ADVANCES IN *SOFT COMPUTING*

Barbara Dunin-Kęplicz · Andrzej Jankowski
Andrzej Skowron · Marcin Szczuka
Editors

Monitoring, Security, and Rescue Techniques in Multiagent Systems

Springer

31

Intelligent System for Environmental Noise Monitoring

Andrzej Czyżewski[1], Bożena Kostek[1,2], and Henryk Skarzyński[2]

[1] Gdańsk University of Technology
ul. Narutowicza 11/12, PL-80-952 Gdańsk, Poland
ac@pg.gda.pl
http://www.multimed.org/

[2] Institute of Physiology and Pathology of Hearing
sekretariat@ifps.org.pl
ul. Pstrowskiego 1, 01-952, Warsaw

Summary. The telemonitoring system, developed at the Multimedia Systems Department of the Gdańsk University of Technology is discussed, aimed at environmental noise levels monitoring. A system presentation was provided, consisting of descriptions of the following elements: noise measurement units, computer noise measuring software, Internet multimedia noise monitoring service and soft computing algorithms applied to the analysis of the system database content. The results of noise measurements were compared to those obtained with acquired subjective opinions on noise annoyance. A new GIS layer was produced on the basis of this study employing data produced with soft computing algorithms. The engineered intelligent application may help in diminishing hearing problems and other diseases occurrence caused by environmental & industrial noise.

31.1 Introduction

A considerable portion of hearing and psychosomatic diseases is caused by excessive industry, urban and traffic noise or any unwanted sounds occurring in everyday life. Consequently, it is expected that a reduction of their occurrence will be achieved as a result of implementation of the solutions that have been developed within the project scope. The latest technological advances in information technology were used in the course of the project realization [1][2]. Consequently, it is shown in the paper that the presented solutions are based on some innovative ideas and inexpensive technical means for measuring noise and assessing its annoyance [6][7][8]. The intelligent processing of resulting data allows fast evaluation of noise influence on humans. It is expected that implementation of the noise telemonitoring system covering whole country will contribute to rising awareness of society and authorities with regard of the influence of noise on health. Furthermore, it turns out to be an essential factor in the future improvement of the environmental noise conditions.

31.2 System design

The recently developed multimedia noise monitoring system is addressed to all users interested in problems related to noise. It offers not only objective noise measuring methods, but also electronic questionnaires for subjective opinions survey. The measuring noise system consists of the following functional elements: a USB device with a measuring microphone which is used for signal acquisition (the device can be connected to any PC computer equipped with USB interface) and a software for calculating noise parameters (Fig. 31.1) according to valid norms [3].

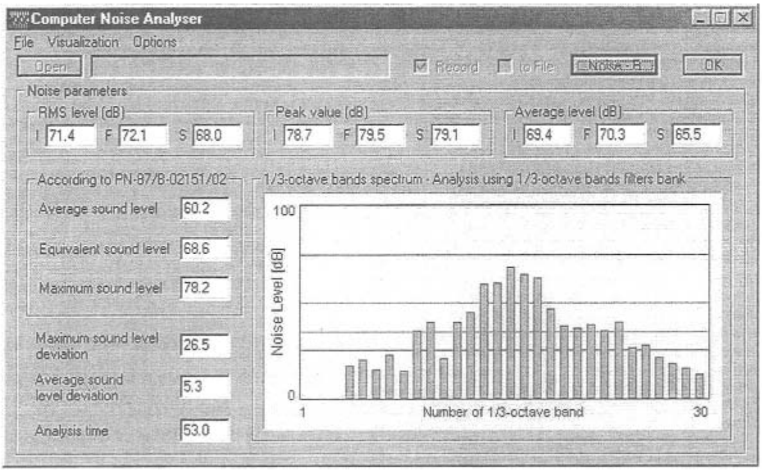

Fig. 31.1. Sample window of the noise measurement program.

The application cooperates with the USB device and another system component, which is an Internet service with specially dedicated database open to exploring with data mining algorithms. For the needs of remote and continuous noise measurements, another device based on specially designed microcomputer was developed. The device enables continuous measuring of noise and makes it possible a wireless transmission of results to the database of the system. Consequently, the system was equipped with a modem for data transmission by the GPRS protocol. The elements of the device are presented in Fig. 31.2.

