codebook. The organizational structure should be presented through tables: forestry management area, forestry authorities, business unit, department, branch office, operational unit and forestry administration.

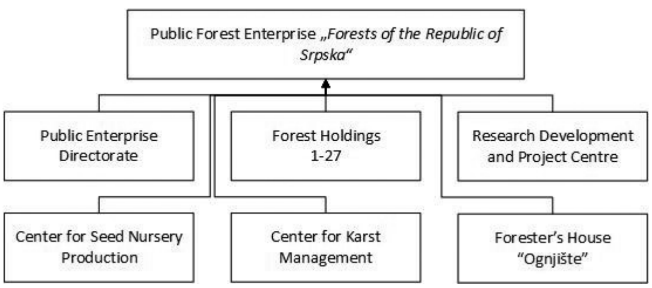
In addition to the above tables, another table should be created regarding wildfire records, containing spatial data related to wildfires, as well as other attribute data.

Previous records on wildfires were kept in prescribed forms, which is prescribed by the Ministry of Agriculture, Forestry and Water Management of the Republic of Srpska. In most cases, the lowest level of record keeping regarding the occurrence of wildfires is kept at the departmental level. This means that there is no exact geographical location of the wildfire determined, but only the indication of the micro-area where the fire had occurred. However, this is not the case when the records are not adequately kept or when a wildfire has affected a larger area than single forestry management area. In such case, only forestry department or numerous departments are entered in the records, but even then there is no information of the exact geographical wildfire location. Besides to the listed data on wildfire location, the document/form also contains other groups of data: type of fire and area affected by the fire; type of plants affected and type of burned forest stand; wildfire duration; damage caused per plant type and amount of damage, damage value; causes of fires and key factors in extinguishing fires.

All mentioned groups of attribute data contain fields that more clearly label and define wildfires.

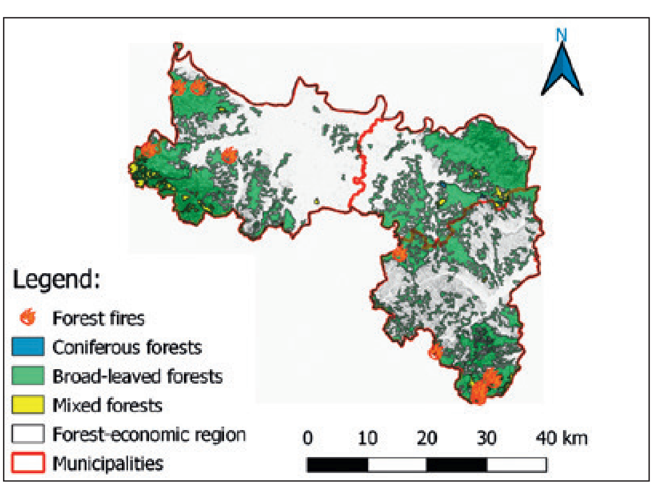
For the purposes of this project, it is needed to collect historical data on wildfires, which are recorded in the prescribed forms by each forestry department in written form. Each form refers to single forestry department and single calendar year. These data should then be entered into the database and according to data on the wildfire location (forestry management department, business unit, department and branch office) should then be linked with associated layers, i.e. graphic images and survey data in the GIS.

Public Forest Company "Forests of the Republic of Srpska" JSC Sokolac has 32 organizational units.



Picture 3. *Organization of Public Forest Company "Forests of the Republic of Srpska" JSC Sokolac*

Out of 32 organizational units, 28 organizational units keep records on wildfires in the prescribed forms (all Forestry Management Departments and the Karst Landscape Management Center). For the purpose of this research paper, historical data were collected, i.e. records on wildfires at the area governed by Forestry Managament Department "Gradiška" with its headquarters in city of Gradiška - beneficiary of forestry-economic department called "Posavsko". Historical data for the current subject period (ten years), starting from 2013, were collected. All collected data were in written form, and in accordance to data on economic units, departments and branch offices, each data was entered into map governed by forestry - economic department "Posavsko" in the form of points (centroids) as of the end of 2020.



