Application Ground Penetrating Radar & Geomagnetic Method for Subsurface River-Crossing Oil Pipeline Detection

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Abstract

A new pipeline route is often designed to align with the existing surface facilities such as oil, gas, high voltage cable, water etc. Exact location of the previously built facility is important to be mapped in order to avoid damaging it. However, construction of the existing underground and underwater utilities could slightly deviate from the initial blueprint. Therefore, the exact location of the oil pipeline especially that is buried underground and submerged under the river should be verified with non-destructive and economically low-cost method.

Ground Penetrating Radar (GPR) survey was performed to detect the presence of buried oil pipelines which is less than 6 meters deep on the western and eastern area of the river. Based on field observation, velocity of the medium is considered as intercalation of shale to dry sand with the average wave propagation velocity of ±0.1 m/ns. Processed GPR data has been confirmed to be able to detect hyperbolic pattern which is interpreted as anomalous objects positioned at 0.1 to 3.5 meters' depth. These objects are associated with the existing oil pipelines in across the riverside.

Magnetic survey was done in the river area to assist the GPR survey. Analytic signal was generated from Total Magnetic Intensity data. High anomaly value of analytic signal pinpointed area of anomalous object directly located below the river. These high anomalies are interpreted also interpreted as oil pipelines which submerged underwater.

Anomalous objects pick from the processed GPR data are overlain with base map of the existing pipeline routes. Anomalous object that is aligned with the exposed pipeline are interpreted as the underground pipeline route. Interpreted pipeline are delineated to the edge of the river. Estimated depth of the pipeline route is approximately 0.3 to 1.5 meters. Delineation of submerged pipeline at the river are made based on high anomaly of magnetic data. Nine (9) pipes are detected from GPR and magnetic data interpretation and possibility of other three (3) pipes which is not drawn in as built drawing.

Keywords: GPR survey, Magnetic survey, underground pipeline route, submerged pipeline route

Introduction

Oil pipeline is a national vital object that is used to transport oil from wellhead to onshore production facilities (OPF). It supports oil and gas industry operation throughout the country that in turn used distribute energy to its citizen. However, more than often, old facilities were designed and kept in paper format that could easily get damaged or lost. To exasperate the problem, actual construction of the pipeline could slightly deviate from the original blue print. Thus, exact location of the oil pipeline becomes uncertain. It becomes important to know the exact location when the operator want to construct new facilities without damaging the older facilities. The challenge in this investigation is to mapped a pipeline that crosses a river. The paper illustrate how geophysical method could be well utilized to accurately pin point man-made object beneath the surface and water.

Methodology

Geophysical investigation that consisted of Ground Penetrating Radar (GPR) and Geomagnetic survey was conducted to detect underground pipeline. The survey is divided into two areas, one area where the pipe is buried underground and the other where it is submerged underwater. First, the exposed oil pipelines were used as a reference for the survey trajectory design. The land areas on both side of the river were surveyed using the GPR while river area was inspected with the geomagnetic.

GPR were recorded with 200 MHz central frequency antenna and set to maximum depth about 140 nanoseconds. Velocity of the medium considered homogeneous which is consist of dry sand as seen on the field to obtain penetration depth about 7 meters. The elimination of the effect of noise and electromagnetic-noise signal amplification anomalous object below the surface is done through the stages of standard GPR data processing. GPR survey was done along semi-grid spaced at both riversides (**Figure 1**). Crossline refer to line that crosses the suspected pipeline route based on the base map.

