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Article

The first attempt of a PIV system: a case study

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Abstract

Digital tracer imaging (Particle Image Velocimetry), which belongs to the class of non-contact optical methods, makes it possible to register instantaneous velocity fields in the measurement plane. One of its most important advantages is the absence of a disturbing influence on the flow. PIV systems can be used to observe the internal distribution of velocities in a liquid or gas flow, in particular when conducting experiments on wave propagation. This article discusses the The first attempt of a PIV system and development of the PIV system based on the LMNAD laboratory — Laboratory of Modeling of Natural and Anthropogenic Disasters (Nizhny Novgorod State Technical University na RE Alekseev, Nizhny Novgorod), the construction of the system in relation to the hydrodynamic wave tank, observation of wave effects, simulation and the development of methods of collection and visualization of experimental data.

Key words: PIV, wave tank, computer vision, remote sensing, visualization

1. What is the PIV system

PIV is an abbreviation for Particle Image Velocimetry (particle image anemometry) — a method of visualizing two-dimensional vector fields of the velocities of liquid or gas flows by digital processing of images of particles introduced into the flow. This method is applicable as a non-contact method for measuring the speed of particles in a liquid or gases, assessing the transfer of particles by the flow. The hydrodynamic wave tank described in (Rodin and others, 2018) is equipped with a PIV system, which includes an upgraded system for video recording and visualization of laboratory experiments (Kurkin and others, 2019), as well as a laser installation for illuminating the liquid and visualizing vector fields (Fig. 1).

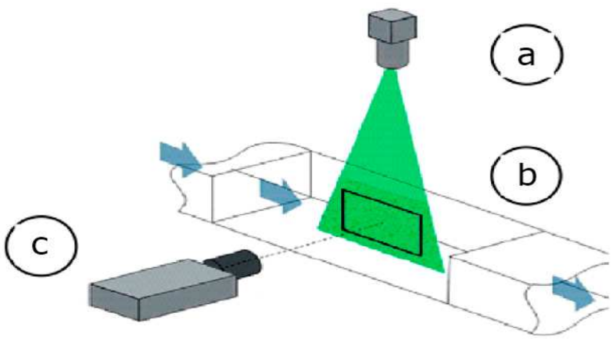

Fig. 1 PIV setup. Emitter with lens group (a), hydrodynamic pool and section with "laser knife" illumination (b), photo-video capture camera (c).

The use of the method makes it possible to register instantaneous velocity fields in the measurement plane and to observe an instantaneous flow pattern within the plane of the laser knife. The advantages of the described method include:

- no disturbing influence on the flow
- wide dynamic range of measured velocities (about 500: 1), which makes it possible to use it for studying intra-wave activity (solitons)
- the ability to register instant spatial velocity distributions
- the ability to obtain information about the dynamics of structures, their scales, calculation of differential characteristics, spatial and space-time correlations, as well as statistical characteristics of the flow.

All the described capabilities of the method impose serious restrictions on the choice of equipment for implementing the system in laboratory conditions. The use of optical sensors (cameras), the choice of a laser "knife" and their mutual synchronization is a complex engineering problem.

Methods for registering and recognizing particles in a video stream and estimating the velocities of particles in a vector field are one of the subtasks that can be solved using computer vision tools. This paper highlights approaches to solving the problems of constructing a laboratory PIV system. The following paragraphs of the article describe an approach to the first experience of building such a system based on the LMNAD laboratory.

2. Equipment description: PIV system in detail

2.1 Hydrodynamic wave tank

A hydrodynamic wave tank is installed on the basis of the LMNAD laboratory — Laboratory of Modeling of Natural and Anthropogenic Disasters (Nizhny Novgorod State Technical University na RE Alekseev, Nizhny Novgorod), which allows carrying out various experiments on the generation and propagation of both surface and internal waves. Hydrodynamic wave tank of N.N. R.E. Alekseeva has the following characteristics: length — 6.5 meters; width — 0.5 meters; height — 1 meter (figure / inset). The PIV system will not allow observing the entire pool at once, the possible coverage area of one system is about 90x90 cm. To cover a larger area, it is possible to install several laser-camera pairs, followed by stitching of a panoramic image and subsequent analysis of the combined image. This approach has a drawback, since it is not possible to ideally match the fields of view of the cameras, the final presentation of the panoramic image will be segmented, which increases the possibility of losing some of the important visual data.

