DEVELOPING A REMOTE LABORATORY FOR ENVIRONMENTAL MONITORING USING MOBILE TECHNOLOGY

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Abstract: ***This paper presents the mobile technology utilization in improving the remote access to the data acquisition processes of several automated monitoring system for air quality, water quality, and crop canopy microclimate. The system facilitates mobile environmental management and decision making by using in-situ measurements, GSM/GPRS informational fluxes, Pocket PCs, dGPS and mobile GIS resources. Data is retrieved via GSM/GPRS data modem to remote computer using digital (GSM) phone network. The main outcomes of this study were as follows: 1. designing the hardware, communication and software infrastructure of the system using telemetry features, 2. establishing the wireless connections and remote access from PDAs to the measurement servers, 3. programming and testing specific control virtual instruments (Vis) in NI LabVIEW^{TM}, 4. obtaining a portable solution of statistical analysis and survey with PDA Vi (Virtual Instruments) interfaces for Pocket PC to gather, store, customize and report data combined with statistical processing functions, and 5. identifying mobile GIS applications for the environmental protection. The remote-accessing of the GIS server features, provided in-situ electronically reviews, mark up, and precise measurements of the site pollution plans. One possible solution to overcome the PDA hardware and software restraints is enabling the remote access and control of the DAQ and GIS software resources of the measurement server via internet.***

Keywords: ***Environmental Monitoring, Remote Control, Pocket PC, GPS, GIS, Virtual Instrumentation***

1. INTRODUCTION

The population growth and industrial development are factors that determine a continuous pressure on the water requirements, air and soil quality, and contribute to the pollution expansion disturbing ecosystems equilibrium.

Unfavorable conditions such as high concentrations of contaminants require immediate intervention on the part of management team so that potential environmental problems can be avoided. Real time information and automation of the monitoring systems are necessary for fast response times in the surveillance process. Recent developments of ICT, hardware and geospatial technologies have broadened the scope of environmental monitoring throughout the world. A multitude of digital monitoring devices exists to respond to the demand of methods requiring less time, less manpower and less financial effort. Such systems provide accurate on-line analysis of more and more environmental parameters, and collect more samples giving a complex dimension of the air, water and soil quality status and evolution in many potential polluted areas [1].

Data acquisition processes applied in the environmental monitoring require complex data acquisition systems, which might include ambient fine particulate monitors, ammonia continuous emission monitors, hydrogen sulfide monitors, mercury continuous emission monitors, multi-metal continuous emission monitors, onboard mobile emission monitors, optical open-path monitors, portable multi-gas emission analyzers, and portable NO/NO_2 analyzers. Examples of system categories for water include security water monitoring technologies, multi-parameter surface water probes, on-line turbidimeters, portable water analyzers for pollutants, nutrient monitors for wastewater and ambient waters, and waterborne pathogen detectors. The quick development of monitoring devices requires new approaches to data analysis. Using short logging intervals implies complex databases. The specialists may collect vast quantities of data that challenges the man's ability to understand and assimilate them [2].

A real-time environmental monitoring system (e.g. multi-parameter water probe or air quality station) may record and transmit in one year more than 320 000 values when a log interval of 15 minutes is used. Such amount of data requires multiple exporting steps between different software for data processing. Because more and more data is acquisitioned and added in the DBMS, a time problem occurs in plotting graphs and in statistical interpretation. One possible solution is the real-time statistical processing and

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automatic report generation using LabVIEW Vi programming features.

PDAs (Personal Digital Assistant) tend to replace the conventional data loggers or other handheld meters in many environmental applications. Pocket PC air velocity meters, Palm air quality meters or Pocket PC water datalogging (e.g. Hydras 3 Pocket [3] for Hydrolab) are several examples of reliable and ergonomic mobile monitoring systems. Furthermore, PDAs have integrated GPS capabilities, wireless connectivity, and operating systems that permit software utilization and programming. Differential GPS or dGPS employs a base receiver transmitting differential corrections to a roving receiver making use of the coarse acquisition code. Accuracies are typically in the sub-meter range. dGPS may be of use in mapping applications such as topographic or hydrographic and EIA surveys. The dGPS station receives signals from a number of satellites, and then works backward to determine the satellites errors by comparing those signals to the exactly-known position of the station. The dGPS then immediately transmits a set of corrections for receivers using the radio signals from the satellites analyzed.

