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Sensor Data Gathering for Innovative Climatic System for Effective Water and Nutrient Management

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Abstract

Climate change is having a major impact on various sectors such as agriculture and water management due to changes in the distribution of rainfall. Mitigation of climate change impacts can be achieved through early detection of these changes by monitoring systems and the adoption of appropriate adaptation measures. One of the main goals is to design and develop a next generation monitoring and alerting system to support the optimization of water and soil nutrient management in agricultural domain. Sensors and sensor data management play an important in this kind of monitoring systems. A complete sensor data chain was developed based on modern wireless sensor networks and IoT technologies that covers the data gathering up to the data publication by interoperable interfaces. The monitoring system was tested on vineyards in pilot localities in Czech Republic and in Argentina.

Keywords

Sensors, monitoring, alerting, water management, wireless sensor network, data processing.

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Introduction

Sensors and sensor data provide important methods on how to get current and up-to-date information about various phenomena in different domains. A very important role for data collection representing sensors in agriculture, fishery, and forestry (Rogotis et al., 2021). Especially, IoT technologies and communication protocols have provided a wide spectrum of different sensors with various applicability and connectivity. Decreasing hardware prices, lower energy demands, coverage of modern communication networks enabled spreading of sensor utilization. Agriculture as a domain has taken a lot of advantages of sensors and IoT. Utilization of sensor data and its analyzing with a combination of other datasets can improve the decision-making process and allow it to react to any events on farms. Modern IoT communication networks allow continuous monitoring with low power consumption data transmission to the Internet (Java et al., 2021). Agriculture is very dependent on environmental conditions and other external events therefore a monitoring and alerting system can support decision-making processes and prevent loss on crops and yield. Based on data from monitoring and alerting systems, effective optimization of water management and nutrient management can be implemented. Where the monitoring part depends on sensor data gathering in fields and effective processing of observed data. Typical crops where utilization of sensors in production is growing rapidly are high-cost crops – fruits, vegetables, wine, etc.

Wine production is a domain where sensors and IT technologies have been playing important roles already for more than 20 years. Incorporating of sensors and modern technologies provided a shift from traditional methods to precise viticulture and define challenges in production and management of vineyards (Arnó et al., 2009). Modern technologies like monitoring, modelling or remote sensing are involved in optimizing water management in vineyards (Mirás-Avalos and Araujo, 2021). Building wireless sensor networks on vineyards to monitor different phenomena is a task for incorporating different technologies and modern approaches to gather relevant data. Different sensor networks and computing technologies monitor maturity of grapes and influences of freeze on production (Burrell et al., 2004, Beckwith et al., 2004, Galmes, 2006). But not only in-situ sensors are used for monitoring, remote sensing and image processing improves methods to detect different diseases and overall status of plants (Lloret et al., 2011). Monitoring networks are focusing on complex climate conditions in vineyards by monitoring air and soil conditions and incorporating weather forecasts (Togami et al., 2011, Catania et al., 2013) to increase quality of grapes and reduce operation costs. Monitoring of soil conditions in vineyards is important for detection of water stress during the whole season (Ginestar et al., 1998) as well as the spatial variability of the water stress in fields to optimize irrigation mechanisms based on need of water (Bellvert et al., 2014).

A modern monitoring and alerting system (AgriClima) of the new generation was designed to provide a monitoring and support system to optimize water and nutrition management in agriculture with pilot focus on viticulture. The system was designed to incorporate modern IoT technologies as well as interoperable interfaces. This paper is describing the monitoring sensor network and sensor data management part of the whole monitoring and alerting system AgriClima. The Materials and methods section describes components of the system from hardware and sensor part and data transmission as well as the sensor data flow from receiving on server to publication. The Results and discussion section describes new results as the alerting mechanism and data visualization and evaluates the operational status of the sensor network.

