IoT and GIS Data Platform Solutions in Agricultural

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Abstract

The research is focused on the multidisciplinary process of converting data into useful information. For the applicability of research into a wide range of scientific and research projects, which are focused on obtaining physical information from the surrounding environment, new methods are used to obtain large amounts of data using battery-powered sensors. For example, to use data in the field of precision agriculture, or within the framework of the Smart Building and Smart City management and their resulting presentation to users in a clear and easy to understand form. All using Internet of Things (IoT) and Geographic Information Systems (GIS) technologies. For the overall processing of the resulting and functional whole it is essential to focus on the following sub-disciplines in two basic areas. The first area is IoT, which is mainly concerned with measurement and sensor technology, data transmission, data processing, statistics-Big Data and Artificial Intelligence. And in the second area (GIS), these are primarily tools for real-time data processing, additional data layers, tools for user interface (UI) and user testing when working with UI / UX. It is also important to monitor the economic impact and contact with potential partners, in which some parts of the research could be directly applied in practice. This study outlines, inter alia, possible partners, particularly in the agricultural sector.

Keywords [1]

IoT, GIS, Localization, Precision Agriculture, Smart City. Smart Building

1. Introduction

This review study presents a research project that focuses on the complex issue of transferring information from the real world to the computer technology environment. Specifically, it is concerned with the intersection of two major technological areas, which are IoT (Internet of Things) and GIS (Geographic Information System). The intention may seem very simple at first glance, however based on literature research and practical experience, it has been found that this is a very young field and thus many sub-topics are not addressed at all, especially those that have a multidisciplinary overlap. Alternatively, work in this area has been only recently produced. An example of such application of research, can be, for example, the localization of IoT end devices communicating within the LoRaWAN technology. The possibility of such localization was theoretically introduced at the beginning of the technology, as it is based on general physical assumptions. However, it is only now that the gradual deployment in practice shows that there are still many areas to be researched, such as the development of an algorithm for finding the optimal location of individual base stations (Gateway), considering the real physical environment, which is made up of rough terrain or buildings in the city, for example, by using GIS. Thus, the subject of the research itself is the elaboration of partial problems, hypotheses, or questions. Some already known opportunities are listed under the chapter "Research Opportunities". Thus, the object of this review study is to introduce the concept shown in Figure 1, which demonstrates the simple concept in an illustrative way. Where a sensor device located in a mountainous area measures the quality and condition of the water in a stream, the data is processed in real time in an automated analytical manner and the operator receives only the required information, completely accurate and already statistically processed.

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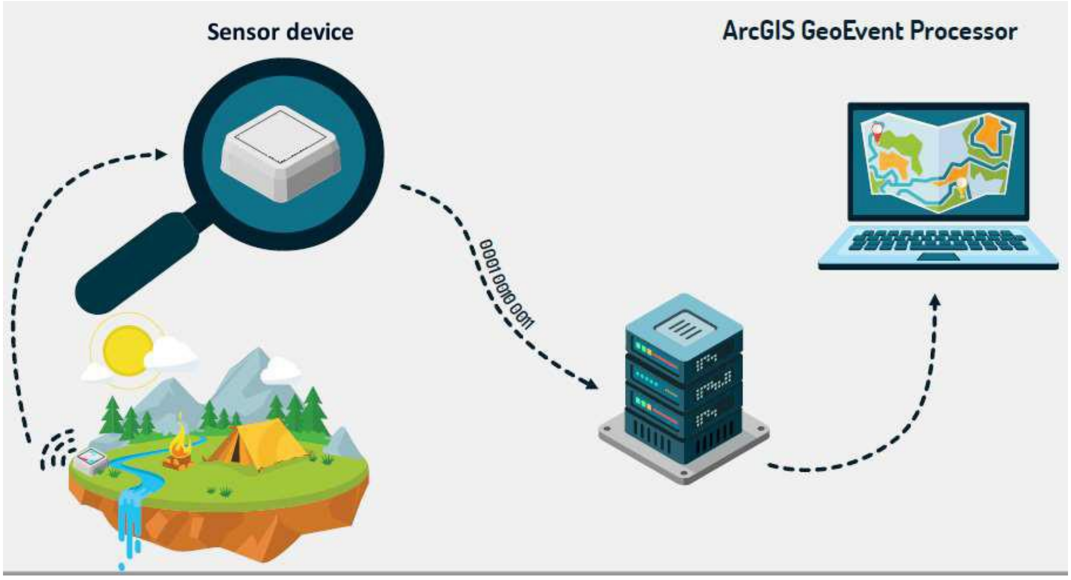

Figure 1: Conceptual scheme of the intent

2. GIS Environment

It seems, that ESRI software is suitable option in GIS area. Thanks to its long history, in 1969, Jack Dangermond—a member of the Harvard Lab—and his wife Laura founded Environmental Systems Research Institute, Inc. (Esri). The consulting firm applied computer mapping and spatial analysis to help land use planners and land resource managers make informed decisions. The company's early work demonstrated the value of GIS for problem solving. Esri went on to develop many of the GIS mapping and spatial analysis methods now in use. These results generated a wider interest in the company's software tools and workflows that are now standard to GIS [1].