With the special designed DAQ PCMCIA or CF cards, PDAs became preferred platforms in the development of portable dedicated data acquisition systems. LabVIEW PDA module and Microsoft eMbedded Visual Tools are programming tools used to develop software solutions for PDA [4]. Furthermore, PDAs have superior power autonomy and better resistance to harsh environments than notebooks.

GIS analysis is the key to help government and commercial entities monitor the environment more efficiently and cost-effectively. It is also the key to help organizations and businesses comply with the environmental regulations that are the result of growing global markets. For the environmental management, spatial data is crucial. It is essential that the specialists have the adequate *in-situ* tools to take full advantage of all their assets, data and spatial information.

With the rapid development of mobile communications and wireless technologies, more and more mobile GIS applications have emerged from the fields of location-based services, vehicle navigation and tracking, and mobile mapping [5, 6].

Most of these applications have adopted Pocket PC, PDA, or handheld PC as mobile computer devices. However, most web-based GIS systems have limited analysis functions. Analytical tools are essential for many comprehensive GIS applications in the environmental field [7].

One possible solution to overcome the PDA's hardware and software restraints is enabling the remote access and control of the PC measurement server resources and services (e.g. DAQ process and GIS capabilities) via internet.

This study intends to investigate PDA utilization in improving the remote access to the data acquisition processes of an automated integrated monitoring system of air quality, water quality data, and crop canopy microclimate facilitating mobile environmental management and decision making.

Specific objectives were as follows:

1. To design the hardware, communication and software infrastructure of such informational - decisional system using telemetry features;
2. To establish the wireless connections and remote access from PDAs to the measurement servers;
3. To program and test Control Graphic User Interfaces (GUI) in LabVIEW™ of National Instruments to manage DAQ processes on the measurement server;
4. To obtain a portable solution of statistical analysis and survey with PDA Vi (Virtual Instrument) interfaces for Pocket PC to gather, store, customize and report data combined with statistical processing functions;
5. To access mobile GIS technology using specialized software features such as digital air pollution maps of urban environments.

2. System infrastructure

The infrastructure contains the ground segment (*in-situ* measurements network, telemetry component, and measurement servers at the base station) and the aerial segment (satellite base positioning GPS, and aerial photogrammetry). The ground segment monitors, logs, and communicates to the measurement server, real-time air quality, water quality, meteorological, and crop canopy microclimate data from multiple locations established in Târgovişte area – Romania (fig.1).

Data Acquisition (DAQ)

Instruments – A multiparameter water quality sonde Hydrolab DataSonde® 4a was used for the unattended and simultaneous monitoring of 12 water quality parameters in Priseaca Lake (N44°55.379, E25°24.574). Automatic weather station provided automatic data collection of air quality conditions from several sampling points (e.g. N44°54.657, E25°27.710; N44°54.864, E25°28.090) in Târgovişte urban area.

Soil and crop canopy microclimate monitoring, which provided the required parameters for automated irrigation control were ensured using a special designed DAQ system based on 80C552 IMC 500 development device [8] in Ulmi (N44°53.154, E25°30.330).

Photovoltaic modules powered all types of system for continuous and long term monitoring [9].

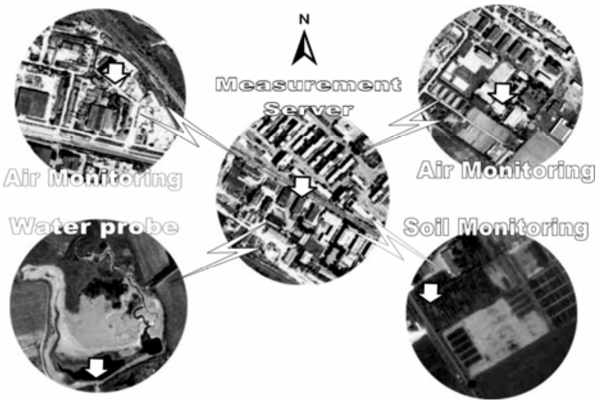

Fig. 1 Monitoring points tagged on digital orthophotos using GPS

Data transmission

GSM/GPRS data acquisition systems give the ability to deploy environmental monitoring stations in remote areas, far away from power grids and phone lines. Data is retrieved via GSM/GPRS Siemens data modem to remote computer using digital (GSM) telephone network. In on-line mode (data mode), the modem is communicating with the remote station. Data coming through the RS232 serial link are treated as data and transmitted to the called part, and data received from the called part are transmitted to the terminal through the RS232 serial link. Online mode is activated by successful completion of a command, manually or automatically, to originate or answer a call from the measurement server.

