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Ferromagnetic Underwater Target Detection Based on a Magnetic Anomaly Map[3]

Abstract: A magnetic anomaly map of an underwater area indicates the places where the distortion of a magnetic field has occurred. Through the interpretation procedures, a hydrographer can easily indicate the places where the ferromagnetic objects are, then calculate the level of each distortion – by the value of total anomaly – and initially, based on their own knowledge, try to classify the sources of distortion. Objects that induce micro anomaly changes (>30 nT) – like industrial infrastructure, such as pipelines and cables; to unintendingly located targets with ferromagnetic characteristics: wrecks (vessels, planes, cars), military mines, UXO, lost anchors and chains. Interpretation of such a map with the attempt to identify the source of magnetic field distortion, requires a specific knowledge as well as experience.

In this article the author presents the research results of dimensioning and location of potential ferromagnetic underwater objects based on a magnetic anomaly map. For further consideration an anchor of buoyage system is taken into account. Geolocation of ferromagnetic sources, contours extraction and dimensioning algorithms of ferromagnetic targets have been carried out in Matlab software. The map of magnetic anomaly enhanced with extracted information was developed in ArcGIS. The analysis was carried out for the purpose of the dissertation thesis and the results are used in further research.

Keywords: hydrography, ferromagnetic objects, magnetic anomaly, magnetic field, image segmentation

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1.   Introduction

Magnetic surveying in a water area is a commonly used method for detection of underwater subbottom ferromagnetic objects, such UXO (unexploded ordnance), mines, wreck, pipelines or anchors [1, 2]. It is carried out by marine magnetometers – towed equipment [3]. There are several types of marine magnetometers, the most popular being Ovehauser ones. Magnetometer measurements involve determining the size, direction and changes of the magnetic field. While processing magnetic data, the operator needs to relate the measurements to the magnetic field measured by specialized shore research stations (in Poland this is done by the Hel station). Thanks to this operation it is possible to determine the occurrence of a magnetic anomaly and determine its size. A magnetic anomaly means the difference between the local magnetic field, measured at specific area, and that measured at the nearest shore station of more than 30 nT. The detection of a magnetic anomaly depends on many factors: from the technical specifications of the device itself: resolution, sensitivity, operating frequency, and registration parameters such as the height of the magnetometer above the bottom, towing speed or distance between profile lines. The measurement itself is not affected by atmospheric conditions, as the device records data underwater. However, when referring to the value of the magnetic field measured locally to the shore station, the occurrence of a magnetic storm should be considered.

The size of the anomaly means the presence in the water body – on the bottom or in a certain layer of the bottom – of an object with ferromagnetic characteristics, e.g. anchor, pipeline, ship/ship wreck, underwater barrel/mine or crate with metal fittings (Fig. 1).
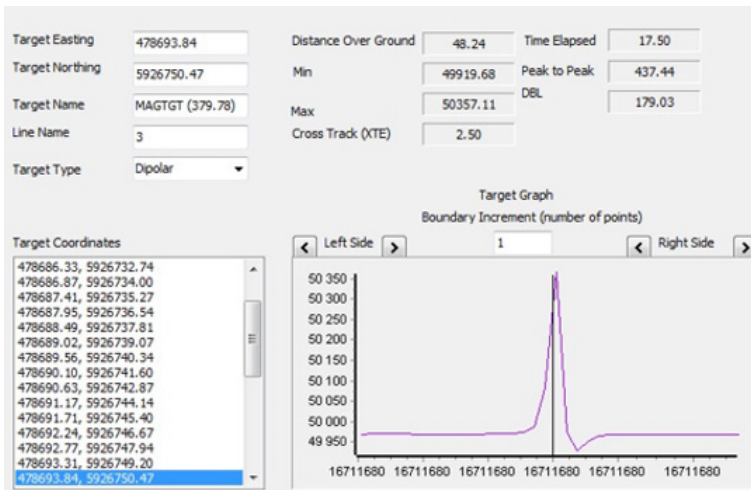

Fig. 1. Distortion in magnetic field in water area –
Hypack hydrographic software screen

It is assumed that the value of the deviation in the magnetic field strength of more than 30 nT is considered as a magnetic field distortion – a magnetic anomaly. It may be the equivalent of the existence at the bottom of an object with a ferromagnetic characteristic. Final products of marine magnetics surveying are magnetic anomaly maps, presented either as a digital terrain coverage model or as a contour map (Fig. 2).