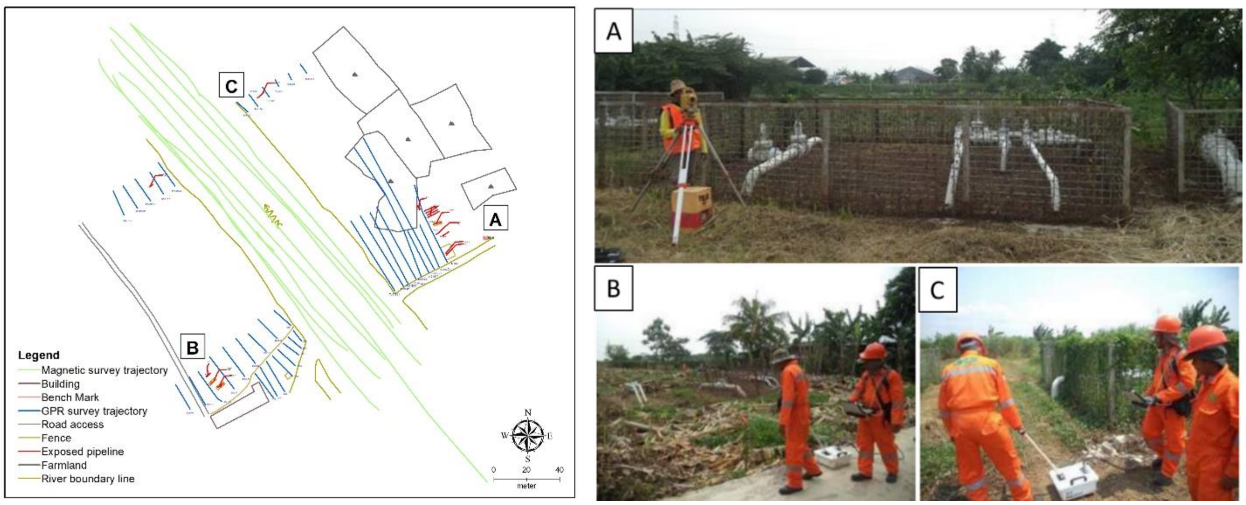

Figure 1 Survey trajectory design and exposed pipeline that is used for as a reference points in this investigation.

Ground Penetrating Radar Survey

GPR was conducted to map the pipeline trajectory located below the surface. It utilized electromagnetic wave with frequencies that ranges from 25 MHz to 2 GHz. Transmitter antenna inside the tool emits pulses of electromagnetic waves that will be bounced off by stratigraphic layers beneath the surface. The reflected wave will be measured back by a receiver inside the antenna. The two-way travel time is going to be measured and processed to get a section (Davis & Annan, 1989). The measured two-way travel time in the field before the processing stage is about 150 ns. The soil type found in the measurement location is shale to dry sand. Using the assumption that subsurface materials with shallow depths are considered homogeneous, the average wave propagation velocity is about 0.1 m / ns (Table 1).

The acquired GPR data was processed to eliminate the effect of noise and amplify the noise signal from anomalous object alone. The standard stage of processing consists of subtract-mean (dewow), static correction, bandpass filtering, time gain, and background removal. Dewow is a temporal filtering to remove very low frequency components of the GPR data (Annan, 1999). The very low frequency contained is caused by the large energy input from the airwave, groundwave, and near surface reflectors, the GPR receiver becomes signal saturated and unable to adjust fast enough to the large variations between vertical stacks. Thus, arrivals time on the shaded wiggle traces tough to distinguish. The saturation is constant across each trace and can be corrected for by a bulk DC offset shift in amplitude towards zero.

Velocity static shifts occur when the near surface has significantly different radar velocities than underlying units. The velocity pushes down effect appears to be greater further down in the section for each static and a time delay of the first arrival time occurs. Static Corrections compensate for noise that is introduced by shifting the reflector within a specified time window (specified by the number of samples) so that it is realigned. Another function of Static Corrections is that it allows you to filter horizontally without influencing the vertical frequency of the data (Singh, 2017).

Bandpass filtering is a temporal filtering along the time axis of the GPR data. It uses fast Fourier transform (FFT) technique by means of various types of linear and non-linear time domain convolution filter operators. The bandpass filter does not affect the signal shape whereas the dewow filter slightly changes the signal of GPR data in consequence of its non-symmetrical shape. The bandpass filter may also be used in order to eliminate of high frequency or monochromatic noise (Sandmeier, 2017).

The waves will loose significant energy during travelling through the subsurface due to spherical divergence and intrinsic and scattering attenuation. The time series must have a zero mean value, otherwise a significant DC offset especially at later times may occur. In addition, the noise level at greater times should be as small as possible. Time gain is done very carefully to avoid unwanted artificial wavelets.