Measurement server is a specialized computer in the base station (N44°55.295, E25°26.828), which controls the network of instruments and devices that provided acquired parameters, has information about the instrument capabilities and possible measurements and allows graphical communication with the specialist using programmed LabVIEW GUI (Vis).

PDA Pocket PCs

Two Pocket PCs were used as follows:

Garmin iQue M5 powered by a 416-MHz Intel® PXA 272 microprocessor provides 64 MB of RAM, 64 MB of ROM, 12 GPS channels, and compatibility with 2 GB SD-Card for data external storage. Differential GPS (WAAS/EGNOS) ensures precisions less than 3 m [10].

Magellan MobileMapper CE ARM920T based processor delivers real-time sub-meter accurate GNSS positioning using SBAS or Beacon corrections. It offers the added flexibility of NTRIP and Direct IP network communication for RTCM real-time corrections. It has 14 GPS channels, 128 MB SDRAM, 128 NAND Flash memory and RS232 port [11].

The embedded Bluetooth® transceiver of both devices allows establishing a wireless personal-area network with computer systems and Bluetooth-enabled devices such as mobile phones, other PDAs, and printers.

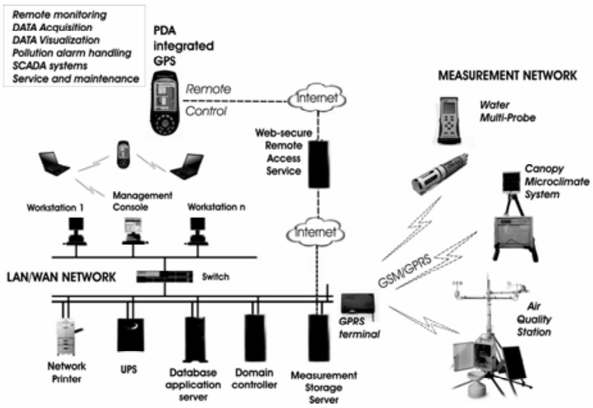

Fig. 2 System infrastructure and informational fluxes

A SDIO 56kbps modem adapter was installed, enabling Internet access to Pocket PCs.

Remote Access Service

Remote access and control of the measurement server were established through web site secured access from PDAs via internet [12].

3. Experimental Results

3.1 On-site Environmental Data processing

Site inspections and site assessments used to develop EIA plans often need *in-situ* estimation of the data acquired by the digital monitoring devices.

Measurements stored in the data logger memory are transmitted to the PDA using RS232 cable. PDA Vi are compiled versions of the PC Vi host that can be executed on PDA OS. A PDA Vi detains the corresponding GUI, but without the associated diagram that is compiled by the PDA Builder. A PDA Vi was developed in LabVIEW PDA Module [13].

The resulted Pocket PC application (fig.3) was a downloadable *exe.* file [14], which collects, displays raw data and distribution histogram, and computes on-site important statistical parameters (Mean, Median, Standard Deviation, Coefficient of Variance, Minimum and Maximum, summation and intervals).

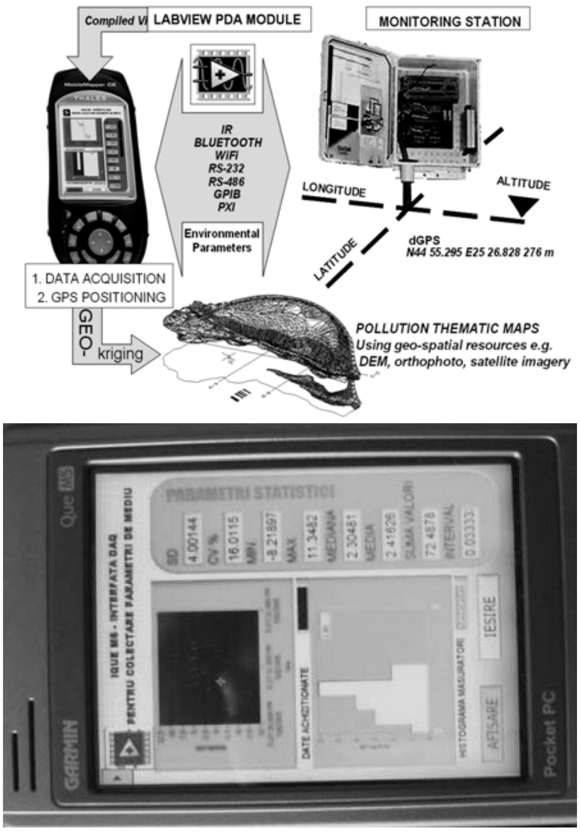

Fig. 3 In-situ data logging via RS232 using a LabVIEW PDA Vi with statistical processing of the canopy microclimate measurements on Pocket PC.

