COMPUTER VISION-BASED ALGORITHM FOR DETECTING FLOATING WASTE AND ESTIMATING ITS AREA AT PUMPING STATIONS

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Abstract

The efficient and stable operation of pumping stations largely depends on the hydraulic conditions at the water inlet. During practical operation, various wastes accumulating on the water surface can negatively affect the operation of pumping units and impede the free movement of water flow. As a result, hydraulic resistance increases, additional load is created on the pumping system, and its efficiency decreases. In this research work, an approach based on video monitoring and image processing technologies was developed to detect wastes accumulating on the water surface at pumping stations. In the proposed method, wastes on the water surface are separated using image segmentation and object recognition algorithms and their area in pixels is calculated. A mathematical model was proposed that allows estimating the share of the area occupied by wastes based on the obtained image data. This approach serves to determine the amount of wastes on the water surface in real time, automate the process of their monitoring, and ensure the efficient operation of pumping stations.

Keywords: Pumping station, water surface monitoring, video surveillance system, image segmentation, object recognition, computer vision technologies, mathematical modeling, waste area.

Introduction

Today, the implementation of technological and algorithmic measures aimed at optimizing the operation of water management equipment and systems is becoming an important task. This allows, along with increasing the production of industrial technologies, to optimize the operation of industrial technologies, reduce the operational and monitoring costs allocated to them. In particular, special attention is paid to the issues of automation of monitoring and control at water management facilities. One of the important technological elements of the water management system is pumping stations, which transfer water in the required direction and height during irrigation, drainage and water supply processes. The efficient and stable operation of pumping stations largely depends on the hydraulic conditions at the water inlet. During practical operation, leaves, plant residues, plastic products and other types of waste can accumulate at the inlet of pumping stations along with the water flow. Such waste impedes the free movement of water flow, leads to an increase in hydraulic resistance and a decrease in the efficiency of pumping units. Therefore, timely detection, elimination and control of waste accumulating on the water surface are important for ensuring the reliable operation of pumping stations. In particular, the use of modern monitoring technologies, video surveillance and image processing methods can effectively help in monitoring this situation, timely detection and elimination of problems [1-6].

A lot of scientific and practical work is being carried out to identify various mechanical impurities, plant residues, household waste found in the water flow at the inlet of pumping stations and to assess their impact. In this case, as a result of the accumulation of waste accumulating on the water surface in the pump grates, the hydraulic resistance increases and the efficiency of the pumping units decreases. Therefore, the issue of detecting and monitoring waste accumulating on the water surface is one of the important scientific and practical problems[7-10].

In the current scientific work, various methods have been proposed for detecting and monitoring waste in water bodies. In traditional approaches, the process of detecting waste is mainly carried out using visual observation, mechanical cleaning devices or sensor systems. However, such methods often require constant human supervision and do not provide accurate real-time information. Therefore, monitoring systems based on computer vision and image processing technologies are widely used. These approaches allow for automatic detection of objects on the water surface, their classification, and remote monitoring [11-14].

There are many image segmentation and object recognition algorithms in computer vision technologies. Using image segmentation methods, objects in an image are divided into separate segments and analyzed. Object recognition and classification algorithms separate objects in an image by type and determine their geometric or statistical properties. Although many studies have considered the issue of determining the presence of waste accumulating on the water surface, the issues of accurately assessing their area on the water surface and determining the level of accumulation in real time have not been sufficiently studied. In current research, the issue of developing a mathematical model based on image data to estimate the amount of waste at the inlet of pumping stations was analyzed. Therefore, one of the current scientific directions is the development of a mathematical model that detects waste on the water surface based on video monitoring, separates it using image segmentation, and estimates the area of waste based on pixel data [15-17].

In this research work, an algorithm based on video monitoring and image processing methods was developed to detect waste accumulating on the water surface of the inlet of pumping stations, and a mathematical model was proposed to estimate the area occupied by waste. Based on this approach, the amount of waste accumulating on the water surface is determined through video surveillance and effective monitoring is organized. The research task was to obtain water surface images through video monitoring, extract waste objects through image processing, segmentation, classify the detected objects, and develop an algorithm for calculating the area occupied by waste based on pixel data in the image. The work carried out on these works is presented below.

In recent years, the issue of detecting and monitoring waste in water bodies has been widely studied in the fields of ecology, water management and digital monitoring systems. Rivers and canals are one of the routes that transport plastic waste from land to sea. Therefore, detecting and assessing the amount of waste on the water surface is considered one of the important areas of environmental monitoring. The study of the transport, distribution and ecological impact of plastic waste in rivers is considered one of the key issues on a global scale [17].

