Geo-radar scanning and GIS mapping of an old water utility network in Paphos District area in Cyprus under the project: 'Upgrade of the hydraulics laboratory for the modeling of water supply networks & design and operation optimization study'

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ABSTRACT

This work is part of a research project named as 'HYDROGIS LAB'. A preliminary underground survey using the newly acquired ground penetrated radar is presented. This technology provides accurate scanning and 3D spatial representation of the underground piping network. The main aim is to refine the digital imprint of the water supply network under consideration. Work has also been initiated in the development of a GIS platform for managing all information (maps, satellite imaging, 3D scans, network system components etc). The geo-radar scanning is required to support the modeling of water supply network, design and operation.

Keywords: Geo-radar, GIS, water utility

1. INTRODUCTION

The project aims to satisfy the dire need for authorities to solve the extremely serious problem of water supply as a result of continued water shortage. The grave and chronic problems of water losses in the water supply network pipes, the uncontrolled and non-optimum operation of pumping stations, the often wrong design of the networks because of various interventions (e.g. town planning, wrong mapping of existing networks), are some of the most important problems which need to be resolved in order to optimize the performance of the networks and, consequently, save on this precious resource, as well as, on the energy consumed. The innovative aspect of the Project is that, for the first time, state-of-the-art technologies will be combined for the mapping of water networks through the Global Positioning System (GPS), Radar Scanners and Satellite Remote Sensing (SRS). The data will be entered into a Geographic Information System (GIS), with the aim of developing a digital imprint and the mapping of the network. Several other attempts have been made for using GIS for managing and mapping utility network in Pafos area in Cyprus [1, 2]. Following, a representative part of the network will be selected and modeled in the new upgraded laboratory for conducting detailed experimental studies, which will be correlated with computational/mathematical studies. The main scientific challenge of the project, which also characterizes its broader innovative aspect, lies in the possibility to optimize the design and also the operation of all the components of the network through the combined use of hydraulic simulation models and multi-criteria evolution algorithms. The scientific challenge extends also to developing the information infrastructure needed for the supervision and management of the networks, as well as defining guidelines for the optimum design of new networks and for corrective interventions in existing ones. The proposed research infrastructure will fill the considerable gap

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between basic and applied research in the area of fluid engineering and fluid machinery, which are of extensive use in industry and society in general. The Laboratory in which the project will take place will be designed based on international standards and will be equipped with the latest and most specialized instruments, in order to enable the expansion of its capabilities through its flexibility. The Cyprus University of Technology (CUT) is orientated towards applied research, aspiring to establish for itself a role in supporting the state and society in their efforts to confront problems. In cooperation with the Water Development Department of Cyprus, the National Technical University of Athens, the Paphos Municipality and other associates, the project will ensure the best possible use of the new infrastructure in the current development needs of Cyprus. The upgrading of the infrastructure opens up opportunities for Cyprus to participate in European projects, through a significant contribution to the conduct of experimental work.

2. MAPPING AND DEVELOPMENT OF A DIGITAL IMPRINT OF EXISTING SELECTED WATER SUPPLY NETWORK IN PAPHOS MUNICIPALITY

2.1 Ground-penetrating radar (GPR)

Current research [3,4,5] states there is a trend is toward development of more and more sophisticated systems including the ground penetrating radar (GPR) technique, which is safe for use in urban environments and also protects the geological, environmental and archaeological integrity of subsurface settings [5]. GRP is a geophysical method that uses radar pulses to image the subsurface. It is a nondestructive method uses electromagnetic radiation in the microwave band of the radio spectrum, and detects the reflected signals from subsurface structures [6]. GPR interpretation of this reflected energy may yield information on subsurface structural variation and condition of the media, as indicated in figure 1.