a)   b)   c)
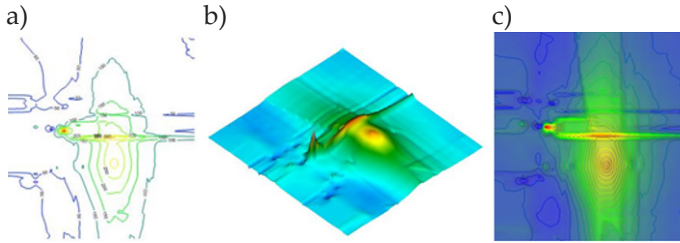
Fig. 2. Final products of magnetic field surveying:
a) magnetic anomaly contour map; b) digital terrain coverage model of magnetic anomaly;
c) magnetic anomaly grid with a contour map

Magnetometer data interpretation is not as obvious as in the case of other hydrographic data such as a digital seabed bottom model from bathymetry or sonar imagery. In this case, it is experience and extensive knowledge that play the key role in ferromagnetism and registration parameters, such as distances between profile lines, height of the magnetometer above the seabed bottom, speed of acquisition, the magnetometer operating frequency and potential targets weight [4]. Data taken to be interpreted are magnetic anomalies – the value of magnetic field interference in survey area. The dependence of the magnetic anomaly value on the size of the object, the distance between the magnetometer and the object and the distance between the profiles is presented in Table 1.

Table1. Dependence of magnetic anomaly value on the size of the target
and distance to the target

Target	Approximate weight [kg]	Anomaly value [nt]	Target	Approximate weight [kg]	Distance to target [m]
Engine	3,000	39.77	UXO	9	3
Anchor	2,500	35.73	Anchor	100	6
	9,500	137.34	Canon	2,000	27
Ship wreck	180,000	341.89	Ship wreck	10,000	46
	1,600,000	3,830.40		100,000	100
	21,000,000	7,000		1,000,000	216

Source: [4, 5]

To summarize the contents of Table 1, it should be concluded that the smaller the object detected, the closer the magnetometer should be merged. Marine magnetometers are collecting the data with different frequencies. Most popular are 10, 5, 1 and 0.5 Hz. These have influence on the data coverage and data density. Taking into consideration vessel speed during registering and the frequency of the magnetometer recording, one can conclude that the registration parameters should be a compromise between acquisition speed and data density.

Taking the above into account, and treating the map of the magnetic anomaly as an image, it can be stated that it would be possible to identify and classify detected objects.

2.   Material and Methods

The procedure of magnetic anomaly map analysis in order to detect, locate and dimension the potential ferromagnetic target is presented in Figure 3. It assumes that the map of magnetic anomalies is prepared with due diligence and in accordance with the hydrographic and geophysical state of art. For dimensioning purposes (metric system), the resolution of a map must be known. The co-ordinates X_F, Y_F are presented in a map reference system, and the F value is a total anomaly value. More preliminary information is needed for classification purposes, such as: magnetometer depth, frequency of registration, distances between profile lines and vessel speed during acquisition. In this paper, the authors presented the stages 1, 2 and 4. Stage 3 – classification – needed a database of master objects which is currently under development.
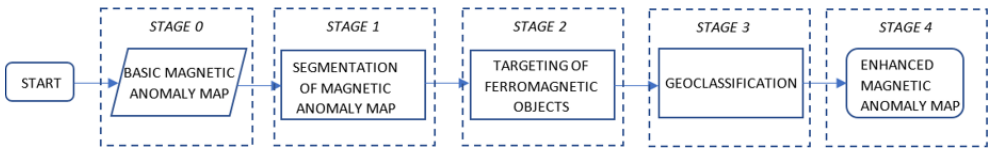

