# Underwater electromagnetic remote sensing

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**Abstract**

Utilization of non-destructive and non-invasive methods for the real-time underwater remote sensing is one of the challenging and desired tasks in the maritime security and safety as well as the harbour surveillance. Our aim was to develop and verify advanced electromagnetic sensors for a seabed objects detection and inspection. The seabed is a complex environment often covered with the sand, dense aquatic vegetation and rocks. Hence, it is difficult to investigate the seabed by only one conventional method. Usually a combination of the sonar and video system is used for the detection and classification of underwater targets. In this paper, we verified the operation and efficiency of two EM imaging sensors, a ground penetrating radar (GPR) and an electromagnetic continuous wave sensor (CWEMS).

**Keywords**: electromagnetic sensors, GPR, remote sensing, underwater detection.

## 1 Introduction

The underwater remote sensing technology plays a key role in investigations of the underwater environment and detection of unknown objects. Nowadays, several techniques (Fig. 1) exist in this field; the most important among them are acoustic, electromagnetic and optical devices [1-6]. Electromagnetic (EM) sensors have long been recognized as a useful tool for the geophysical exploration and remote sensing. However, no system currently available on the market is capable to accurately survey and map the location of objects buried under the bottom sediments or vegetation. The technology that we selected includes an adapted version of the ground penetrating radar (GPR) and the continuous wave electromagnetic sensor (CWEMS) which are competing tools against the SONAR (sound navigation and ranging) and metal detector. The preliminary results achieved by these two EM sensing methods are presented in this paper.

## 2 EM sensing methods

The EM propagation in water is very different from the propagation through air due to the high permittivity and electrical conductivity of water. In freshwater the conductivity is 0.1 - 10 mS/m, whereas in sea water this value is around 4 S/m. Another difference is a greater attenuation loss of the propagation pulses in water. It depends on the selected frequency and salinity of water. Hence, for the freshwater and sea water the attenuation loss at 100 MHz is 0.1 $dBm^{-1}$ and 100 $dBm^{-1}$, respectively, whereas at 1 GHz it increases to 1 $dBm^{-1}$ and 1000 $dBm^{-1}$, respectively. Furthermore, the propagation velocity and corresponding wavelength in water decrease by a factor of about 10 in comparison to the velocity and wavelength in air [1-3].

### 1.1 Ground penetrating radar

The ground penetrating radar or GPR is a non-destructive geophysical method based on the propagation of high frequency electromagnetic waves. The GPR method images structures in the ground that are related to changes in the dielectric properties [1]. If a very short EM pulse is transmitted by an electric dipole into the medium, it propagates in the subsurface with a velocity depending on the electrical properties of the medium. For a layered subsurface with contrasting electrical properties, a part of the EM energy is reflected back to the surface where it is detected by a receiver dipole and recorded. Synchronization between the transmitter and the receiver systems allows the determination of the time taken for the EM pulse to be reflected back. In our case, several candidate sites were surveyed to find out a test area with the desired water depth for the underwater GPR investigation. We selected the lake Podpeč, a location near the city of Ljubljana. The lake is located in the Karst region and it is the deepest lake in Slovenia with a depth of 47 m.  The experimental work was conducted using a commercial GPR system equipped with a 250 MHz and 50 MHz antenna. The design of the 250 MHz antenna ensured that the transmitted radar energy is emitted only from the bottom of the antenna housing and protects the receiver element from an external noise. The antenna was placed in a rubber dinghy on the water surface. The experiment with a 50 MHz antenna was performed from the wooden pier at the lake shore. The 50 MHz antenna with a flexible "snake"-like design allows easy manoeuvring and provides optimum results in difficult environments as well as a deeper signal penetration into the medium.

