Detection and Localization of Underground Networks by Fusion of Electromagnetic Signal and GPR Images

Meriem Hafsi, Philippe Bolon, Richard Dapoigny

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LISTIC, Université Savoie Mont Blanc, FRANCE.

ABSTRACT

In this paper, we purpose a new approach to the post-processing of multi-sensor detection based on knowledge representation and data fusion provided by several technologies. The aim is to improve the detection and localization of underground networks. This work is part of the G4M project, leaded by ENGIE LAB CRIGEN, the objective of which is the design of a versatile device for a reliable detection and localization of underground networks. The objective of this work, which is at the core of the G4M project, focuses on the validity of current detection methods, to optimize the process of detection using these methods and to establish a 3D map of subsoil networks.

Keywords: Data fusion, Knowledge representation, Detection of underground networks, GPR, EM detection

1. INTRODUCTION

Multimodal data processing and big data have recently emerged in various application domains such as the detection of underground network. Whereas the new regulation PR NF S70-003* imposed a drastic improvement in both the detection and the localization of such networks, the objective is to check the validity of the current methods of detection, to optimize the process of detection using these methods and to establish 3D maps of subsoil networks. However, the detection of buried pipelines appears as a very complex and challenging task.

In this paper, a new approach to the post-processing of multi-sensor detection is proposed; it is based on knowledge representation and data fusion. Several methods are used to detect and locate underground networks, each of them being specific to a given class of pipes and depending on its material, the carried product and the properties of the soil in which it is buried. In our research project, we will use the ground penetrating radar (GPR), the electromagnetic method (EM), the gas tracker method (GT) and the detection by RFID (ELIOT). Each of these methods is able to detect one kind of underground network. The GPR technique is able to detect some pipes according to soil properties by sending electromagnetic waves in the soil and measuring the travel time and amplitude of the reflected electromagnetic waves between a transmitter and a receiver. The speed and amplitude of theses waves are controlled by the permittivity, conductivity and permeability of the crossed environments. The GT method can detect only plastic pipelines carrying gas by injecting an acoustic signal in the pipe; this signal will be received by an acoustic detector on the ground surface. Alternatively, the EM method is able to detect cables and metallic pipes by injecting an electromagnetic signal which creates an electromagnetic field and propagates it throughout the underground network; this field will be received by a detector on the ground surface. Finally, the ELIOT method can only detect pipes that contain RFID tags.

The expected goal is to solve the problem of detecting underground networks by using the four methods together and merge the information and data they provide. For that purpose, we must be able to provide an accurate location of underground networks regardless of their material, their function, the product carried or the soil. The first step of our work is to check independently these distinct methods taking into account the a priori information about the ground and the necessary setting parameters to each method and then, to merge the results obtained by computing associated trust levels. To reuse all the information about the ground and the parameters of the method we can obtain before the work, we propose to formalize and represent them into an ontology. The use of an ontology allows to compute the trust level attached to each result by reasoning on

Corresponding author (E-mail): Meriem.hafsi@univ-smb.fr

*New reglementation PR NF S70-003 (FRANCE): Decree of 19 February 2013, Ministry of Ecology, Sustainable, Development and Energy,Ministry of Equal Housing and Territories the knowledge previously collected and improves the automatic detection. The second step is to merge domain ontologies populated by the context with the results obtained by each method in order to achieve and obtain an accurate and reliable single result of detection and location.

2. RELATED WORKS

The detection of underground networks is an industrial problem; therefore, the research in this domain is confidential and not disseminated to the public. The research project Assessing The Underground (ATU) aims to develop a multi-sensor geophysical platform that can improve the probability of complete detection of the buried pipes including research and development of a multi-sensor device that will employ four geophysical location technologies which are: GPR, vibro-acoustics, low-frequency electromagnetic fields, and passive magnetic fields.[1] For that purpose, some research works are done about each technology at first, like the detection and the localization of power cables using measurements of the magnetic field produced by the currents in the cable[2][3].[4] GPR is also used in[5] to investigate an algorithm for utility pipeline mapping based on street survey and GPR data. The map being generated by data association which connects the observed manholes and GPR detections (obtained manually) using the nearest neighbor standard filter and joint compatibility branch and bound methods. Finally, a Bayesian data fusion approach is proposed in[6] to automatically generate maps of buried networks from three kinds of inputs: GPR data manually interpreted, survey manhole and their spatial location.

