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Radiometric method for soil moisture portraits obtaining to study the hydrology of dams

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Abstract: **The methods for the artificial hydraulic structures condition monitoring using trace microwave radiometers are considered, in order to timely detect places of underground leaks to ensure trouble-free operation. Several practical examples of the use of microwave radiometers on various ground-based mobile carriers are described. The characteristics of microwave radiometers used in practice for hydrological monitoring of earthen dams are given. The possibility of detecting potentially dangerous sections of dams, places of erosion of the dam cover, possible places of underground leaks is shown. The possibility of combining microwave radiometers with other means of remote sensing, such as optical video cameras, thermal infrared cameras and georadars, is being considered. The advantages of multisensory sensing to increase the reliability of detecting places of underground leaks are substantiated.**

Keywords: **microwave radiometers, earth dam, remote sensing, radio brightness temperature, relic radiation, unmanned aerial vehicles, soil moisture**

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Contents

1. INTRODUCTION

There are examples of the practical use of microwave radiometers to monitor the hydrological situation along pipeline routes [1], to detect oil films on the water surface [2], to monitor the condition of highways

[3], to determine the coordinates of forest and peat fires [4], to determine the moisture content in the productive soil layer for the needs of digital agriculture [5]. This article is devoted to the urgent topic of microwave radiometric monitoring of earthen dams in order to detect places of underground leaks, for timely measures to prevent a catastrophe [6], based on many years of practical experience in the use of microwave radiometers [7-14].

To protect low-lying areas in river valleys and sea coasts from flooding, to regulate water flow for water supply, for agricultural and industrial needs, according to a rough estimate, tens of thousands of kilometers of dams of various types have been built in the world. There are no exact statistics on the total length of dams in the world, only the largest objects included in the register of dams by the International Commission on Large Dams are taken into account. Safe, trouble-free operation of artificial hydraulic structures is an extremely important task, since, as a rule, a dam break leads to catastrophic consequences with significant economic damage, human casualties and serious environmental consequences for the entire region that has been flooded, especially if oil and gas infrastructure facilities, pipelines, production, processing or storage facilities of hydrocarbon products have fallen into the flooding zone. It may take years to eliminate the consequences of the disaster…

The most common cause of a dam break is overflow, which may occur due to the discrepancy between the actual spillway and the calculated values, clogging of the spillway with extraneous debris. The second most common cause of accidents is subsidence of the soil and instability of the slopes of the dam. The third cause of accidents are underground leaks that cause internal erosion of the dam body, the formation of voids with subsequent subsidence or movement of the soil.

Therefore, timely detection of underground leaks in earthen dams with their subsequent elimination of leaks allows preventing possible accidents and catastrophes.

In the Kingdom of the Netherlands, about half of the country's territory has been reclaimed from the sea and is located below sea level. The coastline is formed by alluvial dunes. Behind them are the lands reclaimed from the sea, called polders and protected by dunes and artificial dams from sea waters. The total length of the protective dams exceeds three thousand kilometers. In the Netherlands there is also the longest dam in Europe – Afsleitdijk, thirty kilometers long. The problem of flood protection and water balance regulation is especially relevant in the Netherlands, where a special flood protection department, the Watershap, is organized, which organizes continuous monitoring of artificial hydraulic structures using the most modern remote sensing methods, including the method of microwave radiometry.

The purpose of this work is to show the results of the practical use of microwave radiometers for monitoring the condition of earthen dams, the possibility of searching for places of underground leaks, identifying places with violation of protective coatings of dams and identifying places of erosion of the dam under the protective layer, using various means of transporting radiometers – unmanned aerial vehicles, special machines, quad bike and hand cart.

2. EQUIPMENT AND RESEARCH METHOD

Microwave radiometers designed for remote sensing can be placed on various platforms – space, aviation and ground. Radiometers placed on space satellites, for example, the well-known MIRAS radiometric system developed by the European Space Agency, operating in the L-band with passive aperture synthesis, designed to measure soil moisture and ocean water salinity, the best in its class in many respects, is completely not applicable for detecting leaks in earthen dams, since the system provides the size of the pixel is more than 35 kilometers, which exceeds the length of the longest European dam [7]. Previously, experiments were conducted to detect leakages in earthen dams using a scanning radiometer placed on board the aircraft from a height of 300 meters [1]. The pixel element was approximately 20 meters. This resolution is clearly not enough to accurately determine the coordinates of the leak location. Acceptable resolution, of the order of half a meter, can be provided by trace radiometric systems placed at extremely low altitudes, since the resolution of trace radiometers without synthesis of the antenna aperture is determined by the width of the main beam of the antenna pattern, which is approximately equal to the ratio of the wavelength to the aperture value. Usually, the aperture value of such antennas does not exceed 1-2 wavelengths, which for the *L*-band (wavelength 21 cm) will be about half a meter. This characteristic size determines the minimum dimensions of the radiometer. Radiometers with such dimensions can have a mass of two to twenty kilograms and can be easily placed on an unmanned aerial vehicle, a special road vehicle, an ATV or moved on a trolley. The use of a UAV as a carrier of a microwave radiometer (**Fig. 1**) has the advantage that almost any section of the dam becomes available for shooting when movement on the ground is difficult. The disadvantages of this method of movement are the reduced resolution or detail of the sensing. The resolution of the microwave radiometer is equal to the height of the radiometer above the earth's surface. When flying a UAV over a dam to ensure flight safety, the height must be at least 10 meters, respectively, and the permitted element will have a size of about 10 by 10 meters. This is enough to detect places of underground leaks, but it is absolutely not enough to accurately identify places of erosion of dams. When moving the radiometer using a crane (**Fig. 2**), the resolution will be from 1 to 2 meters, depending on the setting of the crane boom, but this value may vary significantly due to road surface irregularities. In addition, a