Fig. 3. Magnetic anomaly map interpretation stages for targeting purposes

2.1. Segmentation of Magnetic Anomaly Map Image

As a first stage of the detection of ferromagnetic targets, a magnetic anomaly map was prepared, followed by its segmentation. The boundary condition of the segmentation is the information on the map resolution and registration parameters. This is important for the location and dimensioning of the detected anomalies. Image segmentation is based on dividing the image/ photo/ graphic/ map into parts which are referred to as homogeneous areas or regions in terms of certain selected properties [6]. In case of magnetic anomaly map image, these areas are sets of pixels

representing a similar value. Criteria for the homogeneity of the areas that are often chosen are: the level of pixel values or pixel groups, color, texture [7–9]. The image obtained as a result of segmentation is simplified in relation to the image subjected to segmentation. It means that the image does not contain detailed information appearing in the original image. The adopted procedure for the image of magnetic anomaly map segmentation is presented in Scheme 1 (Fig. 4).
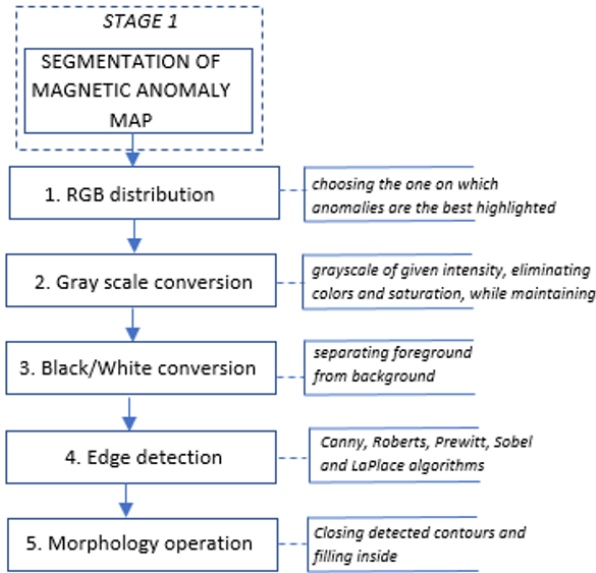

Fig. 4. Stage 1: magnetic anomaly map segmentation

All segmentation steps are realized as a Matlab Application. The first step in the adopted method is RGB distribution. This is used for checking the best results for highlighting the anomaly on the map image. Next, all of the three images are converted to grayscale images, in order to eliminate colors and saturation and to retain luminance. Further, the grayscale images are converted to black/white images in order to separate the foregrounds from backgrounds. Going forward, the edge of the magnetic anomaly is detected. For better results, and according to the art of image analysis and processing, the magnetic anomaly map image was subjected to blur. This is crucial for the better indication of changes at pixel values boundaries.

The main goal of magnetic anomaly edge detection is to highlight the pixels of the map in which the luminance changes rapidly. Sharp edges in the image usually reflect important events and changes, in this subject – magnetic anomalies. Edges detection reduces the amount of data significantly. At the same time, it filters information that can be perceived as less significant, while maintaining important structure properties [7–10]. The edge is the boundary between two uniform regions, so it is possible to detect edges by comparing the intensity of neighboring pixels [6].

In this case, changes in the border between two colors are taken into account. The implemented techniques of edge detection which are commonly used in image analysis are Sobel, Canny, Roberts, Prewitt and LaPlace filters. A number of studies on edge detection were carried out using parameterization related to intensity, thresholding and sensitivity. The best results are presented in [6] and later on in this article.

Having knowledge about the edge of the anomaly, it is possible to calculate its dimensions. The dimensioning was based on closing and filling out contour areas. It was also done as a Matlab Code – the next step in application of magnetic anomaly map segmentation. The closing contours and filling the area inside is termed morphological operations. Having closed and filled areas, it is possible to determine coordinates and the dimensioning of anomalies.

2.2. Targeting Ferromagnetic Underwater Objects

The second stage in magnetic anomaly map interpretation is the potential detection and location of ferromagnetic objects. It is demonstrated in Scheme 2 (Fig. 5).
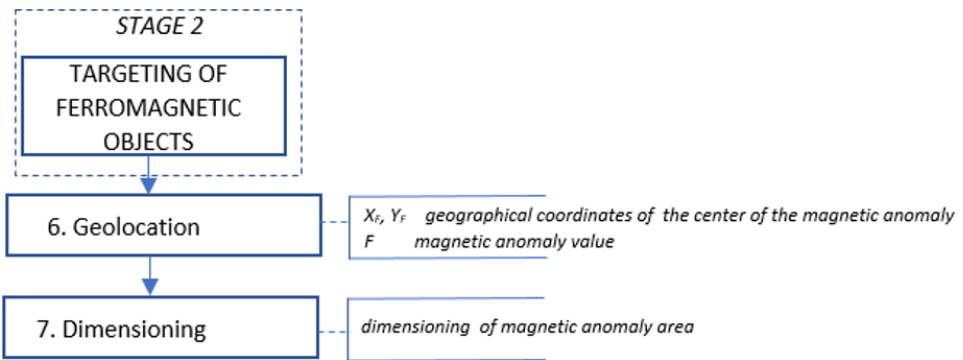