In early studies, the detection of waste on the water surface was mainly carried out based on visual observation and manual counting. However, such approaches are time-consuming and limit the possibility of monitoring large areas. Accordingly, automated monitoring systems based on video surveillance and computer vision technologies are proposed in modern studies. In particular, a method for detecting plastic waste using deep learning algorithms based on images taken by cameras installed on the river has been proposed. The results of the study showed that such systems are more effective than traditional visual observation methods in detecting plastic waste density on the water surface [18].

Developments in the field of computer vision have enabled the widespread use of deep learning models for detecting surface waste. In particular, the YOLO (You Only Look Once) algorithm based on convolutional neural networks is effective in detecting surface waste in real time. Studies have shown that the model developed based on YOLOv5 increases the accuracy of detecting small and densely located waste on the water surface [19]. This approach allows detecting waste even in the presence of light reflections, aquatic plants, and other complex background conditions in the aquatic environment. Also, some studies have used object recognition and tracking algorithms based on video images to detect surface waste. In particular, a method for detecting and tracking floating waste in rivers by using the YOLOv5 and DeepSORT algorithms together has been proposed. Experimental results have shown that the accuracy of detecting various types of waste using this method reaches 80–88% [20].

Another important area for detecting surface debris is remote sensing and monitoring based on satellite images. In this case, it is possible to detect surface debris using segmentation algorithms. In particular, a model developed based on the U-Net and DeepLabV3+ architectures has been shown to detect floating debris in rivers using satellite images [21].

Recent studies have developed algorithms that work in real time based on video monitoring. For example, a model developed based on YOLOv8 has high accuracy in detecting plastic debris in water streams, and in experiments it was noted that the F1 index reached 0.98 [22]. This indicates that there is a possibility of detecting surface debris in real time based on video monitoring.

The development of computer vision algorithms requires a large data set, and special image databases have been created to detect plastic debris in rivers. In particular, the RiSID database contains more than 7000 river images and provides segmentation annotations at the pixel level. This database can be widely used in the development of algorithms for detecting surface debris on the water surface [23]. Also, some studies have proposed the use of images obtained using unmanned aerial vehicles (UAVs) to detect surface debris on the water surface. It has been reported that the accuracy of detecting plastic debris on the water surface using YOLO algorithms based on UAV images has reached 0.81 mAP [24].

Based on the studies studied, it can be seen that effective algorithms for detecting surface debris on the water surface have been proposed. However, many works have mainly studied the issues of detecting and classifying debris, and the issues of determining the area occupied by them on the water surface and assessing the level of accumulation based on mathematical models have not been sufficiently studied. Therefore, one of the important steps is to develop a mathematical model based on video monitoring to detect waste on the water surface at the inlet of pumping stations and calculate the area occupied by waste using pixel data in the image.

Methodology

In this research, an approach based on video monitoring and image processing methods was proposed to detect and estimate the amount of waste accumulating on the water surface at the inlet of pumping stations. This involves continuous monitoring of the water surface, digital processing of image data, and assessment of the share of the area occupied by waste. The proposed approach consists of the following steps.

Step 1. Data collection system based on video monitoring. A data collection system based on video monitoring was developed to detect waste accumulating on the water surface at the inlet of pumping stations. This provides continuous monitoring of the water surface and prepares image data for subsequent digital processing stages. The monitoring system includes a surveillance camera, a computing device for image processing, and a data storage module.

The surveillance camera is installed at the water inlet of the pumping station, that is, in the area where the most waste accumulates on the water surface. The camera location is set to maximize the visibility of the water surface. The camera height and viewing angle are selected to ensure the clarity of objects on the water surface and reduce geometric distortions in the image. As a result, waste, plant residues and other objects located on the water surface can be clearly observed in the images obtained by the camera. Images of the water surface are continuously captured by the video monitoring system at certain intervals. The obtained images are stored in digital format and image processing algorithms are used. The camera resolution, frame rate and lighting conditions are important in the process of capturing images. Therefore, a high-resolution digital camera is used in the monitoring system, which provides the ability to clearly distinguish objects on the water surface.

In the process of image processing, it is important to determine the relationship between the real area and the pixel area in the image. Therefore, the geometric dimensions of the camera's observation area are determined and correlated with the total number of pixels in the image. If the water surface area is A_S and the total number of pixels in the image is N_t, then the real area per pixel is defined as follows.

$$A_p = \frac{A_S}{N_t},$$

where A_p is the real area corresponding to one pixel.

