Automation of activated sludge quality monitoring in wastewater treatment using computer vision technology

Evgeny Verteletsky[1*], *Ralia* Yulmetova[1], *Bogdan* Volkov[1], and *Dmitry* Rumyantsev[2]

[1]ITMO University, 49, lit. A, Kronverksky Ave., St. Petersburg, 197101, Russian Federation
[2]St. Petersburg State University of Industrial Technologies and Design, 18, st. Bolshaya Morskaya, St. Petersburg, 191186, Russian Federation

Abstract. This paper explores a method for automating the monitoring process of activated sludge quality control at biological wastewater treatment plants using computer vision technology. The implementation of such a system will reduce the need for manual intervention on the part of microbiological laboratory technicians and provide continuous monitoring of the cleaning process. This method is based on in-depth analysis of activated sludge images obtained using an automated microscope, and subsequent processing of the data using a machine learning model to determine the number and types of microorganisms. The results obtained make it possible to assess the quality of activated sludge based on its microbiological composition in order to, based on the assessment obtained, take the necessary actions to change and adjust the processes of biological wastewater treatment.

1 Introduction

In today's industrial world, environmental and safety issues are becoming increasingly important. One of the most important challenges facing manufacturing plants is the treatment of wastewater before releasing it into the environment. In Russia, as in many other countries, there are a significant number of factories producing various types of products, and as a result of their activities, a significant amount of wastewater enters water resources.

It is important to note that the volume of wastewater discharged in Russia in 2022 amounted to 11.3 billion cubic meters, which emphasizes the need for an effective wastewater treatment system to minimize negative impacts on the environment and preserve the aquatic ecosystem.

The main stage of treating contaminated wastewater at wastewater treatment plants is biological treatment [1]. This method is based on the use of biocenosis, the most important part of which is activated sludge. Activated sludge plays a key role in the biochemical degradation of contaminants in wastewater, making it an integral part of the treatment process [2-3]. The advantages of the biological purification stage are the high degree of

* Corresponding author: verteletckii.evgenii@yandex.ru

purification and environmental friendliness of these processes, as well as economic efficiency due to the absence of high costs for equipment and energy.

However, for activated sludge to work effectively, it is necessary to provide certain conditions conducive to its vital activity, reproduction and functioning. These conditions include a number of factors such as temperature, oxygen content, pH level and others.

The prerequisites for creating an automated activated sludge quality control system are:

- Low automation of the process of quality control of activated sludge at wastewater treatment plants.
- The process of quality control of activated sludge is subjective and lengthy.
- The emergence of technologies that simplify and automate this process.
- The importance of timely response to changes in the quality of activated sludge.

Thus, in this article we will consider the importance of activated sludge quality control and possible approaches to its automation using modern technologies, such as computer vision, we will analyze existing research and control methods, and also present possible ways to optimize wastewater treatment processes to reduce the negative impact on water bodies and ensuring sustainable development of enterprises.

2 Materials and methods

The purpose of this study is to develop an automated system for monitoring the state of activated sludge during wastewater treatment.

To achieve this goal, it is necessary to solve such problems as creating a database of images necessary for training a computer vision model; training a model on prepared data, developing several models using different methodologies for identifying objects and training them on prepared images; creating an architecture to ensure transport of acquired images to a model that will ensure efficient transfer of images from the data source to the trained model for analysis [4].

The primary objective of the research was to create a database of images necessary to train a computer vision model. This step involves collecting and preparing images of activated sludge microorganisms with different characteristics, positions and states.

To operate an automated activated sludge quality monitoring system, it is proposed to use a computer vision model using the image segmentation method using the TensorFlow and Keras libraries. The use of the model will make it possible to recognize indicator microorganisms in the studied activated sludge sample, as well as classify them. To train a computer vision model in order to automate the process of quality control of activated sludge by identifying protozoan microorganisms, a database of images of protozoa microorganisms, namely rotifers and attached ciliates, was created. Figures 1, 2 show some of the images used.