2.1. ESRI GIS platform data sources

ArcGIS GeoEvent Server stores and processes geospatial data in real time. It also provides tools for online import of IoT sensor data. Using defined filters and detailed selections, data can be drilled down to focus on a specific problem. The GeoEvent server automatically updates maps and databases, allows alerts to be sent when threshold is met, or an event occurs. GeoEvent server allows dynamic data to be linked to the entire ArcGIS system. For example, the Operations Dashboard is an application that is fully suited to receive real-time data [2–5].

The Collector for ArcGIS is also part of the Geospatial Cloud platform. Mobile apps are an effective tool for use in the fieldwork. Users can add, edit, and describe elements on the spot and data is automatically uploaded to the server for other users or for subsequent analysis. The app supports offline mode using downloaded maps on the phone. The app is currently supported on Android and iOS mobile platforms [6,7].

ArcGIS Notebooks provide users with a Jupyter notebook environment, hosted in your ArcGIS Enterprise portal and powered by the new ArcGIS Notebook Server. Because it works with the Docker container allocation technology to deliver a separate container for each notebook author, it requires specific installation steps to get up and running. Once you've installed ArcGIS Notebook Server and configured it with your portal, you can create custom roles to grant notebook privileges to the members of your organization so that they can create and edit notebooks [8].

2.2. ESRI GIS analysis tools

Spatial analysis is a complex part of working with the data. It includes visual analysis of maps and imagery, computational analysis of geographic patterns, finding optimal routes, site selection or advanced predictive modelling. Analysis uses data from all kinds of technologies – GPS, IoT sensors, social media, mobile devices, satellite imagery and many more. Geographic information systems use functional tools, such as QGIS, ArcGIS Desktop or ArcGIS Pro [9,10]. "ArcGIS can analyze data, locate a site according to specified criteria, optimize vehicle routes and perform advanced predictive modelling. In a user-friendly and interactive map, one can view, for example, the intensity of a phenomenon in selected areas, branch revenues in individual periods or, even data about customers in the context of the general demographics of the area and the collected data about competitors. Many companies and government organizations use ArcGIS tools to plan their investments." [11,12]

2.3. ESRI GIS visualization tools

Visualizations may include maps, graphs, statistics, and cartograms that show, for example historical changes and current developments. The importance is given on clarity and accuracy. For the users themselves, ease of use is essential, which is satisfied, for example, by following ESRI programs:

The operations Dashboard application (Figure 2) is designed to create thin clients. In addition to the features common for web map applications, it also includes tools specialized for continuously changing data tracking. The application accesses individual data as well as map layers and uses a user interface (UI) to guide the user through the creation of individual operational views. User can create the views themselves through the individual tools. These tools can be a map, a table, a graph, or others [13].

Figure 2: Operations dashboard application screenshot

ArcGIS Earth is an easy-to-use lightweight client for 3D data visualization. By viewing data in a spatial context, it lets us see features that are not well represented on a conventional map. Therefore, we can upload data in KML, shapefile and various other web layers and explore their interrelationships [14].

Web AppBuilder for ArcGIS is intuitive what-you-see-is-what-you-get (WYSIWYG) application that allows to create 2D or 3D web application without typing a single line of programming code. It also includes powerful tools for configuring fully functional HTML [15–17].

Story maps are a combination of maps, text, images, and multimedia content. They facilitate the use of the power of maps and geography to tell a story [18].

3. Data transmission

3.1. LoRaWAN technological area

Open specification LoRaWAN is a low-power, broadband network protocol (LPWAN) based on LoRa technology. The LoRaWAN protocol is designed for wireless connection of battery-powered devices in regional, national, or global networks, using unlicensed radio spectrum in Industrial, Scientific and Medical (ISM) band. Its architecture is shown in Figure 3. LoRa defines the lower physical layer, whereas LoRaWAN provides upper networking layers, this provides seamless interoperability between devices. While Semtech provides radio chips with LoRa technology, the LoRa Alliance®, a non-profit association and fastest growing technology alliance, is driving the standardization and global harmonization of the LoRaWAN protocol [19–22].