Using image data obtained from video monitoring, waste on the water surface is detected and an initial database is collected to estimate its quantity.

Step 2. Image processing algorithm. When analyzing images obtained through a video monitoring system, digital image processing algorithms are used to detect waste on the water surface. Image processing consists of several steps, which include image pre-processing, segmentation, and object detection.

Image pre-processing. Images obtained from a video camera may contain different lighting conditions, reflections on the water surface, and noise. Therefore, it is necessary to filter the image before processing it. In practice, a Gaussian filter is often used to perform such tasks. This filter allows you to reduce high-frequency noise in the image and smooth the boundaries of objects. The Gaussian filter is defined by the following expression.

$$G(x,y)=\frac{1}{2\pi\sigma^2}e^{-\frac{x^2+y^2}{2\sigma^2}},$$

where $G(x,y)$ is the value of the filter function, σ is the filter dispersion parameter, and x,y are the coordinates in the image. This filter reduces the noise in the image and makes the boundaries of the debris objects more clearly visible.

Step 3. Image segmentation. This allows you to separate different objects in the image from the background. The threshold segmentation method is often used to detect debris on the water surface. It divides the image into two parts depending on whether the pixel intensity in the image is greater than or less than a certain threshold value. Threshold segmentation is determined based on the following conditions:

$$g(x,y)=\begin{cases}1, & f(x,y)>T\\ 0, & f(x,y)\le T\end{cases},$$

where $f(x,y)$ is the pixel value in the original image, $g(x,y)$ is the binary image resulting from the segmentation, and T is the threshold value. As a result, the waste objects in the image are separately identified.

Step 4. Threshold segmentation. Based on the binary image generated as a result of segmentation, waste objects on the water surface are identified. Contour detection algorithms are used in this. Contour detection algorithms are used to find the boundaries of objects in the image and determine their geometric properties. As a result, it is possible to obtain information about the number of pixels and shape of each detected object. The stages of the image processing algorithm are shown in the figure below.

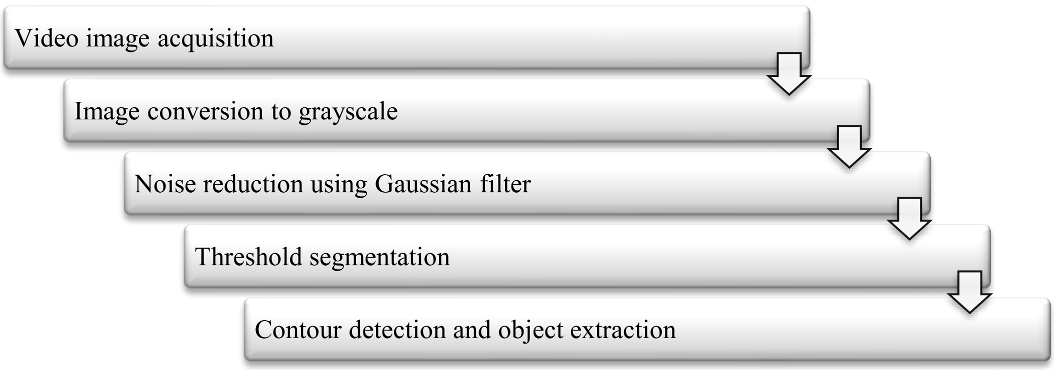

Figure 1. Image processing algorithm

This algorithm detects surface debris and calculates the pixel area in the image. This data serves as the basis for building a mathematical model that estimates the area occupied by the debris. Thus, the image processing algorithm is an important part of the automatic detection and monitoring system for surface debris at pumping stations.

Step 5. Contour detection and object extraction. After the surface debris objects are extracted using segmentation and contour detection algorithms during image processing, it is necessary to determine their quantity and area. For this purpose, an algorithm for estimating the area of the debris based on pixel data in the image was developed. This algorithm allows you to determine the area occupied by the surface debris and calculate their relative share in the total water surface.

In the binary image generated by segmentation, the waste objects are represented as white pixels, and the water surface is represented as the background. As a result, when detecting waste, it is possible to estimate their area by counting the number of waste pixels in the image. If the number of waste pixels in the image is N_d, and the total number of pixels in the image is N_t, the proportion of waste on the water surface is determined as follows.

$$S_d = \frac{N_d}{N_t}.$$

This is used to calculate the area covered by the debris on the water surface. If the area of the water surface observed by the camera is A_S, then the area covered by the debris is given by:

$$A_d = S_d \cdot A_S.$$

In practical calculation, the waste objects are extracted using an edge detection algorithm and the pixel area for each object is calculated. If there are k waste objects in the image, then their total pixel area is calculated as follows:

$$N_d = \sum_{i=1}^{k} n_i,$$

where n_i is the number of pixels of the i-th waste object, and is the number of detected waste objects in the image. This allows us to calculate the total area of all waste objects in the image. At the same time, a special threshold value can be entered to estimate the amount of waste. In particular, if the waste fraction is above a certain critical value, the system can signal that waste is accumulating at the pump inlet. Such a condition is defined as follows.

$$S_d > S_{crit},$$

where S_{crit} is the critical value of the waste fraction.