A similar method was used in (Kurkin and others, 2019) to expand the area captured by cameras. The creation of the PIV system at the LMNAD laboratory (Nizhny Novgorod State Technical University na RE Alekseev, Nizhny Novgorod) will allow obtaining more information about the course of experiments by collecting data on the distribution of velocities within the fluid flow during experiments with internal waves as a non-contact method for measuring the flow rate and the rate of particle transfer by the flow both on its surface and in the depth of the liquid. To develop this system, the laboratory was modernized - special dimmers were installed on each light source, the video capture system was installed on a special guide and in order not to create glare during shooting, a special spandex curtain was used. These are minor but necessary measures to ensure the best possible image quality and to minimize the glare when reflected from the acrylic walls of the wave reservoir itself (Fig. 2).

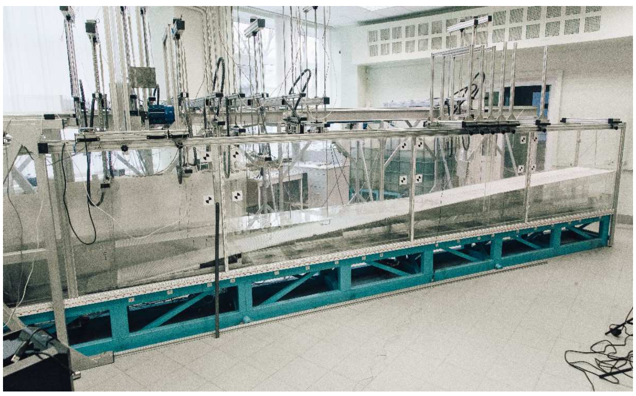

Fig. 2. Hydrodynamic wave tank

2.2 Hardware main parts

The PIV system in its simplest version consists of a laser emitter-camera pair. This version of the system uses high-speed cameras Baumer VCXU-23M (Fig. 3) with a set of wide-angle lenses, a pulsed laser and a system of cylindrical lenses to form a plane of laser radiation also called a "laser knife".

Fig. 3. Camera Baumer VCXU-23M

The main parameters of the cameras used are presented below:

- 1920 x 1200 px
- Sony IMX174
- 1/1.2" CMOS
- 159 fps
- USB 3.0 available

Cameras with such parameters allow fixing vector displacement fields with high accuracy.

The laser for this setup must be synchronized with the moment the camera takes the picture. Pulsed laser emitter with parameters — 532nm 1W 1000mW Green Dot Laser (Fig. 4) with a set of lenses is used to create a linear zone of illumination of the liquid layer in the observed section of the hydrodynamic wave tank(Fig. 1— a). A high-power green light laser is the optimal solution for creating PIV systems, since its task is to penetrate into liquid layers up to 1 meter deep and illuminate particles with maximum brightness.

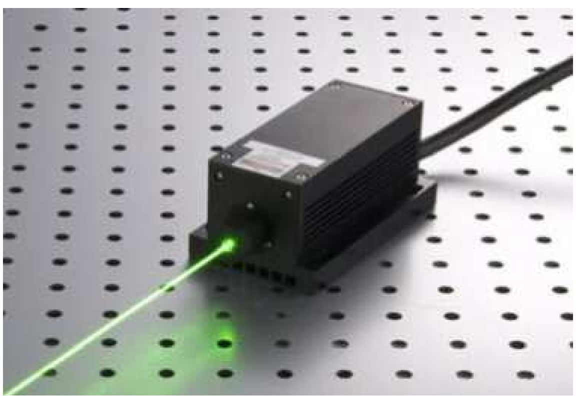

Fig. 4. Green Dot Laser (532 nm, 1000mW)

For the joint operation of the system, software is being developed that allows high-speed recording to an internal or external medium and also synchronizes the laser radiation pulse and the shutter of the camera itself in the area of the experiment.

To synchronize the hardware part of the installation and record video, photo-video data, a modified complex for registration and visualization of laboratory experiments is used (Kurkin and others, 2019). As mentioned earlier, for the post-processing of the obtained visual data of the experiment, a specially developed software package will be used, which is an add-on to the already used software package "visualization and processing of experimental data" (Kurkin and others, 2019). This software package composes of a system for recording video experiments, a synchronizer for controlling the capture of the camera shutter and a laser flash, and post-processing of data. Significant changes have been made to this complex in terms of expanding the GUI (graphical user interface), adding a new module to control the entire installation. The first version of the installation is a patented software package. In the future, after testing the entire complex, it is planned to apply for registration (patenting) of a computer program for controlling and visualizing the data obtained. Now the application is being replenished.