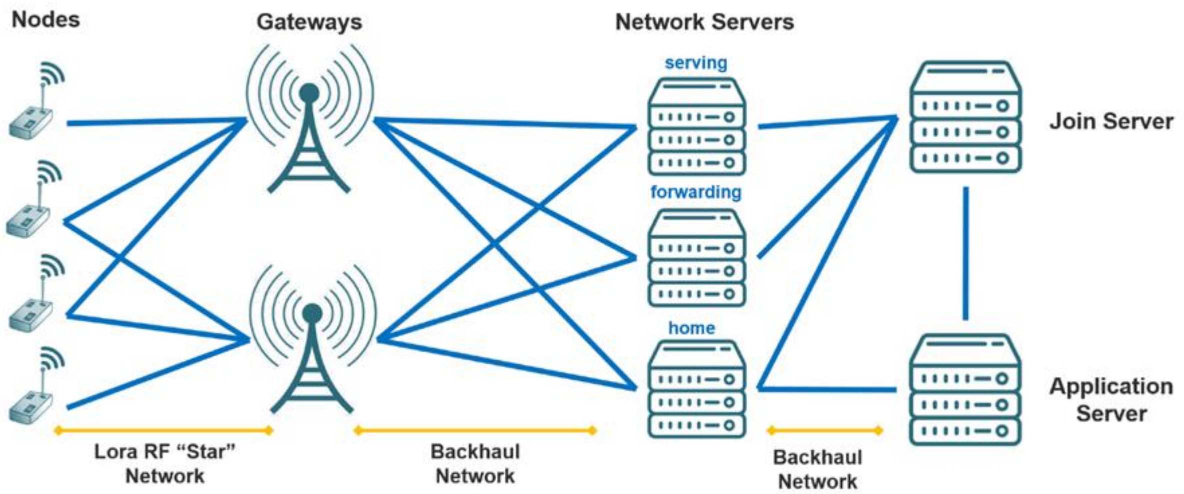

Figure 3: LoRaWAN network architecture [23]

3.2. LTE-NB and LTE-M technology area

Within the technologies that are provided as "classic mobile", the IoT area can also include LTE-M and LTE-NB technologies. These are very similar technologies, that are designed for communication between battery-powered devices. The difference between these technologies is explained in the following example found in the next paragraph [24–26].

Automotive systems nowadays come typically with integrated connectivity to the internet, making it possible to present up-to-date traffic information or send diagnostic information to the manufacturer to analyze the behavior of internal systems. When the device is in operational mode, in most cases, there is sufficient power to allow the user to be online with the current mobile operator connection. However, the vehicle needs to be "online", i.e., connected to the Internet even when the vehicle is parked. This creates a new requirement for a completely different behavior of energy requirements than in normal operation. LTE-M is the solution for all scenarios with moving transmitters. Another possible type of devices in the network are small stationary sensors that monitor physical quantities, such as temperature, humidity, air pollution, flow rate, etc. These simple sensors are usually battery powered and have to make do with a minimal data transmission for their operation. The end devices need a minimum amount of energy to transmit information about changes in their status so that they can perform their function for several years. LTE-NB technology is used for similar devices [27].

4. IoT location tools

4.1. General localization methods – RSSI, TDoA

The RSSI value has been considered as a metric in most distance measurement algorithms. Although the inefficiency of RSSI is mentioned in the literature, not many attemps have been made to implement it in practice. Elnahrawy and colleagues explored the idea of using RSSI in location algorithms carried out in indoor environments and found that for improve the accuracy of RSSI-based methods when used indoors, more sophisticated models and algorithms are needed. The use of artificial intelligence and machine learning has great potential for better use of the RSSI method [28-30].

TdoA is another technique where nodes are localized using 3 or more base stations with precise time references obtained from the GPS signal. The method is particularly applicable to the technology of LoRaWAN. The method is illustrated in Figure 4 [31,32].

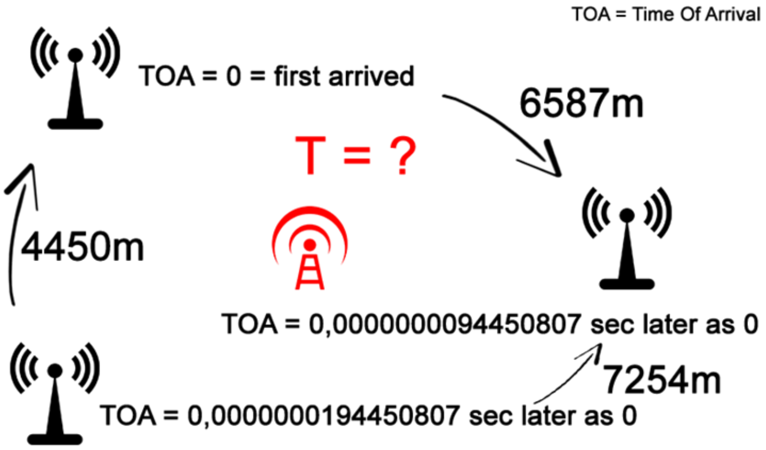

Figure 4: TDoA principle [33]

4.2. Wi-Fi and Bluetooth systems

Some of these location methods are already used in commercial solutions available nowadays. Given the availability of the technologies, two representatives from traditional manufacturers were chosen, both with many years of experience in wired or wireless computer networks.

Cisco Meraki Access Points (Aps) generate information about the presence of any Wi-Fi enabled device by detecting AP requests from unconnected devices and 802.11 data frames when the device is connected to the network. Wi-Fi devices typically issue AP request at regular intervals based on the status of the device. Smartphones send probe request to discover nearby wireless networks to make the networks available to the user. Cloud Meraki aggregates raw client location data and provides a real-time estimate of the location of Wi-Fi devices (associated and non-associated) and Bluetooth Low Energy devices (BLE) in real time. A Scanning API is also available that allows data to be delivered to a user application, data warehouse or business intelligence systems, all in real time [34–36]. Some research makes use of this, for example [37,38].