When connected to the DAQ system, the Pocket PC application permitted the selection of the measurements from different sensors (e.g. air temperature, soil temperature, soil moisture, relative humidity or solar radiation) and statistical analysis of the values.

Using Mobile Bluetooth RS-232 dongles enables the data wireless transmission between conventional data loggers equipped with RS232 serial port and Bluetooth-enabled PDAs without RS232. This feature increases the monitoring operations ergonomics, when several DAQ equipments are deployed in the same sampling location.

The next step was to establish the wireless connections and the remote access from on-site PDAs to the measurement servers at the base station.

3.2. Remote access and control of the DAQ measurement server

A SDIO 56 kbps modem adapter was configured, enabling Internet access for Pocket PCs. Remote access internet service was identified as the most reliable solution for the control of the measurement server.

Remote irrigation control

Figure 4 presents a PDA remote control example of the photovoltaic-powered automated irrigation system located in Ulmi. LabVIEW program started on the measurement server and the corresponding Vi was launched using browsing and executing from Pocket PC. The same GUI was displayed on Pocket PC TFT touch-screen. Communication with the irrigation installation microcontroller was established via GSM/GPRS using the dedicated module.

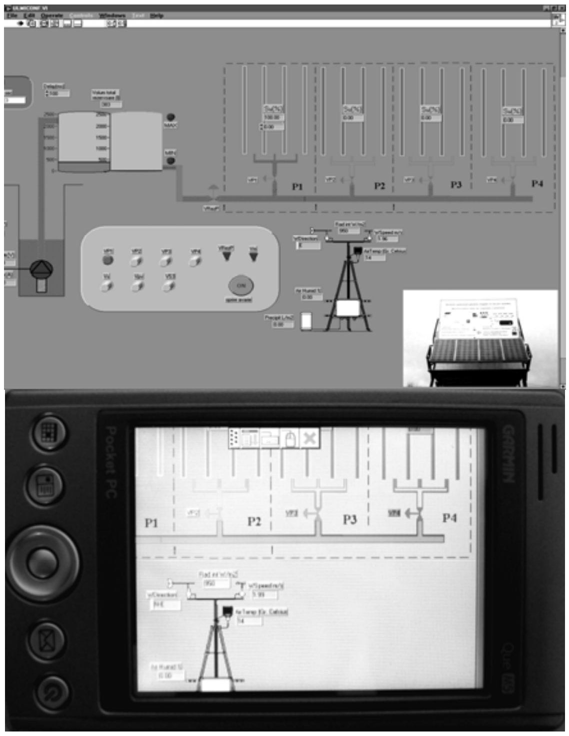

Fig. 4 Control graphic user interface of the Photovoltaic-powered automated irrigation station located in Ulmi displayed on the measurement server and the remote access of the system using PDA interface via internet

Through the remote access to the irrigation microcontroller via measurement server, the user visually checks the process parameters acquired from the specific sensors and transmits commands such as pump on/off and/or electro-valves on/off by triggering corresponding buttons on the PDA touch-screen.

Remote air and water quality control

The same procedures of PDA remote access and control, but without automation elements, were used for the water and air quality monitoring systems. With Vis programmed in NI LabVIEW, data from multiple locations were displayed in real-time on the PC measurement server.

The Virtual Instruments automatically retrieved data from the sensors of water multi-parameter probe (fig.5) and from the automatic air quality station (fig.6), providing graphical displays, online statistical processing and automatic report generation. Interpreting water quality data was somewhat more complex than interpreting other environmental quality data because more variables were measured, and the interactions between different components were more complex, water having a variety of different uses. Water measured parameters included Ammonia, Chloride, Conductivity, Depth, Dissolved oxygen, Nitrate, ORP, pH, Temperature, Total dissolved gas, Transmissivity and Turbidity. The automatic weather station provided meteorological and ambient air parameters.