Fig. 5. Ferromagnetic potential objects targeting

Due to the characteristics of the ferromagnetic objects, and having the knowledge of magnetism laws, it is possible to designate the geolocation of the targets [11]. Such targets disturb a vector of intensity, which can be represented by one extreme value (only positive or only negative) or two extreme values (both: positive and negative) on a magnetic anomaly map. If it is one extreme value, it can be assumed that the potential source of magnetic field distortion is located in a middle of an anomaly; if there are two extreme values – a location is between two deflections, in the neighborhood of the maximum signal [12]. The ferromagnetic coordinates include the geographical coordinates X_F, Y_F in specific reference system (the same as a whole map) and the value of magnetic anomaly – F [nT]. In cases of one extreme value, this step is done by indicating the middle of an anomaly on a map. In case of two extreme values, the algorithm determines a profile passing through the extreme

points. Then the intersection of the designated line with the anomaly diagram is referenced to the axes representing the geographical coordinates.

According to the detected regions of magnetic anomalies, and knowing what the map resolution is, it is possible to dimension them. This step is also prepared as a Matlab Code. It uses the pixel dimension scaling according to the known map resolution. First, it indicates the border points and then the weight and length between them is calculated.

2.3. An Attempt at Geoclassification

The last stage is a method for magnetic anomalies classification. The geoclassification of ferromagnetic objects is assumed to be done by taking into account the registration parameters, such as the speed of the vessel, depth of the magnetometer, density of measurements, frequency of acquisition and also magnetic anomaly map resolution. This stage will be developed as a next part of the thesis.

3. Results and Discussion

In order to detect potential ferromagnetic objects on the magnetic anomaly map, an application in Matlab Software was developed. The application assumes the implementation of the aforementioned stages, omitting stage 0 – the final product preparation: magnetic anomaly map creation.

At the very beginning, the image of a map is binarized by changing the color scheme into a black/white image. It is realized by conversion to RGB images and then into grayscale images. Black/white conversion is carried out for the best results of the previous ones. After binarization, edge detection is realized. In the application, Robert, Sobel, Prewitt, Canny and Log filters are implemented. The filters were selected on the basis of previous tests of their operation on magnetic anomaly map images. The thresholding parameter is also implemented as an enhancement for the filter operation. Several steps of thresholding have been selected and its results are presented in [6]. For the purposes of this article, the Canny filter with a threshold parameter 0.25 was selected. For further analysis, the anomaly that is illustrated on the top left corner is taken into consideration. This represents the anchor of the buoyage system. The next step is to calculate the dimensions: length, width – of the area that occupies the anomaly. It is realized by indicating the most distant pixels and the calculation is based on the values of the distance between them. The calculated values are the distance in non-metric – pixels distances, hence the need to rescale values, knowing the initial resolution of a map.