4.3. Data flow processing – Node-RED

The Node-RED application can be run on virtually any computer. Node-RED is an Internet of Things (IoT) programming tool that connects hardware devices, APIs, and online services. It provides a browser-based editor that allows you to easily link data streams using a variety of nodes. Only the interpretation of the code precedes the start of the application. It is therefore visual flow-based programming and thanks to its simplicity and clarity allows users to quickly create applications using a simple drag-and-drop interface. Node-RED is built on Node.js®, so it is an "agnostic platform." It runs as easily in the cloud as on the Raspberry PI. With more than 600 community features available to expand the range of features. An active community moves the whole project forward.

5. Practical

The practical section presents several ways in which data can be loaded into the ArcGIS platform. First, the actual data message displaying the information retrieved from the device is presented. This data message is the same for all three options regarding the loading of sensory data into the ArcGIS platform. The first option is the possibility of connecting ArcGIS to a PostgreSQL database, the second is the possibility of using Python script and the last option presented is the use of ArcGIS GeoEvent Server.

5.1. Sensor data structure

Sensor data constists of the values of individual sensors and the corresponding metadata. In addition to the identification of the device and the individual sensor, location information is also included within the data structure. This information is obtained by RSSI or TDoA method using LoRaWAN technology. The position information is important for further data processing withing the geographical information system itself.


```json
{
    "deviceIdentificator": "JO-TEST-ASMkN0zRWJr0",
    "deviceModel": "E1-SBLX/AVBX-AVBX",
    "measurements": [
        {
            "time": "2021-09-03T08:18:12Z",
            "quantities": [
                {
                    "key": "dev_temperature",
                    "value": 25.61,
                    "unit": "°C",
                    "min": -40,
                    "max": 85,
                    "decimal": 2,
                    "name": "nazev",
                    "adr": "I.1"
                }
            ],
            "position": {
                "altitude": 999,
                "lat": 50.0908992,
                "lon": 14.4006189,
                "positionAccuracy": 18,
                "positionDiff": 0,
                "speed": 0,
                "source": "LWR",
                "EPSG": 3857,
                "format": "(D+[.d*])"
            },
            "networkParam": {
                "nType": "LoRaWAN",
                "provider": "CRA",
                "data": {↔}
            }
        }
    ]
}
```


Figure 5: Data structure

5.2. Node-RED

The first presented method of transferring data to the ArcGIS platform is to store the measured data in a database and the connect this database as a data layer. The following figure shows a visualization of the code in the Node-Red application that is storing the data in the database.

In the Figure 7 it is possible to see an example of how to the data can be inserted into the different geographical layers after connecting the database.This solution requires the use of other applications in addition to the ArcGIS platform itself, making the entire solution complicated and more difficult to maintain and extend. For example, user and application permissions must be handled separately in several places. The following two examples focus only on direct use of the ArcGIS platform.

