57
Review paper
Doi 10.61892/stp202401048R
ISSN 2566-4484

Aleksandar Ristić, University of Novi Sad, aristic@uns.ac.rs
Željko Bugarinović, University of Novi Sad, zeljkob@uns.ac.rs
Milan Vrtunski, University of Novi Sad, milanv@uns.ac.rs
Aleksandra Radulović, University of Novi Sad, sanjica@uns.ac.rs
Milka Šarkanović Bugarinović, University of Novi Sad, milkasb@uns.ac.rs
Dušan Jovanović, University of Novi Sad, dusanbuk@uns.ac.rs

DETECTION OF DISTRICT HEATING PIPELINE USING UAV-MOUNTED THERMAL CAMERA AND GPR SCANNING

Abstract

In this paper the benefits of integration of UAV-mounted (Unmanned Aerial Vehicle) thermal camera and GPR (Ground Penetrating Radar) are analysed. As an example we analized a district heating pipeline in a part of university campus in Novi Sad. Thermal camera mounted on UAV enables fast mapping of routes. These data are then used to detect critical zones where leaking or some other problem occurs and to validate utility cadastral data. Detailed inspection of zones is done using GPR scanning. This provides data such as geometry, precise location of damage, etc. In the last section of the paper advantages of non-invasive detection of district heat line combining active and passive sensors with UAV are explained.

Keywords: GPR, thermal camera, UAV, district heating pipeline, mapping

ДЕТЕКЦИЈА ТРАСЕ ТОПЛОВОДА КОРИШЋЕЊЕМ ТЕРМАЛНЕ КАМЕРЕ НА БЕСПИЛОТНОЈ ЛЕТЈЕЛИЦИ И СКЕНИРАЊЕМ ГЕОРАДАРОМ

Сажетак

У овом раду анализиране су предности интеграције снимања термалном камером постављеном на беспилотну летјелицу и технологије скенирања георадаром. Као примјер за анализу узет је дио трасе топловода у кампусу Универзитета у Новом Саду. Термална камера на беспилотној летјелици омогућава брзо мапирање трасе. Ти подаци се потом користе за одређивање критичних зона или за провјеру валидности катастарских података. Детаљна претрага зона се изводи скенирањем георадаром. На тај начин се долази до информација о геоетрији, тачној локацији оштећења итд. У посљедњем дијелу рада објашњене су предности детекције коришћењем беспилотних летјелица са активним и пасивним сензорима.

Кључне ријечи: георадар, термална камера, беспилотна летјелица, топловод, мапирање

1. INTRODUCTION

District heating networks function by circulating heat through underground pipes containing hot water or steam from a central power plant. Common issues include heat loss due to damaged insulation or media leakage from cracks, exacerbated by the aging of pipes, some of which have been in use for decades in certain cities. The loss of media or energy is not only costly but also environmentally detrimental [1, 2]. Modern remote sensing technologies are more and more applied for fast and efficient detection of underground infrastructure. Their main advantage is that, unlike usual detection methods, they cannot cause damage to underground objects. Also, they have an important role in creating, updating and maintaining of the utility cadastre. Due to its wide area of applications, Ground Penetrating Radar (GPR) is the leading Non-Destructive technology (NDT) for underground utility detection [3-5]. Contemporary methods for non-intrusive examination and evaluation (NDT) of district heating pipelines fall into two main categories: technologies aimed at detecting and analyzing the geometric features of the pipelines, such as Ground Penetrating Radar (GPR), thermal cameras, and electromagnetic locators (EML); and technologies focused on analyzing the condition of the pipelines, including thermal cameras, ultrasound methods, leakage detection systems, and monitoring systems for pipeline flow and pressure [6-8].

In this paper we are analyzing the advantages of integrated system for district heating line detection. Data obtained with GPR and UAV-mounted thermal camera are combined. Thermal camera provides fast localization of heating lines and identification of zones with possible damage. This method involves generating a georeferenced image where pixel colors denote temperature. Establishing the position model of the district heating pipeline network entails identifying pixels along the route with higher temperatures compared to those outside the route, while considering all relevant constraints [6]. In the papers [9] and [10] authors have explored ground thermography using handheld cameras. In comparison to aerial thermography, this method has several drawbacks, such as limited access to many areas of interest and reduced scalability. Aerial thermography for locating heating pipelines involves generating a georeferenced image where pixel colors denote temperature. Establishing the position model of the district heating pipeline network entails identifying pixels along the route with higher temperatures compared to those outside the route, while considering all relevant constraints. On the other hand, GPR is used to check the localization and to obtain additional data on heating lines, such as depth, radius or dimensions of concrete channel or earthen trench [11].
Main advantages of integrated system are:

- Fast and efficient acquisition, with relatively low costs
- Easier identification of district heating infrastructure
- Prevention and detection of damages
- Automated data extraction

2. TEST AREA

Zone within the University campus in Novi Sad, in front of the building of Scientific-Technology Park is chosen to be the test area (Fig. 1). Part of district heating line route lies in this area, in Veljka Petrovica and dr Ilije Djuricica streets. This part of the network involves heating pipelines of different diameters, with many turns and pipe joinings, and this complexity makes it a good example for procedure examination.

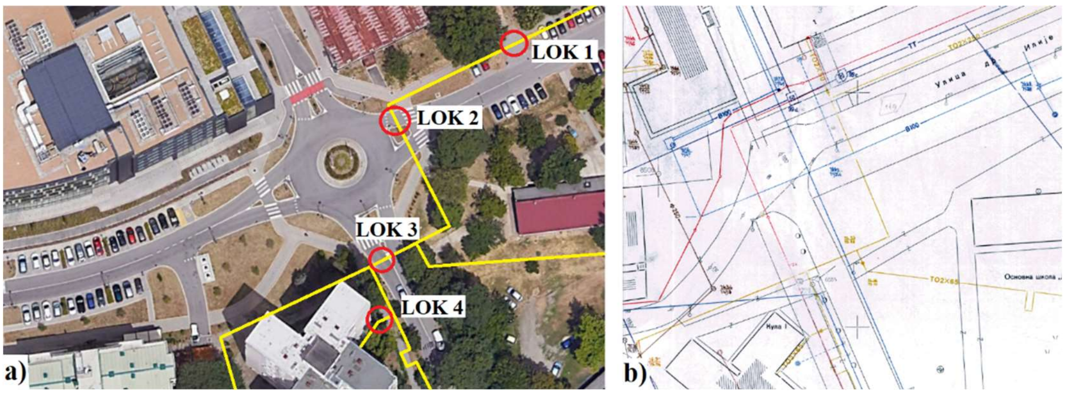

Figure 1. Test area with marked locations of GPR scanning

Test locations are shown in Fig. 1 and numerated with 1 to 4. They are selected with the aim of having all important elements of district heating network, such as deviations, junctions, heat compensators. Convenience for GPR scanning is important as well. Along with locations, approximate routes of heating lines are represented in Fig. 1. These routes are drawn based on existing records in cadastral maps. In this paper utility cadastral data are important since they are used as the initial information on the heating network in the survey zone and as a data that results can be compared to.

3. SENSORS

GPR scanning and UAV-mounted thermal camera are used for data acquisition (Fig. 2).

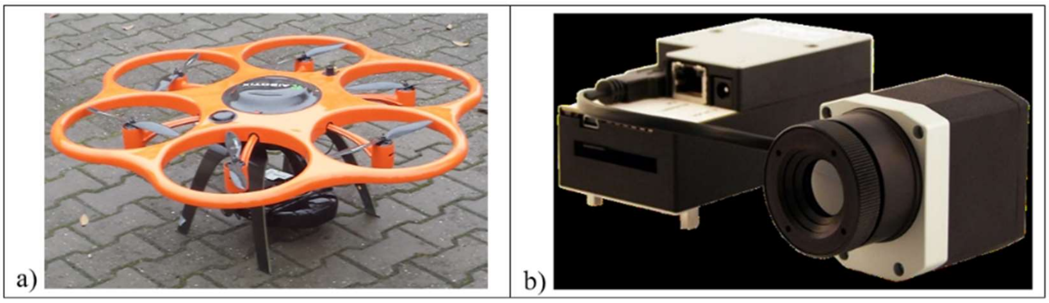

Figure 2. Unmanned Aerial Vehicle (a) and thermal camera (b)

Specification of Aibot X6 UAV and PI400LW are given in following table.

