Intelligent water treatment management system for swimming pools

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Abstract. The article presents the assessment methodology for anthropogenic water pollution in swimming pools, based on intelligent video monitoring of people physical activity, as well as a model for correlation data analysis and a regression model for the main parameters of chemical water contamination and doses of introduced reagents. The ultimate goal of the project is to create an intelligent water treatment management system for swimming pools. It is planned to use YOLOv4 neural networks to implement an intelligent pattern recognition module (swimmers in the pool) in the data stream coming from video cameras in real time. This innovative system will make it possible to automatically make managerial and technical decisions to determine the required amount of introduced reagents at various time intervals depending on the actual amount of organic contaminants, as well as other factors determined by the results of the correlation-regression analysis of the data. A review of information resources has shown that such a methodology does not exist both in Russia and abroad.

1. Introduction

Maintenance of modern water treatment systems is bound with the frequency of water parameters measurements and, as a rule, do not take into account the actual level of water contamination due to the high cost of regularly conducted chemical-analytical and microbiological studies. At the same time, as expert studies show, irrespective the actual contamination level leads to an over expenditure of operating costs for water purification using introduced reagents by 10-50%, which on average ranges from 70,000 to 200,000 thousand rubles per year for one facility. The main goal of the project is to reduce the cost of maintaining the water treatment system by predicting the environmental load on the water treatment system depending on the visitors’ water activity applying machine learning technologies.

Being public facilities, swimming pools require strict adherence to sanitary, hygienic and technological requirements. Violation of the pool operation technology can lead to conjunctivitis, epidermophytosis, allergic and other diseases (in particular, as a result of high chlorine, ozone and other reagents concentrations in the water) [1]. The problem of ensuring a disinfection level in swimming pools, providing them with harmless water, creating favorable conditions for the users’ health is becoming more urgent [2]. Studies carried out abroad have shown that each visitor brings up to 30 thousand microorganisms into the pool while staying in it for 30 minutes. It has been found that a swimmer who has not done sanitary treatment brings 5 times more bacteria and 3 times more Escherichia coli into the pool. At the same time, young children pollute water much more intensively
than adults [3]. Such facts must be considered when designing pools: capacity, users’ age, water exchange mode, the need for additional clean water amount.

Research by Maarten G.A. Keuten (Netherlands) [4] in 2018 showed that sweat is one of the main sources of persistent anthropogenic pollution from swimming pools. With average physical activity (classes in the recreation pool, the level of oxygen consumption VO₂ ≤70%), sweat production was 0.1-0.15 l / m² per hour (at a temperature of 28°C), with intense physical exertion (during training and competitions, the level of oxygen consumption VO₂> 70%) sweat production increased to 0.8 l / m² per hour (at a temperature of 28°C). It has also been shown that the environmental load on the pool is highly dependent on the swimmer's body area and the intensity of physical activity. Based on these studies, we put forward a hypothesis about the possibility of predicting the time of water treatment system servicing, depending on the number of visitors, their body parameters and swimming activity. To do this, we proposed to estimate the number of people, their physique and activity by analyzing the video stream of CCTVs.

To solve the set tasks, the initial information include water pollutants concentration in the swimming pool, data on the chlorine-containing reagents doses introduced, ozone consumption, and video from surveillance cameras.

The solution to the problem must be divided into 3 main stages:

- building a model to determine the doses of the introduced reagents depending on the amount of anthropogenic pollution from the pool visitors and other factors,
- development of an intelligent information system for the water treatment management in swimming pools, with video monitoring of people physical activity in the pool,
- approbation of the developed assessment methodology for anthropogenic water contamination, taking into account video monitoring of the users’ physical activity in the pool.

