

Dynamic management of water supply systems: A tool to build scenarios by merging GPR surveys and augmented reality

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Abstract: Water Supply Systems (WSS) are extremely complex assets. Suitable knowledge of their components and the changes they undergo are necessary to control and productively manage these systems. Currently, non-destructive methods for exploration of WSS components, in contrast to other destructive testing methods, are intensely promoted. However, with the complexity of WSS spatial layouts, along with the steady growth of the cities, and the huge volume of information generated by non-destructive methods, data analysis become more complex, and this result in inefficient WSS management. The aim of this work is to propose a first step towards the development of a framework where data from the components of WSS obtained by non-destructive methods may suitably be interpreted and combined with the real environment. To this purpose, we make use of augmented reality (AR) techniques to combine the real (urban) environment with visualizations of WSS components obtained from ground penetrating radar (GPR) surveys. As a result, a first proposal to recreate WSS on an AR platform, based on the non-destructive characteristics of the used sensors, is devised where the physical elements of WSS may be easily explored and updated. This will definitely help promote the concept of dynamic management of WSS.

Keywords: Augmented reality; Ground penetrating radar; Dynamic management of WSS; Pipe layout and characteristics visualization; non-destructive methods

1. INTRODUCTION

Suitable knowledge of the layouts and characteristics (condition, age, e.g.) of water supply system (WSS) components (pipes, valves, etc.) is essential for efficiently and dynamically manage these systems. This knowledge is crucial to achieve such goals of WSS management as: illegal connection identification, water leakage detection and control, simulation and operation of networks, study of the evolution of pollutants into the networks, planning of supply systems, and maintenance, rehabilitation and renewal of components, among others. However, many WSSs managers do not have suitable information about their assets, do not even have correct reference systems, or have just started to implement incipient reference systems. With the passing of time and due to many operational and maintenance activities, the networks of a given WSS may have been intervened, modified or even closed down. Frequently, these changes in the network are not registered, and the reference systems (in the case they are available) have become obsolete. Sometimes, this information remains in the personnel memory or in simple map annotations, being eventually forgotten.

To find and/or update the WSSs layouts or characteristics, surveys through road excavations are commonly used. This exploration form carries high economic and social impact. To get additional information about the system, sometimes other common activities, such as various tests undergone by company senior personnel are carried out. In addition, locations of valves, manholes and other visible components are used to get an intuitive idea about the layout of the network. However, these activities only provide managers with partial and inaccurate information about the networks, and thereby leave gaps in the information system.

On top of the problems derived from inadequate reference system and incorrect updating (if any) of the operational activities in the network, we have to consider the complexity of inspection tasks

and execution of various activities in the network. This difficulty may be attributed to the fact that management plans are sometimes coarsely annotated in maps. However, accurate judgment of this kind of information requires that the personnel apply some mental transformation from the map (often inaccurate) to reality to carry out the corresponding management activity (Schall et al., 2008). This additional mental process makes even slower any effective implementation of actions and, as a result, the dynamic management of WSS is hindered.

This document proposes a first step to try to solve the above mentioned problems. Our aim is to promote efficient and dynamic management in WSSs regarding such aspects as: data collection, inspection, prevention, maintenance, decision-making and implementation plans. To this purpose, we make use of augmented reality (AR) as a visualization technique to combine the real (urban) environment with virtual environments. To generate virtual environments for components of WSSs we propose the use of data obtained from non-destructive methods. This is because currently the use of non-destructive methods to trace layouts and discover features of hidden components of WSSs has been favored in order to minimize the social and economic impact caused by the conventional inspection practices employed. To do this, we propose merging various interpretations of ground penetrating radar images (GPR) so as to generate virtual environment systems of augmented reality. GPR selection is here considered due to its characteristics of non-destructive method, which allows to discover layouts and features in both metallic and non-metallic pipes. GPR has also important application in discovering other WSS characteristics such as leaks.

This paper is organized as follows. In the first section we have shortly introduced the work performed. AR systems and some applications in WSSs are shown in the following section. Then, we propose the introduction of GPR inspections in WSSs within the AR framework. Next, an example of using GPR interpretations within AR is considered. Finally, a concluding section closes the document.

2. AR SYSTEMS AND APPLICATIONS IN VISUALIZATION OF WSS COMPONENTS

AR systems are based on a combination of real and virtual environments. When the real environment prevails over the virtual one in a mixed reality, the so-called augmented reality appears. These systems arise with the aim of providing on-line displays of further information regarding the space under study. Such systems have many and varied applications, and are used in games, interactive books, museums, or in other specialized fields such as Medicine (Mischkowski et al., 2007), Engineering (Kumaran et al., 2007), Archeology (Bernardini et al., 2012), and Environmental Management (Romão et al., 2002), among others.

