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Probabilistic maps for buried pipes location based on GPR images

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Abstract. In this work, statistical methodologies are used to generate automatic probabilistic maps of pipe layouts in water supply systems (WSS) based on street surveys using ground penetrating radar (GPR). Probabilistic maps are based on the analysis of GPR images along with a multi-agent generation of pseudo-random walks, and a process to discard areas with less probability of pipe existence. This is an iterative procedure that we have integrated into a system that produces GPR sampling walks, and eventually set up a reliable location map of buried pipes. As a result the survey time is optimized and the amount of data needed to conduct records of the components of WSS is minimized.

Keywords: Automatic Pipe Location, Ground Penetrating Radar, Non-destructive methods, Water supply system.
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1. Introduction

Records of components, layouts and characteristics exhibit great inaccuracy or are even non-existent in many cases in WSSs companies. To cope with this situation, street surveys are usually undertaken through road excavation. This type of exploration involves high economic and social impact. As a consequence, growing interest for non-destructive methods in exploration of WSS components, instead of other destructive testing methods, is currently observed. However, even though information retrieval by non-destructive methods is worthwhile, the complexity of spatial layouts of WSS networks, along with the steady growth of cities, the huge volume of generated information, and the interpretation of data, usually require high levels of skill and experience. The purpose of this work is to improve the usual exhaustive scanning systems with GPR.

2. Proposed system

The proposed system is based on an iterative analysis process aimed at generating automatic probabilistic maps of pipe layouts in WSSs using GPR as a sensor. This system may be described in terms of three procedures.

1. *Acquisition and sampling GPR data.* Firstly, the interest (square) area to inspect is selected, and some features, namely origin, axes and coordinate system, size ($L \times L$, in meters), are established. Next, we use the Latin square sampling (LSS) technique to explore ground variation sources. After initializing the process with the LSS, new sections are added to the routes for the agents to walk. The general rules for agent movements are: a) no reverse direction in the walks, b) only horizontal or vertical movements are allowed, and c) perpendicular movements to the previous movement are favored.

2. *Analysis and interpretation.* In the second procedure, the pipe existence plausibility in the analyzed image is evaluated. The underlying rationale behind the first stage consists in cleaning zones where the presence of a pipe is less likely in the obtained image [1]. To this purpose, first, the obtained profiles are transformed to $T14$ and $T15$ images [2]. Then, the Hough transform, a segmentation technique, is used to detect and remove the horizontal lines from both images. These images are then merged; thereby a new image is generated. The second stage for this activity is used to interpret the final image in the last stage, and establish the plausibility of this image belonging to the pipe layout location sought. For the any analysis, we flatten the matrix associated to the image at time t onto a vector, crv_t, by row concatenation. In addition, only matrix cells with a value of 1 will contribute to crv_t. Then, an autoregressive model of order 4, $crv_t = \phi_1 crv_{t-1} + \phi_2 crv_{t-2} + \ldots + \phi_{mo} crv_{t-mo} + a_t$, is applied. ϕ_s, $s = 1, \ldots, mo$ are the parameters to be estimated, mo is the order of the autoregressive model, and a_t is the white-noise disturbance. It can be observed that the pipe existence plausibility in the image substantially increases the value of the model coefficients. Once obtained the parameters of the model for a specific route, the vector $\phi = (\phi_s)_{s=1}^{mo}$ is built. Then, a new vector, $\vec{vt}_s$, is obtained: $\vec{vt}_s = \{1,$ for $\text{abs}(v\phi_s) \geq R$ or $0,$ otherwise$\}$, where R is a threshold. R has been obtained after analyzing a set of 200 classified images obtained both in lab and field tests. A scalar vt is afterwards obtained by accumulating the values of $\vec{vt}_s$: $vt = \sum_{s=1}^{mo} \vec{vt}_s$. Finally, the plausibility indicator aci (area color indicator), to establish criteria about pipe existence plausibility when considering a given slice, is built: $aci = \{$green, if $vt > 3$; yellow, if $vt = 3$; & red, otherwise$\}$, where 'green' and 'red' represents high and low plausibility of pipe existence, respectively, and 'yellow' is assigned if a conclusion is not clearly obtained.

3. *Generation of probability maps.* The interpretation or perspective gained by a new breed of agents in relation to the existence of pipe from the slices previously obtained are called 'point of view'. The new breed of agents, amoeba-like objects, endowed with a set of six sensors, will explore for either horizontal or vertical pipe locations in the area of interest. The underlying idea is that agents evaluate the slices to build perspectives for likely existence of a pipe in both directions. These agents have the following characteristics and behavior: a) an agent will be created for each segment with aci 'green' or 'yellow', b) an agent will explore perpendicularly to the segment it was created from and will never go out of the interest area, c) three out of the six sensors will explore in one direction and the other three in the other, and d) sensor points will move away to expand the agent as much as possible with the only constraint of stopping when encountering a segment with $aci =$ 'red'. The patches of the areas identified by the agents are then assigned a value of 1, while the outer patches will be assigned 0. This process is repeated for a number of epochs decided by the user.

Each point of view obtained previously, in both directions, is accumulated, thereby generating a global view of the problem and a map demarcating the likely location of the pipeline, with high reliability. This process determines potential hot spot locations of the pipe in the study area. If after 20% of the total number of epochs selected by the user, the sum of viewpoints remains equal to zero in the accumulated point of view, both for vertical and horizontal directions, the algorithm stops and a decision is made about no existence of pipes in the interest area.

3. Experimental study

The case-study corresponds to an urban area (see, Figure 1,a). After the application of the proposed system, we eventually obtain the pipe layout in the interest area (Figure 1,d).

4. Conclusions

The application of the proposed system facilitates the analysis and interpretation of the images obtained with GPR in an interest area, favoring the mapping of unknown pipe layouts in WSSs. This is because the system reduces the data capture time, the amount of dealt data is minimized, and the relevant data is suitably identified. These results allow more complete analysis since they also discard areas with low interest.

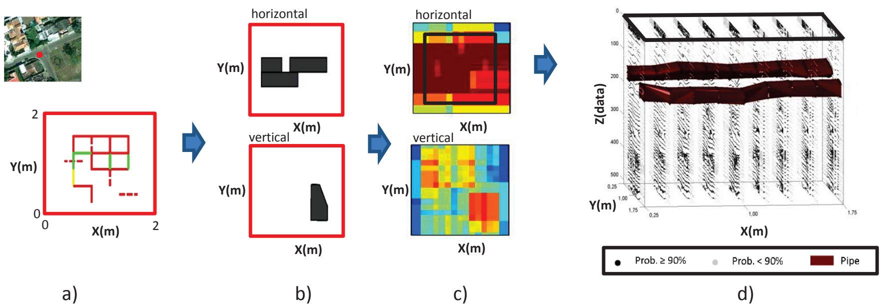

Figure 1: a) Interest area and agent walks for one epoch, b) one example for the horizontal and vertical point of view, c) horizontal and vertical probabilistic maps, d) horizontal map results.

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