Sound-maps of environmentally sensitive areas constructed from Wireless Acoustic Sensors Network data

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Abstract. “E-SOUNDMAPS” is a distributed microelectronic system for the sound/acoustic monitoring of areas of environmental interest that is based on an appropriately designed wireless acoustic sensor network (WASN). It involves the automated generation of multi-level sound-maps for environmental assessment of areas of interest. This paper focuses on the method and the software application for the construction of sound-maps, which is developed as part of the integrated “E-SOUNDMAPS” system. The software application periodically produces geographically-referenced, accurate environmental sound information, based on real-field measurement data, and integrates them in the geographic map of the area of interest in a concise and comprehensive manner. Following the field recording of sound and the hierarchical recognition/classification of sound events and corresponding sources, the obtained sound sources characterization tags feed the specific software application. The output is a multi-level soundmap, constructed on the basis of the data and published electronically on the Web, for human inspection and assessment. All necessary steps for handling, archiving, monitoring, visualization and retrieval of sound data are also presented.

1. Introduction

In recent years, electronic monitoring of areas of environmental interest has emerged due to the advances in electronics, computers, and radio communications and has attracted considerable interest by academia and industry [1, 2]. In the context of environmental protection and prevention strategies, the sound/acoustic component plays an important role, since it provides critical information related with both the current status of environmentally sensitive areas and the spatio-temporal evolution of anthropogenic activities and/or natural/meteorological/geological phenomena that significantly influence this status. By exploiting sound/acoustic monitoring instead of other alternatives, i.e., optical monitoring by cameras, is time- and cost-efficient, as well as less sophisticated. The exigencies for protection of high quality acoustic environments has been also recognized by EU Directives
This paper considers an integrated system, called “E-SOUNDMAPS”, which incorporates a distributed microelectronic networking system (DMNS) for the sound/acoustic monitoring of areas of environmental interest. This subsystem is based on an appropriately designed small-scale wireless network of acoustic sensors, i.e., microphones, and attempts to automatically generate multi-level soundmaps for environmental assessment. In general, sound maps concisely depict the results of recognition and illustrate in a specific geographic point on the map the sound sources information in multiple levels of detail [5–7]. As far as field measurements of sound/acoustic events in a selected area of environmental interest are conducted, a hierarchical recognition/classification scheme for the classification, recognition and characterization of sound/acoustic events and sources (fauna, meteorological, anthropogenic and further detailed analysis into subclasses) is developed and the generation of multi-level soundmaps is automatically generated. In this paper, a valuable software web application for sound/acoustic monitoring fed by the sound sources characterization tags is presented. This application is capable of visualizing the recorded sound/acoustic environmental information based on real-field measurement data (provided by the aforementioned DMNS) on the geographic map of the area of interest and automatically publish and update the critical information for human inspection and assessment. A relational database model and a client-server architecture are exploited to construct the proposed application.

The remainder of the paper is organized as follows. Section 2 describes the system architecture, whereas Section 3 outlines the design and implementation of the database, where the useful information is stored. Section 4 details the web application that visualizes the processed sound data. Finally, Section 5 provides concluding remarks.

2. System Architecture

In this paper, a DMNS equipped with acoustic sensors is considered. The DMNS is capable of recording the sound/acoustic information of a specific area and then transmit this information to the central network site, after conditioning, pre-processing and coding for compression. The field-recording of sound/acoustic sources and events, at a selected set of cartographic points span the area of interest, taken at seasonal, daily and spatial resolution. Signal detection and digital processing methods are employed to localize sound sources and events (onset and endpoint of sources of interest, possibly overlapping) across the sound recording; a novel hierarchical scheme is developed for the classification, recognition and characterization of the sources. Sound sources characterization tags feed the software application that generates multi-level soundmaps and publishes them electronically for human inspection and assessment. A pilot wireless sensors network (WSN) is employed to support the software applications as well as the study of requirements (in hardware/computations, energy, communication resources) for the scaling up of the pilot network into a full-scale deployment. This deployment involves several tasks, such as programming and managing the sensors, programming the gateways, interpreting and processing the data streams, and setting up servers for data archival and retrieval.