Fig. 1. *Placement of the radiometer on the UAV.*

Fig. 2. *Sounding of the dam using a crane.*

Fig. 3. *A system of two radiometers on an the quad bike.*

bulky crane may not pass everywhere. The placement of the radiometer on the ATV significantly increases the cross–country ability, but the resolution is stable and is 1 meter – the height of the installation of the radiometer (**Fig.3**). But the ATV also cannot always move across the entire surface of the dam. For hard-to-reach places, moving the radiometer on a trolley (**Fig.4**) or carrying it on your hands is used.

The main parameters of the radiometer are presented in **Table 1.**

The method of detecting leaks in dams is based on the fact that a microwave radiometer is able to receive and measure the power of its own radiothermal radiation that originated underground in depth, passed through the rock thickness and radiated into open space. Simultaneously with the radiation of the dam, the radiometer also receives part of the relic radiation of the celestial sphere reflected from the earth's surface with the addition of its own atmospheric radiation. Radiation can be received simultaneously at one or at different wavelengths (frequency ranges) and at two wave polarizations – vertical and horizontal. The depth of sounding is determined by the selected wavelength, humidity and mineralization of the soil, and usually lies in the range from one to five wavelengths. For dams sensing, it is convenient to use the *L*-band (wavelength 21 cm.), since this ensures sufficient depth of sounding and in this range there is a frequency band (from 1400 to 1427 MHz), specially allocated for the operation of radio astronomers and passive locators. According to the measured values of radio brightness temperatures on the vertical T_{bv} and horizontal T_{bh}, the I_p polarization index is calculated by the formula:

$$I_p = (T_{bv} - T_{bh})/(T_{bv} + T_{vh}).$$

The value of the polarization index weakly depends on the temperature of the soil layer and is mainly determined by the value of the dielectric permittivity of the soil, which depends on the moisture content. The dependence of the polarization index on soil moisture varies under different conditions and depends on the material and

Fig. 4. *Moving the radiometer on the trolley.*

Table 1

Radiometer parameters

Parameters	Value
The central frequency of the receiving module, MHz	1412±30
Reception bandwidth, MHz	50 ±20
Number of receiving channels	1
Sensing method	Along flight line
Viewing width, H - height above the ground	1.0xH
Sensitivity, K degree	0.5
Card Type	SD-Card
Continuous recording time, at least an hour	8
Supply voltage, V	12
Power consumption, W max	6
Weight, kg	8.5
Size, mm	500X400X80

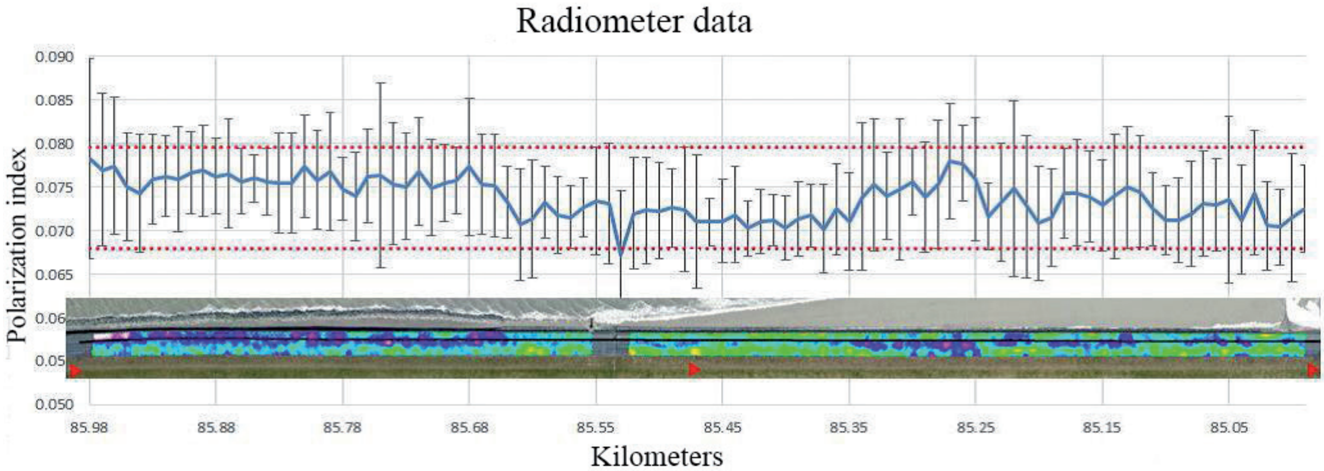

Fig. 5. *The study of the kilometer section of the dam results.*

thickness of the dam coating, the material of the embankment, the presence of vegetation, etc. To accurately determine the radiation-humidity dependence, a special calibration of the radiometric system is required, in relation to specific conditions.