To train the model, 50 images were obtained for each microorganism under study. Images of rotifers and attached ciliates were provided by the microbiology laboratory located in the wastewater treatment plant at one of the Russian pulp and paper enterprises.

Fig. 1. Image of a rotifer.

Fig. 2. Image of attached ciliates.

3 Results

Activated sludge contains hundreds of different types of microorganisms and protozoa, which are indicators of the quality of activated sludge and demonstrate that the processes of biochemical decomposition of pollutants in wastewater at the biological stage of treatment are completed completely and provide the expected high efficiency of wastewater treatment.

Currently, quality control of activated sludge at wastewater treatment plants is carried out manually. To do this, laboratory technicians take samples from certain sampling points,

after which they apply the sample to a glass slide and examine the activated sludge using a microscope. Laboratory technicians record the amount of each microorganism in the sample and transfer the data into a table, from which they construct a pie chart and assess the quality of the activated sludge, on the basis of which the engineer decides whether it is necessary to change the process parameters.

When working with an automated activated sludge quality control system, the laboratory technician, after collecting a sample, applies it to a glass slide and installs it in an automated microscope (AM), shown in Figure 3, which is equipped with an automated movement and focusing device, as well as a motorized stage and a control unit [5].

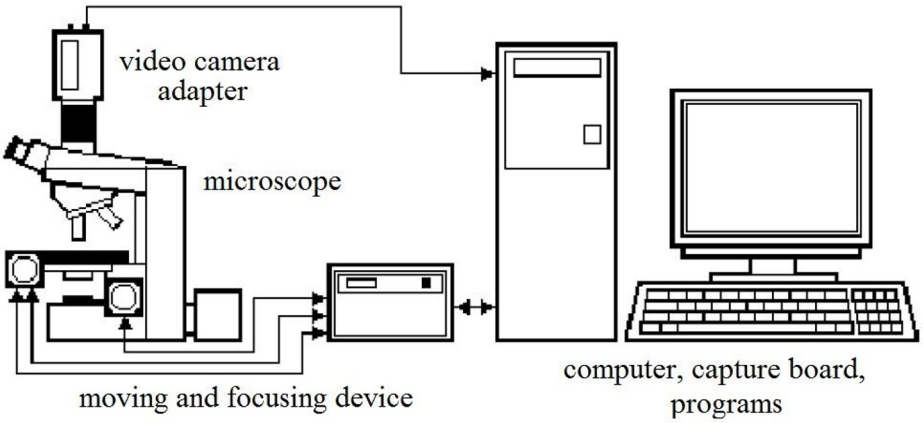

Fig. 3. Automated microscope device.

The main purpose of using an automated microscope is to automate simple routine, repetitive microscopy operations. This type of microscope software provides tools for a worker to create automated microscopy programs that can control various aspects of microscopy, such as the type of stage movement, focusing, filter changes and lighting, and outputting frames according to a predetermined trajectory and timing diagram [6]. Next, the microscope passes the sample along a given trajectory and takes many photographs, which are sent to the computer, where a model previously trained on a large number of images of activated sludge identifies microorganisms in a given sample and, as a result, provides an assessment of the quality of activated sludge based on quantitative data obtained from the images of the sample.

The computer vision model was trained using the Python programming language in the Google Collab development environment using the Keras and TensorFlow libraries. The model was taken as a basis from an open source [7]. During the work, the original model was modified many times to better suit the goals of this work. At the beginning, it was necessary to download the image database for training the model into a folder and specify the path to it. After this, the model creates masks of the original images, as shown in Figure 4, with which it will then compare the input image and determine whether the microorganism depicted on it fits a particular class.

Fig. 4. Image of a rotifer and its mask created by the model.

The result of identifying a particular microorganism is the loss function graph shown in Figure 5.