Depending on the area coverage schemes, different communication protocols between network units and associated network architectures can be utilized. In particular, for limited area coverage, the Integrated Peripheral Units (IPUs) are distributed over the area of interest and communicate wirelessly by using the IEEE-802.11.x protocol (wireless local area network – WLAN) with the Central Network Unit (CNU). On the contrary, a number of appropriately distributed Intermediate Network Units (INUs) gather a group of IPUs each (local area network – LAN) and communicate with the CNU by using Worldwide Interoperability for Microwave Access (WiMAX) or Global System for Mobile Communications (GSM) technologies (wide area network – WAN), when extended area coverage is required. The hardware of DMNS and the communication network architecture and protocol are designed and realized in a
functional prototype form and support long-term operation. The scope of the aforementioned system is the development of a software application for the localization and hierarchical recognition/characterization of sound sources and events within sound recordings. This application superimposes, regularly updates, and electronically publishes the sound data on the digital geographic map of the area in web format and in multiple layers of detail for visual inspection. The primary information produced by the proposed software should be initially processed. This information can be properly visualized and the soundmaps can be composed, as long as the processed information is transferred and stored in a database. Next section handles the design and implementation of this database.

3. Design and Implementation of Database
The database is designed according to the simplified entity-relationship (ER) model [8] shown in Fig. 1, where primary key attributes are underlined. Entities correspond to (a) the sensor

![Figure 1. The simplified database entity-relationship model.](image)
network nodes, namely the Central Processing Units (CPU), and the Integrated Peripheral Units (IPU), (b) to the sound events generated by the IPUs, and (c) to the classes to which these events are associated. Network node attributes are selected such as to allow the identification of each specific node, i.e., via the “identifier” attribute, the definition of its precise location, i.e., via its geographical coordinates, together with other spatial information if applicable, i.e., sensor coverage radius, as well as its position within the network hierarchy which is, for instance, determined by the code of the CPU to which a specific IPU is attached. Similarly, sound events inherit the spatial properties of their parent IPU, while temporal information, i.e., a timestamp, is also necessary in order to define an events location on the time line. Incorporating the results of the classification procedure, each sound event is also mapped to a specific class that is explicitly identified by its 1st, 2nd and 3rd level category codes. The structured design of the database allows the generation of alternative soundmap visualizations, based on different spatial and temporal criteria, as well as the composition of various statistical reports, as described in the following section.

The practical implementation of the database follows a client-server architecture, where a MySQL database server is used for central storage of the information, in order to ensure security and compatibility and ease development and integration. MySQL is widely accepted and supported across many platforms and coding languages and capable of describing the network hierarchy, the classified sound events collected from the network nodes (tagged in space and time), as well as the class hierarchy used for sound event categorization. Remote access to the stored information is allowed to soundmap clients, which can apply custom queries in order to retrieve spatiotemporal slots of information, based on user preferences.

4. Design and Implementation of Web Application
In raw data format, a soundmap consists of all the spatio-temporal information that describes the classified sound events being collected from a specific sensor network. While data related to the network topology is stationary requiring update only after network modifications, i.e., when sensor nodes are added or removed sound event data correspond to a rather large volume of information that should be periodically updated. Such a procedure, that involves loading recent classified sound events to the database, is performed by the sound event classification software and is indicated as “soundmap synthesis/update” in Fig. 2 (see interface I1), which illustrates the modules involved in soundmap generation and visualization. In order to provide a soundmap visualization according to user preferences, a web application was designed that

![Figure 2. Soundmap synthesis, update and visualization modules.](image-url)
handles the interaction between users and the database, and is responsible for querying the appropriate information and for its visual representation in the users web browser (see interface I2 in Fig. 2). This application has been implemented using open-source web technologies, e.g., php, Google maps, javascript, etc.

A typical soundmap visualization is shown in Fig. 3, where the graphical user interface (GUI) is also presented. The soundmap visualization provides a graphical representation of the supervised area of environmental interest, where the sensor network elements are presented as marker overlays. Classified sound events associated to a specific IPU over a certain time interval are also represented by their corresponding class markers, while the classification tree level is user configurable. A control panel provides access to recent event information, while the user can navigate to older soundmap snapshots using the “history” selector. Furthermore, the user can request the generation of various statistical reports by defining several criteria, such as the period of time, specific IPUs, specific sound events/classes etc. Based on similar criteria, the GUI also allows the definition of specific alerts which are automatically activated when the user-defined rules are reached or violated.