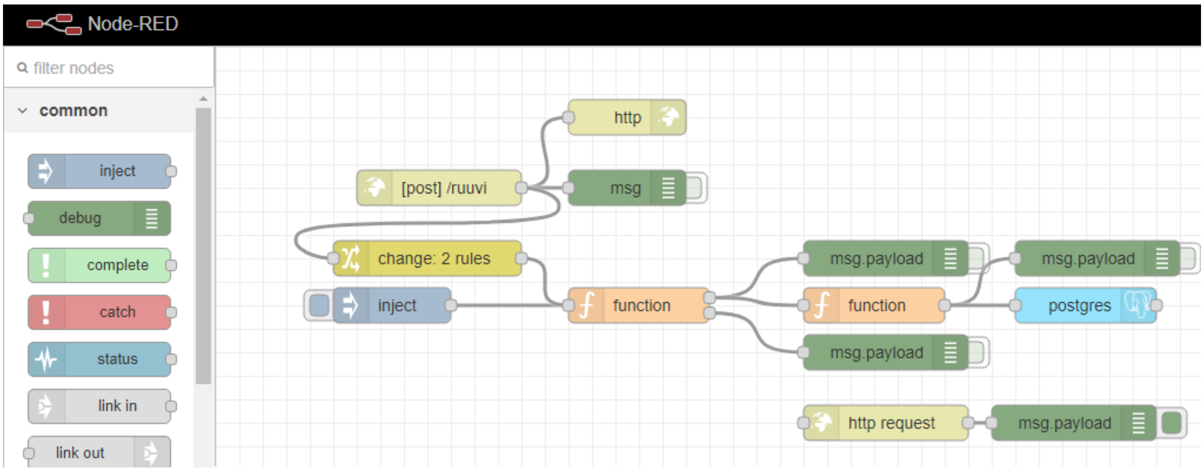

Figure 6: Node-RED application

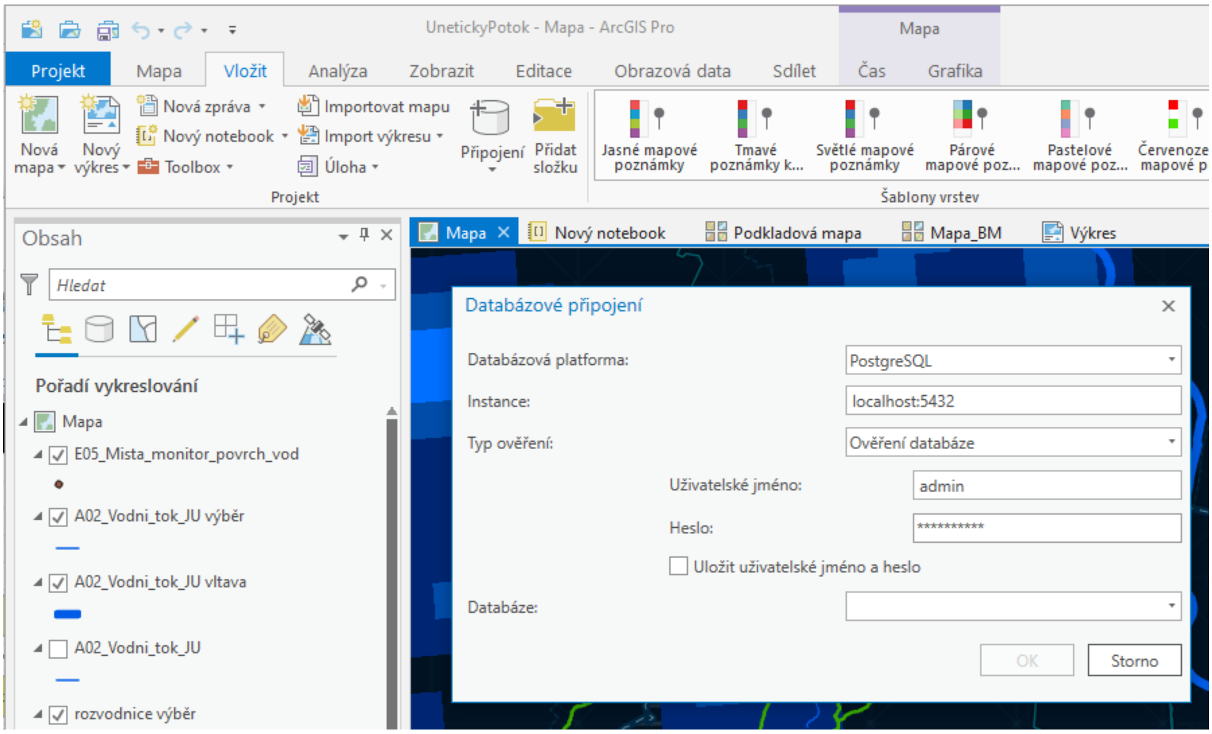

Figure 7: Arc-GIS Pro database connection

5.3. Python script

The Python scripting language support built into the ArcGIS platform provides an ideal solution for data transformation and analysis. With libraries, the script can access services within ArcGIS online and ArcGIS enterprise. The following Figure 8 shows a script for loading, editing, and publishing data within the ArcGIS platform.

The advantage of this solution is considerable flexibility and simplicity of implementation. The disadvantage may be the necessity of knowledge of the Python environment and individual ArcGIS libraries. In contrast, the following solutions using ArcGIS GeoEvent Server offers an ideal and robust solution for all GIS users, as this solution is not primarily coded but configured, unlike the previous examples.

```python
In [1]: from arcgis.gis import GIS
import pandas as pd
import requests
import json
import csv

def fetch_api_data(url):
    session = requests.Session()
    session.headers.update({"Content-Type": "application/json"})
    response = session.get(url)
    data = json.loads(session.get(url).content.decode("utf-8"))

    timestamp_modified = pd.Timestamp(data["modified"], tz="Europe/Prague").tz_convert("UTC")


    df = pd.DataFrame(data["data"])
    column_names = {"id":"deviceIdentificator","key": "key", "value": "value","unit": "unit",
                    "min": "min", "max":"max", "time": "time", "lat":"lat", "lon":"lon"}

    df = (
        df
        .rename(columns=column_names)
        .assign(date=lambda x: pd.to_datetime(x["time"], format="%Y-%m-%d").dt.tz_localize("UTC"))
        .assign(id=lambda x: x ["time"].dt.strftime("%Y-%m-%d")+ id)
        .assign(modified=lambda x: timestamp_modified) .sort_values(by=["time"])
        ---
        ---
        ---
        )
    output_columns = ["id","time", "key", "value", "unit", "min", "max","lat","lon"]
    print(df)

    ---

    # let us publish service
    service_item = gis.content.create_service(name='IoT_data', service_type='featureService')

    ---
```

Figure 8: Python script

5.4. GeoEvent server

The following Figure 9 shows the portal in which the complete configuration of this extension takes place. In function, it is like the Node-RED application, but is ready for scalable, robust and long-term operation.

On the “Inputs” page, see Figure 10, it is possible to set any commonly used interface. From IoT perspective, it is necessary to choose protocols that allow real-time communication. For example, WebSocket communication containing data in JSON format is suitable choice that meets this requirement. An alternative option is, for example, the MQTT protocol. Outputs are set up in a similar way, on the “Outputs” tab.

The executive parts of this add-on are the functions in Figure 11 (marked in yellow), which allow to perform arbitrary operations on the data. The basic functions are already prepared. If necessary, there is an SDK in Java programming language, which can be used to create a custom functions. After setting up the inputs and outputs, which are shown in Figure 11 (marked in green and blue), everything can be interconnected.