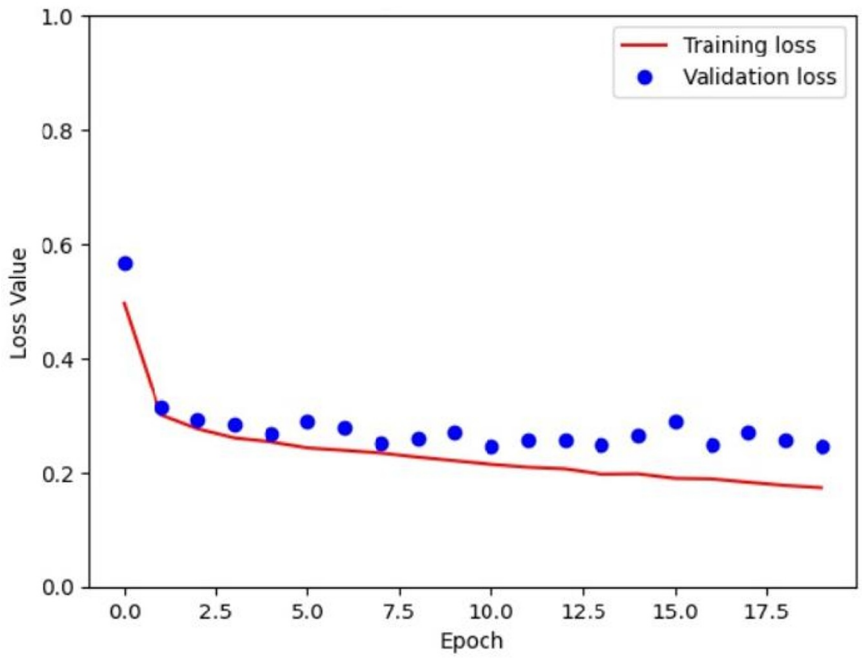

Fig. 5. Loss function graph.

The loss plot is the prediction error that was determined by the model in the neural network. The loss function is used when evaluating a machine learning model to make observations on a data set. The graph shows the dependence of errors on the number of model training epochs completed. This shows that the model works correctly and its accuracy increases with each new training cycle [8].

When a new image is fed to a trained computer vision model, the microorganism represented in it is correctly identified. The result is that the rotifer in the image is identified by the computer as a rotifer, as shown in Figure 6.

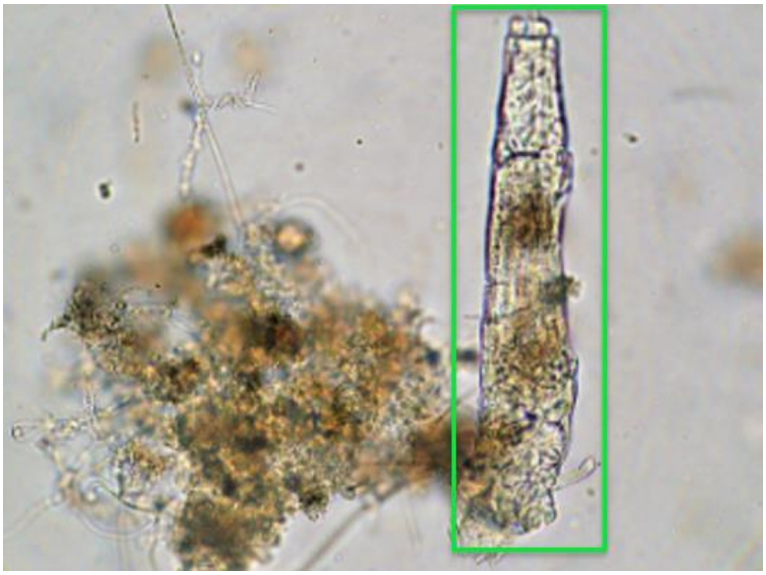

Fig. 6. Identifying a rotifer in an image.