The proposed algorithm allows you to detect waste on the water surface, assess its area, and monitor the level of waste accumulation. This approach serves to timely detect waste at the inlet of pumping stations and effectively organize technical maintenance.

The proposed approach is aimed at automating the process of detecting and assessing the amount of waste accumulated on the water surface at the inlet of pumping stations. Images obtained using a video monitoring system are analyzed using image processing algorithms, and waste objects are extracted using segmentation and object recognition methods. Then, based on the pixel data in the image, the share of the area occupied by waste is calculated and correlated with the real water surface area. The proposed approach allows you to determine the level of waste accumulation on the water surface in real time and serves to effectively organize monitoring and technical maintenance processes at pumping stations.

Mathematical model

It is not enough to simply identify the waste that appears on the water surface at the inlet of pumping stations, but it is also necessary to quantitatively assess the level of its accumulation. Therefore, this study proposes a mathematical model that represents the state of waste as a time-varying process. The model numerically represents the current state at the pump inlet by jointly assessing the observed waste cover on the water surface, its density, and the rate of accumulation.

In the proposed model, first of all, the current state of the area covered by waste on the water surface is considered as a function of time. In this case, the level of waste coverage is determined as follows:

$$D(t)=\frac{A_d(t)}{A_S},$$

where $D(t)$ is the waste coverage coefficient over time, $A_d(t)$ is the waste area determined at time t, and A_S is the total area of the observed water surface. This coefficient takes a value between 0 and 1 and indicates the volume of the water surface occupied by waste. When the value is small, the impact of waste is low, and as the value increases, the free movement of the flow in the water inlet is limited.

Sometimes it is not enough to assess the state of waste only by area, because waste occupying the same area may have different spatial distribution. For this reason, the waste fragmentation indicator is also included in the model. The density of waste objects in the image is determined as follows.

$$F(t)=\frac{k(t)}{A_S},$$

where $F(t)$ is the density of waste objects, $k(t)$ is the number of individual objects detected. This indicator determines whether the waste is present on the water surface in the form of small pieces or large accumulations. This is because small and scattered objects and large and combined waste layers have different effects on the pump inlet.

One of the important parts of the model is to assess the dynamics of waste accumulation. The amount of waste in front of the pump is variable, increasing or decreasing over time. Therefore, the rate of growth of the waste coverage is determined as follows.

$$V_d(t)=\frac{D(t)-D(t-\Delta t)}{\Delta t},$$

where $V_d(t)$ is the rate of waste accumulation, Δt is the time interval between successive observations. If $V_d(t)>0$, it means that the amount of waste is increasing, if $V_d(t)<0$, it means that it is decreasing. It is this indicator that allows the monitoring system to assess changes in the near future, in addition to the current state.

For a comprehensive assessment of the general state at the pump inlet, an integral indicator is proposed in the model. It combines the degree of waste coverage, the density of objects and the rate of accumulation.

$$M(t)=\alpha D(t)+\beta F(t)+\gamma V_d(t)$$

Where $M(t)$ is the integral monitoring indicator, α is the area, β is the density, γ is the dynamic change weight coefficients.

Using this indicator, it is possible to assess the state of waste at the inlet of the pumping station at three levels. If $M(t)$ is in a small range, the system is considered to be in a normal state. At medium values, it is necessary to take precautionary measures, and at high values, there is a need to immediately eliminate waste. Thus, the proposed mathematical model allows, in addition to the simple detection of waste on the water surface, to assess its accumulation state quantitatively, structurally and dynamically over time.

Results

In order to evaluate the effectiveness of the proposed algorithm and mathematical model, experimental observations were carried out at the water inlet of the pumping station. During the experiment, a video monitoring system was used to detect waste appearing on the water surface, and the obtained images were analyzed using processing algorithms. The main goal of the experiment was to determine the amount of waste accumulating on the water surface using the developed model and monitor its change over time.