The implemented calibration method allows ones the usage of the developed sound interface and the measuring microphone. When the measurements are over, the program can send results through the Internet to the central server for their common storage, processing and analysis.

Noise measurement in Multimedia Noise Monitoring System uses client's PC system or dedicated embedded miniature PC computer system for automatic measurements. The prototype device developed to achieve these goals offered extended functionality compared to the requirements of MNMS (Multimedia Noise Monitoring System) system [2]. The extensions resulted from the idea that the same device could also be used in telemedical applications developed earlier by the staff of the Multimedia Systems Department with a close co-operation with Warsaw-based Institute of Physiology and Pathology of Hearing [4,5].

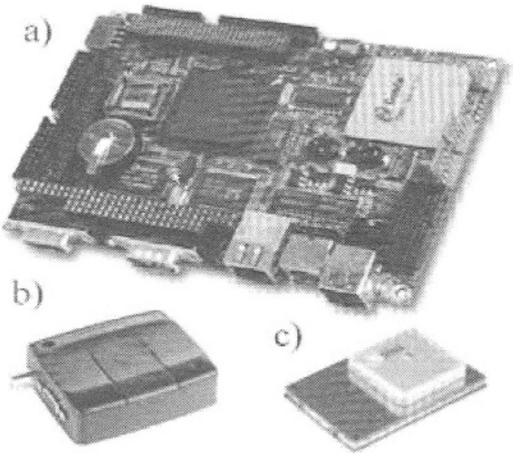

Fig. 31.2. Components of the environmental noise monitoring system: a) compact computer; b) GPRS (General Packet Radio Service) sender; c) GPS (Global Positioning System) receiver

It was assumed that every measurement would be triggered by the PC host and would consist of two phases. During the first phase the system records a noise sample which is used for further calculations. The acquisition of geographical location data takes place afterwards. After the successful measurement completion the device is put into suspension mode in order to reduce power consumption and prolong its effective use outdoors. The proposed device acts as a meter allowing for a simultaneous measurement of noise and geographical localization data. This can ease and speed up the generation of noise maps and allows quick discerning places where the noise level is dangerously high. The device itself, along with the accompanying software, should be an interesting alternative to noise level meters currently available on the market.

The scheme of the general MSMH system characteristic is seen in Fig. 31.3. The system architecture allows for measurement data acquisition using two methods. The first one is based on the application of specially prepared network communication protocol. It is also used to control automatic measurement stations. The second method involves direct data entry into the database using the SQL text protocol. The database is accessible through a Web service.

A dedicated server has been set in order to support the monitoring devices. TCP/IP communication support has been implemented, compliant with the prepared protocol. The server supporting TCP/IP protocol and the communication with the SQL database has been equipped with additional abstraction classes.

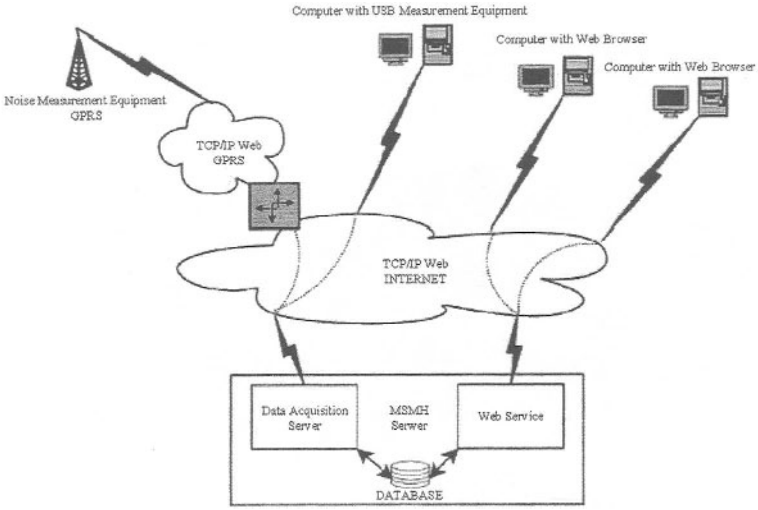

Fig. 31.3. The general MSMH system lay-out

Common C++ class lets clients to be independent from the operating system, on which the server runs. The Gnome Database Access library allows significant flexibility in server's co-operation with various SQL databases. Such an approach resulted from the need of easier modification and upgrade of the system in the future. The second key server component is the Web service responsible for the presentation and processing of data collected by the engineered multimedia noise monitoring system. The PHP (PHP Hypertext Pre-processor) has been selected as a principal programming language. The service modules responsible for database operations and chart generation have been underscored. This approach, separating the presentation part and the data storage part (operated by the use of static templates of Web pages) from service logic enables simple modification of the content and behavior of the service. The Web service of the Multimedia Noise Monitoring System consists of a number of modules and sub-modules, whose mutual relations have been presented in Fig. 31.4. The main part of Web service consists of three basic modules: Administrative Panel, System User Zone and Operational Module.