Background removal is the final stage of processing to remove bands of ringing noise. Low frequency features in the GPR data will be removed. The filter performs a subtracting of an averaged trace which is built up from the chosen time or distance range of the radargram. Background removal also can be done by high pass filter or an average trace removal.

Table 1 Physical properties of common material (Davis & Annan, 1989).

MATERIAL	DIELECTRIC CONSTANT	CONDUCTIVITY mS/m	VELOCITY m/ns	ATTENUATION db/M
Air	1	0	0.30	0
Distilled Water	80	0.01	0.033	0.002
Fresh Water	80	0.5	0.033	0.1
Sea Water	80	30000	0.01	1000
Dry Sand	3 - 5	0.01	0.15	0.01
Saturated Sand	20 - 30	0.1 - 1.0	0.06	0.03 - 0.3
Limestone	4 - 8	0.5 - 2	0.12	0.4 - 1
Shale	5 - 15	1 -100	0.09	1 - 100
Silts	5 - 30	1 - 100	0.07	1 - 100
Clays	5 - 40	2 - 1000	0.06	1 - 300
Granite	4 - 6	0.01 - 1	0.13	0.01 - 1
Dry Salt	5 - 6	0.01 - 1	0.13	0.01 - 1
Ice	3 - 4	0.01	0.16	0.01

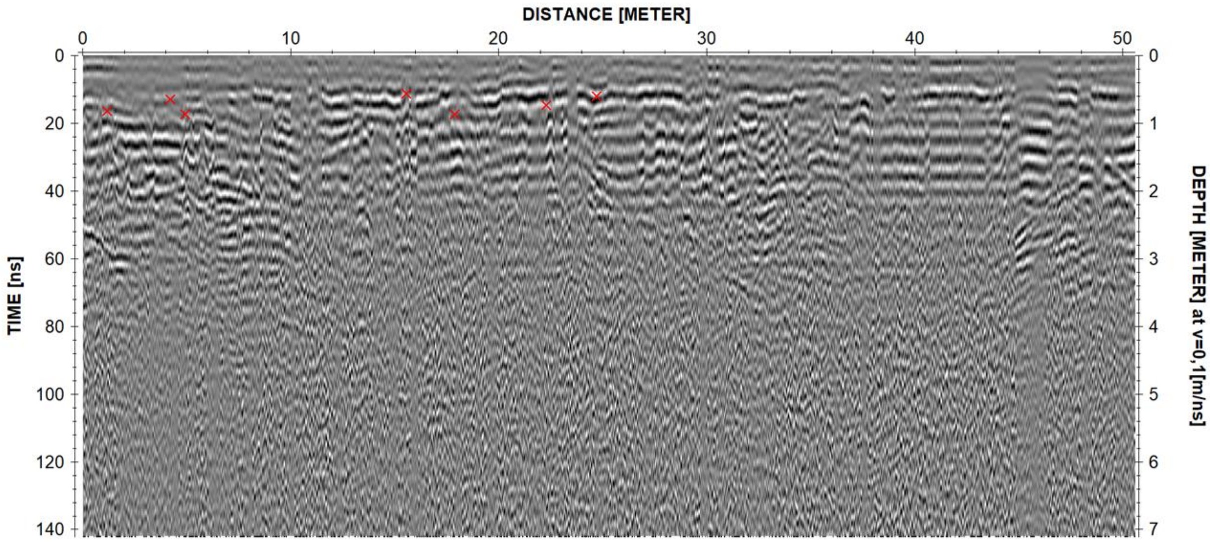

Figure 2 *Example of radargram that shows hyperbole anomaly.*

Magnetic Survey

The magnetic fields of geological bodies are superimposed on the background of the Earth's main field. Variations in magnitude and direction of this field influence both the magnitudes and shapes of local anomalies (Milsom, 2003). Local anomalies can be related to manmade objects induced by the Earth's magnetic field.