The main AR components are capturing a real environment, and generating a virtual environment. However, there is an intermediate step that involves the projection of the model that represents the virtual environment onto the real environment for the fusion to be effective. Tools, like ARToolKit library (ARToolKit), have been developed with the aim to extract features from real environmental projections and to transform them to the virtual environment in a correct fusion. In addition, for these AR systems a number of tools exists that can be used to get various levels of visualization. For instance, "X-ray vision" and "floating vision" are two of the most commonly used visualization methods. Both define different combinations of the real and the virtual environments. Similarly, there are tools that promote understanding about what is displayed (especially viewing buried structures), such as: "excavation tool", "metadata querying tool" or "filtering tool" (Schall et al., 2008). The final aim of these tools is to build more realistic AR, so that the user may interpret what is seen in a more clear way.

There are many and varied applications for visualization of WSS pipes that use augmented reality: works for visualization (Roberts et al., 2002) or positioning (Roberts et al., 2007) of buried utilities, where AR is used in combination with GPS and INS (Inertial Navigation System) or GNSS (Global Navigation Satellite Systems), respectively. There also exist uses of Handheld AR for the visualization of underground infrastructure focused on outdoor works (Schall et al., 2009). Similarly, there are works that use Context Rendering in combination with AR for the on-line

visualization of underground structures (Chen et al., 2010), and proposals like the one by Bentley (Bentley, 2012), in which it is possible to introduce data from pipeline excavations and combine them with raw GPR images. However, most of these applications are based on 3D models generated from plans formatted in CAD or GIS systems. In many cases these methods are not up-to-date, and updating them would result in substantial increase in renovation costs, since they would have to be performed by conventional methods (excavation, e.g.). In the next section, we propose an alternative to create a 3D model from the scratch that can feed the virtual environment of AR with real data. This will serve to update – using GPR as a nondestructive sensor – 3D data in already established AR systems.

3. THE PROPOSED SYSTEM

The proposed system in this document is based on the introduction of a new AR-variant in the generation of the virtual environment. In this variant, data from WSSs components are obtained by GPR surveys avoiding any information captured by conventional methods. This variant is presented in Figure 1. The details are explained below.

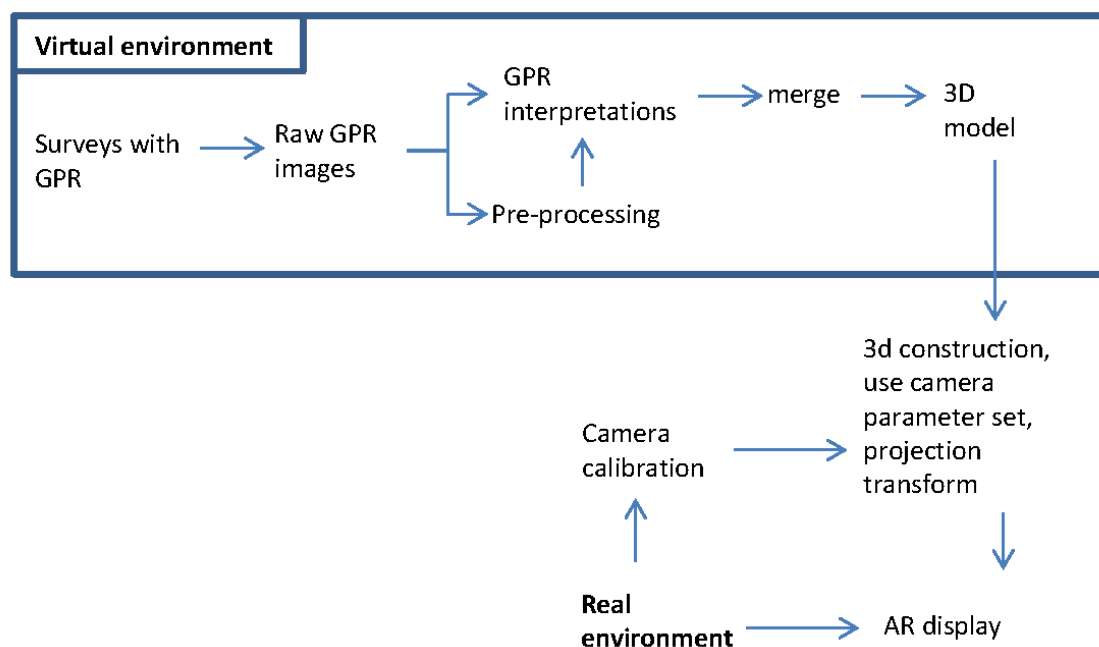


Figure 1. Schematic AR fusion of a proposed modification into a virtual environment using GPR interpretations.