While soundmap synthesis and update are rather simple procedures that involve loading the tagged sound event data into the database, soundmap visualization is a complex procedure that involves several interoperating software modules, as shown in Fig. 4 and described below. A client-server architecture is adopted, where the servers functionality is implemented in system S2 (see also Fig. 2) to which client systems have access through the World Wide Web. This system hosts the database (DB) and also incorporates web server and dynamic web-page generation software modules. Client communication with the server is exclusively performed through the clients web browser software. Apart from the main soundmap server (S2), client machines also retrieve spatial and terrain-specific information from the geographical map providers server, i.e., Google Maps, and may also connect to other external servers in order to maintain access to specific services, i.e., statistics visualization.

Fig. 5 illustrates a simplified sequence diagram [9] that describes the phases involved in soundmap visualization. The corresponding steps (indicated by the circled numbers shown in
Figs. 4 and 5) are analyzed as follows:

(i) Clients web browser software sends a soundmap web-page request to the server 1.
(ii) Web server requests the main soundmap web-page from the dynamic web-page generation software 2.
(iii) Dynamic web-page generation software connects to the database, from which the current digital soundmap representation is retrieved in order to synthesize the soundmaps main dynamic web-page that incorporates all specified functionality provided by its graphical user interface 3.
(iv) Main dynamic soundmap web-page is forwarded from the dynamic web-page generation software to the web server 2.
(v) Main dynamic soundmap web-page is forwarded from the web server to the clients web browser 4.
(vi) By execution of the client-side software code that has been incorporated to the soundmaps web-page, the client may establish connections to external servers, in order to complete soundmap visualization, namely to retrieve and display the underlying geophysical map and also to provide statistics visualization features 5, 6.

Note that the soundmap dynamic web-page retrieval sequence shown in Fig. 5 is repeated periodically in an automatic manner, with a frequency that is related to the database update frequency. However, external services call is a user-initiated procedure.

Due to the wide employment of MySQL during the last years, many software packages and interfaces have been developed to facilitate the communication between the database and several programming language and software applications. Among these applications, Microsoft Excel is a simple and user-friendly but operational way of interconnection with a MySQL database. Alternatively, MATLAB software package can be used, which represents a complicated and
approach. Microsoft Excel enables the organization of data in rows and columns, the accurate and efficient process of data, the automatic realization of mathematical operations, and the visualization of data through graphs. To enable the automatic interaction between the MySQL database and spreadsheet files of Microsoft Excel, the “MySQL for Excel” Add-in is used [10]. This simple, flexible, friendly, and accurate tool allows for real-time data import/export. In particular, the MySQL data can be imported into Excel, Excel data can be exported into MySQL as a new table or appended to a current table, and MySQL for Excel enables the edit of the MySQL data directly though Excel. MySQL for Excel is loaded and executed by selecting the “Data” menu tab in Excel, and choosing the “MySQL for Excel” Database icon. Then, a new Excel sidebar with the available MySQL for Excel options is opened. To access the data obtained from previous layers of the proposed web application, the desired information is sent to a gateway computer and exported into Comma Separated Values (CSV) files using specialized algorithms, which analyze and separate the raw byte stream [11]. The CSV format files store tabular data, i.e., numbers and text, in plain text. Hence, the file is interpreted as a sequence of characters and each line of the file is a data record, which consists of one or more fields, separated by commas. Indeed, these files represent sets or sequences of records in which each record has an identical list of fields and can be directly read by various software packages, including Microsoft Excel, Matlab, Open Office Calc, Google Docs, etc.

Figure 5. Simplified sequence diagram for soundmap visualization.
5. Conclusions
In this paper, a valuable web application that registers and accurately and periodically records and visualizes sound/acoustic environmental information on the geographic map of the area of interest has been presented. The periodic update of soundmaps is designed on the basis of real-field measurement data that are electronically communicated to the software application. Using this application, environmentally sensitive areas can be monitored and the impact of anthropogenic activities/uses as well as the evolution of natural factors (fauna, climate) can be demonstrated. Target groups for the exploitation of the proposed web application are environmental/ecological groups, organizations or agencies as well as central and local governmental agencies involved with development and protection of the physical environment.

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