31.3 Presenting Acquired Data

One of the main functions of Multimedia Noise Monitoring System is the presentation of data in a form comprehensible for the user. The function offers two methods of data visualization: traditional charts and noise maps.

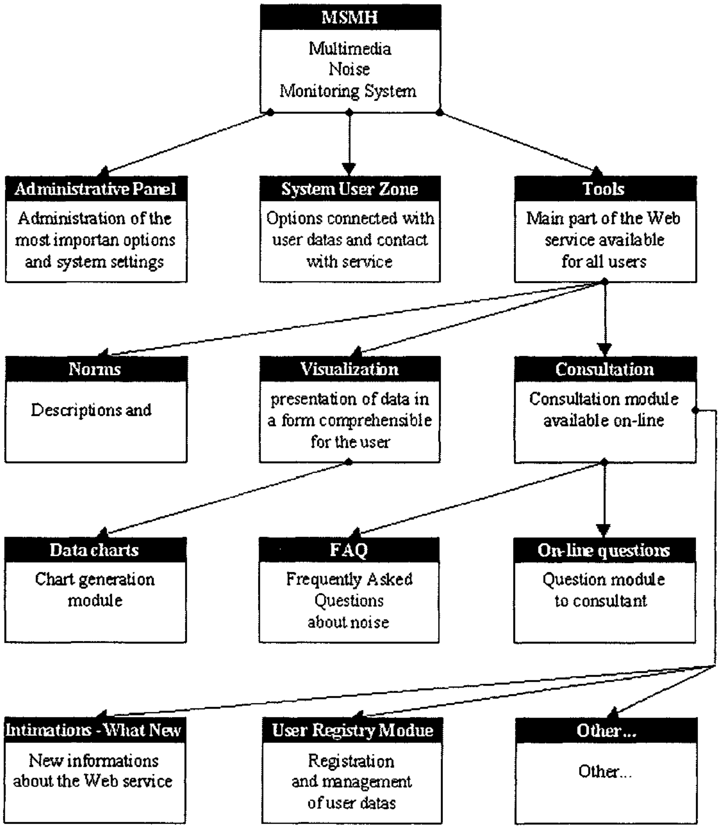

Fig. 31.4. Web Service structure

31.3.1 Noise map modules

The engineered service has been designed for displaying simple noise maps. The main feature of a noise map is the visualization of sound intensity in a specifically defined area. In various GIS (Geographical Information System) systems noise maps are one of many information layers presented to the user. In case of the noise maps module of the system the multi-layer rule has also been maintained, but it is simplified in order to allow its display in a Web browser. The presentation of the system's noise map consists of a series of overlapping raster images. An example of a noise map for Gdansk University of Technology is presented in Fig. 31.5. When the map is displayed in a Web browser, specific images are adjusted to the zoom and offset coefficient entered by the user.

In a hierarchy of a series of images a noise map layer is presented as the lowest positioned layer. Raster image presenting the sound intensity information in a given area is read from the Web server, just like the remaining images. In majority of cases it is a final result of calculations and simulations in a given application supporting noise maps creation.