Table 1. UAV „Aibot X6“ and thermal camera „PI400LW“ specification

UAV - Aibot X6 [12, 13]		Thermal camera - PI 400 LW	
Length/Width	1.05m	Detector	UFPA, 382x288 pixels
Weight	3.4kg	Spectral range	7.5...13μm
Max. payload	2kg	Temperature ranges	-20...100°C, 0...250°C, 120...900°C
Max. speed	up to 50km/h	System accuracy	- ±2°C do ±2%
Climbing speed	8m/s		
Max. height	1000m		
Flight duration	30min		
Operating temperature	-20°C do 40°C		

Since maximum payload of UAV is 2kg various sensors can be mounted, such as digital camera, thermal or multispectral camera, which widens the area of application.

Information on the depth of heating pipes or the cover of concrete channel cannot be obtained using thermal camera and therefore GPR scanning is used. In this survey we used GSSI SIR3000 control unit and antenna with 200MHz central frequency (Fig. 3).

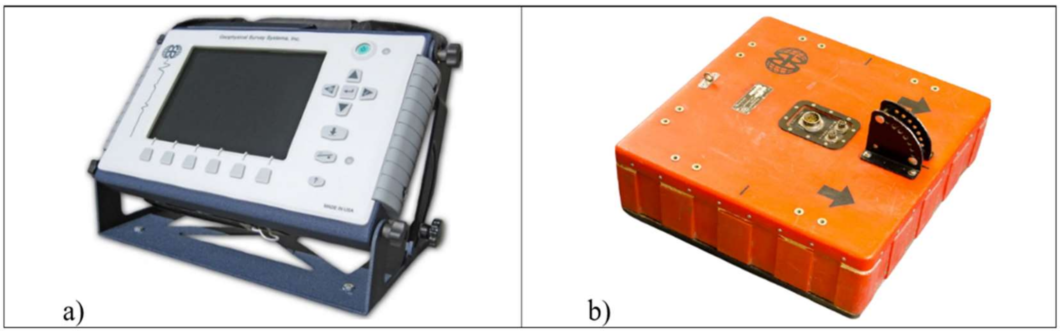

Figure 3. GPR control unit GSSI SIR3000 (a) and GPR antenna of central frequency 200MHz (b)

4. METHODOLOGY

In the first phase a fast localization of existing district heating pipeline is done using thermal camera records. Data acquisition was done during winter time when small differences in temeprature of surface above the heating line and surrounding soil could be recorded. Also, these data are used to detect potential damage zones, differences between actual route and the one in cadastral maps and to recognize the parts with and without concrete channel.

Second phase of survey involved GPR scanning to acquire additional data such as depth and dimensions of concrete channel or earthen trench. Scanning is done on locations suitable for GPR. Acquired data are then analysed using different strategies for automated processing [14-19]. Application of these methods is possible since district heating pipes are installed in specific way (two pipes in concrete channel or earthen trench) which have a signature reflection in a radargram. In case of earthen trench there are two intersecting hyperbolic reflections with constant mutual distance along the entire route. There are algorithms that use these reflections to automatically assess pipe's radius [14, 20, 21]. In case of concrete channel reflections from the cover and sidewalls can be seen in the radargram and then standard dimensions of the channel are used to estimate pipes' diameters [11].

5. RESULTS

Results of integrated application of mentioned NDT technologies show that in only 10 minutes of flight over 50000m2 area it is possible to detect and georeference the route of district heating pipeline. To examine each location using GPR 5 minutes on average is sufficient. Data from thermal camera are then used to generate raster maps of test area with the colour of each pixel corresponded to relative temperature. The difference between temperatures above the heating pipeline and surrounding soil is up to 4˚C. Besides, preinsulated heating pipes placed in concrete channel are successfully detected. GPR scanning provided additional information:

- Heating pipes are placed in concrete channel on entire route of the pipeline
- Depth of the concrete cover is between 20 and 30cm
- Two different widths of concrete cover are detected, 130-140cm (1) and 75-80cm (2).

Survey results are shown in following figures (Fig. 4 – Fig.7). Four representative images from thermal camera are selected (on left-hand side of the figure) as well as four radargrams collected using GPR (right-hand side of the figure). Black arrows indicate location and direction of GPR scanning.