The experimental work of the ATU project can be improved on several levels: GPR data are used in two ways, manually or automatically by estimating the pipe direction from the manhole. However, they are not present on some sites or are not accessibl. It follows that the presented treatment is based only on the existence of these manholes. The EM detection can localize all cables and metallic pipes, Furthermore, several modes of EM detection exist, (i) the active mode is the most reliable and can estimate the depth of pipes or cables, (ii) the passive mode and the induction are less reliable and the error rate is higher in these modes. The above works use passive EM detection and detect only the power cables through this method.

To solve the problem of the detection of buried networks, we present an automatic detection approach based on knowledge representation in ontologies and reasoning on this knowledge to compute trust levels and improve treatments of the data coming from three kinds of inputs: GPR meta-data and data processed automatically with two methods[7][8] , EM meta-data and data with the active mode and prior information about the soil, the environment, the provided map, etc.

3. ONTOLOGIES AND KNOWLEDGE REPRESENTATION

3.1 Information Domain

In practice, the operator in charge of the geo-detection of underground networks proceeds in several steps. The first step is to collect the maximum of information about the ground and the environment together with his knowledge about the standards of installation of underground networks and the use of detection methods. He is guided during the investigation and can make decisions related to each detection method. In our context, we distinguish four kinds of important information for a reliable and efficient detection.

3.1.1 Using GPR

Detection of pipes using GPR is intricate for two main reasons. First, noise is important in the resulting image because of the presence of several rocks or layers in the ground e.g.: in soil backfill. Thus, wave speed and object responses depend on the relative permittivity e.g. in moist or clay soil, waves do not penetrate or in reinforced concrete, the energy is absorbed by the scrap metal which prevents the detection of pipes underneath.[7]

3.1.2 Using Electromagnetic (EM) detection

The electromagnetic detection is effective and reliable when environmental conditions are favorable because the sensor is highly sensitive to the electromagnetic fields that can be generated, by railway track, electrical power lines, etc. Furthermore, errors can occur if several networks are buried in the same place since the electromagnetic field always focuses to the most conductive network leading to the detection of a wrong network.

3.1.3 Underground networks installation standards and manhole

According to his knowledge about the installation standards of underground networks, the operator connects the parts of underground networks present on the ground surface by knowledge-based reasoning to estimate the position of the network and facilitate its detection.

3.1.4 Practical information

Knowledge acquired by experience and practice of the operator is useful for better detection. In GPR images for example, the contrast of the hyperbola generated by a pipe, can determine its material because the reflected signal varies thereof (very important for metal and very low for polyethylene). The diameter and depth can also be determined according to the form of the hyperbola. If a network is detected by the passive electromagnetic method then one can infer that the network is either a metal pipe, a power cable or a telecommunication cable.

This kind of information is required for a reliable and accurate detection of underground networks. Therefore, the proposed method will include such an a priori knowledge, when available, in the automatic detection process. Since this information cannot be stored in a database, we have to formalize it into symbolic knowledge. Knowledge representation[9] is a field of artificial intelligence that provides a set of tools and methods for representing and organizing human knowledge in a formal language allowing them to be understood and reused by computers. Formal ontology appears as one of the most promising tool used in knowledge representation.[10] In the scope of computing systems, a formal ontology can be seen as a set of concepts and their properties interconnected by different kinds of relationships.