Picture 4. *Overview of wildfire locations at Forestry Economic Department "Posavsko" for the period 2013-2020*

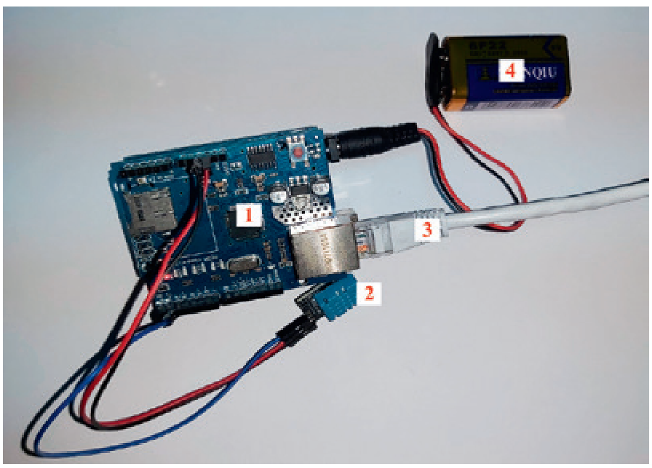
Picture 4 shows the spatial structure of forests and forest land located within Forestry Economic Department "Posavsko" and occurrence of wildfires is presented within graphical image in the form of points. In addition to the map display, in accordance to the data entered into the spatial data geo-base, various analyses related to wildfires can be performed. In this example, digitized data for one organizational section of the Public Enterprise are presented, and data digitization for other organizational units is in progress. With the completion of the activities of digitization of historical data for the entire area of Republic of Srpska, beneficiary PFE "Forests of the Republic of Srpska" JSC Sokolac shall be in position to create future electronic archival records on wildfires. Some of the advantages of the use of GIS regarding wildfire records are digitization and centralization of databases, as well as numerous analyses that can be performed using imputed data.

INTERNET OF THINGS AND GIS

In addition to the records of wildfires, this research paper shall also show how to use sensors to collect data that may warn and indicate the potential occurrence of wildfires. For the purposes of this work, a prototype based on Arduino was developed, which contains a communication module and a temperature and humidity sensor DHT11.

Above mentioned DHT11 sensor is a simple temperature and humidity sensor, which is connected to the Arduino with just one pin bringing back two values: temperature and humidity. This sensor does not require calibration or additional time to be started. By connecting the sensor to the Arduino and by loading its software library, the sensor starts working. The sensor is simple, small in size and as such meets the minimum hardware needs for use within remote detection system. Once a communication channel is established with Arduino, which collects temperature and humidity data, it can be used as an IoT data collection device.

The use of this type of sensor faces several challenges related to the power supply of the device. Since these devices are to be installed in a forest where the availability of electricity is limited, it is necessary to use some of the alternative power sources. In this particular case, an external battery was used, and it is also possible to use a solar power panel at appropriate clear locations, because in a forest it is difficult to find abundant sunlight location.



Picture 5. *Prototype of IoT sensor (1-Arduino; 2-sensor; 3-UTP cable; 4-battery)*

Also, one of the challenges is sending data to a central location, as the position of the sensor is primarily in remote forest areas, which, in most cases, are not covered by cellular network. Optimal method of sending data is via 3G or 4G cellular network and in the initial stages of system establishment it is important to select areas where communication channel can be established with high quality available signal to collect data and system to be tested. Since the tested area was not far away from urban environment, the prototype was connected with an RJ45 network cable. It should be noted that this type of connection should not be ruled out, because there are many forest field facilities that are suitable locations for the installation of sensors. Also, the sensor has the capability to store data on memory card, but in such case it loses its primary function of remote detection. This option only makes sense in collecting data and needed parameters for historical data analysis.

After loading and initial running of the program in Arduino, the system starts to deliver data to the geo-spatial database. The device should be placed at the intended location, and as the data are being recorded, the exact date and time of its reading is generated for each record.