Materials and methods

Pilot localities

Pilot localities for the monitoring use cases were selected based on used methods of production according to changing meteorological conditions, data availability, acceptance of proposed actions, level of technological support etc. While the research project was focused on cooperation in the Czech Republic and Argentina, localities were selected in both countries (Boukalová et al., 2019).

As the pilot locality in the Czech Republic, a vineyard was selected located in the north-west part of the country near to the city of Most (see Figure 1). The vineyard Most – Čepirohy is located on the Čepirohy spoil bank of the brown coal strip mine “Šmeral”. Vineyards in the surroundings of the city of Most are situated on the area of 30 hectares and are part of the Litoměřická wine sub-region and they are the most northern vineyards in the Czech Republic. Grape vine (Vitis vinifera, L.) has been used as a revegetation plant during the mine reclamation process since 70's in the locality of the city of Most. The monitored part of the locality was the vineyard “Mariana” which was selected as experimental part with new planting of grape vine in 2020 using biochar (Hendrychová et al., 2021). Biochar applied with compost should provide support during taking of roots for young plants. There were both methods for planting – traditional one only with compost and experimental one using compost with biochar.

Source: Processed by the authors

Figure 1: Location of the Čepirohy pilot locality.

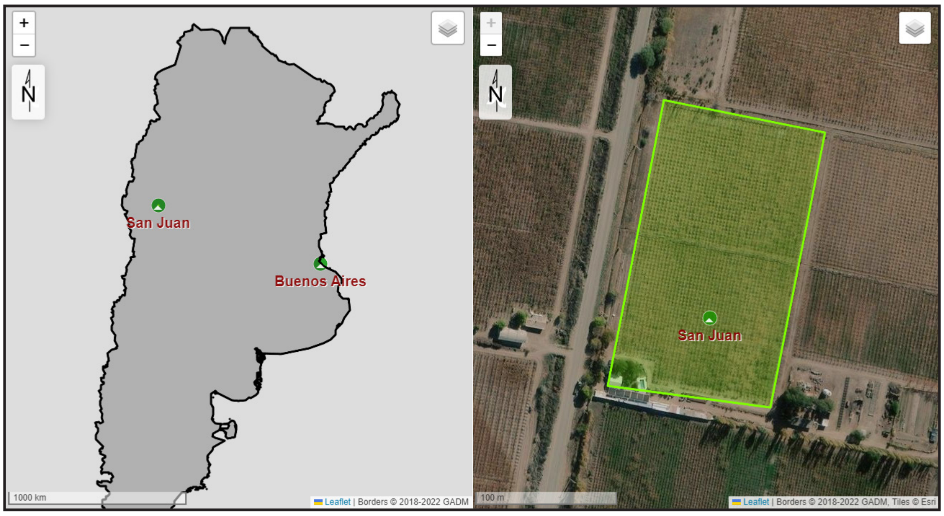

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Figure 2: Location of the San Juan pilot locality.

Sensors for monitoring soil moisture and soil temperature were deployed randomly to both types of planting.

The pilot locality in Argentina is located in San Juan province where agriculture and especially viticulture is an important part of the economy (Boukalová et al., 2019) (Figure 2). The local climate, characterized by a high level of sunshine, is very beneficial to the health of the vines, which generally have a very low risk of fungal or other diseases. The major challenge in the area is the lack of water for irrigation. The monitored pilot was vineyard "ECOHUMUS". The locality is characterized by water scarcity, the vineyard is irrigated by surface water from a remote reservoir through a system of canals. The water that comes to the locality by canals to irrigate the crops is not adequate. To prevent the vines from drying out, the lack of water from the canals needs to be replaced by groundwater from wells on the locality. Thus, the sensor monitoring system and experimental application of biochar was important for optimization of irrigation in the locality.

Used sensors in sensor network

The proposed system for data collection was based on Internet of Things (IoT) technology applied to wireless sensor networks. The data collection system was designed taking into account the local and regional conditions in pilot sites and the needs of individual end users (Křivánek et al., 2020). The individual sensor network measurement nodes transmit the current values of the measured phenomena, together with the identification of each individual sensor and a timestamp, to the respective IoT network, from which they are sent to a data server.