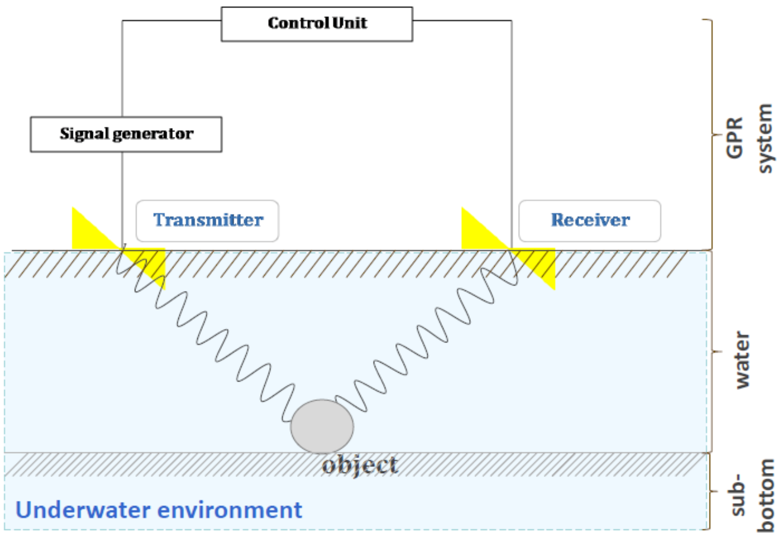


**Figure 1**: The GPR system for underwater measurements.

## 1.2 Continuous wave electromagnetic sensor

In the CWEMS method, the primary magnetic field produced by the transmitter coil is changed in such a way that a higher density of magnetic flux lines occurs due to the presence of metallic objects [5]. The modified magnetic field is detected by a receiver coil. Additionally, eddy currents occur which originate from metallic objects and have an important effect on the induction of the receiver coil field. The CWEMS sensor has proven to be very effective in detecting both ferromagnetic and nonmagnetic metallic targets lying on the sea bottom or buried in the seabed. The scenario for CWEMS monitoring was comprised of the CWEMS sensor composed of eight probes mounted on a wooden pole (Fig. 2). Moreover, the constructed CWEMS sensor was moving on a quadratic holder made from wood to reduce destructive interferences from other objects. For the investigation purposes, samples with simple circular and rectangular cross sections were selected.

The samples were located on the wooden plate with the constant distance from the sensor which was in the range of a few centimetres. The investigated area was limited with dimensions of 45 cm by 90 cm. A special software was prepared to acquire signals from all eight probes simultaneously. The raw signals in a matrix form were imported in the Matlab programming environment. In order to obtain a more realistic circular or rectangular cross section of the detected objects, the 2-D interpolation between the data in matrix was applied. Furthermore, the obtained plots were smoothed using a MatLab built-in cubic interpolation function. The final results were visualized as an intensity plot.