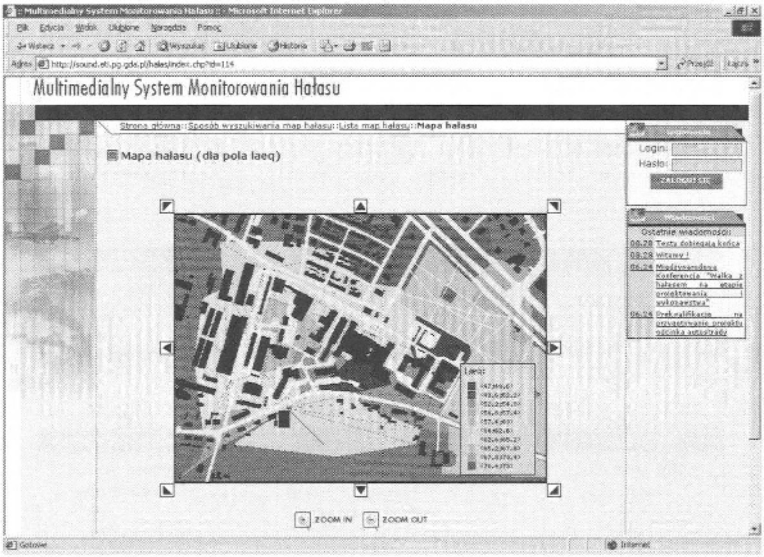

Fig. 31.5. Sample acoustic map – noise at the area of Gdańsk University of Technology

31.3.2 Measurement Results Data Visualization

The user must specify which region the searched measurement point is located in. For the selected region a list of cities with measurement devices is displayed. After selecting the city the user will see the map of the selected area with marked measurement points. The final selection concerns a specific measurement point. It can be selected by clicking a box on the map or by selecting a measure point from the list. For each measurement point one can specify a time range, for which specific parameters will be presented. An example of a selected measure point can be observed in Fig. 31.6.

After selecting a measurement point and specifying a required time range one can display the results in graphic or table form. Measurement card for a given point contains a table including available noise parameters and a chart presenting the results in a graphic form. Fig. 31.7 presents an example of a page containing the results of measurements. By clicking a selected parameter in the table one can add of remove it from the chart. To simplify the process of viewing the results for other points, appropriate links have been added. Therefore one can select another measurement point for the same city or specify a new location.

31.3.3 Visualizing Survey Results

The Web service offers access to the survey to every interested user. The survey enables users to express their own, subjective opinion about the acoustic climate in the place of residence. Subjective research is a perfect addition to objective measurements, as it allows collecting information about noise spitefulness directly from the inhabitants of an area. Survey results are automatically processed by the system. A number of results' presentation methods have been prepared. They may be charted on the map of regions of the country, for a given city in the form of circle charts or in the form of collective circle charts for the whole country. The user may select an appropriate presentation method.

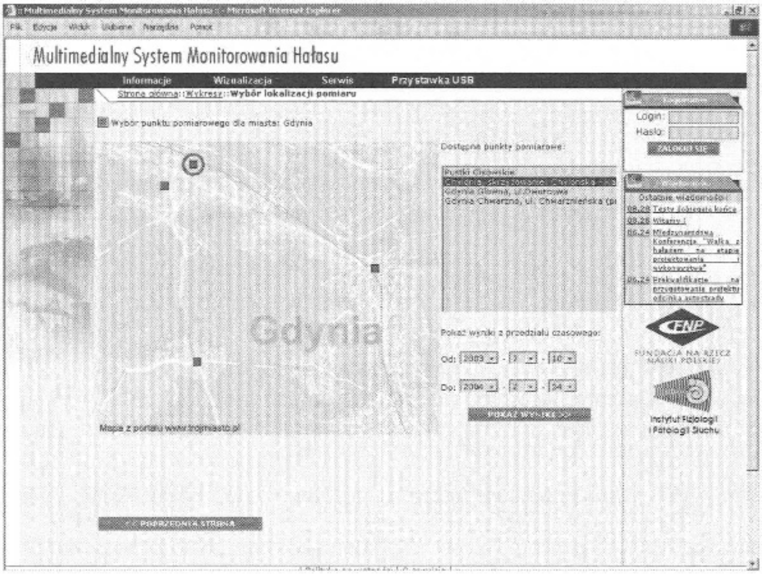

Fig. 31.6. Selecting location at which the measurements are made.

31.4 Analysis of database content

The content of the database can be analyzed in various ways. One possibility is assessing the subjective impression of loudness of environmental noise by people living or working in the areas endangered with excessive noise levels. This is a way of assessing hearing acuity together with overall sensitivity to sound which may be determined also by some psychological causes (tiredness, nervousness or reverse: habituation effects). The second case assumes that overall response to noise revealing noise annoyance and possibly the risk of hearing diseases may be determined also on the basis of analyzing data gathered from subjective opinions.