3.2 The developed ontology G4M

Using Methontology[11] as a development process, the creation of our ontology is performed according the following steps: the first step is to prepare a formal document describing with sufficient precision the domain to represent. The second step is the conceptualization which consists of the definition of all the concepts, the properties and the relationships, an example of the concept underground network is given in the figure 1. The third step is to formalize the conceptual knowledge in a formal knowledge representation language which enables them to be understood by computers. The formal ontology is expressed in Description Logics language[12] and implemented with the OWL format[13] in the editor Protege 4.3.

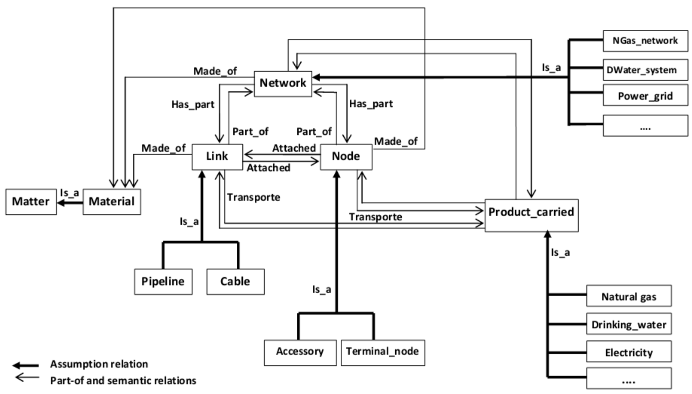

Figure 1. An extract of the conceptual ontology developed describing an underground network.

3.3 Use and reasoning on the ontology G4M

The goal of knowledge acquisition process is to enrich the assertion component (Abox) of the ontology from information supplied by the operator and the data acquisition through an interface. At first, Abox of soil is enriched and reasoning on the rule base of soil is done to infer a new knowledge; then Abox of the underground networks is enriched if they are known and reasoning on the rule base is done to infer a new knowledge about the probable architecture of the networks presents in the ground. The final step is to save all acquisitions data with EM and GPR on the ground saving the geographical position of each acquisition. From the general Abox, a new knowledge is inferred by reasoning on three rule bases defined with the SWRL format (figure 2).

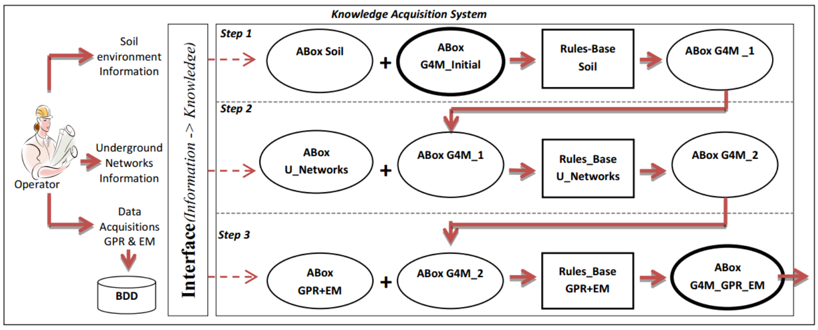

Figure 2. Process of knowledge acquisition by reasoning and translation of information and data into symbolic knowledge.

4. AUTOMATIC DETECTION OF UNDERGROUND NETWORKS

4.1 GPR

4.1.1 General method

The automatic detection by GPR consists in analyzing the signal or the image obtained by a GPR acquisition also called B-scan and to extract automatically the hyperbolas generated. Several methods are proposed with two approaches: the first approach is based on GPR signal processing[7] and the second approach is based on image processing to treat the GPR images using Hough Transform[14][15], Neural network [16] or Wavelet.[8] These methods give promising results but they are not able to detect buried pipes or cables from a single acquisition which correspond to one pass 2D on the ground and the presence of an hyperbola means there is a punctual-like object, for instance a pipe or a rock.[8]