6. Economic and commercial overlap

Insights from practice can lead to new research questions and, in turn, research results can be positively evaluated financially, thus supporting further research. Thus, mutual collaboration and exchange of experience/know-how can lead to workable and useful solutions.

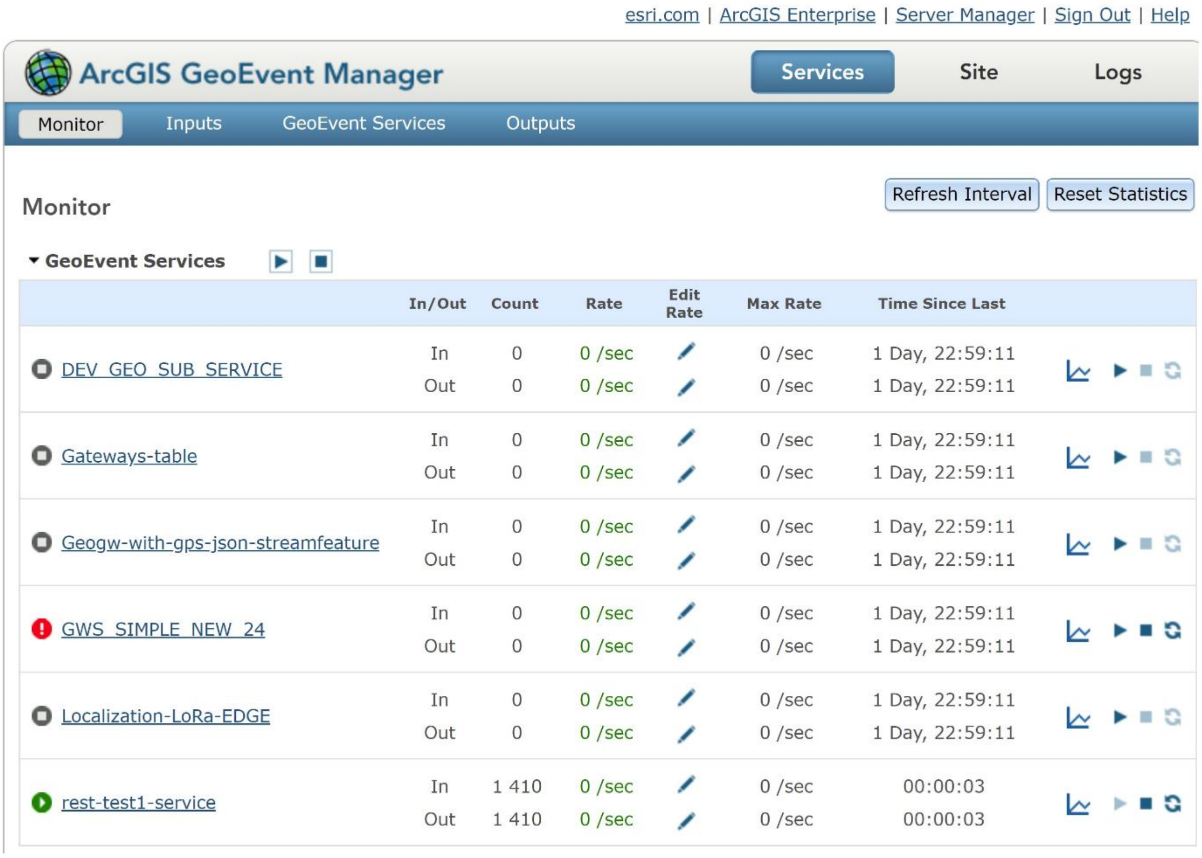

Figure 9: GeoEvent dashboard screenshot

6.1. Floods protection - focus

An example of a possible scientific and commercial application of the above-mentioned methodology combining IoT and GIS technologies is presented in the further text. The example leverages cooperating sensors coordinated by a geographic information system.

Figure 12 on left shows a model replicating a real environment including precipitation. The slope and water absorption of the terrain and the system of watercourses. These rivers are monitored by a network of IoT sensors (shown on the right). These sensors provide, for example, real-time level data. Thanks to the knowledge of their location within the model, it is possible to better predict the development of the situation and thus not only ensure the protection of property, but also optimize the operation of the sensors themselves.

6.2. Further research

The intention of the research is to address partial research within the complicated process from measurement of data and its wireless transmission using LPWAN technologies, especially to save energy of the sensor device itself. Furthermore, verification of their quality and credibility, after obtaining valuable information and its subsequent use, either for further research or direct presentation, using geographic information systems.

For data processing in geographic information systems, it is desirable to add location information or information about the time of the event to their data. For this purpose, it is also necessary to address the area of location information extraction. From the point of view of the potential application of this research, it is also important to ask about possible practical application or business and economic benefits. For this reason, it is seen as important to be in contact with potential end-users or intermediaries as a part of the research using the results of the research and to support the possible transfer of technology and knowledge from research into practice.