3. DAM SOUNDING RESULTS

A system of two radiometers combined with a satellite navigation system receiver was used to study the asphalt pavement on the Lauwers-Mer dam (Netherlands). The system measures the intensity of its own radiothermal radiation of the underlying surface simultaneously at two polarizations in the L-band, and stores its digital readings together with navigation information. The radio brightness temperatures measured by the system are particularly sensitive to changes in the dam coating material and soil moisture (dielectric properties). For example, the dielectric constant of water is 80, asphalt-about 5, air-1. By measuring the radio brightness temperatures simultaneously in two polarizations, the polarization index is determined as an indicator of the asphalt structure. The graph of the dependence of the polarization index on the longitudinal coordinate obtained during a full-scale experiment on the Lauwers-Mer dam is shown in **Fig. 5**. The same graph shows a fragment of a soil moisture content map constructed from these data along the trajectory of the carrier. On the map, sections of the dam with normal moisture are shown in green, areas with increased moisture are shown in blue, and places with critical waterlogging are shown in purple. Such places were registered, photographed and samples (pits) of asphalt pavement were taken in them in order to identify the causes of waterlogging. Photos of critical places and asphalt samples are shown in **Fig. 6**. During the laboratory examination of the samples, it was revealed

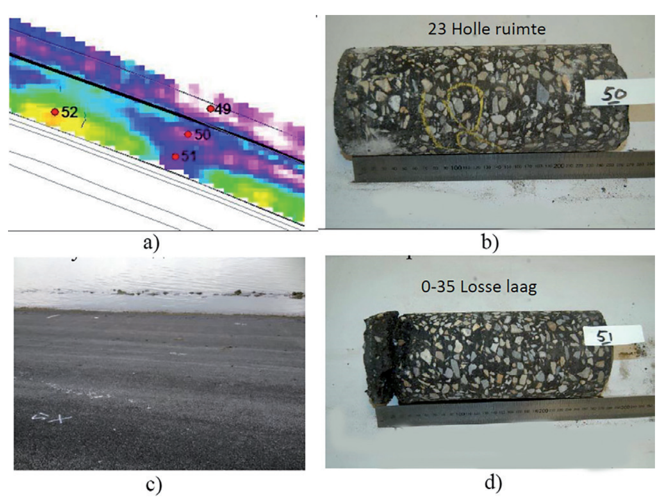

Fig. 6. *A map of the dam site with photos of coating samples at critical points. a) dam moisture map; b) photo of the core at point 50 – emptiness; c) photo of the dam section; d) photo of the core at point 51 – loose structure.*

that the first sample contains internal voids, and the second contains places with a loose asphalt structure. In both cases, the coating is able to effectively protect the dam from external meteorological factors and requires repair. During the experiment, along with radiometric survey, photo and video shooting was performed to document the results, as well as shooting with a thermal infrared camera, the data of which correlates well with radiometer data and complements them with more accurate information about the surface temperature of the dam.

The presence of places with damaged asphalt pavement of the dam, over time, can result in erosion of the dam body, underground leaks, leaching of soil and, as a result, to the formation of voids that can cause soil movement or partial collapse with catastrophic consequences. Microwave radiometers, which are capable of detecting water in the depth of the dam, are completely insensitive to underground voids. But ground-penetrating radars can be successfully used to detect underground voids. Georadar is specialized active radar designed to probe underground objects. The principle of its operation is based on generating and emitting an electromagnetic pulse into the ground through a transmitting antenna and receiving signals reflected from various underground in homogeneities. The reflected pulses are received by the receiving antenna with some delay depending on the distance of the inhomogeneity from the antenna. The complete absence of reflected signals in any range of band means that there is a void in this range. Thus, the combined use of several types of sensors – microwave radiometers, optical cameras, infrared cameras and georadar provides enough data for a comprehensive survey of the condition of dams with recommendations for measures to ensure long-lasting and trouble-free operation.

4. CONCLUSION

As a result of the research carried out, the following conclusions can be made:

- the method of microwave radiometric sensing can be successfully used to monitor the condition of dams, search for places of underground leaks and erosion of the coating;
- an unmanned aerial vehicle, a crane, an ATV or a trolley can be used as a carrier of the radiometer;
- multisensory sensing using, in addition to a microwave radiometer, an optical video camera, a thermal infrared camera and a ground-penetrating radar increases the likelihood of detecting places of underground leaks, erosion of the coating and the presence of underground voids.

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