Magnetic survey measures total field magnetic of Earth's main field and local anomalies. The value is highly influenced by minerals that contains iron (Fe) or magnesium (Mg) (Lowes, et al., 1988). The presence of metallic object such as oil pipeline would normally give off an anomalously high magnetic value measurement.

Magnetic data observed over the river surface is presented as Total Magnetic Intensity (TMI). TMI data has dipole characteristics, where objects with high magnetic values (objects made of metal) are shown as two pairs of high and low anomalies. In order to transform the dipole to monopole characteristic, an analytic signal is performed so that a metal object is centered above the magnetic body (MacLeod, Jones, & Dai, 1993) in the maximum. The analytic signal could be used to locate the edges of magnetic source bodies such as metallic object, particularly where reminisce and/or low magnetic latitude complicates the interpretation. The analytic signal (as) of map is define as the square root of the sum of the squares of the derivatives in x, y, z directions (dx, dy, dz):

$$as = \sqrt{dx * dx + dy * dy + dz * dz}$$

The vertical derivative is calculated using the FFT process, while horizontal derivative is calculated by applying a space domain convolution filter (Whitehead & Musselman, 2010).

The high magnetic anomaly value of the signal analytic map is interpreted as the presence of a magnetized object. This magnetized object is associated with a pipeline that lies beneath the surface of the river. Delineation of submerged pipeline at the river has successfully verified the presence of nine (9) pipelines that is connected to the exposed pipeline at the onshore. The three (3) anomalous objects that has been detected through GPR could be seen to be giving off equally high anomalous value as the confirmed metallic oil pipelines. Though, the other three anomalous objects require to be verified with an excavation pit prior to be concluded as a pipeline.

Result and Discussion

The processed radargram delivers sub-surface imagery in the scanned area. Anomalies are commonly seen on the radargram of layers and hyperbolic patterns resulting from the contrast of dielectric values between one medium and the medium below. The pattern of the layers gives a picture of the actual geometry of the boundary between the layers below the surface. The difference between the object's dielectric values and the medium in which the object is located will cause a hyperbolic diffraction pattern. Those hyperbolic patterns are interpreted from GPR data to determine the location of anomalous objects (position and depth). Depth of all anomalous object in travel time are converted to meter by using average velocity of 0.1 m/ns. Each hyperbolic patterns are detected on the processed radargram are marked and mapped in the base map, so that the lateral anomaly distribution of the object is obtained (Figure 3). The anomaly is plotted in a base map using colored symbols. The symbol coloring is based on the depth of the anomaly object with 5 depth classifications: less than 0.3 m; 0.2 – 0.6 m; 0.6 – 0.95 m; 0.95 m – 1.5 m; more than 1.5 m.

