Device for Research of Water Flow Dynamics in Situ Based on the PIV Method

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Abstract. The article discusses a developed device designed to study the dynamics of water flow, based on the use of the PIV method. The device block diagram is shown, the principle of its operation is given. The experiments performing technique using the developed device is described. The results of field tests are considered. The created meter makes it possible to carry out full-scale measurements of the current velocity and to obtain data on the dynamics of the water flow with velocity amplitudes up to 2 m/s.

1. Introduction

At present, in the context of an increasing anthropogenic load on coastal areas, more and more attention to the ecological monitoring of the aquatic environment is paid. For this purpose, various devices and instrumental systems are being developed for comprehensive observation of its condition. One of the main devices is flow rate meters. There are various methods and instruments intended for these tasks. For example, there are ADCP acoustic doppler profilers designed to study the spatial structure of the flow [1, 2], devices based on ultrasonic measurements [3, 4], as well as electromagnetic induction [5], etc. When studying rivers, hydrometric propellers [6] or express methods are most commonly used, which are based on the determination of the parameters of the movement of various surface floats [7]. A detailed review of the existing instruments and methods used to study flows is given in the studies [8, 9].

For a deeper understanding of what is happening in the coastal zone, it is necessary to obtain the detailed information about the dynamics of the water flow. The existing technical means do not allow to obtain such data in full. In accordance with this, the development and creation of new methods and instruments for solving these problems is relevant. For this purpose, the optical methods based on the use of photo and video recording [10, 11] are the most suitable. Among them, the PIV method [12, 13, 14] is mainly used to study flows. This method is used in the automobile and aircraft manufacturing industries while solving various scientific problems. For example, when modelling the processes of gas flows on the solids surface [15], as well as in hydro- and aerodynamic experiments [16, 17, 18]. Due to technical difficulties, in most cases, the PIV method is used mainly in the laboratory. However, the possibility of its use to obtain vector fields of the current velocity distribution for the study of small-scale processes occurring in the coastal sea zone is a very promising direction.

The purpose of this work is to show the capabilities of the developed device for studying the water flow dynamics based on the PIV method.
2. Hardware and software development

In accordance with the tasks set, a device was developed. It consists of a backlight device, a digital video camera, mounting / positioning elements and data processing software. Its diagram is shown in Figure 1.

![Diagram of the measuring complex](image)

**Figure 1.** The measuring complex diagram design.

As a backlight, a sealed light source - 1 was used, assembled on 5730 LED diodes (with a total power of 20 W), providing sufficient illumination of the investigated area. A digital camera YI4K + [19] was used for registration, placed in a special box, ensuring airtightness - 2. Its main advantages are the compact size, high resolution and the required shooting speed of 240 fps. A specialized lens was used for focusing, its characteristics can be found in the documentation [20]. It has high resolution and allows to adjust the focusing distance and depth of field as required.

To position the device in the flow direction, a special plate - 3 was made, which also served as a screen for obtaining more contrasting particles images.

The measurement technique using the device consisted of sequential execution of a number of stages:

1. System setup. It included focusing in a given area (the size of the registered area is 150x100 mm), setting the camera shooting parameters: resolution and frame rate, the backlight activation for continuous operation with maximum power.

2. Calibration. A calibration frame was taken for the subsequent determination of the correction factor.

3. Measurements. The device was lowered into the water using a telescopic rod. Further, three horizons were assigned at each station: the surface, the middle of the station depth, and the bottom area. At each horizon, a survey was performed with an exposure of 200 s to obtain averaged data. Owing to the use of a special plate (Fig. 2), which acts as a weather vane and is located at the base of the swivel rod, the installation was turned in the direction of the flow, making it possible to record video images in its longitudinal section.

4. Software processing. The obtained video data were processed using the adapted software based on Matlab [21, 22].

In the standard PIV method, for registration, special particles, tracers, are used, which are artificially introduced into the area; however, the use of this technology in situ is rather a labour-intensive procedure, since it requires additional time to prepare each measurement. In addition,
consumable items are added. In the developed device, instead of tracers, natural suspended particles that are already present in the flow were recorded, which made it possible to significantly simplify the technology of the experiment and reduce the cost of its implementation.

3. Verification of the results
Based on the results of field experiments carried out during expeditionary studies on the Black river of Sebastopol in 2020, the data on the dynamics of the river water flow were obtained. Figure 2 shows an aquatic environment image fragment obtained using the created device. The registration was carried out in the bottom area. To obtain the final data containing the velocity distributions, the video files were processed using the adapted software.

![Figure 2](image_url)

**Figure 2.** An example of a frame of the received video image.

The software operation algorithm consisted of sequential execution of a number of subroutines. Initially, preprocessing was carried out, which consisted of gamma correction, the contrast adjusting, image brightness and binarization performing. Next, the original video file was divided into consecutive frames with a certain time interval between them, that resulted in the creation of an imagery in *jpg* format. The final stage was cross-correlation processing.

The software results in instantaneous flow velocity fields for each horizon. As an example, Figure 3 shows an image with a constructed instantaneous current velocity field, in which the structure of the current in the bottom area is clearly visible.

Statistical averaging of the obtained fields makes it possible to obtain the distribution of the average velocity for each set horizon and to construct histograms of the distribution of the average flow velocity of the water flow, an example of which is shown in Figure 4.

The data obtained was verified using standard measuring instruments, namely a hydrometric turntable.
The obtained average values of the current velocity by both devices are in good agreement, the discrepancies do not exceed 10%. This confirms the reliability and sufficiently high accuracy of measurements using the created complex.
The obtained average values of the current velocity by both devices match, a discrepancy are less than 10%. It confirms the reliability and sufficiently high measurements accuracy using the created complex.

4. Conclusions
Thus, the developed device makes it possible to obtain instantaneous and averaged distribution fields of the current velocity in a wide spatial and temporal range, due to which it can be used to study complex turbulent flows, processes of bottom sediment transport, which in turn allows to obtain a more detailed picture of the natural processes and their features.

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