It can also be noticed that the anomaly is arranged in the shape of the digit eight, so one can conclude that there are two extreme values (both: positive and negative values). The last stage, classification, is currently under development. Fuzzy logic and Neuro Adaptive Fuzzy Logic is being taking into consideration.
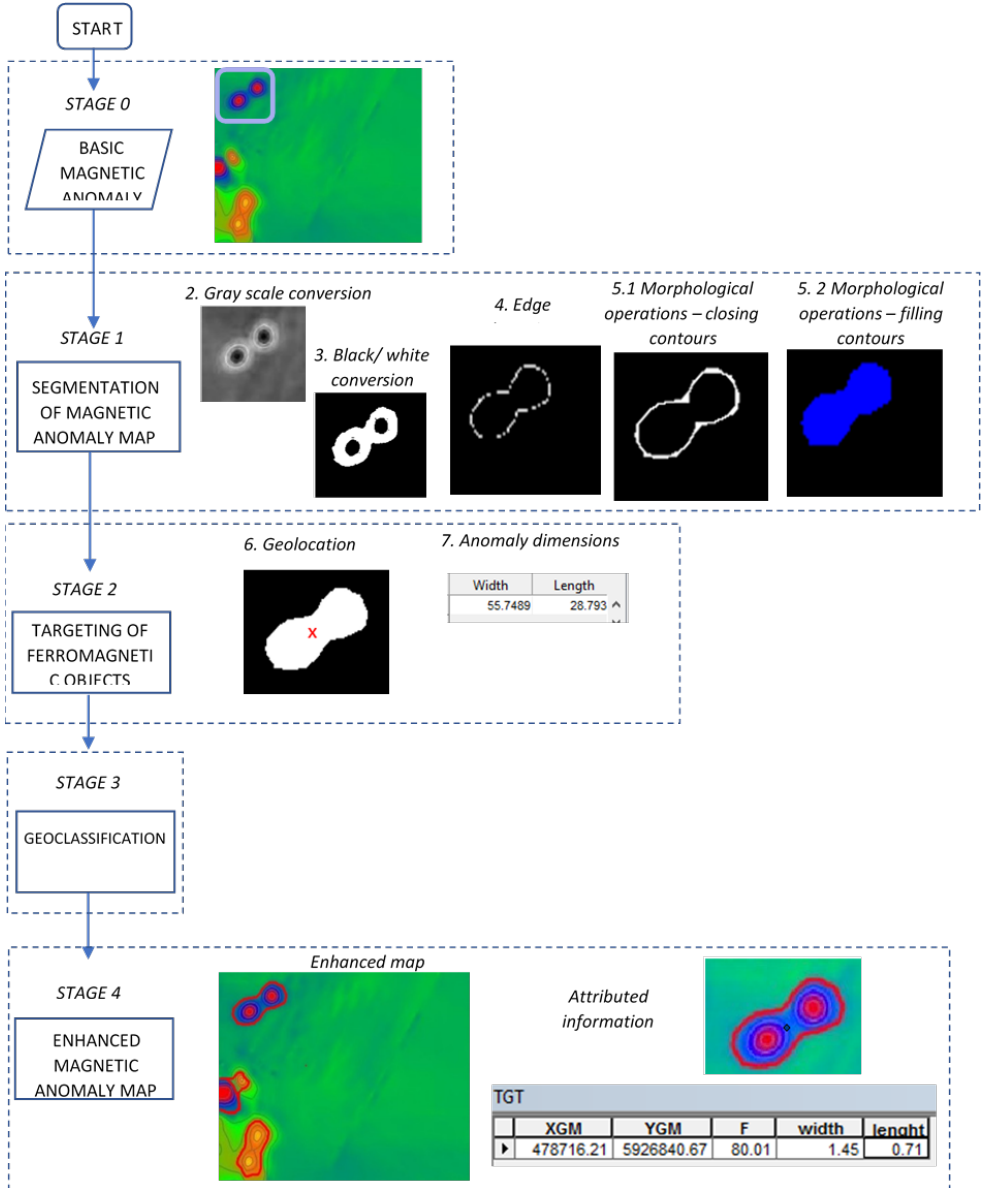
Fig. 6. The ferromagnetic target detection, dimensioning and location – Matlab Application

The magnetic anomaly map, enhanced with information about a detected potential ferromagnetic target with its descriptive attributes is an integrated map: the initial map with the information after procedure of segmentation and dimensioning. All of the information can be added to the initial map as new information layers. These contain information about the ferromagnetic target location (point): X_F, Y_F and

the value of the anomaly: F and the dimensions of the area it occupies (polygon): width, length. The dimension of the magnetic anomaly area does not correspond to the size of a ferromagnetic target. It can be measured/calculated through stage 3 – geoclassification and requires registration parameters, among others: magnetometer depth during collecting the data.