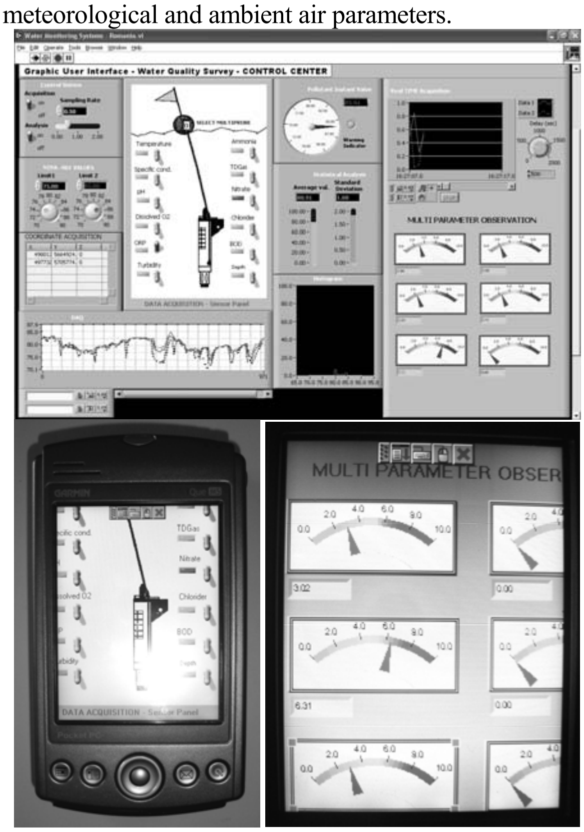

Fig. 5 Virtual instrument of the data acquisition process from the water multi-parameter probe (Priseaca Lake) displayed on the measurement server and the PDA control of the specific Vi

Advanced Real-time Data Analysis

The specialized GUI integrating real-time statistical processing of acquired raw data was a time saving method, which permitted better interpretation of the parameters evolution according to specialist's requirements [15]. LabVIEW provided powerful algorithms and functions designed specifically for measurement analysis and signal processing to extract information from acquired data and unique measurements, to generate, modify, process, and analyze raw data, to add intelligence and decision-making capabilities to monitoring applications, and to perform inline and offline analysis [16].

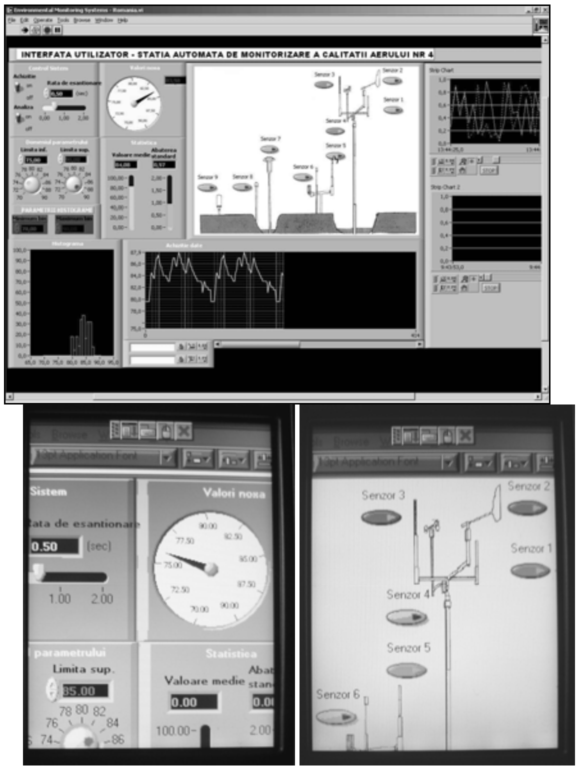

Fig. 6 Control graphic user interface of the data acquisition process from the air quality station displayed on the measurement server and the PDA control of the specific Vi

The graphic user interfaces allowed settable high and low limits according to the water and air quality standards regulations to define set points for several parameters and trigger acoustic and optical alarms.

3.3. Mobile air quality digital mapping

Several geo-referenced orthophotos images (*TIFF* file format with adjacent referenced file *TFW*) of the region were used for raster-vector conversion using geo-applications (*GeoMedia*, *MicroTop* and *GeoTrans*) to produce and actualize digital maps.

A DEM (Digital Elevation Model) was developed for four urban localities, containing the most important stationary emission sources (fig.7). For establishing the areas were the level of pollution generated by the fixed pollution sources is maximum, it was used a Gaussian mathematical model that incorporates source-related factors and meteorological factors to estimate pollutant concentration from stationary sources. The results from previous work [17] are linked to the development of the pollutant dispersion maps (CO, NO, NO2, SO2 and PM10 dusts), reflecting the situation for four important locations (cities) in Dâmbovița County: Târgoviște, Fieni, Titu and

Doiceşti. The isolines show the momentary maximum concentration for each pollutant.