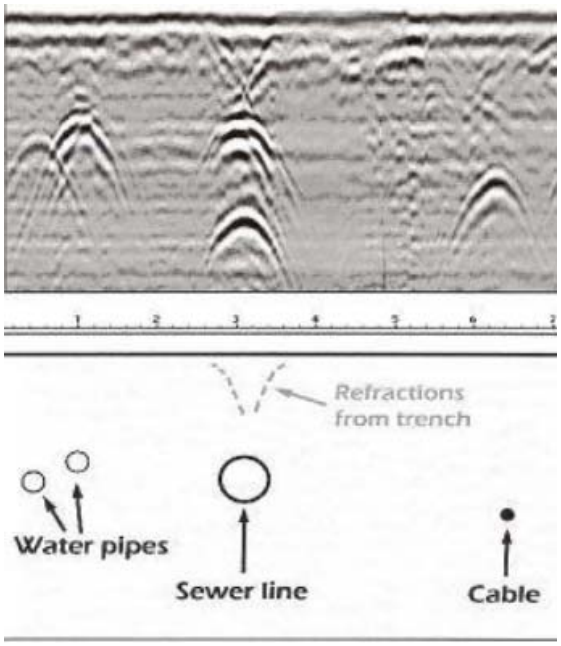

Figure 1- Reflected signals from subsurface structures

The advantages of GPR include its low cost and ease of use. Expertise is required to collect the data. Secondly, the instrumentation is easily portable (unless very low frequencies are exploited thus increasing the physical size of the antennas) and allows to survey regions also of thousands of square meters in reasonable time. Finally, the flexibility of

the GPR system is ensured by the adoption of antennas (mostly portable) working at different frequencies and that can be straightforwardly changed on site [7]. GPR uses transmitting and receiving antennas or only one containing both functions. The transmitting antenna radiates short pulses of the high-frequency (usually polarized) radio waves into the ground. When the wave hits a buried object or a boundary with different dielectric constants, the receiving antenna records variations in the reflected return signal. Individual lines of GPR data represent a sectional (profile) view of the subsurface. Multiple lines of data systematically collected over an area may be used to construct three-dimensional or tomographic images. Data may be presented as three-dimensional blocks, or as horizontal or vertical slices. Horizontal slices (known as "depth slices" or "time slices") are essentially planview maps isolating specific depths.

GPR is also one of the most used tools in the field of the water monitoring and management especially in the fields of the drainage pipes detection and characterization , water leaks in pipe detection and determination of the time-behavior of water content in the soil [8-11]. GPR can accurately pinpoint buried pipeline leaks without digging. The leaking substances can be identified at the source by the radar via the changes in the surrounding soil's electrical parameters. The GPR is able to generate 3D underground images of pipes, power, sewage and water mains. As well, it can identify leaks in buried water pipes either by detecting underground voids created by the leaking water as it erodes the material around the pipe, or by detecting anomalous change in the properties of the material around pipes due to water saturation. Unlike acoustic methods, application of ground penetrating radar for leak detection is independent of the pipe type (e.g., metal or plastic) [3]. The principles involved are similar to reflection seismology, except that electromagnetic energy is used instead of acoustic energy, and reflections appear at boundaries with different dielectric constants instead of acoustic impedances.

2.2 Survey and GIS

Paphos Municipality is one of the municipalities in Cyprus facing very serious problems with the water supply network, due to the age of the network, rapid town development and the urgent needs for expanding the network in an unorganized manner. One of the aims of the HYDROGIS project is the study of an existing selected water supply network in the Municipality in an effort to understand the 'logic' of the network and select a representative part of it that will include almost all the components (i.e. pumping station, main piping, valves, flowmeters etc) present in the networks of the Municipality in order to conduct a comprehensive study. Therefore, the mapping and development of a database using GPS and GIS technologies has the aim of developing a digital imprint of a representative water network in Paphos Municipality and the creation of scale modeling for detailed experimental studies.