GPR Surveys. It is proposed to capture profiles spanning the interest 3D area by collecting specific GPR images: mutually perpendicular slices are captured to obtain maximized information of the area of interest. This system is proposed for workers with low experience in GPR management.

Raw GPR images. The signal emitted by the GPR is then received by the computer after passing through the different materials that make up the inspected underground. These responses are accumulated over time building what is known as a trace. Energy values received are transformed into the audio-frequency spectrum, whereby the temporal wave amplitude values corresponding to each trace are obtained. The successive accumulation of these traces is performed according to the displacement of the antenna generating the so-called radargram. The GPR image is obtained by applying a color scale (usually grey scale) to these wave amplitudes. Sometimes, highly experienced operators in interpreting these images are able to find anomalies or objects in the underground. However, this is a rather complex and unfeasible process for high volumes of information.

Pre-processing. This process is performed in order to clean the noise of GPR images. This noise can be originated by the process itself, or by external signals embedded in the underground material gathered on the signal path. The aim is better visualization of the contrasting images and observing features of the objects under the ground. This is the way in which image preprocessing in WSSs is performed by the application of procedures adapted from other methodologies. This is the case of the application of background removal and Migration, used by Olhoeft (2000) for cleaning GPR images to find metallic pipes. Works such as the one by Simi et al. (2008) use the Hough Transformation in the pattern recognition of the hyperbolas formed in GPR images. There also are works regarding leakage as the one by Tavera (2008), in which Hilbert and Fourier transforms are employed, or works for the enhancement of the visualization plastic pipes (Ayala-Cabrera et al., 2010). Other works, based on intelligent systems for automatic pipe detection by GPR images use neural networks (Al-Nuaimy et al., 2000), support vector machines (Pasolli et al., 2008), fuzzy logic (Ciu et al., 2010), or multi-agent methodologies (Ayala-Cabrera et al., 2011), among others.

GPR interpretations. Contours that can represent features of interest in the prospected underground are extracted either from the raw or the preprocessed images. When interpreting images of radargrams the features most commonly analyzed are hyperbolas. They are demarcated by the color intensity within the image. A non-automatic process is proposed in this document with the aim of determining the feasibility of the interpretation of GPR data. In addition, we are interested in observing if these interpretations are reliable and can gain relevance for understanding features of WSS components. However, if this process is effective, it could be implemented automatically.

Fusion process and 3D model. The fusion of the GPR image interpretations is achieved by their projection onto a common space. Firstly, a classification of common zones in the GPR interpretations that may correspond to specific cross sections of the area or volume is performed. Then, a mesh in the 3D space is constructed. After that, each of these volumes or surfaces is added to a common space, shrinking thus into the 3D model. There are a number of applications to achieve this kind of fusion usually employed in photography or painting (Russell et al., 2011), which can be adapted to generate 3D models of the GPR interpretations.

4. AN EXAMPLE OF AUGMENTED REALITY REGARDING PIPES

This section is based on the approach previously described in which we have introduced a variant in the generation of 3D models for AR systems by GPR interpretations of WSSs components. The results of a laboratory test are shown. In this test a commonly used pipe is buried in a tank with dry soil. The buried pipe has an external diameter of 98 mm. The survey is performed using an antenna of 1.5 GHz and a rate of sampling of 20ns per trace. A total of 12 slices (cross sections) are obtained: 6 of them are taken transversally to the pipe, and the other 6 in the longitudinal direction; the spacing between them is 0.20 m in both directions.

The GPR images obtained in this test were individually analyzed. Candidate anomalies were located based on these images. Then these traces were extracted thus generating what we call GPR interpretations of raw data. These interpretations were organized as a mesh, thus generating a 3D space of GPR interpretations. The fusion of the different slices was performed, with which we finally obtained the 3D model of raw data interpretations, which feeds the AR system. In a parallel way, raw images were preprocessed, using the preprocessing methodology proposed by Ayala-Cabrera et al. (2013). The images obtained after preprocessing underwent the same treatment of interpretation, extraction, fusion and 3D model creation, as the raw images. Thus a 3D model was obtained for preprocessing image interpretations.