The remote-accessing of the GIS software features, provided *in-situ* electronically reviews, mark up, and precise measurements (distance and point rectangular coordinates) of the site pollution plans (fig.9).

Fig. 7 Pocket PC *In-situ* electronically measurements (distance between points and point rectangular coordinates) on the orthophotoplan and DEM – Târgovişte area.

The obtained vector pollution maps with several layers were accessed at Pocket PC level using the GIS software started on the measurement server (fig.8).

Fig. 8 Pocket PC *in-situ* visualization of the air pollutant dispersion map using the measurement server GIS software features – Târgovişte area.

Such solution mobilized digital design and mapping data and ensured that current drawings, maps, and associated data are distributed out to the handheld computers in the field for environmental monitoring sampling and measurements. Records of monitoring information shall include:

- the date, exact place, and time of sampling or measuring;
- the individual(s) who performed the sampling or measurements;
- the date(s) and time(s) analyses were begun;
- the individual(s) who performed the analyses;
- the analytical techniques or methods used;
- the results of such analyses;
- and the results of all quality control procedures.

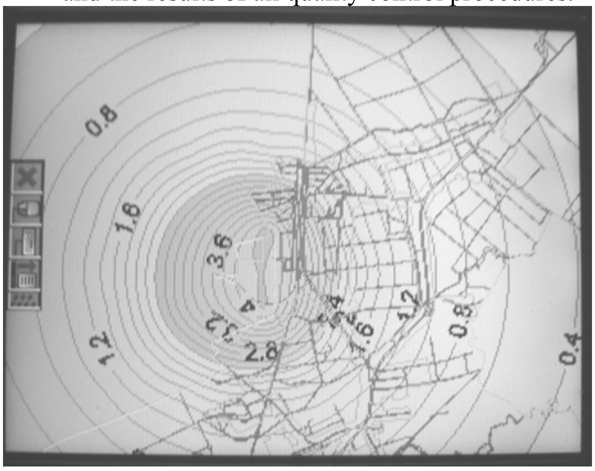

Fig. 9 Pocket PC *in-situ* analysis of the dispersion digital maps

PDA with dGPS functions facilitates automated correlation of environmental quality data with exact spots in the field to ensure that the survey is made in the same sampling point. Other features includes mapping a mixing zone for discharge approval, indicating a site for bioremediation by another team with GPS capabilities and checking that data are collected in the sampling points established in the monitoring plan and tagged via GPS. The results of quality control procedures shall be tabulated and/or statistically analyzed in order to establish quality assurance documentation for each test procedure, instrument and analyst.

GIS and GPS technologies link geographic and attribute data, such as lab and field data, which allows building predictive modeling for planning and compliance purposes. With mobile digital mapping to help with site assessments, site inspections, and feasibility studies, organizing and refining data are facilitated. Specialists may modify and exchange files via Internet or Bluetooth improving decision making and optimizing allocated time in an environmental protection project.

4. Conclusion

The system is designed to track ongoing events, and to detect trends and events in the evolution of environment quality that classical spot checks might not reveal. Furthermore, such automated monitoring system for environmental quality assessments integrated in a Local Monitoring Plan is expected to provide useful information for decisional support and reliable answers to:

- The standards and regulations demands concerning qualitative and quantitative aspects;
- The trends of environmental quality modification due to various factors;
- The long-term effects of environmental quality deterioration on ecosystems;
- and the efficiency of strategies and management action for pollution control.

This system was successfully used as a tele-education tool improving environmental engineering students' perception and skills on water, air and soil quality monitoring processes.

Future work might consider the development of the system complexity by adding more monitoring devices such as water multi-parameter probes to ensure surface-water control sections, air quality stations to establish an urban climate-covering network and sound-meters to survey phonic pollution. A web-based GIS is envisaged to be developed using Autodesk Map 3D 2007 and MapGuide resources.

Several limitations of the presented system were identified as follows:

- PDA hardware and software restraints when using local *in-situ* utilization;
- a lag time might occur when executing remote control commands on PC measurement server from PDA, due to slow connection speed;
- necessity to develop a private remote access service.

5. ACKNOWLEDGMENTS

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