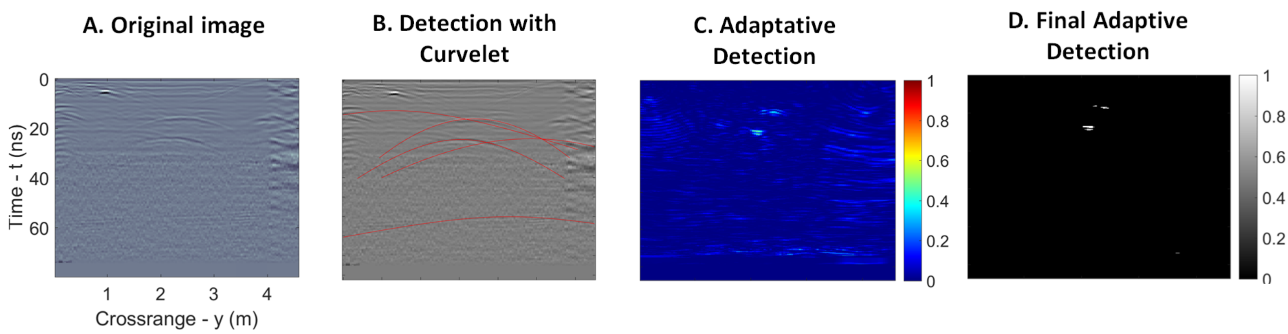

Figure 3. Example of automatic detection using two approaches on a B-scan PRC000041.scan obtained from Savigny-Sur-Orge site (Paris, France) at 18/10/2016.

Figure 3 is an example of a B-scan obtained on a test where a metallic pipe is buried. The image (3A) correspond to the original GPR image and (3B) correspond to the result of the automatic detection of hyperbolas using Curvelet,[8] five hyperbolas are detected which two are visible but only one is generated by a pipe. The second algorithm treats the GPR signal with an adaptive method[7] and gives detection results with contrast between 0 and 100 as shown in image (3C) and the final detection results are binary as shown in image (3D): four hyperbolas detection are obtained which two are visible but only one is generated by the pipe.

4.1.2 The proposal

To solve the problem of reliable detection of underground network by GPR, we propose an approach of spatial representation of multiple GPR acquisitions in the same ground in order to search the hyperbolas generated by a pipe or cable and to eliminate false-alarms (bad detections). This spatial representation is done with an algorithm which represent the ground site in a matrix of objects and projects all the GPR acquisitions with

