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Online data mining services for dynamic spatial databases II: air quality location based services and sonification

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This paper introduces online data mining services for dynamic spatial databases associated with environmental monitoring networks. In particular, it describes an application that uses these services with sonification for air quality location based information services to the general public.

The data mining services use Artificial Neural Networks, to find temporal relations in the monitored parameters. The execution of the algorithms performed at the server side and a distributed processing scheme is used to overcome problems of scalability.

In addition, two other families of web services are made available to support the discovery of temporal relations: vectorial and raster map? services and a sonification service. The map services were implemented in DM Plus, a client application presented in part I. The sonification service is described in this paper and illustrated through an application study that implements an air quality index with sonification for mobile phones.

KEYWORDS

Online data mining services, location based services, sonification, artificial neural networks, dynamic spatial databases, air quality monitoring networks.

INTRODUCTION

Wireless Internet users are realizing the value and potential to make information services highly personalized. One of the most powerful ways to personalize mobile services is based on location. The increasing importance of cellular location systems allowing people to identify their location using a cellular phone is promoting the growth of location-based services [16].

Location-based services (LBS) are services that are provided to a user based on his or her location. They filter and deliver information most relevant to the users. LBS play a major role in the evolution of wireless data services and may provide significant revenue to mobile operators and content providers.

An increasing number of examples of LBS applications can be referred. These applications have geospatial data handling functions and the integration of geo-referenced information with other types of data. LBS may allow getting driving directions, real-time traffic information, routing and nearest business and attraction locations. Other applications include weather and travel schedules associated to the specific location of the user or the integration of location-based service and emergency response systems. This specific area of application is associated to public safety which includes issues relevant to everyday concerns such as accidents, local disasters, natural threats such as hurricane/cyclone or tornadoes, personal security, and health related issues [17].

This paper describes a sound data mining application to provide air quality location-based information services to the general public. Given the importance of this data to public health, the obtained air quality previsions/forecasts? are provided for the next day, thus resulting in a way to prevent exposure to high levels of certain air pollutants. The data mining services are described In the first paper “Online data mining services for dynamic spatial databases I” that presents the first two layers in greater detail together with DM Plus (client application) implemented on a fixed Internet platform. Part II is described in this paper and will focus on the application for an air quality monitoring network using a mobile platform with sonification services as the front-end interface.

LOCATION BASED AIR QUALITY INDEX FORECAST

The air that we breathe affects the health of populations, mainly of the sensitive group whose breathing capability is still developing or injured (children, elderly and asthmatic patients). Urban population is exposed, day by day, to dangerous levels of atmospheric pollution inherent associated to multiple effects on human health including breathing diseases, increase factor of suffer from cancer or heart diseases.

For pollutants like the ozone, the actual measured concentration is of the most importance in alert systems for air pollution. Besides the actual values, the prediction of the concentration of the pollutants over time represents an important field for the evaluation of the risk associated with a specific pollutant or an assemblage of pollutants through an air pollution index.

The forecast of future pollutant concentrations has been made by numerical models, statistical methods and more recently by techniques known as data driven modeling. The later has been wining popularity in the scientific community by the growing historical information of the pollutants and by the growing mathematical knowledge of the data mining techniques used like, for example, the training of artificial neural networks (ANNs).

Numerical models are quite difficult for pollutants like the ozone because the meteorological variables and photochemical reactions involved in its formation are complex. This, associated with the success of ANNs over the “traditional” regression models, has been fostering the use this data mining technique in air pollution prediction [13].

The Air Quality Index , available online through the air quality monitoring network Web site managed by the Portuguese Environmental Institute (IA), allows a simple and direct air quality classification. The Web site also provides information about immediate public health associated hazards, based on present monitoring values.

The application study in this paper used a similar index for the prediction of air quality in the north metropolitan area of Lisbon. The applied data series were taken from three monitoring stations in this area: Entrecampos, Olivais e Loures. The air quality index is composed by the following parameters: nitrogen dioxide, ozone, sulphur dioxide and inhalable particles [7]. Each parameter can be classified according to its concentration in the air, ranging from Very Good to Bad. The index is calculated as the lowest of these four parameters.