Figure 2 a & b - Geo-radar Scanning of the Paphos water utility network

A representative section of the water supply network in the Pafos Municipality area, all the features and systems which compose it, including pumping stations, reservoirs, valves, and flowmeters have been recorded and the selected network was digitized. A survey through the use of a latest technology radar scanner has been conducted. The specific radar scanner is a MALA ground penetrated radar designed for urban areas and background noise. The shielded antenna used consists of both transmitter and receiver antenna elements in a single housing. After the GPR survey was concluded, the GPR data were analyzed using the GroundVision 2 and RadExplorer software, where the pipes were identified, according to their diameter, material and depth. Following, each survey point was inserted into a GIS system, including all the data acquired. The network was then connected from each survey point, as indicated in Figure 3.

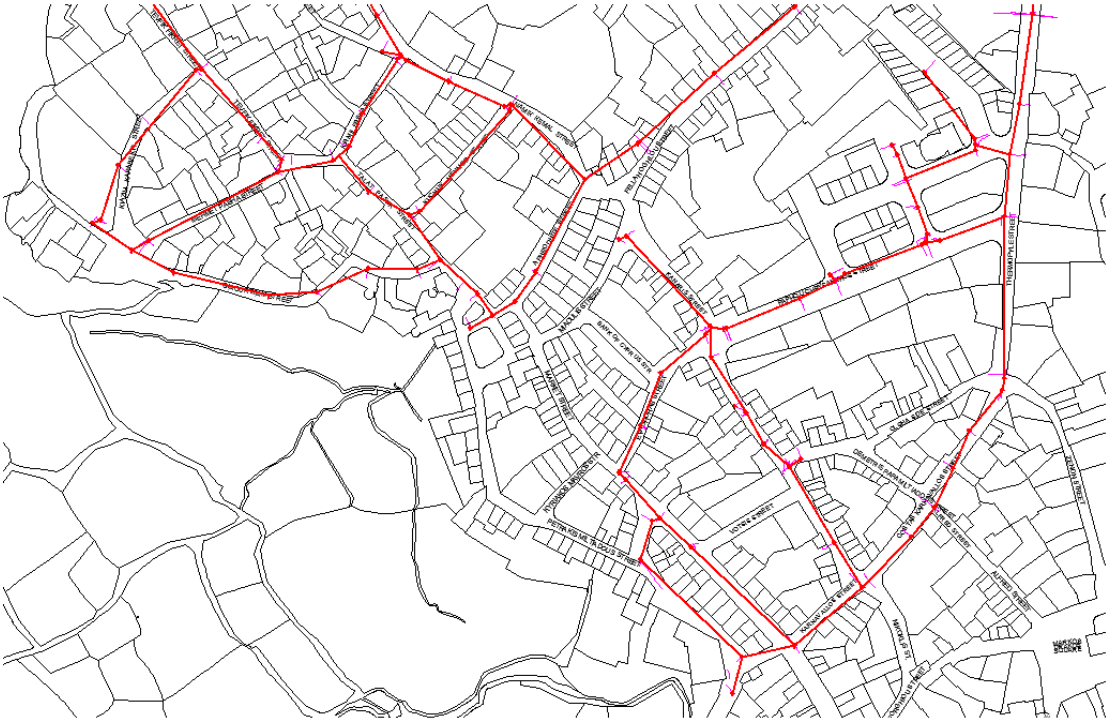

Figure 3 - The water network following the GPR survey

GIS was used to develop a comprehensive management system of the information, including cartographic and quantitative data, as well as text. Maps from Paphos Municipality depicting existing buildings, streets, etc were used in creating the digital map. The use of the radar scanner permitted the imaging of all required information regarding the existing water supply pipes, including altitudes, grading, location of other services, diameters, etc. Satellite data of the region of Paphos Municipality, including Quickbird, IKONOS, Landsat TM or SPOT satellite images, will be used to retrieve the present conditions. The capturing of satellite data at any moment in time using remote sensing techniques can provide the current construction development and, therefore, the immediate water supply needs in the municipality. In conjunction with the maps and ground measurements, it will be possible to develop an accurate digital imprint.