3. Possible applications and future scope

3.1 Particle registration. Digital image correlation method

The technology (method) of digital image correlation is used to register particles and estimate the velocities of vector fields on the final block of video data of the experiments. It is an optical technique used in image identification and tracking techniques for accurate flat and volumetric measurements on an image. The method is often used to estimate such effects as deformation of solids, displacement fields in an optical flow. Digital image correlation and tracking, (DIC / DDIT) has proven itself as a robust method for strain assessment and optical flow rate measurements in experiments using light-emitting or reflective markers in the form of specially applied toner or reflective particles (Sutton and others, 2009).

All conditions are met for the application of this method. The implementation of this method in the software package for registration and visualization of laboratory experiments is supported by the opensource power of the OpenCV library as a powerful tool for image processing using computer vision technologies, based on methods and approaches to image processing, the method for recording the displacement of the secondary fields of incoming particles in the video image is implemented. Since the output data is a video sequence or a set of frames obtained sequentially at a high speed (up to 160 fps), there is a necessary and sufficient amount of input data to accurately estimate the displacement and velocity of particles in a liquid. Among the stages of preparation for the implementation of the method are:

- sample preparation (distribution of markers in the liquid layer)
- setting, aiming and focusing cameras on the sample
- camera calibration
- test execution and image registration
- image correlation
- viewing and automatic data processing

5. Conclusion

This article describes a technique and approach to the first implementation of hardware and software parts of the PIV installation for assessing the displacement rates of particles in a fluid flow both on its surface and inside the fluid layer. The component composition and method of registration, evaluation and visualization of the final data of laboratory experiments carried out on the basis of LMNAD laboratory — Laboratory of Modeling of Natural and Anthropogenic Disasters (Nizhny Novgorod State Technical University na RE Alekseev, Nizhny Novgorod). This system is under development. The software complex for the management of the PIV system and post-processing is under testing. Also, the hardware part is undergoing modernization. Some standard parts were replaced with custom ones, fasteners were modernized using 3D modeling and printing methods. The application of this system will be tested in experiments with two-layer and three-layer fluids being conducted at the laboratory, evaluating the velocity of fluid displacement in experiments on modeling solitons, and fluid displacement in evaluating the internal propagation of a fluid when evaluating wave run-up on various types of coastal geometry. The PIV system will also be useful as the main system for registering the particle velocity, but it is planned to use it in combination with the existing equipment. Set of bottom pressure sensors, liquid columns sensors installed over the entire area of the pool bottom, as well as more than a ten string capacitive and resistive wave height sensors allows you to improve the quality of experiments (Fig. 2). The use of PIV technology for the Laboratory of Modeling of Natural and Anthropogenic Disasters (Nizhny Novgorod State Technical University na RE Alekseev, Nizhny Novgorod) opens up new possibilities in processing digital experimental data and expands the experimental basis itself, which will allow obtaining more detailed and high-quality results.

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References

Rodin A., Kuzin V., Kurkin A., Likhodeev N., Zemlyanikin A. (2018) Features of the dynamics of long waves of different polarity along the flat slope: laboratory experiments and numerical experiments. *Proceedings of the 33rd International Symposium on Okhotsk Sea & Polar Oceans.* 348-351.

Kurkin A.A., Kuzin V. D. Tyugin D.Yu., Kurkina O.E. (2019) The system of video registration and visualization of the results of laboratory experiments. *Proceedings of the 34th International Symposium on Okhotsk Sea & Polar Oceans.* 287-290.

Sutton M.A., Orteu J.-J., Schreier H.W. (2009) Image Correlation for Shape, Motion and Deformation Measurements. *University of South Carolina,* 364.

Jianyong Huang, Xiaochang Pan, Shanshan Li, Xiaoling Peng, Chunyang Xiong, and Jing Fang (2011) A Digital Volume Correlation Technique for 3-D Deformation Measurements of Soft Gels. *International Journal of Applied Mechanics.* 335-354.

Sheng, J.; Malkiel, E.; Katz, J. (2008). Using digital holographic microscopy for simultaneous measurements of 3D near wall velocity and wall shear stress in a turbulent boundary layer. *Experiments in Fluids*. **45** (6): 1023–1035.

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