2. Materials and methods

Patent information research showed that most of the studies on the assessment of pool water contamination is associated with the assessment of bacteriological one [1,2,3,5-8,10,11]. It is noted that when bathing, a variety of pathogenic microorganisms enter the water, while only a few of them are recorded in the quality control process, which determines high requirements for the quality of water treatment and the need for careful disinfecting reagents dosing [9]. Information on the assessment of the chemical pollution of swimming pool water was found only in the works of the Dutch scientist Maarten G.A. Keuten [4]. Research led by Maarten G.A. Keuten in 2018 reviled that taking a shower prior to swimming reduces anthropogenic pollution of the pool water, and therefore the required consumption of disinfecting reagents. At the same time, the amount of contaminants washed off from a person during a 60 seconds shower was measured, which is the so-called one-time discharge of pollutants. The work also assessed the continuous discharge of pollutants into the water of the pool during swimming, as well as its dependence on the water temperature, the swimmers’ physical activity. It has been found that in addition to sweat the pool water is contaminated with fragments of skin, hair, sebum and microorganisms, as well as by-products of disinfection (products of the interaction of chlorine-containing reagents with anthropogenic pollutants), which can have a carcinogenic effect. When one person bathes for 30 minutes, 250 mg of organic matter (in terms of “total organic carbon”), 77.3 mg of total nitrogen, 37.1 mg of urea, and 10.1 mg of ammonium are released into the water. The work [12] contains a model of the system for neutralizing anthropogenic contamination operation in the swimming pool of the Kuban State University. At the same time, as noted in the article, the model proposed by Danish scientists from the University of Aalborg is taken as a basis. Attempts to create a model of water contamination were also undertaken by foreign authors [4, 10, 11]. However, these works do not include the development of an assessment methodology for water contamination in swimming pools based on video monitoring of the swimmers’ physical activity. This is the first attempt this task is being solved.

Monitoring the people physical activity in the pool in this project includes determination of: persons, physique, movement trajectories, speed and other related parameters. A large number of
solutions offered on the market are equipped with face recognition modules. Physique modules are found only in specialized non-public facilities aimed at the police and other structures. At the moment, there are a sufficient number of ready-made solutions related to the recognition of objects and their trajectories based on video sequences, however, most of them lack a module for recognizing objects on the water surface. The solution to the problem of tracking speed and direction is based on the use of object trajectory recognition, therefore, most of the previously mentioned software products have a corresponding module, but not for recognizing objects on the water surface.

Among the Russian solutions, there are no software products that fully satisfy this project. There are separate solutions that allow to detect people in the pool, but they are related to safety and cannot determine the physique and / or other parameters. There are no software products that allow optimizing the consumption of cleaning reagents by video monitoring of the pool bowl. Among the world's solutions, there are a number of software products that help to detect the trajectory, speed and direction of movement, but these solutions also do not set themselves the task of determining the physique. Basically, these software products are designed to help lifeguards in the pool. This project includes: tracking pool visitors in order to assess the level of contamination. As for saving the costs of reagents and electricity, there are optimization reserves, since reagents are used with a margin and this situation is typical for every pool in the country. The lack of software products for mass use makes this part of the project very promising in the near future. A number of Russian manufacturers of applied solutions have similar capabilities from the point of view of this project. One can single out Macroscop (https://macroscop.com/resheniya), Ivideon (https://ru.ivideon.com), Center 2M, etc. Ivideon can be considered as a typical representative of services. The solution is implemented as a cloud service, has many ready-made modules for business, including a fitness center. There is no turnkey solution for swimming pools. All the manufacturers considered do not have pool solutions. There is a Xeoma solution with a pool video surveillance module (https://felenasoft.com/xeoma/ru/articles/swimmingpool_videosurveillance/), designed to assist pool staff in observing visitors and ensuring safety. In addition to surface cameras, it includes underwater cameras, has additional modules for face detection, attendance control, but does not take into account the trajectory of movement and is not intended for assessing the pool contamination by visitors. Among the global solutions, there are a number of manufacturers with pool products (SwimEye, Poseidon, AngelEye, etc.). They have modules for detecting the movement trajectory, but like Xeoma they are aimed at ensuring safety. The above analysis of the existing solutions has shown that such scientific research has not previously been carried out. There are no solutions for assessing pool contamination by visitors.

Methods used to solve the assigned tasks:

- experimental research on the basis of existing pools with different water treatment technologies;
- laboratory research in an accredited chemical laboratory;
- ranking of factors influencing anthropogenic pollution of water in pools, applying the methods of system analysis;
- correlation analysis of data and regression model for the main parameters of chemical pollution of swimming pool water and doses of reagents introduced;
- artificial neural network of deep learning for assessing the swimming pool water quality, with reference to the number of visitors and their physical activity in the water;
- creation of an algorithm to determine the physical activity of a person in the pool (determining the parameters of physique, surface area, human energy consumption) by the video data stream.