The sensor network for data collection in the pilot sites was aimed at acquiring data on current meteorological and soil conditions using modern IoT components and transmission technologies (Křivánek et al., 2020). The basic sensor component was a soil water content sensor, which was installed at the depth (or multiple depths) required by local conditions defined by:

- soil type,
- the expected precipitation,
- the existence of irrigation.

The main combination of sensors were the METER TEROS 11 and METER TEROS 21 (see Figure 3) which measure not only the humidity but also the soil temperature. The sensor measurement of the water content in the soil is based on the measurement of the dielectric permittivity of the soil at a frequency of 70 MHz. The permittivity is then converted to volumetric water content (VWC) using an empirical formula that can be adjusted to the specific soil type to refine the calculation of the water content itself.

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Figure 3: TEROS 21 sensor used in pilot localities.

The monitoring of basic meteorological parameters in the locality is carried out by a basic meteorological station METER ATMOS 14 (see Figure 4). The weather station monitors the following phenomena:

- air temperature,
- relative air humidity,
- atmospheric pressure,
- water vapor pressure.

Source: Processed by the authors

Figure 4: Installation of meteostation METER ATMOS 14 in pilot locality.

Dataloggers used in the system worked in semi-online mode. Harvesting of data is triggered by timeout defined by the user (most common 60 minutes for soil phenomena – moisture, temperature, and 15 minutes for meteorological phenomena) or value change of parameter (sensor of water in irrigation channel) or both. Measured value is then stored in internal nonvolatile memory in datalogger and simultaneously sent to server storage through several IoT radio technologies. Sigfox IoT network, that was used in dataloggers on pilot locality on vineyard "Ecohumus" in Argentina, used UNB (ultra-narrow band) radio modulation with very low power demands to achieve high range coverage (Křivánek et al., 2021). Local regulations allow the use of radio modules on free frequency 920 MHz - RC4 (Sigfox Radio Configuration) with duty cycle with frequency hopping, no emission during 20 seconds from last transmission. Used data protocols allowed to send up to three measured values during one radio session.

CRA LoRaWan IoT network was used for data transmission on pilot locality in vineyard Čepirohy in Czechia. LoRa is IoT radio network communication technology based on spread spectrum modulation with long range, low power consumption, low data rate. Local regulation on pilot locality allows the use of 868 MHz frequency band with maximum output power 25 mW and up to 1% duty cycle. In Czechia dataloggers are using the network of local LoRaWan provider České Radiokomunikace (CRA), which covers the whole country. In normal conditions, the uploaded message can be received at least by two base stations.

SensLog system

Measured data are collected and processed by the SensLog system in the proposed solution. SensLog is a web-based sensor data management and processing solution that is suitable for both static and mobile sensors (Kepka et al., 2017). SensLog receives data directly from AgroNode datalogger or from IoT network providers' repositories – using the Receiver component.

SensLog also provides storage and preprocessing of data in the repository in the SensLog Model data model, which is derived from the ISO 19156 (ISO, 2011) standard with an extension to store the metadata of the sensor network and its structure. The data model is implemented in a relational database with a spatial extension, which provides appropriate storage in the relational model as well as storage and processing of the spatial component of the collected sensor data. The relational database stores the original measured data, but also the processed results of analyses and other

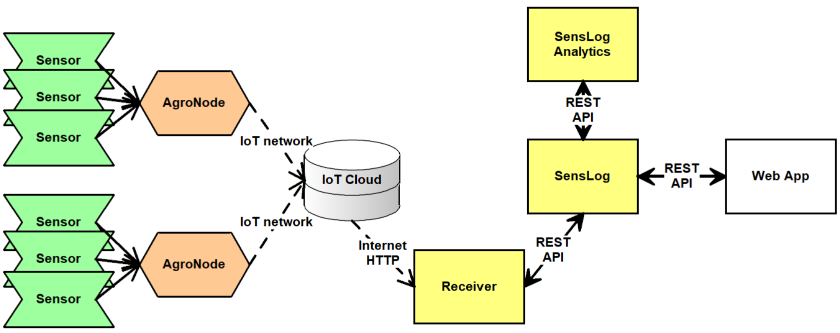

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Figure 5: Schema of data flow from sensors to applications.