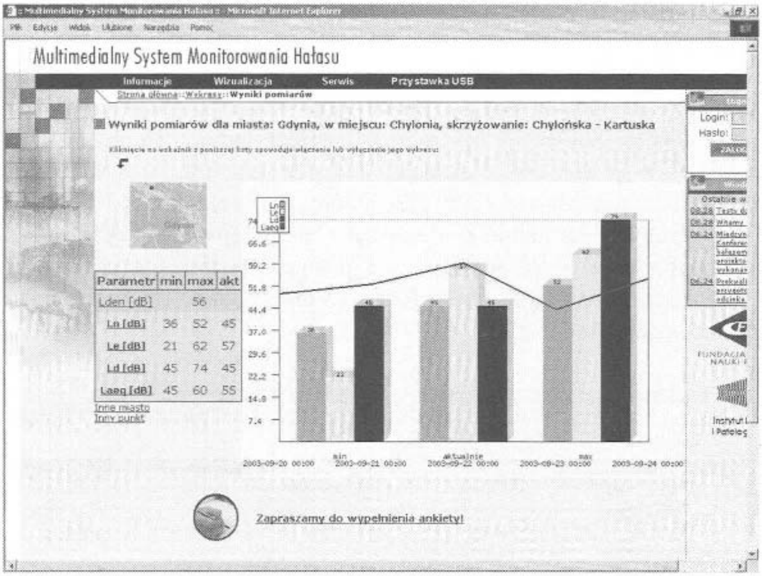

Fig. 31.7. Web page displaying results of acoustic measurements.

The hearing sensitivity is understood in this context as sensitivity to perceived sound (employing hearing sense and psychological determinants). The sensitivity decrease could be objective (hearing loss) or subjective (habituation effects). This kind of a study seems very interesting for hearing pathologists, psychologists and environmental engineers. The analysis can be done employing statistical or data mining tools.

We decided to make database querying with two data mining approaches:

1. basing on assessing fuzzy rules and perception-based data processing principles introduced by Zadeh [9]. The difference **d** between the typical (regular) noise loudness impression and the impression reported by system users (expressed in dB) is the subject of our interest, because it can reflect the decrease of generally understood hearing sensitivity. It is assumed that the users express their subjective impressions in the natural language (from **NONE** to **ULTRA LOUD**), thus fuzzy logic provides suitable tool for the computing in our case [4];
2. basing on collecting subjective assessment results data in a decision table and applying rough set data analysis method. This approach was successfully tried earlier with regard to subjective opinions processing related to "computing with word" concept [10].

31.4.1 Case 1: Perception-based data processing

In the first discussed case there are two premises. One is associated with the information on regular loudness scaling; in further considerations it is represented by the **Norm** variable. The other premise is associated with the investigated results of noisy areas inhabitants' subjective loudness impression; it is represented by the **Sub** variable. In order to differentiate the fuzzy sets associated with individual premises, labels of fuzzy sets associated with the first premise use lower case letters while those of fuzzy sets associated with the second premise employ upper case letters. On the basis of available information one can design a rule basis according to the following guidelines:

- Premises pointing to consistence of loudness sensation evaluation for regular loudness scaling and for the investigated loudness scaling generate a decision stating no scaling differences and marked with the label "*none*".

e.g.: If *Norm* is *soft* AND *Sub* is *SOFT* THEN *d* is *none*

Zero (none) difference is a special case of difference. The experimental results lead to a conclusion that the output of the described fuzzy system can be described by a set of thirteen membership functions (Fig. 31.8) expressing the difference between the loudness sensation evaluation in noisy conditions and the evaluation for regular hearing. Fuzzy sets obtained in this fashion can be described with the following labels (describing the difference size): the MF in the middle of the Fig. 31.8 reflects to the label: none, then to the right there are the following lables: *very small, very small+, small, small+, medium, medium+, large, large+, very large, very large+, total, total+*. Labels marked with "+" sign denote positive difference (hypersensitivity). From the mid MF to the left the assigned labels refer to the negative difference.

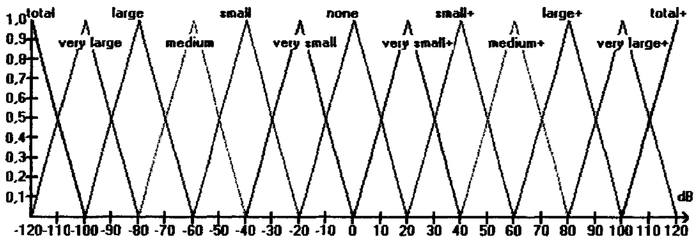

Fig. 31.8. Output membership functions.