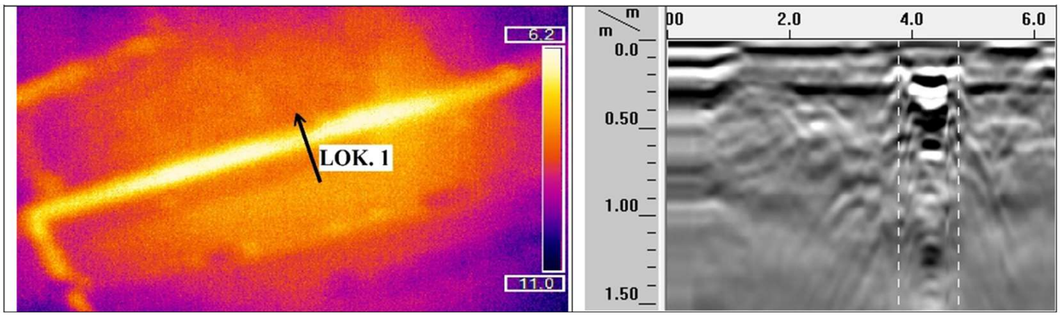

Figure 4. Thermal image and radargram obtained on test location 1

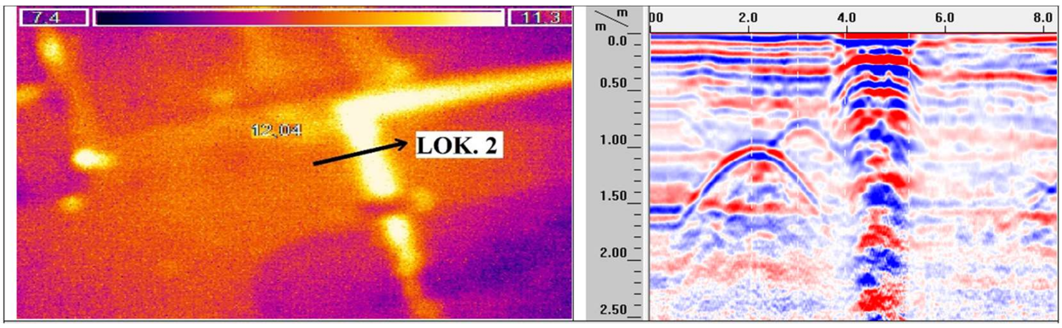

Figure 5. Thermal image and radargram obtained on test location 2

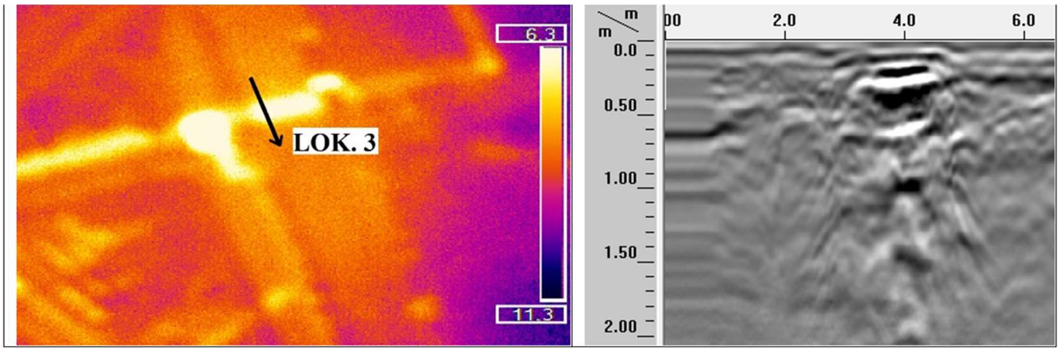

Figure 6. Thermal image and radargram obtained on test location 3

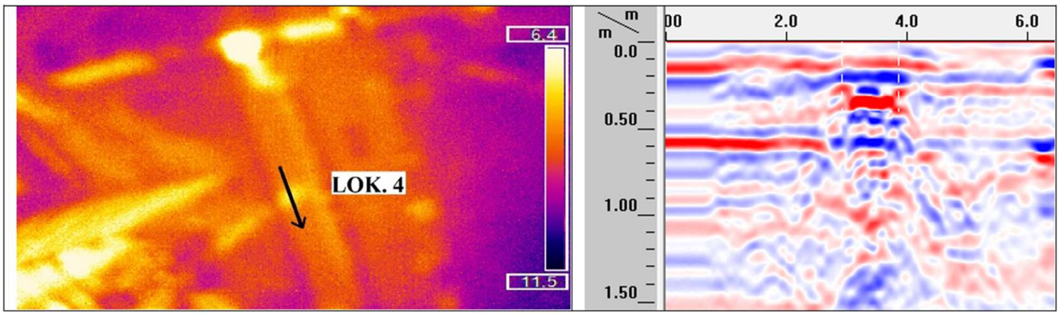

Figure 7. Thermal image and radargram obtained on test location 4

First test location is on straight part of heating pipeline route. The pipes are beneath the sidewalk and GPR scanning can be performed with no obstacles. Data from thermal camera show that there are no significant temperature variations on examined part of the route. Heating district heating route can be clearly distinguished from surrounding soil and corresponds to cadastral data. In radargram obtained by GPR scanning a concrete channel cover can be seen. It is approximately 130-140cm wide and at 20cm depth. Based on these information it is concluded that the pipes have standard diameter of 250mm.