Historical data of concentration values and external estimations of various parameters is used to forecast today’s value of the air quality index [6]. The previous records of the pollutants are composed by several previous days’ measures (usually ranging from one to three days) of certain parameters. Other external parameters are used, not only as historical data, to provide information in order to train the model, but also as estimated values, to set a basis for the prediction of the dependent variable. These variables consist on weekdays, existence of transport company strikes and meteorological forecasts such as maximum temperature, wind direction, wind speed, humidity and precipitation. Applying pre-processing techniques using variable transformations and statistical analysis such as correlation, regression and principal components analysis it is possible to select the data series that better express the dependent variable.

The DM Plus for QualAr was used to train artificial neural networks for the forecast of each parameter of the index [8], [9]. A series of testing procedures were made in order to achieve the most optimized model solution [10], [11]. This allowed the setting of a group of neural networks input parameters (number of iterations, neurons in the hidden layer and fraction of training data for the algorithm) and variable parameters (aggregation and periodicity). Each neural network is automatically re-trained with these parameters on a daily basis by periodically sending tasks with new data using the online data mining services, in order to integrate updated data for future estimations.

By using Location Based Services (LBS) on the air quality index through a mobile platform the general public can obtain localized information, in real time, about the air quality in his/her surroundings. The user can query the system database by providing his/her current location with a mobile phone that reports the current GSM (Global System for Mobile communications) cell. If the information for a nearby station is available, the air quality LBS will report the forecast for the local air quality index.

SONIFICATION ARCHITECTURE

The use of multimodality in human-computer interfaces is motivated by our daily interaction with the world. In everyday life humans communicate and interact using several channels which are interdependent and complementary. In the last two decades the developing Auditory Display (AD) community has demonstrated that using audio at the human computer interface can improve its usability [15].

During the design of an auditory interface system, the relevant context is the interaction in which the sound is used and the context in which the interaction takes place. It is important to analysis the relationship between the context in which a sound is used i.e., interaction with the interface, and the sound itself contributes largely to the perceived aesthetic qualities of the sound, of the interface and hence to user satisfaction. Thus, in our system, the air quality index is sonified based on information analysis from the different pollutant concentrations. Sonification is the use of non-speech audio to convey information [2]. It is of special interest when there is high volume of data and number of variables; in these cases it may be useful to present part of the information visually and part through audio [3]. Audio can also be used to increase perception of the information that is being graphically displayed or may be used to present information that cannot be visually displayed [4]. In our case, the air quality index and each pollutant are associated to a sound. A melody is composed according to a composition rule that specifies the order and duration of each sound.

During the design process, several parameters have to be analyzed as they affect the design's aesthetic qualities. The challenge of the design is to create a sonification that conveys a relevant subset of the information presented in an acceptable time interval. Indeed, one of the main constraints of the design is to keep the duration of the sounds as short as possible. Although there is a lack of work dedicated to auditory interface aesthetics, a few results can be found in the literature mainly on Leplâtre paper [14]. The design recommendations described below have been used by the authors as a basis on the auditory design:

- Homogeneity of the design – Differences between sounds are often maximizing so that sounds are more easily distinguishable. This compromises the homogeneity of the auditory interface and hence its overall aesthetics.

- Temporal envelope – Frequently, sounds in auditory interfaces must be brief and interruptible. Thus, the information expressed by the sound should preferably be located in the onset of the sound and fade-ins and fade-outs should be used to soften the transition between the sounds.

- Sonic density – Briefly, sonic density refers to the perceived density of a sound. Key parameters are duration, intensity, spectrum, number of instruments, etc.

Due to limited graphical capabilities and processing constraints of the targeted platform (wireless mobile phone) a sonification server and sonification service tools were developed. The Sound Server design follows three premises:

- The server must accept requests from clients in different platforms.
- Clients have different audio rendering and synthesis capabilities.
- The server should provide a set of high level sonification modules.

The Sound Server design is based on the idea of sonification modules. A sonification module is an entity within the server that represents a particular sonification method. The server can be configured with a multitude of sonification modules: a module that sonifies an absolute value, a module that implements a parameter mapping sonification, a module for the sonification of a particular descriptor, such as density, and so on. A client may ask for the result of several modules in one single request. The main output of the server is a sound file with the sonification requested by the client.

The sonification modules should be self-describing, i.e., there should be a way for the client to ask the module what tasks it performs and what parameters can be controlled. In its simpler form this description could be just a text message informing the user of how the sound should be interpreted. The server should also provide a listing of the available modules.