If the given result of loudness scaling differs by one category of loudness sensation evaluation, the decision is associated with the output labeled "*small*" in the case of a negative difference or "*small+*" for a positive difference.

e.g.: If *Norm* is *very soft* AND *Sub* is *NONE* THEN *d* is *small*

IF *Norm* is *loud* AND *Sub* is *ULTRA LOUD* THEN *d* is *small+*

...

It was found that the difference by two or more categories are lesfrequent, however they are also supported by adequate decision rules, e.g.:

IF *Norm* is *soft* AND *Sub* is *LOUD* THEN *d* is *medium+*

IF *Norm* is *ultra loud* AND *Sub* is *SOFT* THEN *d* is *large*

IF *Norm* is *medium* AND *Sub* is *ULTRA LOUD* THEN *d* is *large+*

The fuzzy rule processing followed by the defuzzyfying allows for calculating crisp values of **d** for various points on the acoustical map of the investigated region. First the definition of membership function for input variables is needed.

An example of a set of membership functions for the frequency band of 500Hz obtained by approximating the factual values of membership functions with triangles is illustrated on Fig. 31.9. In practice such functions should be determined for various frequency sub-bands, typically with center frequency: 500 Hz, 1kHz, 2 kHz and 4 kHz.

The approximation of fuzzy set boundaries is done algorithmically on the plane containing scattered data. The algorithm used by the authors to determine the triangular membership functions involves the following steps:

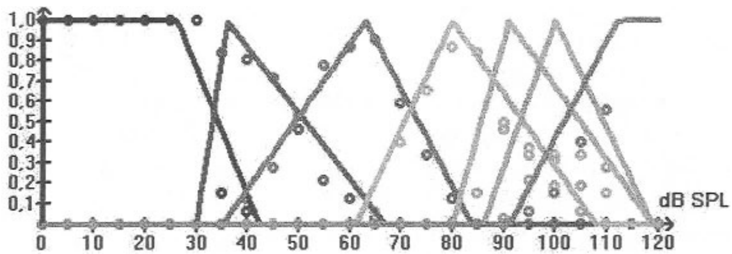

Fig. 31.9. Approximation of fuzzy sets boundaries. Dots represent (processed) answers of noise monitoring system users as to their subjective noise loudness impression (expressed in terms of degree of membership to individual loudness categories). X-axis represents measured noise levels. Labels of membership functions are: *NONE, VERY SOFT, SOFT, MEDIUM, LOUD, VERY LOUD, ULTRA LOUD.*

- Finding the value of the first element belonging to the given fuzzy set (value of the first argument, for which the factual membership function takes a non-zero value)
- For determining the first arm of the triangle one considers all the elements of the factual membership function MF fulfilling the equation:

$$x : \left\langle \underset{x_i}{\forall} \left(MF\left(x_i\right) - MF\left(x_{i-1}\right)\right) > 0 \right\rangle \tag{31.1}$$

where i - indices of arguments of membership functions MF fulfilling condition (31.1),
- Calculating parameters a_1 and b_1 of the straight line: $y = a_1 x + b_1$
- For determining the second arm of the triangle one considers all the elements of the factual membership function MF fulfilling the equation:

$$x : \left\langle \underset{x_i}{\forall} \left(MF\left(x_i\right) - MF\left(x_{i-1}\right)\right) <= 0 \right\rangle \tag{31.2}$$

where i- indices of arguments of membership functions MF fulfilling condition (31.2),

- Calculating parameters a_2 and b_2 of the straight line $y = a_2x + b_2$,
- Calculating the point of intersection of straight lines $y = a_1x + b_1$ and $y = a_2x + b_2$ (determining the triangle vertex),
- Calculating zeros of both lines.

As in this case individual elements may belong to more than two fuzzy sets, further fuzzy logic-based processing is more complicated [4]. A side effect is that membership functions, which share a part of their domain with domains of other membership functions (intersection with more than two other fuzzy sets), may not have the maximum value equal to 1.. It turns out that such situation is only possible when determining membership functions on the basis of averaged results of loudness scaling, as only then each fuzzy set "neighbors" (intersects) at most two other fuzzy sets and there are elements, for which the average value of loudness scaling results points directly to a given category of loudness sensation evaluation. Usually the situation when the whole population of regular-hearing persons would evaluate the hearing sensation of a given test signal level exactly the same does not happen. As in fuzzy processing using functions that reach the maximum membership value of 1 is recommended, in the discussed case one needs to normalize each membership function.