To speed up the video analysis from several surveillance cameras, the progressive hardware-software architecture of parallel computing CUDA will be used, which allows to significantly increase the computing performance due to the use of graphics processors from Nvidia. When using wide-angle lenses, pre-processing of images is also assumed to eliminate distortion. The main element for finding
people in the image will be the head (one of the solutions working in real time https://bitbucket.org/13e_sha/fasterhog). To bind the data received from cameras to metric coordinates, it is necessary to determine the position and direction of the camera, which is supposed to be performed in a semi-automatic mode based on straight lines in the image and the given sizes of some objects. To identify objects, analyze data, algorithms will be implemented using from 1 to 4 video cameras. The main problems are their overlap (requires removal or averaging when combining data) and blind spots (interpolation required). Analysis of routes with a reference to time allows estimating the speed of movement, and the human energy consumption. Determining the type of activity is more difficult, since it requires determining the position of individual joints of a human body and the speed of their movement. At the moment the main solutions are a model from a set of deformable parts and a regression model of a person's position.

To identify objects, video processing technologies, machine learning technologies, including the architecture of the neural network have been developed, the network has been trained, and the work has been carried out to improve the reliability of object detection. The detection algorithm will be trained on large datasets with tagged images. The authors of the article have experience in deep machine learning in related areas - identification and detecting objects in the photo image of the metering instrument panel [13, 14]. For data analysis Python tools (NumPy, Pandas, Scipy) will be used; the creation of mobile and desktop applications using the programming languages C++, C#, Python. Convolutional neural networks CNN [15, 16] using open libraries for machine learning TensorFlow 2.0 [17], Keras [18], library of computer vision algorithms, image processing OpenCV [19] will be used to implement the intelligent pattern recognition (swimmers in the pool). It is also planned to use YOLOv4 neural networks [20] to detect data coming from video cameras in real time, which will allow the detection and classification of objects with optimal speed and accuracy compared to other object detectors EfficientDet, ATSS, ASFF (figure 1).

To develop models and implement algorithms to determine the required parameters, methods of system analysis, mathematical and computer modeling will be used.

![Figure 1. Comparison of the proposed YOLOv4 and other state-of-the-art object detectors for the MS COCO dataset [20].](image)

A functional model developed applying the IDEF0 methodology [21], which determines the main functions of the system, is at the heart of the developed intelligent management system for water treatment in pools:

- information input and storage, generation of reports;
- detection of pool visitors in real time;
- statistics of visits in dynamics allowing forecasting visits;
• video monitoring of the people physical activity in the pool (tracking the dynamics of speed and movement trajectory, determining the time spent in the pool, remote loads, energy costs);
• determining the level of the actual sweating;
• determining the required amount of added reagents depending on the actual amount of organic contamination and some other factors;
• developing recommendations for the water treatment system operation, which allows saving costs on reagents and electricity;
• forecasting changes in the indicators of water quality in pools.

When developing the software interface, the ISO 9241-210 standard [22] will be used, as well as the existing experience of the authors in the development of intelligent monitoring and dispatching systems [23-24]. Thus, the prototype of the interface will be built based on the needs and capabilities of the pool service technician, using ergonomic design principles.

The diagram of the developed intelligent information system for managing water treatment in swimming pools is shown in Figure 2.

3. Discussions
The lack of analogues of an intelligent information system for the water treatment in swimming pools management in Russia and abroad makes the solution of this problem promising and relevant.

![Diagram of the intelligent information system for managing water treatment in swimming pools](image)

**Figure 2.** Information processing in the intelligent water treatment management system for swimming pools

Proof of the latter is the fact that the project is aimed at solving specific problems within the framework of one of the directions defined in the Strategy for the Scientific and Technological Development of the Russian Federation, which will allow obtaining scientific and technical results and creating technologies that are the basis for the innovative development of the internal market for products and services, Russia's stable position in the foreign market, and will provide: "Transition to
advanced digital, intelligent production technologies, robotic systems, new materials and design methods, creation of systems for processing large amounts of data, machine learning and artificial intelligence." In this project, it is planned to develop a methodology for assessing anthropogenic contamination of water in pools based on correlation-regression analysis, which requires the adaptation of machine learning and video analytics methods to identify people and their parameters. The solution of the project problem will allow predicting changes in the water quality indicators of swimming pools and timely warn about the need to adjust the doses of introduced reagents, without resorting to frequent use of expensive multicomponent analytical equipment, which will ultimately help to save operating costs for swimming pools and reduce the likelihood of people becoming infected with waterborne diseases.

4. Conclusions
The developed model of an intelligent water treatment management system for swimming pools simultaneously solves several problems: it reduces energy consumption and operating costs for the swimming pools maintenance (70,000-200,000 rubles per year), and also optimizes the consumption of reagents, protecting visitors from the negative consequences of a possible overdose with chlorine reagent.

This model is applicable for pools with different water treatment technologies: chlorination, bromination, ozonation, ultraviolet disinfection.

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