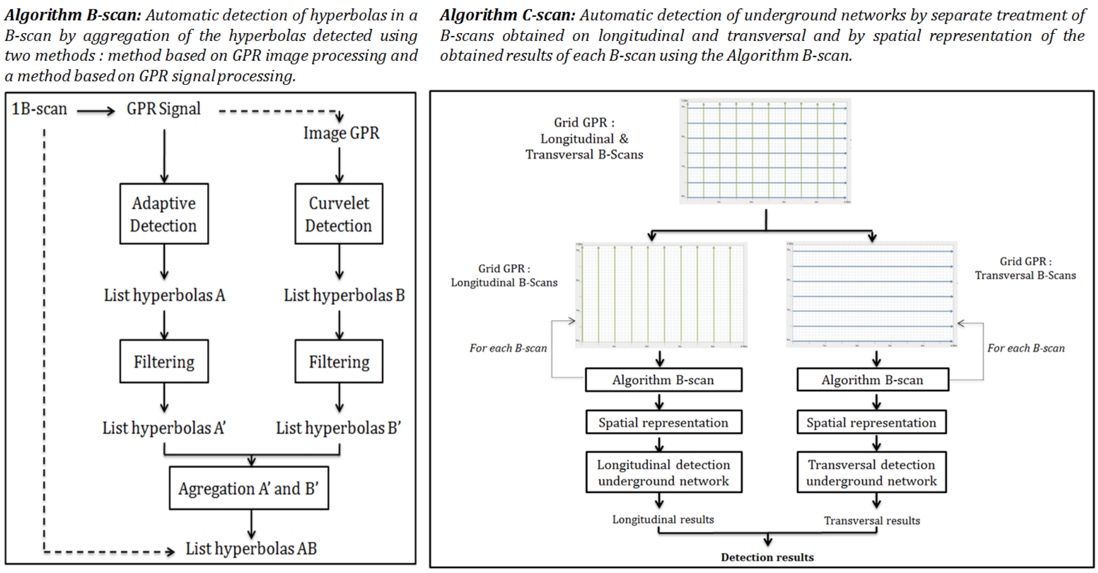

Figure 4. Algorithm of automatic detection of underground networks using GPR.

the detection obtained in the relevant objects. Theses detections are obtained by a treatment of the hyperbolas using the automatic detection by Curvelet[8] and the Adaptive method.[7] Our approach is particular because it is based on the use of two different approaches (figure 4) to analyze the same GPR data and the aggregation of their respective results to improve the detection of hyperbole and reduce the number of bad detection on each B-scan. A first filtering step is done on each hyperbola detected on a B-scan with the purpose of eliminating the noise or improve the quality of the detection. The aggregation of several B-scans will determine whether the detected hyperbolas correspond to a pipe or cable by the monitoring and the evolution of an hyperbola from a B-scan to another.

4.2 Electromagnetic detection

4.2.1 Current method

The EM detection of a pipe or cable is done in several modes depending on the conditions of the ground and the buried networks. In this article, we focus on the active mode which consists of injecting an electromagnetic signal into the buried network and to search the electromagnetic field generated with a detector on the soil surface. This search is done by several perpendicular passages to the cable or pipe, the goal of each passage is to find the maximum of the signal detected and mark it on the floor using paint, the detection result is obtained by connecting these marked points. This process is realized manually by the operator, thereby, it has many drawbacks such as the decrease of the accuracy attached to the position of the cable or pipe because if there is wrong point detection, the whole position is corrupted.

4.2.2 The proposal

To optimize the EM detection, we propose to automatize the current interpretation method and to improve its accuracy with a localization model based on spatial reasoning on the detection points. This model takes the properties of the ground and the detection points as inputs and generates a plan with a route of the pipe or cable. The principle of this model is the study of the spatial coherence between the detection points by creating segments between each sequence of points and then evaluating the resulting variation of angles made between each series of segments according to standard installation networks. This evaluation allows to detect and to correct the wrong detection points, thereby improving the accuracy of the position of the desired pipe or cable.

4.3 Automatic multi-sensors detection

GPR is the only method which is able to detect all kings of underground networks. Sometimes, depending on the ground and properties of some networks, it may not detect them but can be supplemented by other data. Therefore, we propose to merge the results obtained with two detection methods, GPR and EM using a linear combination which takes into account several trust levels for each king of results. Three trust levels are attached to the EM data : the first is obtained from the environmental knowledge, the second from the used mode of EM detection, finally, the number of fake detection points. Four trust levels are attached to the GPR data, they are obtained from: the environmental knowledge, the distance between B-scans and the quality of the detection. The latter is determined if a buried object (pipe or cable) is detected in all the B-scans and if it is detected with both approaches used to analyze and detect automatically the hyperbolas.

5. RESULTS

5.1 Acquisition protocol

GPR and EM acquisitions were conducted on a test ground at Crigen Engie Lab (Paris) where ten pipes are buried with different diameters, materials and depths. The goal is to obtain multi-sensors data to test our algorithms. The test ground is a topsoil with dimensions (10m x 4m) as shown in figure 5. The GPR data

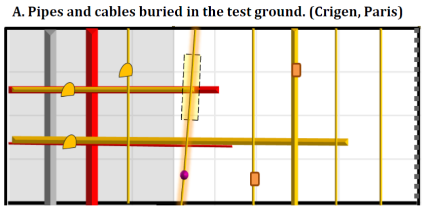

Figure 5. Test site (10m x 4m).

are separated in two sets: the longitudinal B-scans and the transversal B-scans. Each of them allows to detect the perpendicular buried objects. Figure 6 shows the results of treatments on the longitudinal B-scans, the hyperbolas obtained with the adaptive detection (B) and with Curvelet (C) allows to detect the pipes shown in (C) and (D). The figure 7 presents the results of treatments on the Transversal B-scans.