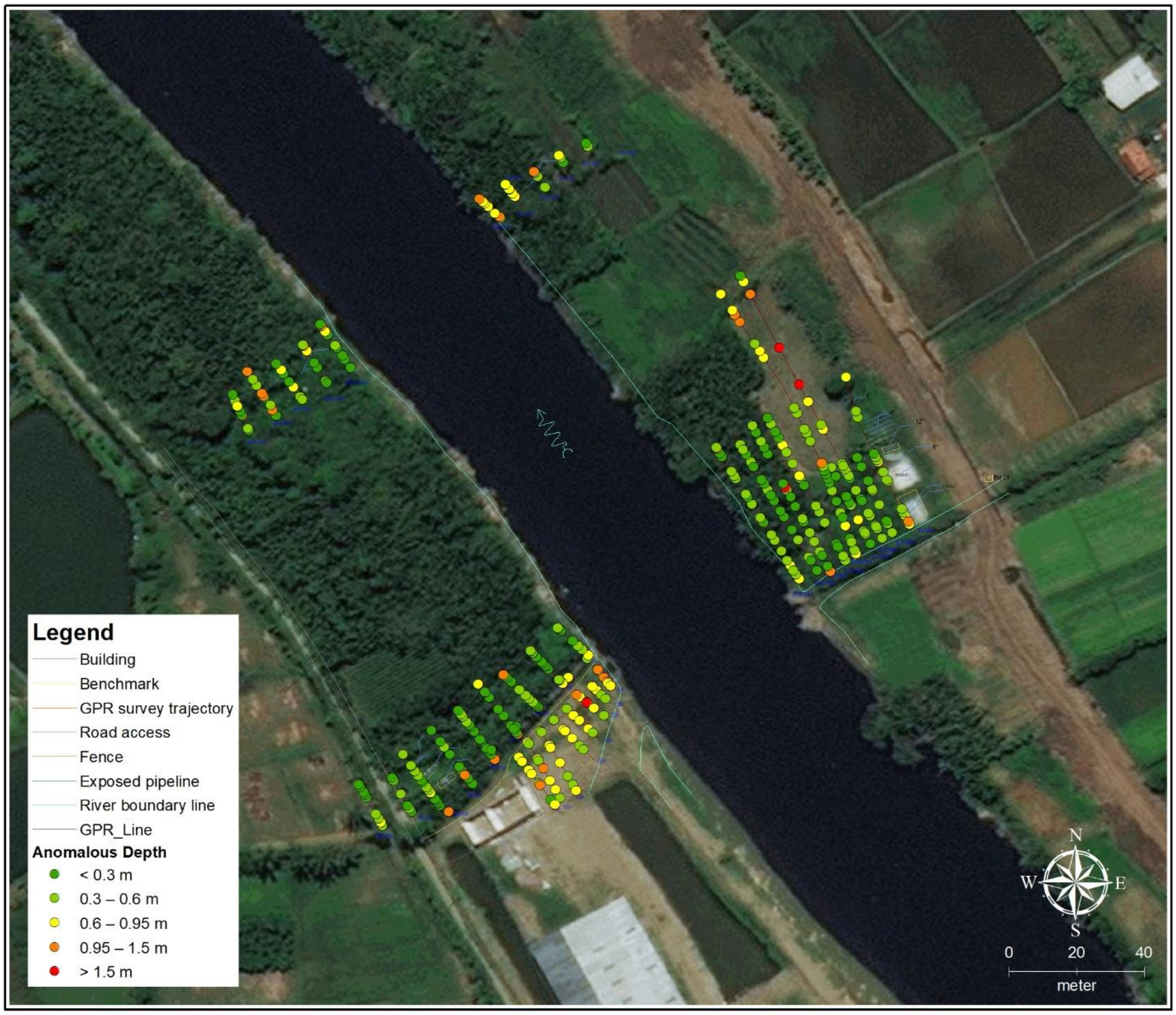

Figure 3 Lateral anomaly distribution of the object obtained from processed radargram.

The anomalous object that is well aligned with the exposed pipeline are interpreted as the buried oil pipeline. Depth of the pipeline is estimated to be around 0.3 - 1.5 meters. A total of nine (9) anomalous object that is well aligned with the exposed pipelines were able to be detected through GPR (Figure 4).

The magnetic survey conducted on the river shows a magnetic anomaly data that could help in delineating the pipeline that crosses from the east side to the west side of the river. Magnetic anomaly that has been through stages of processing and filtering Analytic Signal will have high values, this is indication of the presence of magnetized metal objects, in this case are pipes that are targeted by the GPR survey.

By overlaying GPR and magnetic data we were able to get an exact location of the pipeline. Interpretation of the underwater pipeline could be assisted with high magnetic anomaly map of the northern and southern segments. The eight (8) pipelines could be well identified, one pipeline unused line that is used for waste water thought to be the most south where there are anomalies hyperbole and also the presence of a high magnetic anomaly in the river. An additional of three (3) anomalous objects has also been identified across the survey area.