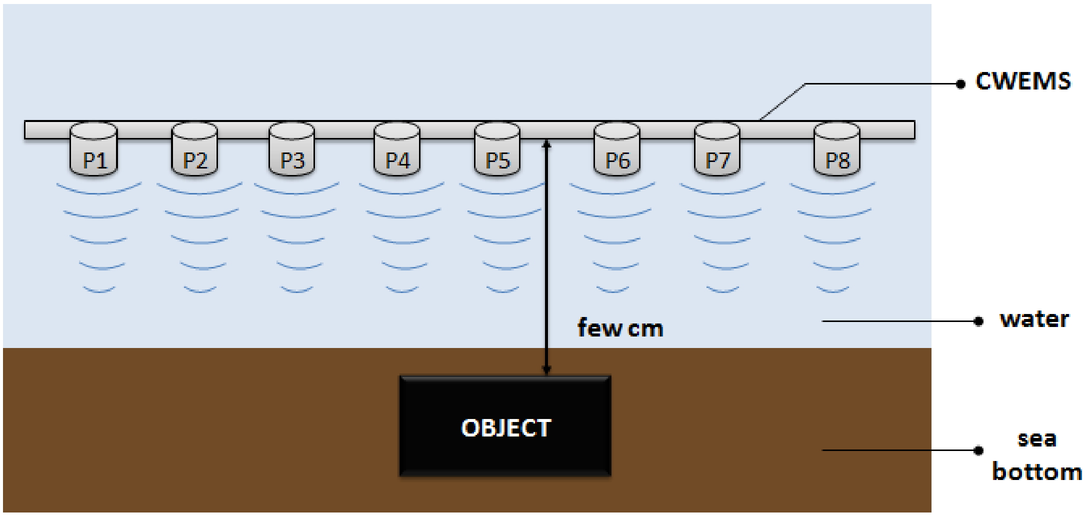


**Figure 2**: The CWEMS sensor adapted for underwater operation.

## 3 Results and discussion

The calculated GPR profile with a 50 MHz antenna shows that we reached a penetration depth of more than 3 m (Fig. 3, right). A distinct subsurface layer with a depth close to 1 m is also visible in addition to a rather homogenous layer observed up to at least 5 m in depth and possibly even lower. Namely, in the Fig. 3 the depth scale is given in the left-hand scale as the double time needed for the calculation of the electromagnetic waves to travel the distance from the transmitting antenna to the observed object or structure and back to the receiving antenna. In the right-hand scale, this double time is transformed to the real underwater depth, using the velocity of the transmission of electromagnetic waves through the water layer, which is about ten times lower than in the air. For the subsurface layer, the velocity of the transmission of electromagnetic waves is much larger than in the water, usually three or four times. The size of the homogeneous subsurface layer is therefore much larger than depicted from the scale, and can be estimated to be at least 10 m.

From the GPR profile with a 250 MHz antenna the results are similar (Fig. 3, left). While the penetration depth is not as deep as with the 50 MHz antenna, the resolution is better, so it is possible to see a more detailed structure of the first meter of the subsurface layer. From Fig 3 it is clear that both selected frequencies are useful for the investigation of the subsurface below the lake bottom. The low frequency 50 MHz antenna provides the deep penetration of more than 10 m, and the higher frequency 250 MHz antenna provides a higher resolution of the observed region closer to the surface.

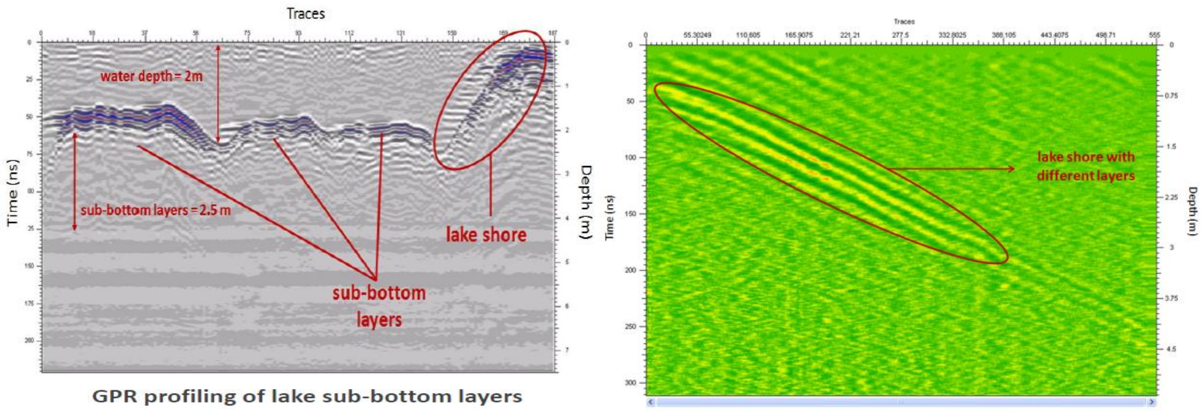


**Figure 3**: 250 MHz (left) and 50 MHz (right) lake profiling with the GPR.

The CWEMS method is used to characterize whether the material within the sensor range is metallic or not. Apart from this, we found out that different metallic objects give the various responses. The probes in Fig. 2 are equidistantly positioned on a wooden pole. In this case, we investigated objects with different dimensions and shapes. The raw EM responses were recorded in a matrix form. With the basic imaging method based on cubic interpolation, 2-D images were obtained (Fig. 4). From these images one can notice that not only the shape and orientation of the objects could be detected, but also some information regarding the metal material characterization could be defined. In Fig. 4 there is a major difference in EM responses between aluminium and iron objects, due to the eddy currents which originate in metallic objects and they are particularly expressed in the case of conductor materials such as aluminium and not as much in the case of the ferro-magnetic materials such as iron.