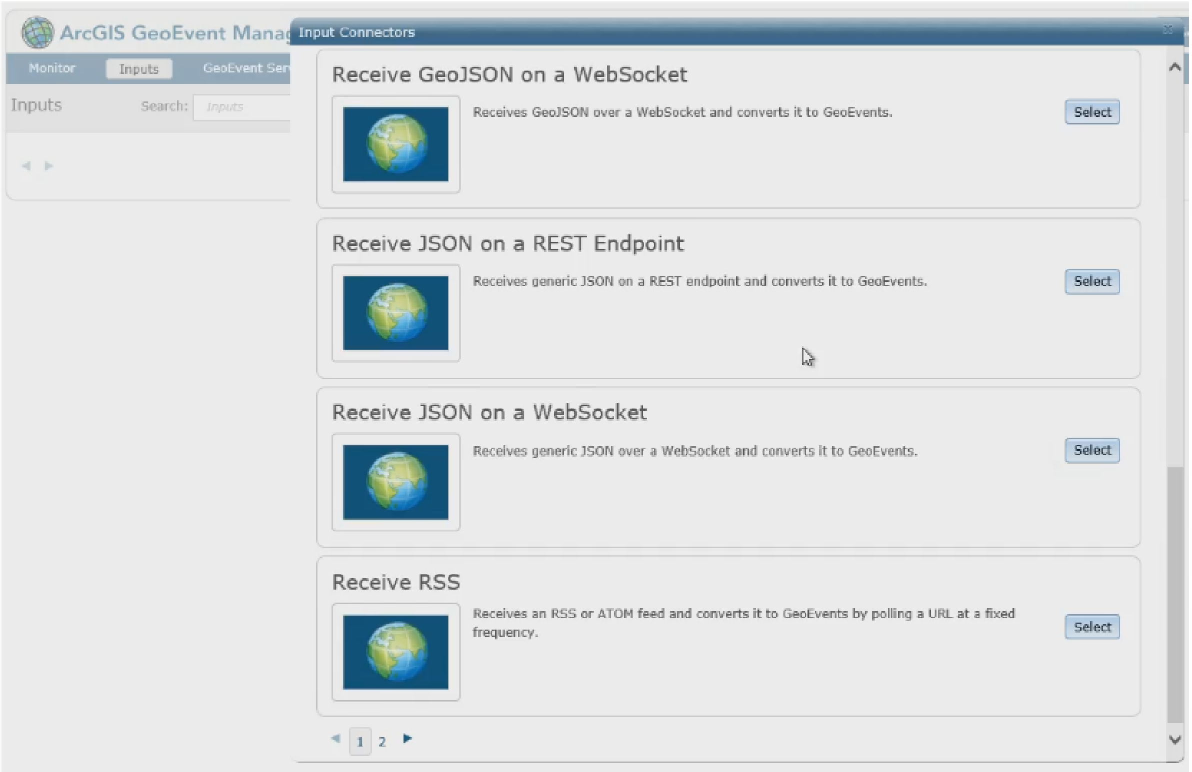

Figure 10: GeoEvent input connectors screenshot

Specific sub-research opportunities may be, for example:

- Verification research to compare the quality and usability of available HW for IoT technologies.
- Use of Big Data and AI analytics for IoT Data Quality Control. In particular, accuracy and calibration of sensors. In the context of data processing with traditional statistical methods, it is necessary to ensure the "purity and uniformity" of the measured data. It is questionable whether new approaches are not able to eliminate this necessity, and example would be trend tracking, for which it is not necessary to know the absolute values.
- Research on technology for analyzing anomalous behavior of IoT sensors in the GIS environment, especially the use of Big Data and machine learning.
- A very specific technological problem is to ensure the decoding of the data message sent by the device, especially in LPWAN networks. Current systems and solutions are very heterogeneous and unsustainable in the long term. The essence of the problem is the necessity to minimize the volume of data send by the device and the desire to transmit as much information as possible for cloud processing.
- Research on methods for low-power positioning using GPS.
- Obtaining the maximum possible information using metadata from the operation of Wi-Fi technology
- Finding the optimal placement of localization devices (AP/GW) to increase localization accuracy. For RSSI and TDoA methods.
- User experience testing to verify the users' ability to receive information presented in the form of a map. For example, whether the form of graphs and tables is perceived better than colored shapes on a map.

7. Conclusion

Significant differences can be observed within the presented methods for loading data into the ArcGIS platform. For each project, the most appropriate approach needs to be selected, taking into account the circumstances. Presented tools and methods are certainly applicable in scientific research.

This review study introduced many topics, that have been scientifically investigated to some extent by partial research in particular areas. However, we were not able to find any such comprehensive work that has addressed this fundamentally new issue in such a context and scope. We are convinced that a comprehensive view of this issue may provide new opportunities and insights.