Experimental observations were carried out at the water inlet of the pumping station, that is, in an area where various waste can accumulate along with the water flow. The camera was installed at a certain height above the water inlet channel to cover the water surface to the maximum extent. The camera location was chosen so that it would allow observing the main flow zone of the water surface. This approach allowed for continuous monitoring of waste appearing on the water surface and accurate image acquisition.

A high-resolution digital camera was used during the experiment. The images obtained by the camera were recorded at certain time intervals and then transmitted to image processing algorithms. The images were saved in a standard digital format, and segmentation, object detection, and pixel-based area calculation processes were performed on them. The camera parameters, image resolution, and observation area were pre-determined to ensure the accuracy of the experimental results. The main technical parameters of this system are listed in the table below.

Table 1 **System basic parameters**

Parameter Value	Value
Camera type	Digital video camera
Image resolution	1920 × 1080 pixels
Frame rate	≈ 25 fps
Surveillance area	≈ 12 m²
Camera height	3–4 m
Surveillance area	Pumping station entrance

During the observation, the waste appearing on the water surface, including plant residues, leaves and various small household waste, was recorded in the images. The obtained images were processed using a developed algorithm at the next stage to determine the share of the area occupied by waste and its changes over time. The results of these observations can serve as a basis for assessing the possibilities of practical application of the developed mathematical model.

In the study, segmentation and object recognition algorithms were used to detect waste on the water surface during image processing. As a result, the water surface and waste objects in the image were separated into separate regions. In the binary images formed as a result of segmentation, waste objects were separated as separate pixel sets, and the necessary data for the calculation stages were formed.

As a result of image processing, the contours of waste objects on the water surface were determined and their number was calculated. The obtained images contain several waste objects at the same time. These objects are located on the water surface in various sizes and shapes, some of which consist of small fragments, and some of which consist of large accumulations of waste. Using the object detection algorithm, the boundary of each waste object was determined and their number of pixels in the image was calculated.

When detecting waste, the pixel area of each waste object in the image was calculated, and the total sum and the total pixel area occupied by waste on the water surface and the share of waste were determined. The results of waste detection for several images obtained during the experiment are presented in the table below.

Table 2 Waste detection results

№	Number of detected objects	Number of waste pixels	Waste percentage
1	6	1450	0.11
2	9	2180	0.17
3	7	1895	0.14
4	12	2650	0.21
5	10	2410	0.19

According to the study, the number of waste objects detected on the water surface and their pixel area in the image vary at different observation times. This indicates that the amount of waste coming with the water flow changes dynamically over time. The results of pixel counting allow us to determine the area occupied by waste on the water surface and estimate their real area using a mathematical model. Thus, the image processing algorithm is one of the main stages in the detection and assessment of waste on the water surface.

Discussion

Based on the images obtained as a result of experimental observations, the share of waste coming with the water flow at the inlet of the pumping station was determined and the dynamics of their change over time was analyzed. The method of segmenting images and calculating based on pixels made it possible to obtain accurate information about the area and share of waste objects. According to the results, it was observed that the share of waste varies in the range of 0.11–0.21. This indicates that the amount of waste coming with the water flow is not constant and varies depending on external factors, in particular, the speed of the water flow and objects on the water surface. An increase in the proportion of waste can lead to uneven flow distribution at the pump inlet and deterioration of hydraulic conditions.

The analysis algorithm developed during the study allows for automatic detection of waste and rapid assessment of its quantity. Through video monitoring and image processing methods, it is possible to monitor in real time the accumulation of waste that may occur at the pump inlet and determine its negative impact on the efficiency of pumping units. Also, automated image analysis reduces the human factor, speeds up monitoring, and serves as an important source of information for improving the efficiency of technical maintenance at pumping stations.

Conclusion

In this study, an algorithmic approach based on video monitoring and image processing was developed to detect and estimate the amount of waste coming with the water flow at the inlet of a pumping station. During the study, images obtained using a camera were segmented, waste objects were calculated at the pixel level, and the amount of waste on the water surface was estimated. The results obtained showed that the amount of waste varies over time and that a significant part of the water surface can be covered with waste during some observation periods. Based on the results obtained, it was determined that the waste share varies in the range of 0.11–0.21, which can negatively affect the flow conditions at the pump inlet and the efficiency of the pumping units.

Based on the proposed monitoring and image processing algorithm, waste accumulating on the water surface is detected and its amount is estimated. This approach has shown high results in organizing real-time monitoring at pumping stations, detecting waste accumulation at an early stage, and optimizing technical maintenance. Therefore, the developed approach can be an important step in controlling the operation of pumping stations and digitizing monitoring systems at water facilities.

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