	ID bigint	Name text	Humidity double precision	Temperature double precision	Time timestamp without time zone
1	71	S1	45	28.9	2021-08-22 13:08:12
2	72	S1	45	28.9	2021-08-22 13:08:17
3	73	S1	46	29	2021-08-22 13:08:22
4	74	S1	46	29	2021-08-22 13:08:27
5	75	S1	46	29	2021-08-22 13:08:32
6	76	S1	46	29	2021-08-22 13:08:37
7	77	S1	46	29.1	2021-08-22 13:08:42
8	78	S1	46	29.1	2021-08-22 13:08:47
9	79	S1	46	29.1	2021-08-22 13:08:52
10	80	S1	46	29.1	2021-08-22 13:08:57
11	81	S1	46	29.2	2021-08-22 13:09:02
12	82	S1	46	29.2	2021-08-22 13:09:07
13	83	S1	46	29.2	2021-08-22 13:09:12
14	84	S1	46	29.2	2021-08-22 13:09:17

Picture 6. *Image showing database recording (PostgreSQL)*

Accordingly, a prototype device was developed for remote collection of data regarding temperature and humidity in a certain area. By installing a large number of IoT devices for remote monitoring of temperature and humidity, a clear overview of climatic conditions can be obtained. Detection of a reading that clearly shows a change of parameters in a certain area, in terms of a sudden increase in temperature including decrease in humidity in specific region, is a warning indication of the wildfire occurrence.

It is obvious that, by collecting a large amount of field data, the system can be perfected to the level to ignore natural phenomena and anomalies, and to be able to clearly separate and detect the changes that more precisely indicate the occurrence of wildfire. At the very beginning following installation of such system, a larger number of false alarms would occur due to various weather conditions and before clarification of received values regarding changes in temperature and humidity that indicate the occurrence of wildfire. Besides, field data regarding climate changes would be collected making it possible to mobilize the necessary manpower and machinery to a potentially specific endangered and critical forest area. It is a well-known fact that climatic characteristics and wildfire occurrence are associated, which is reflected by a larger number of wildfires during extreme hot and drought years. Therefore, the temperature parameter was used as the most important data that characterizes the possibility of wildfire occurrence. For the purpose of this prototype, temperature of 45˚C was defined as threshold value. This value was selected in accordance to the maximum recorded temperature at the territory of Republic of Srpska, which is 41˚C [14].

This example shows case of one used sensor, which monitored changes during time interval of 5 seconds. This is probably an excessively demanding short interval, due to the needed time for weather condition to be changed and the amount of data that needs to be transferred to the central database. Table with collected data from the IoT sensor shows designed trigger which is activated once the temperature exceeded a defined value, in this case the defined 45˚C.

Organization of the database should be established by setting an activation trigger for each new input data which analyzes the value of the new data in relation to the previous or several previous values checking the difference if any. This difference would be more precise after the transition period, following collection of large amount of data needed for defining and elimination of false alarms. Accordingly, the system becomes fully functional and applicable for practical use. In accordance to the data received from Public Forest Enterprise, we can select the period with the largest number of wildfires including wildfire incident map and in accordance to these data we can test the system in real life conditions, which may ultimately indicate all possible shortcomings and possibilities to improve the system.

Finally, it should be emphasized that this system is a prototype, and potential problems related to power supply and communication with the central location may arise due to its robustness, and prior to putting into operation of IoT sensor it is necessary to provide these resources.

Conclusion

This research paper presents the work method and type of software packages needed to create a business environment based on open source software. The architecture of the system is described, which consists of servers, workstations, mobile devices and sensors with supporting software whose central part is a group of open source software packages: GeoServer, PostgreSQL/PostGIS, QGIS and QField. Using the listed software packages, it is possible to perform all the tasks that are expected from particular business system. A huge advantage of such system is that it is being distributed under an open source license which is free having no significant restrictions. In addition to the benefits reflected in reduced costs, there are many other benefits of using open source software, such as less time and less bureaucracy associated with purchasing licensed software. Although this licensed software is free, as in any other implementation there are costs related to training, implementation and development time for solution customization [15].