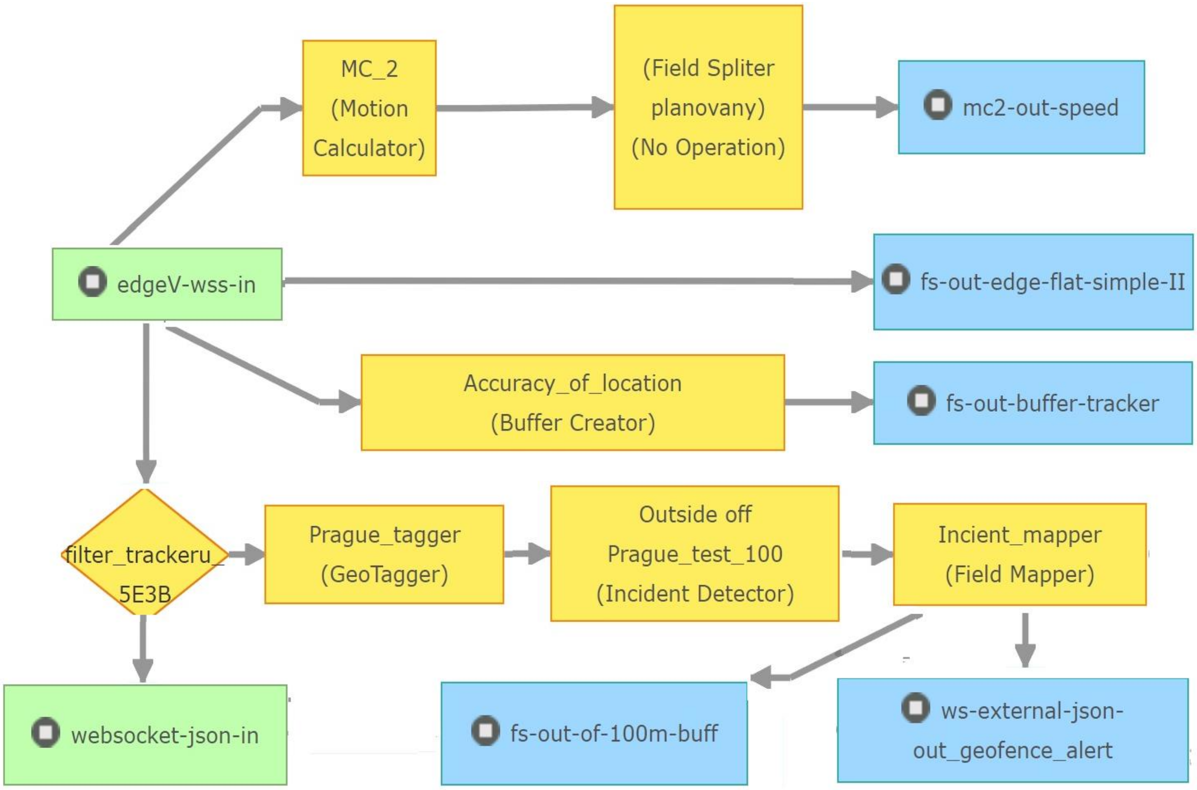

Figure 11: Operations dashboard application screensh

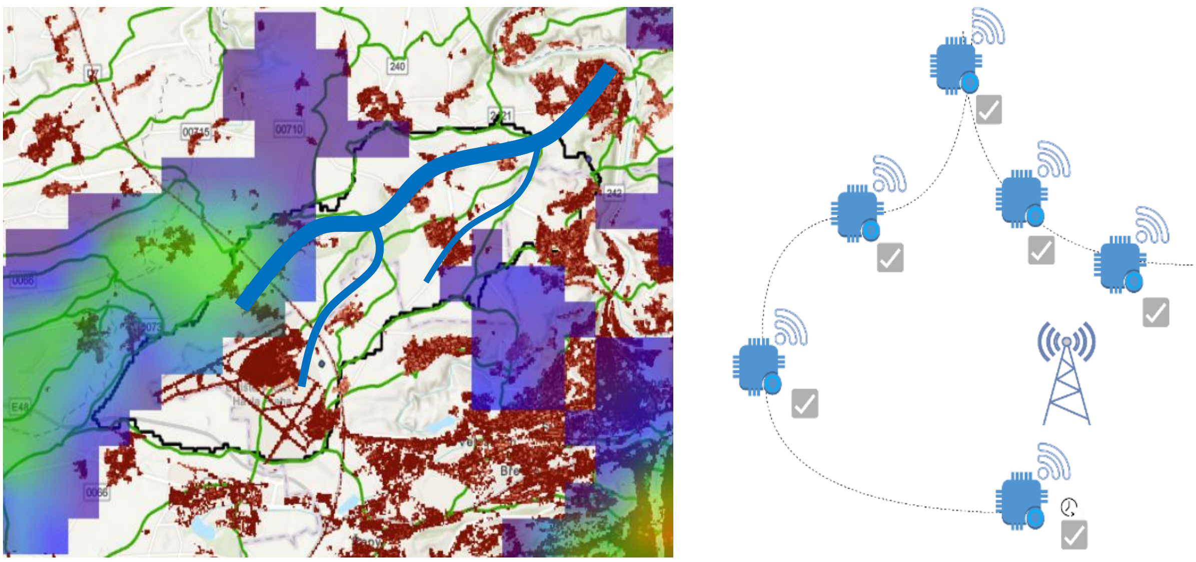

Figure 12: practical connection of GIS and IoT

8. Acknowledgements

The results and knowledge included herein have been obtained owing to support from the following institutional grant. Internal grant agency of the Faculty of Economics and Management, Czech University of Life Sciences Prague, grant no. 2019B0009 — "Life Sciences 4.0".

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