calculations. Measured and processed data are published for visualization and presentation applications, or for further processing by third-party applications using the web services system. Web services based on REST methods publish data in JSON or CSV format, but also in other text formats. Other modules of the solution – Receiver, SensLog Analytics – communicate with the main part of SensLog using the REST API system. The general overview of the data flow between sensors and SensLog component are shown in Figure 5.

Data analyses

The added value of the measured data is the information which can be retrieved from that. Such information is then important not only for an automatization and a trend monitoring, but also as a base for obtaining knowledge for a defined area. Due to these requirements, we developed an application SensLog Analytics performing following four types of calculations:

- calculations of statistical characteristics of measured values for different intervals (average, minimum, maximum for different time periods),
- calculations of cumulative values for defined variables over a given period,
- monitoring of exceeding the defined threshold value of the selected sensor,
- monitoring of a defined combination of values of different variables in a sliding time interval.

The application needs to be fed by raw observations that are further processed (see Figure 6). An approach of retrieving data directly from the SensLog database periodically was chosen, however with an awareness of extendibility with data-stream processing due to the advantage of modular design. Loaded observations go through modules (pipe and filters architecture), which each is responsible for a single task (e.g., threshold checker). The calculating methods represent separate modules as well and the calculation is done based on a type (i.e., calculation model) and its initial configuration, e.g., selected sensors of the required phenomena is the configuration, and a model is the logic for the calculations.

Alerting mechanism is also a crucial part of the application. It triggers an event if some threshold rules are violated. For instance, an advanced scenario can be configured as follows - raw values of a temperature must be in the interval <-10;50>, an average value on a defined interval must be higher than 0. In a case of violating some of the rules, the application sends an alert via email or uses the SensLog Alert mechanism, which can be integrated to other systems (e.g., for automatization). Calculated statistics are then stored back in the database and are accessed via web APIs.

Data visualization

Visualization of measured data and results of analytical functions are important functions for end users of the whole system. The proposed system was using the SensLog Client application. The application is available for web and responsive for smartphone interface. The SensLog Client application provides visualization of sensor data in the form of charts (see Figure 7) as well as a map window with location of sensors (see Figure 8). Visualization of sensor data in form of charts is using the Vega visualization grammar. Vega describes the interactive visualization in JSON format and then the final view is realized by Canvas or SVG graphics. This approach provides effective visualization of different combinations of time series of data and set of user-defined views of collected data.

Map visualization of sensor location provides additional functions for map compositions with other data layers. Map window contains different data layers:

- general base map,
- soil map of the locality with additional information from local samples,
- weather forecasts and meteo models for locality,
- locations of sensors,
- interpolated results of analyses.

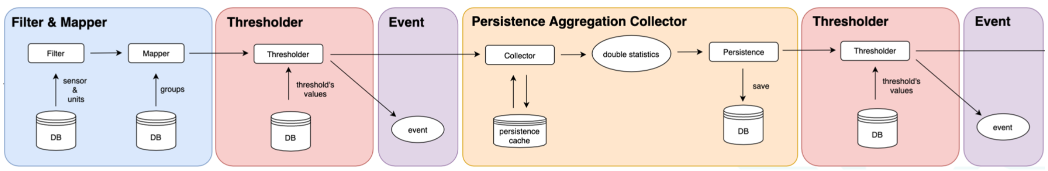

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Figure 6: Structure of SensLog Analyst components.