31.4.2 Case 2: Rough-set based data analysis

Since our system measures noise levels and simultaneously allows people express their subjective opinions about the noise harmfulness (using electronic questionnaires), so that there is possible to investigate the relation of noise occurrence and annoyance of people exposed to noise. Meanwhile, the noise annoyance can be defined also objectively, on the basis of measured data. New noise annoyance indicator is defined according to the ISO 1996-2 norm.

The day-evening-night level L_{den} in decibels (dB), is defined by the following formula:

$$L_{den} = 101 \cdot g \cdot \frac{1}{24}\left(12 \cdot 10^{\frac{L_{day}}{10}} + 4 \cdot 10^{\frac{L_{evening}+5}{10}} + 8 \cdot 10^{\frac{L_{night}+10}{10}}\right) \quad (31.3)$$

in which:

- L_{day} is the A-weighted long-term average sound level as defined in ISO 19962: 1987, determined over all the day periods of a year;
- $L_{evening}$ is the A-weighted long-term average sound level as defined in ISO 19962: 1987, determined over all the evening periods of a year;
- L_{night} is the A-weighted long-term average sound level as defined in ISO 19962: 1987, determined over all the night periods of a year;

Adequate norms define permissible noise levels as shows Tab. 31.1 presenting demands for quiet areas.

The assessment of the annoyance provided by the proposed system is based on both: the measurement procedures resulting in L_{den} value, and a collection of information related to the respondent's subjective evaluation. The rough set data analysis serves in the engineered system as an expert procedure allowing for the correlation between objective measure and subjective evaluation. Therefore the main objective is to compare assessments of exposure to noise done by a human with the objective data coming from measuring module of the system. The respondent's answers are obtained from the electronic questionnaires. The corresponding data are collected in the Pawlak's decision table along with the L_{den} value (Tab. 31.2). The attributes A_1,...,A_m are related to parameters such as: respondent's age, perception of loudness, noise occurrence, and noise type, vulnerability to distraction by noise, to noise interference on communication and work performance, to anxiety & fear, and finally to subjective perception of stress. Among the attributes contained in the Tab. 31.2 one can see those related to the categories of loudness perception. This is a way to find the correlation between subjective perceptions and objectively measured values basing on rough set-based data processing. The data may have descriptive character (string values) or can be expressed by numerical ranges. The following decision attribute set is valid for descriptive values: {*none*, *low*, *medium*, *high*, *very high*, *ultra high*}.

Table 31.1. Normative values of noise indicators.

	Equivalent level, L_{den}	Maximum level, L_{AFmax}
Residential areas and noise-sensitive buildings housing public institutions (schools, hospitals, nursing homes, etc.)	55 dB	70 dB
Single buildings in the open country	55 dB	70 dB
Service enterprises (hotels, offices, etc.):	60 dB	75 dB
Recreational areas where people stay overnight (holiday houses, allotment gardens, caravan parks, etc.):	50 dB	65 dB
Other recreational areas where people do not stay overnight	55 dB	70 dB

The form of rules derived on the basis of analyzed cases contained in the respondents' database filelds is of the following form:

(attribute_A_1)=(value_a_{11}) and... ...and (attribute_A_m)= (value_a_{nm}) $\Rightarrow$ *(decision_D)=*{*value_d_i*)

The data are gathered from all respondents over a period of time. Having collected results for number of respondents, these data are then processed by the rough

Table 31.2. Decision table containing respondents' data.

Respondent/ attribute	A_1	A_2	...	A_m	D
t_1	a_{11}	a_{12}	...	a_{1m}	d_1
t_2	a_{21}	a_{22}	...	a_{2m}	d_2
...	...	...	...	...	...
t_n	a_{n1}	a_{n2}	...	a_{nm}	d_n

set algorithm [10]. In Tab. 31.3 some records from data collected by the system are shown. These data are related to street noise evaluation.

Table 31.3. Database of respondents' records.