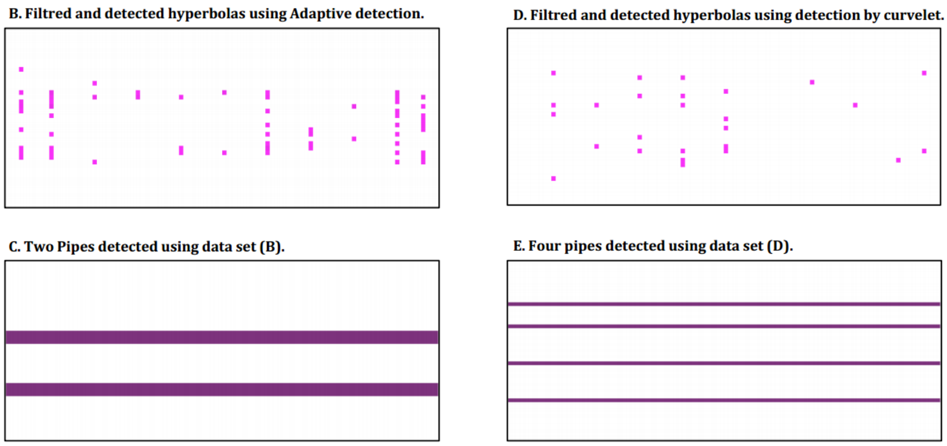

Figure 6. Hyperbolas filtered and pipes detected in the longitudinal set of B-scans.

From the analysis of these results, it seems obvious that the Adaptive method gives reliable detection results while incomplete and the method by Curvelet detects more pipes but with less precision than the adaptive method. Figure 8 shows the result of aggregation of the adaptive method with the Curvelet method (I and

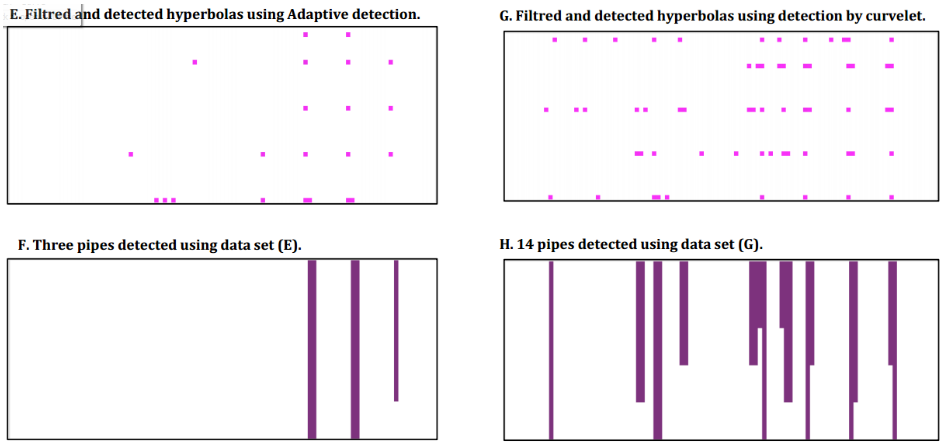

Figure 7. Hyperbolas filtered and pipes detected in the transversal set of B-scans.