The main output of the server will be a sound file with the sonification that the client asked for. The client may ask for the sonification of several modules at the same time, and instruct how the several modules should be grouped together in the resulting sound file. If the client asks for module A and B, it may want the respective sounds on the same channel, or in different channels, synchronized, or displaced in time. The client may also specify other parameters of the output, as the sound quality (bitrate and samples per second), the output format (mp3, wave, aiff), etc.

The server is accessed through HTTP, enabling clients to use it like a regular Web Service. This will facilitate the access by a wide variety of devices since the HTTP protocol is widely implemented. Clients with greater synthesis capabilities should be able to process the sonification locally, needing to communicate with the server only to obtain the sonification module.

The server is composed by two main units: Web Server Unit and Synthesis Unit (Figure 1). The Web Server Unit is responsible for the communication management. This unit functions as a proxy to the Synthesis Unit adapting the requests from the clients to the correct syntax needed by the Synthesis Unit and vice-versa. It will offer the client applications three interfacing modes: URL-encoded parameter-value pairs through the HTTP GET method, XML document encoded requests sent through the HTTP POST method and SOAP-RPC requests through HTTP. Providing these different interface modes will allow for a wider range of supported client platforms and applications.

It also allows for different levels of complexity in the messages exchanged between clients and the server, since messages structured in XML documents can be more complex than messages encoded in the URL, for example. For increased performance, this unit will cache the requests so that the same request is processed only once.

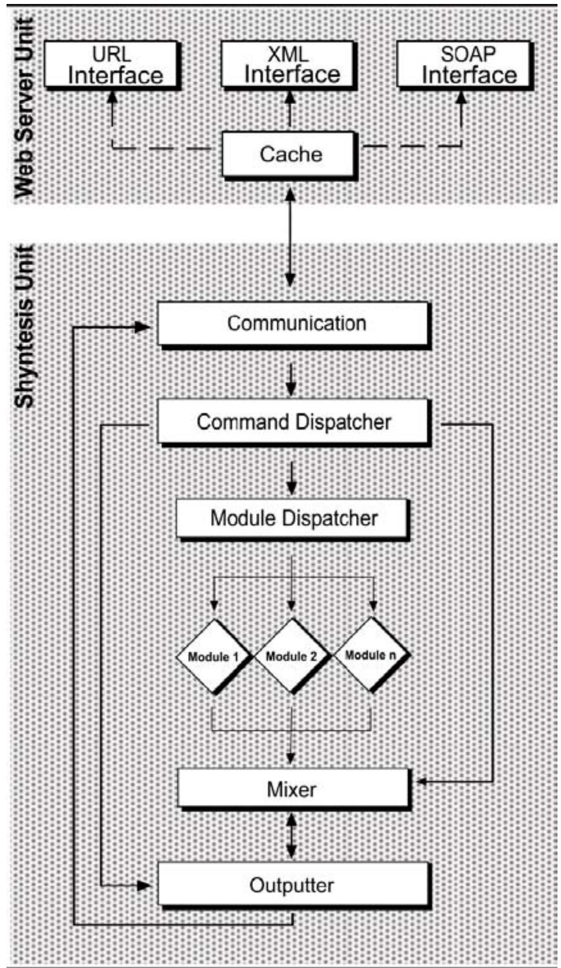

Figure 1 Sound Server Architecture.

The Web Server Unit can itself be decomposed in four subunits:

- **URLInterface** Accepts requests in URL-encoded parameter-value pairs. This is the simplest interface to the server.

- **XMLInterface** Accepts requests encoded in XML documents. This interface will allow for more complex messages to be exchanged between client and server.

- **SOAPInterface** Will provide a SOAP-RPC interface to the server. This interface will allow clients to access the server as a Web Service [5].

- **Cache** Caches requests from all types of requests. The request is routed to the Synthesis Unit only if it cannot be found in the cache.

The Synthesis Unit constitutes the nucleus of the sound server and is where the actual sonification takes place. It is composed by the following subunits: Communication, Command Dispatcher, Module Dispatcher, Sonification Modules, Mixer and Outputter.

The Communication subunit manages the communication between the Web Server Unit and the Synthesis Unit. It is able to manage concurrent requests/responses.

The Command Dispatcher receives commands from the Communication subunit and routes them to the appropriate subunit (Module Dispatcher, Mixer or Outputter). This is needed because both the Mixer and the Outputter can be configured by the client.