The acquired information will be organized in a GIS system, thereby allowing the creation of maps and their analysis at different "layers", including the water supply network, buildings, water supply elements, geographic information, features of the network's systems, etc. The basic structure of the layers is described as follows:

1. The first layer depicts the connections of the pipes to the buildings, including information relating to serviced flowmeters, the main input pipe, the relevant dimensions of the pipes, etc.
2. The second layer depicts the pipes of the network. It includes information on the geometrical elements of the excavation where the pipe is located, features of the wells, the length of the pipe, altitudes of the pipes determining their grading, etc.

3. The third layer will depict the pumping stations of the selected network and will include, in text form, all the features of the pumping station such as supplies, pressures, features of the systems comprising the pumping station such as pumps, valves, flowmeters and relief systems, etc.
4. The fourth layer will depict the reservoirs together will all the junctions/joints of the pipes and will include a description of all the features of the reservoirs.
5. The fifth layer will be the type of material of the pipe network, the diameter, the depth of the network, and the installation year. Moreover attribute table regarding water consumption, flow, water leakages records etc will be included.
6. The sixth layer will be used as a background layer from cadastral maps, elevation, etc.
7. The seventh layer will be the results of the field study of the radar measurements that will be surveyed by GPS technology.

Finally all the retrieved information that are available through the acquired software regarding surveying, analysis, management, processing, will be inserted in the GIS database (Figure 4). The GIS system will be flexible, allowing the addition of any layer considered necessary for the better management of the Project information. It must be noted that depending on the results of the initial study of the networks in Paphos Municipality, the final structure of the digital imprint as well as necessary information to be contained therein will be decided, in order to proceed with an accurate modeling of the representative network.