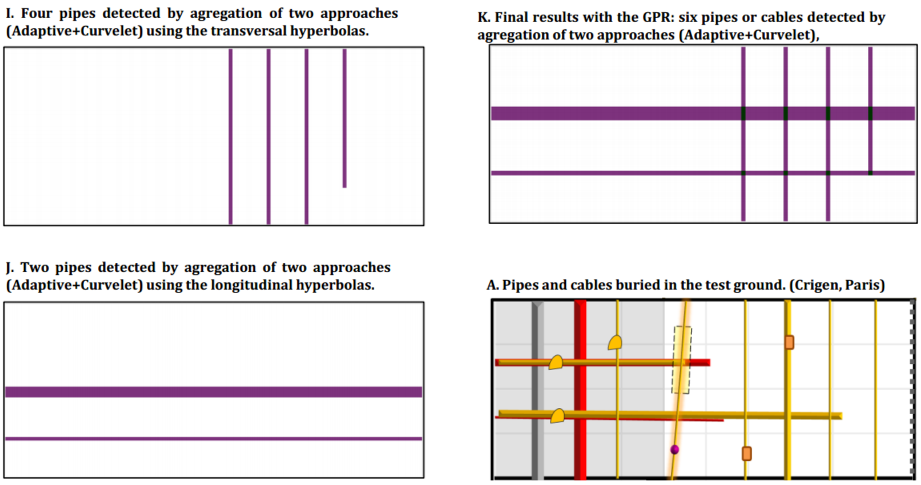

Figure 8. Detection results by the aggregation of two approaches.

J) and the final pipes detected by aggregation of the results on transversal and longitudinal (K). The second investigation is the detection of a metallic pipe using the electromagnetic detection with the active mode as shown in the figure 9. The detection points are presented in (L) and the final detection in (M). The final investigation turns out to merge the results of the GPR with EM, seven (7) pipes among ten (10) are detected as shown in (N). Evaluation of the result is achieved with checking the known configuration plan (A).

6. CONCLUSION

In this paper, a new method to combine GPR imaging and electromagnetic sensors for detecting and localizing buried pipes is introduced. The use of an ontology to represent and reuse important information to the detection process has shown its utility through the experimental tests. The combination and processing of GPR data using two different approaches and multi-sensors aggregation has greatly improved the detection of underground networks as shown in the experimental results. Future work will focus on the multi-sensors aggregation of heterogeneous data provided by several sensors like GPR, EM, GT and Eliot.

ACKNOWLEDGMENTS

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†G4M: http://www.g4m.fr/

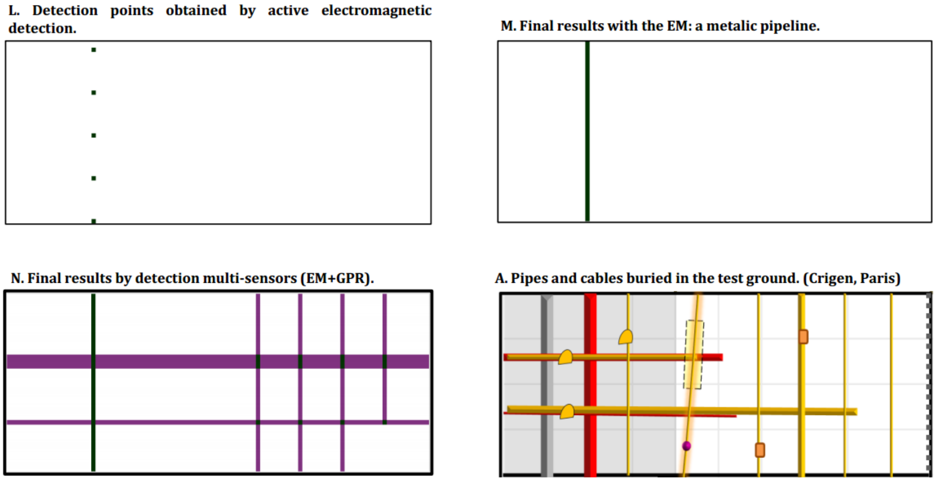

Figure 9. Automatic detection of a metallic pipeline using and results of the automatic detection multi-sensors of underground networks Electromagnetic method.

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