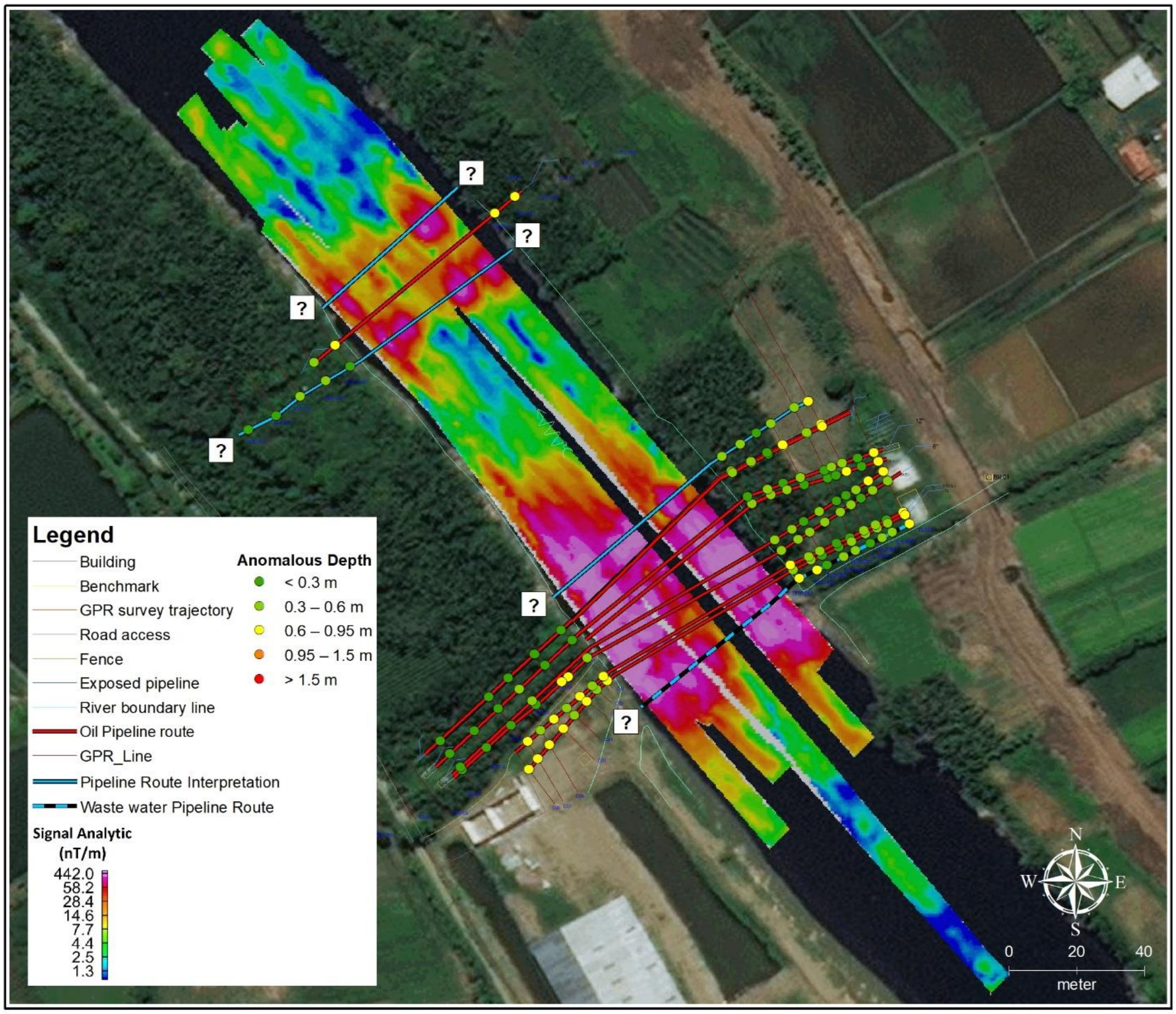

Figure 4 GPR and geomagnetic survey result overlain with geomagnetic survey result that shows confirms the pipeline to be crossing the river.

Conclusion

Integration of GPR survey in land and geomagnetic survey in river has successfully identified and located the presence of pipelines below the surface.

Nine (9) pipelines were successfully detected through GPR survey to be located 0.3 – 1.5 below the surface and confirmed to be crossing the river through geomagnetic survey.

The other three (3) identified anomalous objects that has been identified along the GPR is well aligned with the nine (9) confirmed pipelines gives off equally highly anomalous magnetic value.

Three (3) objects required to be confirmed through an excavation pit before concluding as pipeline.

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