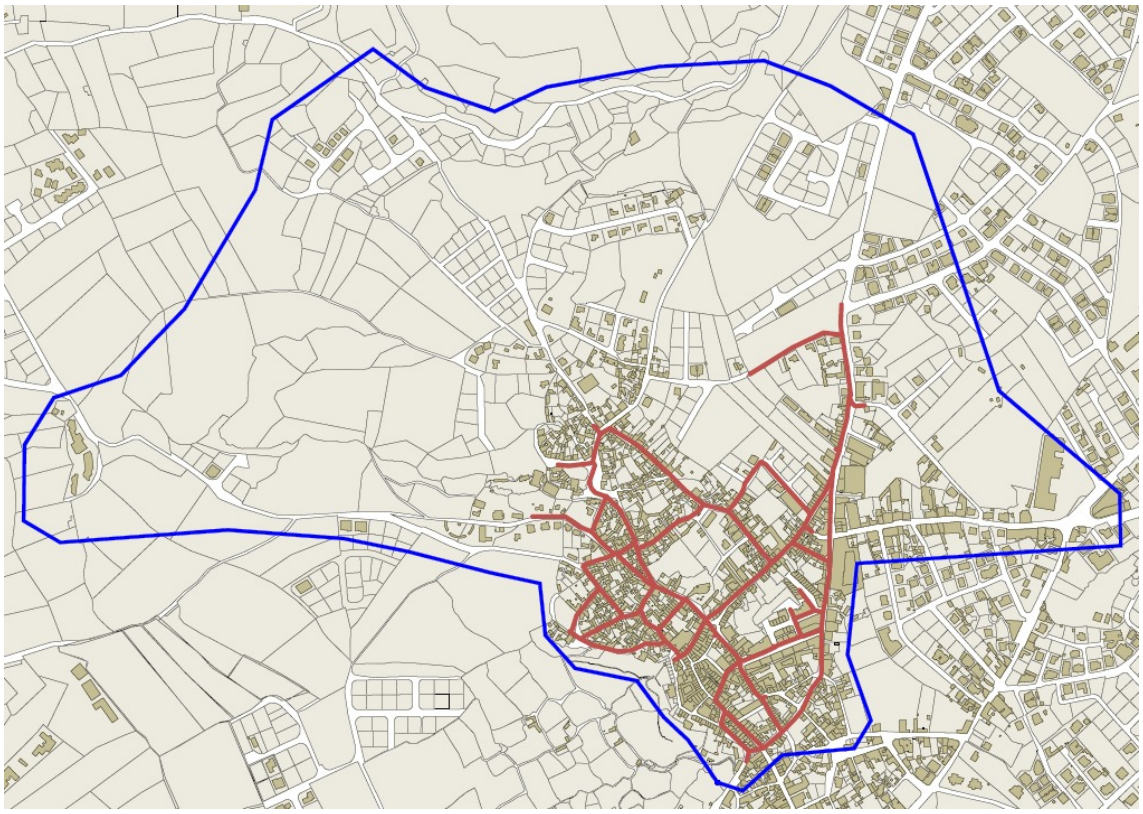

Figure 4 - Area of interest, including the GPR water pipe network survey

3. EXPERIMENTAL REPRESENTATION OF THE SUPPLY NETWORK AND INITIAL LABORATORY TESTS

Based on the digital imprint of the selected network, CUT will develop constructional drawings of the part of the network to be modeled. These drawings will include all necessary information of the piping and locations of all components to be installed. It is important to note that all parameters included in all four layers of the GIS System will be used for the accurate modeling of the network (i.e. altitude and gradients of piping, etc). Using the existing workshop facility, the piping will be constructed and will assemble the network together with all its necessary components. Figure 5 indicates similar 3D drawings of distributions networks. The experimental representation of the supply network, in combination with state-of-the-art methodologies will be used for optimizing the water supply networks, both in the design and in the operation phase, using multiple variables and criteria, which will be identified throughout the study

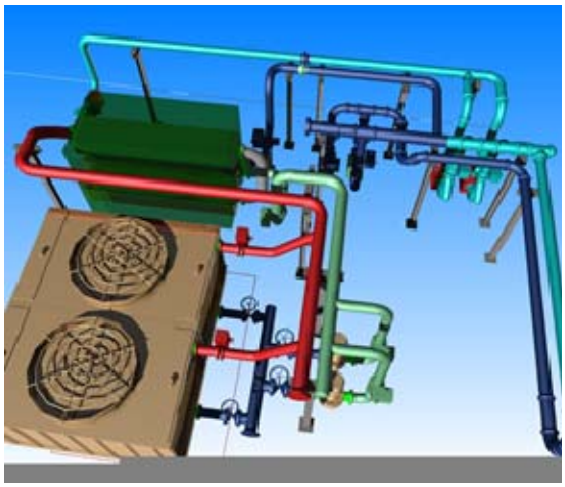

Figure 5 - Typical 3D drawing of a distribution network

A methodology will also be created for detecting and adapting critical parameters of the mathematical models (e.g. surface roughness coefficient of pipes etc), based on actual experimental measurements of the flow field in corresponding hydraulic models. As well, detailed experimental verification of the computational results and the development of knowledge for self-regulation of pumps and valves will be examined in order to satisfy the supply needs in conjunction with the uniform pressure distribution in the water supply network. In this way, guidelines will be developed which could form the basis for developing a user-friendly network simulation software, able to make up for the lack of communication between the different sciences involved in developing/designing and managing water supply networks.

4. RESULTS

The preliminary underground survey conducted for the HYDROGIS project shows positive results in using ground penetrated radar to identify the underground pipe network in the Municipality of Paphos. GPR scanning is a useful tool for modeling the water supply network, design and operation, with the goal of minimizing water loss. The aim of the project is to utilize scanning and 3D spatial representation to develop a GIS platform for managing all information required, including maps, satellite imaging, 3D scans, network system components and others. A methodology will be developed to regarding the critical parameters required for hydraulic models. Because of the nature and importance of the Project, there will be immediate dissemination of the results to all government authorities, including Water Boards, Municipalities, the Ministry of Agriculture and Natural Resources, the Ministry of Communications and Works, Associations of Civil & Mechanical Engineers, etc. It is considered almost certain that the results will be of immediate interest and use, since they can form the basis for solving some of the most pressing water supply problems in Cyprus.

ACKNOWLEDGEMENTS

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