The second part of the research paper describes the use of open source GIS in the business environment of Public Forest Enterprise "Forests of the Republic of Srpska" JSC Sokolac, regarding wildfire database. Wildfire records were kept through manually filled prescribed forms at the level of single Forestry Management Department during single calendar year. It is not possible to perform any serious analysis in accordance to such database records. Provided solution enables digitization and centralization of the mentioned records and the overall result is the possibility of performance of various analyses using other data contained within the GIS. Some of the possible analyses are: periods of wildfire occurrence, wildfire altitude, distance from road infrastructure, average temperature and humidity during wildfires and many other analyses.

The sets of data are listed, i.e. layers required for such system, which can be used in the future for various activities of the Public Forest Enterprise. Historical wildfire occurrence data were collected and entered into the system for the Forestry Economic Department "Posavsko" for the period from 2013 -2020. The procedure of collecting historical data is presented, and activities on recording data for other Forestry Economic Departments are in progress. In addition to historical data, applicable method of real-time field data collecting through IoT is presented which therefore enables timely remote sensing of wildfire by processing these data. This research paper describes a prototype design based on an Arduino microcontroller, which meets the minimum operation requirements. It should be emphasized that the above prototype design can perform required tasks, but may show difficulties in terms of power supply and communication with the central unit, and it is necessary in the future period to find a better solution for these shortcomings.

This research paper showed the possibility of using geographic information systems in an open source business environment, which can meet the needs of a large company such as the Public Forest Company "Forests of the Republic of Srpska" JSC Sokolac. Special attention is paid to wildfire record keeping and the presented solution design is capable to respond to a much larger number of requests not lagging behind commercial software of this type.

References

[1] Valade, Spring into Linux, Addison-Wesley/Pearson Education, 2005.

[2] Official Gazette of the Republic of Srpska, Forest Law. Banja Luka: Official Gazette of the Republic of Srpska, 75/08, page 17, 2008.

[3] Canonical Ltd. [Online]. Available at: https://ubuntu.com, [visited 10.20.2021].

[4] A. Langer, Analysis and Design of Next-Generation Software Architectures, Springer International Publishing, 2020.

[5] The PostgreSQL Global Development Group. [Online]. Available at: https://www.postgresql.org/about/licence, [visited 10.20.2021].

[6] The PostgreSQL Global Development Group. [Online]. Available at: https://www.postgresql.org/about, [visited 10.20.2021].

[7] Planet PostGIS. [Online]. Available at: https://postgis.net, [visited 10.20.2021].

[8] GeoServer. [Online]. Available at: http://geoserver.org/about, [visited 10.21.2021].

[9] DistroWatch. [Online]. Available at: https://distrowatch.com, [visited 10.20.2021].

[10] The Open Source Geospatial Foundation [Online]. Available at: https://www.osgeo.org/projects/qgis, [visited 22.10.2021].

[11] Opengis.ch. [Online]. Available at: https://qfield.org/docs/index.html, [visited 10.22.2021].

[12] Mr. S. Stojković, Collection and integration of spatial data, Belgrade: University of Belgrade – Faculty of Geography, 2020.

[13] S. Monk, Arduino: Programming introduction, Belgrade: Mikro Knjiga, 2017.

[14] Republic of Srpska Institute of Statistics. (2020). Statistical almanac of the Republic of Srpska (second, edited volume). [Online]. Available at: https://www2.rzs.rs.ba/static/uploads/bilteni/godisnjak/2020/StatistickiGodisnjak_2020_WEB_II.pdf, [visited 10.24.2021].

[15] (2020, Jun) PSD Citywide. [Online]. available: https://psdcitywide.com/articles/guide-open-source-gis-software-for-the-public-sector, [visited 10.24.2021].

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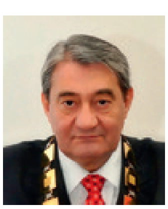

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For citation

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