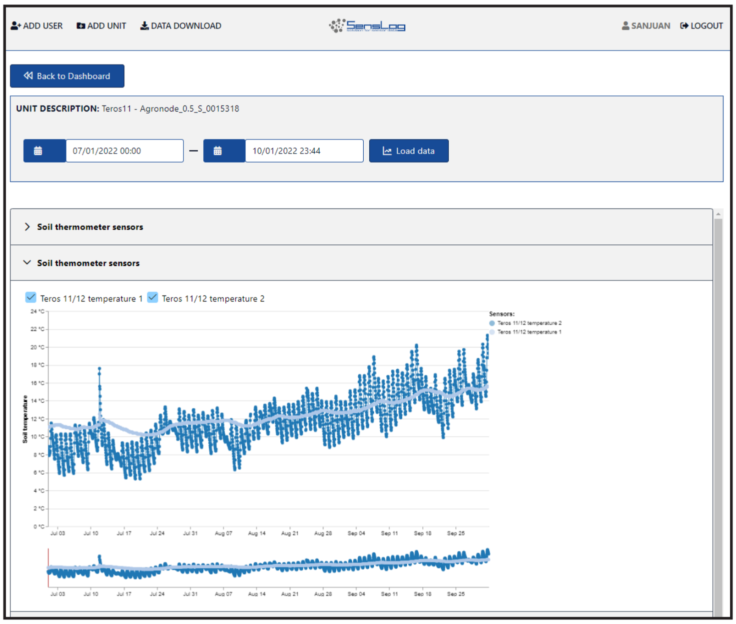

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Figure 7: Example of chart visualization.

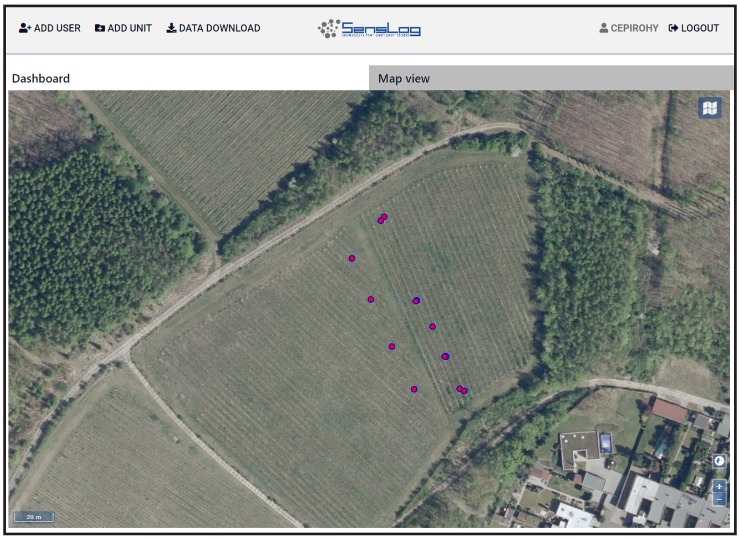

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Figure 8: Example of the map window with locations of sensors and orthophoto layer.

Results and discussion

The developed system provides monitoring and sensor data management part of the whole system for optimization of water and nutrient management. The monitoring system utilizes commercial sensors for monitoring of different phenomena and existing components of the SensLog system to collect, store and publish sensor data.

Monitoring campaign in pilot localities was prepared during spring 2020 in the Čepirohy locality respectively in winter 2020 in the San Juan locality. Data were collected with a frequency of an hour in both localities. Four sets of soil sensors, one meteostation and inundation detector were installed in San Juan locality where sensors collected about 8,000 resp. 17,000 observations during 24 months of installation. Twelve sets of soil sensors, two meteostations were deployed in Čepirohy locality where sensors collected about 13,000 resp. 19,000 observations during 32 months of installation. Sensors in both localities were operating for 65-100% of deployed time. The malfunction cases were generated by different aspects - hardware malfunction, solar panels coverage by leaf, wild animals gnawing of cables especially in Čepirohy locality etc. The detection of non-operating states of monitoring units was improved during the monitoring time by development of a monitoring and alerting component – SensLog WatchDog.