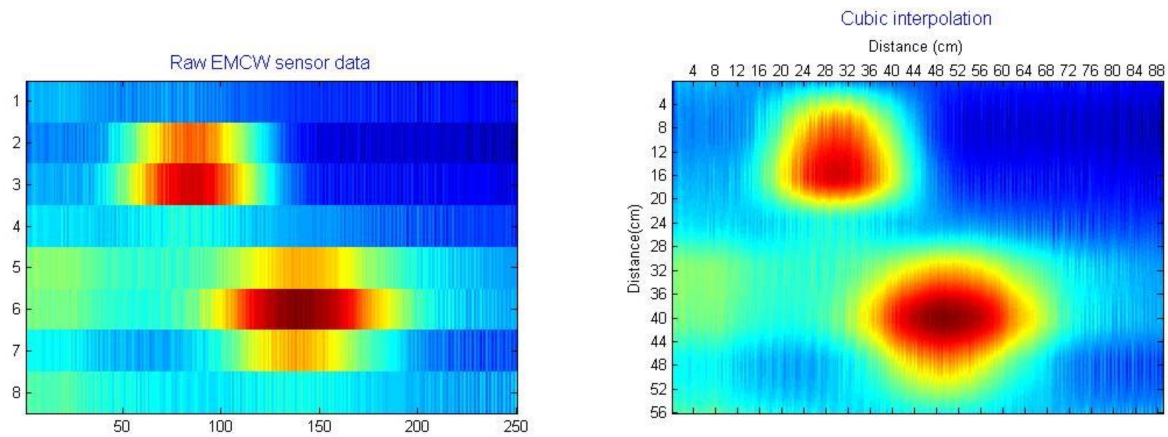


**Figure 4**: CWEMS imaging.

## 4 Conclusions

We measured the structure of the lake subsurface with a commercial GPR at frequencies of 50 MHz and 250 MHz, respectively. The used GPR system is capable to observe the subsurface below 10 m and through more than 3 m of water with the 50 MHz antenna. However, a more detailed structure can be obtained with a higher frequency 250 MHz antenna at the expense of a lower penetration depth. The GPR method has several potential applications in the general exploration and security of the underwater environment as well as in the oil and gas industry. In addition, we measured and imaged several metal objects of different sizes and shapes with the CWEMS sensor. The discrimination between various metallic object is possible, which makes the sensor appropriate for the underwater security imaging.

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## For wider interest

The underwater remote sensing technology plays a key role in underwater investigation and unknown objects detection. Electromagnetic (EM) principles have long been recognized as a useful tool for the geophysical exploration and remote sensing. The technology that we selected includes an adapted version of the ground penetrating radar (GPR) and the continuous wave electromagnetic sensor (CWEMS), which are competing methods against the SONAR (sound navigation and ranging) and metal detector. The ground penetrating radar or GPR is a non-destructive geophysical method, which is based on the propagation of high frequency electromagnetic waves. The GPR method images structures in the ground that are related to changes in the dielectric properties. In addition, the CWEMS sensor has proven to be very effective in detecting both, ferromagnetic and nonmagnetic metallic targets, lying on the sea bottom or buried in the seabed. We measured the structure of the lake subsurface with a commercial GPR at frequencies of 50 MHz and 250 MHz, respectively. The used GPR system is capable to observe the subsurface below 10 m and through more than 3 m of the water layer with the 50 MHz antenna. However, a more detailed structure can be obtained with a higher frequency 250 MHz antenna at the expense of a lower penetration depth. The GPR method has several potential applications in the general exploration and security of the underwater environment as well as in the oil and gas industry. In addition, we measured and imaged several metal objects of different sizes and shapes with the CWEMS sensor. The discrimination between various metallic objects is possible, which makes the sensor appropriate for the underwater security imaging.