4. Conclusions

The purpose of this article was to present the method of magnetic map anomaly interpretation by analyzing its image and supplementing it with additional information about potential ferromagnetic targets. Information resulting from the map image analysis procedure includes, among others: geolocation of the potential metallic object, dimensions of the magnetic anomaly area, its shape visualized as edges of the anomaly region. The obtained X, Y coordinates of the anomaly and its F value can be compared with the algorithms used in the dedicated hydrographic software – Hypack (Fig. 7).
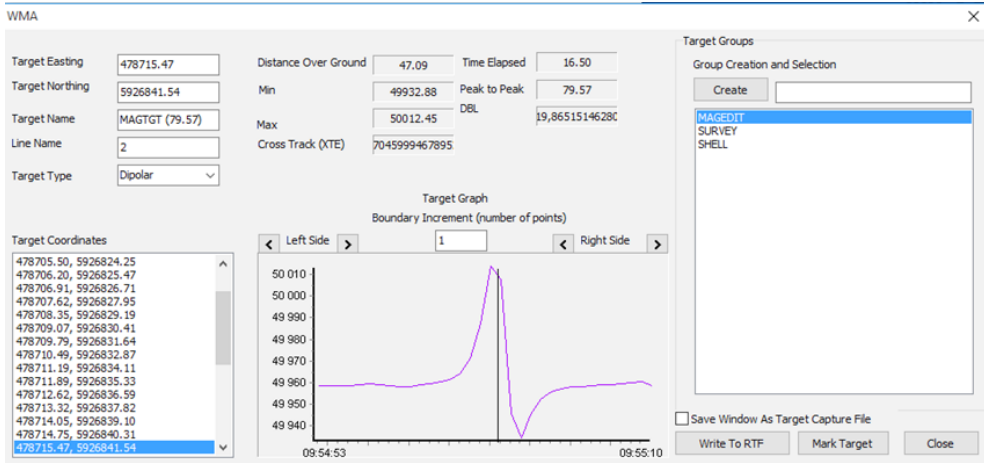

Fig. 7. The ferromagnetic target detection, dimensioning and location – Hypack software

A summary of the results can be found in Table 2.

Table 2. Comparison of data analysis results gained by Matlab and Hypack

	Hypack	Matlab	Difference
X_{GM} [m]	478,715.47	478,716.21	0.74
Y_{GM} [m]	5,926,841.54	5,926,840.67	0.87
F [nT]	80.01	79.57	0.44

By adding information from the data registration process such as magnetometer depth, frequency of the acquisition, vessel velocity and distances between profile lines, the geoclassification of ferromagnetic objects could be carried out. It is assumed that the modified map will allow for the faster and more complete interpretation of the magnetic anomaly map itself.

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Wykrywanie ferromagnetycznych obiektów podwodnych na podstawie mapy anomalii magnetycznych

Streszczenie: Mapa anomalii magnetycznych obszaru podwodnego wskazuje miejsca, w których występuje zniekształcenie ziemskiego pola magnetycznego. Za pomocą procedur interpretacyjnych hydrograf może łatwo wskazać miejsca, w których znajdują się obiekty ferromagnetyczne, a następnie obliczyć poziom każdego zniekształcenia – według wartości całkowitej anomalii – i na podstawie własnej wiedzy spróbować sklasyfikować źródła zniekształceń. Obiekty, które indukują zniekształcenie pola magnetycznego na obszarach wodnych, mogą być różne. Te wywołujące zmiany pola magnetycznego (anomalia >30 nT) to między innymi infrastruktura przemysłowa, np.: rurociągi i kable, a także nieumyślnie zlokalizowane cele o charakterystyce ferromagnetycznej: wraki (statków, samolotów, samochodów), miny wojskowe, niewybuchy, kotwice i łańcuchy statków. Interpretacja takiej mapy w celu zidentyfikowania źródła zniekształcenia pola magnetycznego wymaga specjalistycznej wiedzy i doświadczenia. Całkowita wartość anomalii magnetycznej określa wielkość poziomu ferromagnetyzmu obiektu, a wymiar powierzchni objętej anomalią umożliwia geolokalizację celu i ustalenie jego wymiarów. W artykule autorzy przedstawiają wyniki badań wymiarowania i lokalizacji potencjalnych ferromagnetycznych podwodnych obiektów na podstawie mapy anomalii magnetycznych. Przeanalizowano anomalię magnetyczną spowodowaną przez kotwicę oznakowania nawigacyjnego. Geolokalizacja źródeł ferromagnetycznych, ekstrakcja ich konturów i algorytmy wymiarowania celów ferromagnetycznych zostały przeprowadzone za pomocą oprogramowania Matlab. Porównano i podsumowano wyniki działania różnych filtrów stosowanych do przetwarzania obrazów. Mapa anomalii magnetycznej wzbogacona o wyodrębnione informacje została opracowana w ArcGIS. Analiza została przeprowadzona na potrzeby pracy doktorskiej, a jej wyniki wykorzystano w dalszych badaniach.

Słowa kluczowe: hydrografia, obiekty ferromagnetyczne, anomalia magnetyczna, pole magnetyczne, segmentacja obrazu