SensLog WatchDog

The new component that was developed as a part of the alerting mechanism is the SensLog WatchDog component. Collecting observations is a complex task (see SensLog Data Flow), which consists of several nodes and technologies. And even if they are developed with a high availability by design, some unexpected conditions could appear (e.g., hardware damage by animals, radio jamming) and the fluent data flow is broken. This leads to some problems - a hardware unit (i.e., a sensor) has an issue and should be repaired as soon as possible; and the void of time-series observations cause a problem for the statistics calculation. To minimize such consequences, we developed WatchDog. The application periodically monitors the presence of observations and sends a report to the responsible people.

The core functionality is simple, but the power of this tool is given through its configuration ability. WatchDog is a stand-alone application and uses the REST API of the SensLog, which extends the usability of monitoring more SensLog instances (i.e., a data source) just via one WatchDog. This brings an advantage of summarizing more results to just one report, e.g., sending an email of the results from multiple data sources to a service support.

Sensors and units form a sensor network which then can be grouped and give a name that is usually chosen by the operating area. Due to a diversity of responsible people, not everyone is interested in everything, because such networks could be quite large, so WatchDog enables a detailed configuration of desired level - entire group, particular units, or selected sensors. To allow monitoring from different data sources, the configuration includes an option to merge multiple groups as well. Special functionality is monitoring a single sensor across multiple units or groups. This may be primarily useful for a technician who is interested only in one phenomenon (e.g., battery level) across all networks.

Such configurations of observable entities are further assigned to a message broker. The architecture and the configurations allow further extensibility of multiple message brokers (e.g., instant messages services), however current configuration allows reporting only by email with an option of specifying respondents for each observable entity.

The visible part of the application is the report. It is generated periodically every day at a specific time and contains a present of an observation during the previous day. The result is formatted into two separate tables. The first one contains all configured units where each row is under-colored by linear gradient visualizing an information of how many sensors either passed or not (e.g., 2/4 passed then the background of the row will contain half green and half red color). The second table contains only the failed sensors with timestamp information of the last observation.

Such a report is then sent to the recipients to have a status of their networks of sensors and respond to some issues that could eventually occur as soon as possible.

SensClient configuration & visualisation

Components of SensLog platform mainly operate without a user graphic interface and communication is done via web APIs or static start-up initialization. Nonetheless this approach may be inconvenient for some operators, so the SensClient aims to configure the components in featured oriented style by web application. Such various configurability among other components (e.g., a logged user can enable a monitoring for a specific sensor and the report is sent to his assigned email address) is an aim, however current version allows a management of sensor network.

Beside the configuration abilities, the SensClient visualizes the sensor network as well. The main overview is a dashboard placing all units onto a geographic map. Each unit can be opened, and all assigned sensors will be displayed, and a chosen sensor will then visualize its data in a chart. Some specific multi-sensors also allow multiple curves within one chart (e.g., groundwater measurement in various high levels). Such graphical data visualization is convenient for users due to easy and quick data correctness checking.

Conclusion

The main outcome of the whole activity was the development of a next-generation IoT-based alerting and monitoring system using interoperable interfaces to optimize water and nutrient management in agriculture. A crucial step for the alerting and monitoring system is the design and establishment of a monitoring and sensor data management system. The monitoring and management part is producing sensor data that are stored, processed, and provided for other components for further processing and decision-making. Further components utilizing monitoring data by the set of SensLog services provided soil condition modelling and then evaluation for decision-making. The final product provides data support for decision-making to optimize water management or nutrient management in localities.

The presented monitoring solution provided a complex component of the whole system that provides interfaces by defined APIs to ensure interoperability between components of the system. Amount of collected sensor data and continuity of data time series has shown that selected technologies and processes of the monitoring system are suitable for the defined tasks of the complex alerting and monitoring system.

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