Based on statistical processing of research results, the accuracy of identifying the rotifer in the presented image was 0.82. The obtained result is acceptable and shows that the proposed model is capable of identifying microorganisms based on learning from a given image data [9].

4 Discussion

The results obtained showed satisfactory accuracy and efficiency of the system based on the use of computer vision models. In our case, the model was trained on fifty images of each type, which is not enough to ensure correct and high-quality operation of the model. To achieve the best results, you need to significantly increase the amount of data used for training. A larger number of images of microorganisms will improve the classification accuracy and efficiency of the system [10]. In future work, it is planned to expand the list of studied protozoa and microorganisms in order to cover the widest range of factors affecting the quality of activated sludge. This will make it possible to more fully take into account the diversity of species and conditions of microorganisms, which helps to improve the accuracy and reliability of the activated sludge quality control system.

This work is the basis for the further development of automated activated sludge quality control systems. In particular, the possibility of using more complex machine learning models, integration with other control and monitoring systems, as well as adapting the method to new technological and environmental requirements. Further research in this direction may contribute to the development of more effective and sustainable methods for controlling wastewater quality.

5 Conclusion

The introduction of automated activated sludge quality control systems at water treatment plants is a promising direction in modern laboratory practice, which has significant scientific and applied potential. This approach has the benefits of automating laboratory

processes, speeding up quality control, and the ability to create fully automated wastewater treatment systems.

The first benefit of automation is the replacement of manual analysis of activated sludge samples with automated methods, which will reduce the time and resources required for data analysis and processing. This will also reduce the likelihood of subjective errors and increase the accuracy of the results. The second advantage is to speed up the process of quality control of activated sludge. Automated control systems make it possible to analyze samples much faster, which reduces response time to changes in wastewater quality and increases the efficiency of decision-making.

An important aspect of the implementation of automated quality control systems is the possibility of creating fully automated systems for treating contaminated wastewater in the future. This opens up new opportunities to optimize treatment processes, reduce environmental impacts and improve resource efficiency. Automation of treatment processes, including monitoring the quality of activated sludge, makes the treatment process more environmentally and economically sustainable. Thus, the introduction of automated activated sludge quality control systems is an important direction in modern microbiology and environmental engineering, which can significantly increase the efficiency of contaminated wastewater treatment processes and reduce the negative impact on water resources.

References

1. L. Komarova, M. Poletaeva, Water Use in Enterprises and Wastewater Treatment in Various Industries, Altai State Technical University Publishing House, 174 (2010)
2. Hubbe M., Hermosilla D. Wastewater Treatment and Reclamation: A Review of Pulp and Paper Industry Practices and Opportunities. Bioresources, **11**, 200–211 (2016)
3. Z. Chao, C. Jining, Alternative policy assessment for water pollution control in China's pulp and paper industry. Resources, Conservation and Recycling, **66**, 15–26 (2012)
4. I. Mayorov, D. Chukhin, O. Sokolov, Method for Controlling the Composition of Activated Sludge at Pulp and Paper Enterprises. Forest Journal, **4**, 140–142 (2005)
5. B. Swolin, P. Simonsson, Differential counting of blood leukocytes using automated microscopy and a decision support system based on artificial neural networks – evaluation of DiffMaster Octavia, Clin Lab Haematol, **25**, **3**, 139–147 (2003)
6. H. Asgharnejad, M. Sarrafzadeh, Development of Digital Image Processing as an Innovative Method for Activated Sludge Biomass Quantification, Frontiers in Microbiology, **11** (2020)
7. M. Maynard-Reid, U-Net Image Segmentation in Keras, PyImageSearch (2022)
8. M. Sonka, R. Halvac, Image Processing, Analysis, and Machine Vision, Cengage Learning, 727 (2014)
9. R. Szeliski, Computer Vision: Algorithms and Applications, Springer Science & Business Media, 812 (2010)
10. R. Gonzalez, R. Woods, Digital Image Processing Using MATLAB, Gatesmark Publishing, 827 (2009)