Respondent/ Parameters	A	B	C	D	...	...	I	J	*Annoyance*
1	85	loud	cont.	cont.	...	...	med.	54	med.
i		...	...	...	...	...		...	...
n	85	very loud	impuls.	freq.	...	...	high	54	high

Denotations:
$A - -L_{den}$ [dB]
B – Loudness{none, very soft, soft, medium, very loud, ultra loud}
C – Type of noise{impulsive, non-stationary, stationary, continuous}
D – Occurrence{rare, frequent, often, continuous}
E – Distraction{low, medium, high}
F – Communication Interference{low, medium, high}
G – Performance Interference{low, medium, high}
H - Anxiety & Fear{low, medium, high, very high, ultra high}
I - Stress{low, medium, high}
J – Age category{positive integer value}
Annoyance – {very low, low, medium, high, very high}

The first step of rough set processing is related to the elimination of rows in decision tables that are duplicated (superfluous data elimination). Further steps result in generation of rules and rough set measure, and computation of reducts allowing obtaining the reduced form of rules based on the indispensable attributes only [4][5][7]. Examples of rules processed by the system are shown below. One can see that some cases will be contradictory depending on the respondent's age and his/her sensitivity to the noise exposure, and in addition to the type of noise.

IF A=85 $\wedge$ B=loud $\wedge$ C=cont $\wedge$ D=cont. $\wedge$ E=med. $\wedge F$=med. $\wedge G$=med. $\wedge$ H=low $\wedge$ I=med. $\wedge$ J=54 $\Rightarrow$ *Annoyance*=med.

IF A=85 $\wedge$ B=very loud $\wedge$ C=impulsive $\wedge$ D=freq. $\wedge$ E=high $\wedge$ F=high $\wedge$ G=med. $\wedge$ H=high $\wedge$ I=high $\wedge$ J=54$\Rightarrow$ *Annoyance*=high

The real interest does not concern, however, the meaning of the above shown rules which is obvious to any data analyst, but it is related to the rough measure μ_{RS} associated with these rules. That is because the rough measure can be used in the system as a weighting factor for determining the correlation between the objective values of measured L_{den} and subjectively evaluated annoyance.

The accuracy of decisions produced by the intelligent database analysis algorithm is expected to grow higher as the number of respondents' records is increased.

31.5 Conclusions

Discerning correlation of objectively measured quantities and perception-based categories is one of most important problems in many disciplines of science, including acoustics. The engineered noise telemonitoring system was designed in such a way that it allows to measure noise in endangered areas and to study the influence of environmental noise on humans. Two kinds of soft computing algorithms were employed to that end originating from fuzzy sets and rough set theories. The engineered intelligent application may help in diminishing hearing problems and other diseases occurrence caused by environmental & industrial noise.

References

1. Czyżewski A., Kotus J., Web-Based Acoustic Noise Measurement System. 116th Audio Engineering Society Convention, Preprint No. 6006., Berlin, 08-11 May, 2004.
2. Czyżewski A., Kotus J., „Universal system for diagnosing environmental noise" *Management of Environmental Quality*, pp. 294-305, vol. 15, No. 3, 2004.
3. Directive 2002/49/Ec of the European Parliament.
4. Czyżewski A., Kostek B., Suchomski P., Automatic Assesment of the Hearing Aid Dynamics Based on Fuzzy Logic - Part I., Konferencja IASTED, the Third IASTED Int. Conf. on Artificial Intelligence and Applications, September 8-10, 2003 Benalmadena, Spain
5. http://www.telewelfare.com/
6. Miedema H. M. E., Vos H., Noise sensitivity and reactions to noise and other environmental conditions, J. *Acoust. Soc. Am.* 113 (3), 1492-1504 (2003).
7. D. Ouis: Annoyance from road traffic noise: a review, *Journal of Environmental Psychology*, 21, 101-120 (2001).
8. M. Heinonen-Guzejev, H. S. Vuorinen, J. Kaprio, K. Heikkilag, H. Mussalo-Rauhamaa, Self-report of transportation noise exposure, annoyance and noise sensitivity in relation to noise map information, *Journal of Sound and Vibration* 234 (31.2), 191-206 (2000).
9. Zadeh L.A., A New Direction in AI: Toward a Computational Theory of Perceptions. *AI Magazine* 22(31.1): 73-84 (2001)
10. B. Kostek, „Computing with words" Concept Applied to Musical Information Retrieval. *Electronic Notes in Theoretical Computer Science*, 2003, No 4, vol. 82.