Second location is in line with the first one at the point where the route changes direction. Data from thermal camera show that the direction chance corresponds to cadastral data. Big change in temperature is a consequence of a car parked just above the heating pipe. GPR scanning is done on paved sidewalk. In radargram at distances of 2.1m and 3.1m and at depths of 1 and 0.80m two hyperbolic reflections can be seen. Since they are not in pair, i.e. they are at different depths, they do not indicate a heating pipeline. At di distance of approximately 4-5.4m there is a reflection at 20cm depth, originated from concrete channel containing heating pipes. Estimated width of the cover is 1.3m-1.4m which indicates that pipes' diameter is 250mm.

Data from location 3 show higher values of temperature on the route which corresponds to cadastral data. Highest value is on the part of the route in the vicinity of a manhole on a sidewalk. In this manhole route splits into two directions. Part that continues along the Veljka Petrovića street shows lower temperature which indicates that pipes' diameter may be smaller. Along the second direction the temperature retains almost same value, which indicates that diameter is the same as before the split. These findings are confirmed in GPR data, since in radargram from this location a reflection at 30cm depth (distance 3.1-4.4m) can be clearly seen. According to data pipes on location 3 are 250mm in diameter and placed in the concrete channel.

Fourth location is on the part of the route with smaller diameter pipes, after the aforementioned split. Here the temperature has lower value and detected route does not correspond to cadastral data. Lower values of temperature indicate that the pipes' diameter is smaller. Confirmation for this can be found in GPR data. At depth of 30cm, a reflection of the concrete channel approximately 90cm wide can be seen. Based on these data it is estimated that the pipes' diameter is 60mm or 80mm.

6. CONCLUSION

Research results presented in this paper show that using both UAV-mounted thermal camera and GPR it is possible to perform fast, reliable and high-quality inspection of district heating pipeline.

Thermal images provided detection of heating pipeline route in time-efficient manner. These data enabled the comparison with cadastral data (to detect the mismatch between the actual route and the route mapped in cadastre), as well as detection of locations where the heat is dissipated. This also reduced the zone of GPR scanning. Additional data such as pipeline depth are provided by GPR. In case of pipes in earthen trench, radius estimation is done based on the shape of hyperbolic reflection. If heating pipes are placed in concrete channel diameter is estimated based on the width of the channel and standardized pipes' dimensions for given channel with. At each test location the width of the channel is done successfully.

ACKNOWLEDGMENT

This research has been supported by the Ministry of Science, Technological Development and Innovation (Contract No. 451-03-65/2024-03/200156) and the Faculty of Technical Sciences, University of Novi Sad through project "Scientific and Artistic Research Work of Researchers in Teaching and Associate Positions at the Faculty of Technical Sciences, University of Novi Sad" (No. 01-3394/1).