The Module Dispatcher subunit has a similar function to the Command Dispatcher. It routes commands to the appropriate sonification module, enabling the client to pass parameters to them.

The Sonification Module is where the actual sonification takes place. These subunits are independent modules that can be added or removed from the server. We can think of them as a kind of plugins for the sonification server.

The Mixer is responsable for the final integration of the several sound streams into one file, according to the client specification. It gathers the audio signal from the sonification modules and combines them in a single audio stream.

The Outputter subunit takes the output from the Mixer and generates a sound file in the format, and according to the settings set by the client. This subunit can be configured to generate sound files in different formats and with different audio quality so that each client can adjust the sound to its capabilities.

These two units: the Web Server Unit and the Synthesis Unit can be loosely coupled, i.e., we can have them runnning on different machines, allowing more complex topologies, if necessary.

INDEX SONIFICATION FOR MOBILE PHONES

A java application was develop for mobile phone to access sonification service (Figure 2). The client can connect to the air quality service provider and request information regarding the air quality status. Mobile phones have strong limitations concerning visual data representations. Thereby, a sonification process was thought to add value in reporting the air quality index to the user.

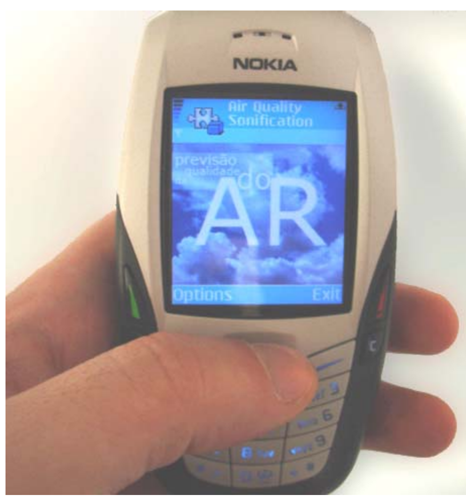

Figure 2 Prototype of Air Quality Sonification.

This process relies on the mobile’s internal synthesis by using the MIDI (Musical Instrument Digital Interface) protocol. Distinct MIDI files are generated on the Sound Server, upon request, and sent back to the mobile phone. The user can then listen to the sonification of both the index and its parameters. The index sonification uses this information to create a melody that represents these values by pitch variations of five midi notes played sequentially.

Several different sonifications were evaluated by a user panel: 5 MIDI based and 2 sound sample based sonifications. The MIDI sonification differ in the number of used instruments (same for all the parameters versus one instrument per parameter), the duration of the air quality index (present all time versus interchange with parameter sound representation). The sample based sonifications differ in the selected sample sounds.

The evaluation tests were conducted through a web survey performed in our facilities (http://soundserver.porto.ucp.pt/sdm/audtest). Each user after hearing a sonification evaluated the index and each individual parameter. Each answer was recorded and the geometric distance to the correct value measure (Table 1).

sonification	Average error per parameter					
	index	sulphur	ozone	particles	nitrogen	distance
MIDI-1	0,06	0,16	0,19	0,23	0,22	0,53
MIDI-2	0,18	0,36	0,26	0,29	0,31	0,85
MIDI-3	0,10	0,33	0,31	0,29	0,32	0,83
MIDI-4	0,14	0,19	0,17	0,21	0,14	0,41
MIDI-5	0,02	0,19	0,43	0,33	0,19	0,82
SAMPLER-1	0,75	0,93	0,58	0,95	0,88	2,37
SAMPLER-2	0,07	0,83	0,36	0,50	0,38	1,47

Table 1 Average error per parameter.

It was also recorded the number of times the user played each sequence and the time duration needed to evaluate each sonification file. The best results were obtained with MIDI sonifications with small computed distance error.

CONCLUSIONS AND FUTURE WORK

This paper has described a sound data mining application to provide air quality location based information services to the general public. A preliminary test to validate if the user's perception of the air quality index sonification is correct has been concluded successfully.

The importance of auditory interface aesthetics and of sound aesthetics in this context needs to be further study. The relationship between sound aesthetics and user satisfaction is crucial and, despite the available existing auditory design methods and guidelines, none are dedicated to achieving aesthetically pleasing designs. In future work, the author plan to conduct an empirical investigation to assess the relationship between the functional and aesthetic value of an auditory interface in this context.

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