After having produced the 3D models, the real environment was obtained by a webcam from which their visualization parameters were extracted in order to adjust the 3D displays to a real space. Figure 2 presents the results of the 3D insertion in the real space.

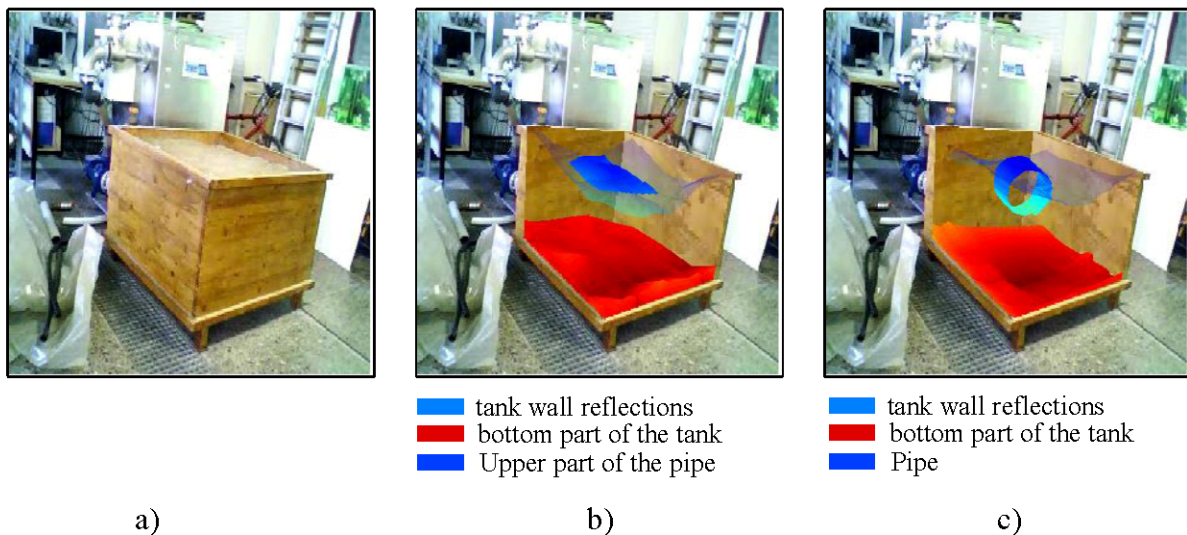


Figure 2. AR example - a) real environment, image without AR, b) image with AR; virtual environment fusion from GPR interpretations in raw data, c) image with AR; virtual environment fusion from GPR interpretations in pre-processed data.

By contrasting the real part of the images (Figure 2.a), with the AR images (Figure 2, b and c), we can observe the contribution of the AR to the environment: it allows better understanding of this environment. Moreover, it must be noted that it is feasible to obtain the information of the virtual environment by non-destructive methods, such as GPR in this case. It can also be observed that performing a suitable preprocessing of the images favors the interpretation of these images and, as a result, new information may be extracted. In our case, it is additional information regarding the characteristics of buried pipes in WSSs. Thus, in Figure 2b, we partially observe the pipe (visualizing only the upper part of it) and in Figure 2c, we can observe the whole contour of it. It should be mentioned that the visualization of the pipe (Figure 2c) is exaggerated with respect to the diameter introduced. This is due to the GPR's reflections, and the vertical resolution of the equipment which diminishes with depth, thus augmenting the pipe diameter. However, although the pipe for this image is obtained in a relative big size, it gives us an approximate idea of this specific buried component. Of course, we could also conclude that by a suitable automated image preprocessing it is possible to achieve more information concerning the case-study presented.

5. CONCLUSIONS

This paper has underlined the importance of using efficient tools to improve the management of water supply systems. In addition, the importance of the fact that these tools are based on non-intrusive methods and that they are fed with real data has also been enhanced. Augmented reality systems have been presented as a potential way that allows on-line visualization of WSSs components, in order to improve decision-making processes and system interventions. Thus, this work is intended to help achieve more dynamic management at different levels. In addition, GPR interpretations were presented as a tool for feeding the virtual environment of the AR. As a result, we also studied the feasibility of obtaining relevant and clear information about the components of WSSs by using GPR.

This work provides an important boost to the construction of environments enabling more efficient and dynamic management of WSSs. This can be accomplished by either existing AR applications or by implementing new ones. Moreover, this work contributes the possibility of updating for AR systems that have already been implemented, but avoiding the high social and economic characteristic cost of conventional methods for data retrieval (such as excavation, for example).

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