LITERATURE

[1] M. Olsson, "Long-term thermal performance of polyurethane-insulated district heating pipes," *Chalmers University of Technology*, 2001 (Ph.D. thesis).
[2] M. Fröling, "Environmental and thermal performance of district heating pipes," *Chalmers University of Technology*, 2002 (Ph.D. thesis).
[3] A. Benedetto, and L. Pajewski (Eds.), "Civil Engineering Applications of Ground Penetrating Radar," *Springer*, 2015.
[4] D. J. Daniels (Eds.), "Ground Penetrating Radar, second edition," *The Institution of Electrical Engineers*, London, United Kingdom, 2004.
[5] H. M. Jol (Eds.), "Ground Penetrating Radar: Theory and Applications," *Elsevier*, 2009.
[6] A. Berg, J. Ahlberg, and M. Felsberg, "Enhanced analysis of thermographic images for monitoring of district heat pipe networks," *Pattern Recogn. Lett.*, 2016, doi: 10.1016/j.patrec.2016.07.0.
[7] A. Ristic, M. Govedarica, M. Vrtunski, and D. Petrovacki, "Integration of modern remote sensing technologies for faster utility mapping and data extraction," *European Geosciences Union General Assembly*, 2015, GI3.1 Session "Civil Engineering Applications of Ground Penetrating Radar", Vol. 17.,EGU2015-2365-1, Vienna, Austria, April 12th - 17th, 2015.
[8] S. B. Costello, D. N. Chapman, C. D. F. Rogers, and N. Metje, "Underground asset location and condition assessment technologies," *Tunn. Undergr. Space Technol.*, vol. 22, pp. 524–542, 2007, doi: 10.1016/j.tust.2007.06.001
[9] B. Bohm, and M. Borgström, "A Comparison of Different Methods for In-situ Deter- mination of Heat Losses from District Heating Pipes," *Technical Report*, *Depart- ment of Energy Engineering*, *Technical University of Denmark*, 1996.
[10] H. Zinko, J. Bjärklev, H. Bjurström, M. Borgström, B. Bohm, L. Koskelainen, and G. Phetteplace, "Quantitative Heat Loss Determination by Means of Infrared Thermography-The TX Model," *Technical Report*, *International Energy Agency*, 1996.
[11] A. Ristić, Ž. Bugarinović, M. Vrtunski, M. Govedarica, and D. Petrovački, "Integration of modern remote sensing technologies for faster utility mapping and data extraction," *Constr. Build. Mater.*, vol. 154, pp. 1183–1198, Nov., 2017, doi: 10.1016/j.conbuildmat.2017.07.030.
[12] Aibotix, "Aibot X6." [Online]. Available: www.vekom.com
[13] Aibotix, "Aibot X6 V2 User Manual." [Online]. Available: www.aibotix.com
[14] A. V. Ristic, D. Petrovacki, and M. Govedarica, "A new method to simultaneously estimate the radius of a cylindrical object and the wave propagation velocity from GPR data," *Comput. Geosci.*, vol. 35, no. 8, pp. 1620–1630, Aug., 2009, doi: 10.1016/j.cageo.2009.01.003.
[15] A. Ristić, Ž. Bugarinović, M. Vrtunski, and M. Govedarica, "Point coordinates extraction from localized hyperbolic reflections in GPR data," *J. Appl. Geophy.*, vol. 144, pp. 1–17, Sep., 2017, doi: 10.1016/j.jappgeo.2017.06.003.
[16] A. Ristić, M. Vrtunski, M. Govedarica, L. Pajewski, and X. Derobert, "Automated Data Extraction from Synthetic and Real Radargrams of District Heating Pipelines," in *9th IEEE Int. Workshop Adv. Ground Penetrating Radar (IWAGPR)*, 2017, pp. 1–5. doi: 10.1109/IWAGPR.2017.7996046.
[17] Ž. Bugarinović, L. Pajewski, A. Ristić, M. Vrtunski, M. Govedarica, and M. Borisov, "On the introduction of canny operator in an advanced imaging algorithm for real-time detection of

hyperbolas in ground-penetrating radar data," *Electronics (Switzerland)*, vol. 9, no. 3, pp. 1–22, Mar., 2020, doi: 10.3390/electronics9030541.

[18] Ž. Bugarinović, S. Meschino, M. Vrtunski, L. Pajewski, A. Ristić, X. Derobert and M. Govedarica, "Automated data extraction from synthetic and real radargrams of complex structures," *J. Environ. Eng. Geophys.*, vol. 23, no. 4, pp. 407–421, Dec., 2018, doi: 10.2113/JEEG23.4.407.

[19] A. Ristić, Ž. Bugarinović, L. Pajewski, and X. Derobert, "Verification of Algorithm for Point Extraction from Hyperbolic Reflections in GPR Data," in *9th IEEE Int. Workshop Adv. Ground Penetrating Radar (IWAGPR)*, 2017, pp. 1–5. doi: 10.1109/IWAGPR.2017.7996109.

[20] S. Shihab and W. Al-Nuaimy, "Radius estimation for cylindrical objects detected by ground penetrating radar," *Subsurface Sens. Technol. Appl.*, vol. 6, no. 2, pp. 151–166, Apr., 2005, doi: 10.1007/s11220-005-0004-1.

[21] A. Dolgiy, A. Dolgiy, and V. Zolotarev, "Optimal Radius Estimation for Subsurface Pipes Detected by Ground Penetrating Radar," *in 11th Int. Conf. Ground Penetrating Radar*, 2006, pp. 1–8.