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FLOW VELOCITY MEASUREMENTS IN THE OPEN CHANNELS

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Abstract. *This study aimed at determining dependencies between incident wave height and flow velocity in open flow channels by utilizing computer vision algorithms. Authors use computer modeling and experimental studies to check possibilities of flow velocity measurement by measuring incident wave height in front of semi-submerged artificial obstacle placed in the open flow channel.*

Keywords: fluid flow, computer vision, artificial obstacle

POMIAR PRĘDKOŚĆ PRZEPŁYWU W OTWARTYCH KANAŁACH

Streszczenie. *Badanie skierowane na wyznaczenie zależności pomiędzy wysokością nadchodzącej fali a prędkością strumienia w otwartych kanałach z użyciem narzędzi widzenia komputerowego. Autorzy korzystają z modelowania komputerowego oraz badań eksperymentalnych do sprawdzenia możliwości wyznaczenia prędkości strumienia poprzez pomiar wysokość fali padającej na częściowo zanurzoną sztuczną przeszkodę znajdującą się na otwartym kanale.*

Slowa kluczowe: przepływ płynu, widzenie komputerowe, sztuczna przeszkoda

Introduction

Measuring the velocity of fluids in the open channels is an important problem in monitoring the state of natural open streams. The 24-hour monitoring of flow velocity in rivers is a key task for the prevention of emergencies and timely public awareness about floods, preventing the erosion of the river bed and collapse of the bridge supports. Available systems are not autonomous and require human participation to conduct measurements near the hydrometric station. This study is aimed at developing a method for measuring the velocity of water in an open stream based on a combined hydrodynamic-optical method.

There are two common methods of measuring the velocity in open channels – contact and non-contact. Among the contact ways, the most widely used methods utilize buoyes, hydrometric turbines and hydrometric tubes. These methods are easy to use but require frequent maintenance and operator presence during measurements and do not provide high accuracy. Typical non-contact methods include thermal, ultrasonic and acoustic methods. Their advantage is high accuracy, however, they require a significant preparations and have high cost [1].

1. Main ideas and methods

Main idea of the developed method is to measure the height of the water level in front of the obstacle, half-immersed in the flow, with the help of modern microprocessor and computer vision systems. Semi-immersed obstacle, creates turbulence zones in the profile of the flow, that result into difference in pressure, water level, change in the direction of flow. With the help of the cameras installed near the obstacle, authors suggest to perform photo and video shooting of the level difference zone (incident wave) in front of an obstacle, and the resulting images are processed by means of computer vision resulting in measuring the altitude of the incident wave with sufficient accuracy.

Most of the available studies in the area of near-obstacle flow are aimed at reducing turbulence around it, but in this study it is important to increase the incident wave height by choosing shape of an obstacle that will create the most disturbance of the flow. Available studies of similar bodies are carried out for vortex flow meters using the Karman effect for measurements, but the obstacles there are completely immersed in the flow [2].

Initially, authors researched the existence of a dependence between the height of the incident wave in front of an obstacle and the flow velocity in the open channel. To choose the optimal form of an obstacle, authors performed computer modeling in Solidworks environment. Main criterias of optimality were the geometric sizes of turbulence zones and the technological availability of selected shape. Authors selected obstacles of different shapes and forms: cylindrical, rectangular, triangular and created 3D models of each of them by means of the 3D-CAD system. To visualize the size of the turbulence zones for different shapes, the model contained four obstacles placed near each other. The simulation was done by the finite element method, and the polygonal mesh of the model consisted of 17460 elements.

A visualization of the flow parameters was performed with emphasis on the size of turbulence zones around the selected obstacle models at a flow velocity of 0.55 m/s (Figure 1). According to the simulation results, cylindrical and rectangular obstacles are streamlined and as a result create small turbulence zones around them. The V-shaped form leads to the formation of a large turbulence zone behind the obstacle, but the size of the turbulence zone in front of an obstacle may not be sufficient to obtain the measurement signal. The A-shaped obstacle fits set criterias of optimality: it is least streamlined and creates the largest turbulences in the flow, with the formation of significant zones of turbulence not only behind but also ahead of obstacles. This will provide a reliable measurement signal and extend the range of measurements, as the turbulence zones will be observed at a lower flow velocities in the open stream.

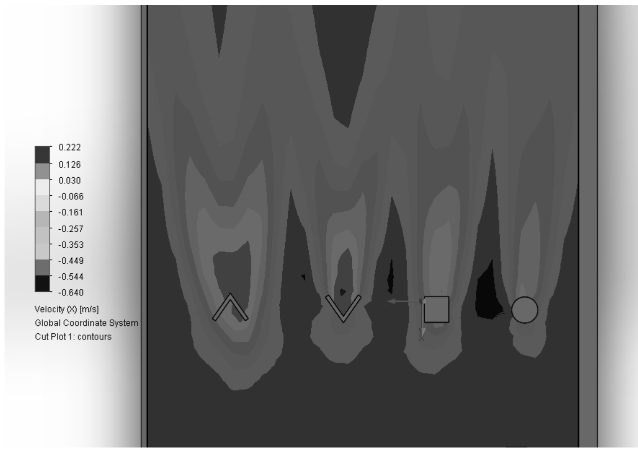


Fig. 1. Modelling of flow around different obstacles in CAD system Solidworks

Based on simulation results, authors performed experimental studies of the flow around obstacles of different shape. Obstacles were placed in the rectangular channel, with a width of 0.965 m (Figure 2), according to the computer model.

During the experiment, authors observed formation of two zones of level difference, in front and behind obstacles, and the formation of zones of turbulence around them (Figure 3).

Measurements were carried out at critical points, in particular at the highest point of the crest of the incident wave and in the zone of the lowest level behind the obstacle. Figure 4 depicts a level difference caused by obstacles of various shapes, where point 1 is the point of reference for water level in an open stream, measured in the zone that was not affected by turbulence; 2 is the point of the highest level ahead of the obstacle, on the crest of the incident wave; 3 is the lowest point behind the obstacle.

The following results were obtained: the largest size of turbulence zones and incident waves were observed for the A-shaped obstacle, which confirms the results of computer simulation.

Fig. 2. Obstacle prototypes placed in rectangular channel

Fig. 3. Photo of turbulence zones around the obstacle: 1 – obstacle, 2 – free surface, 3 – incident wave, 4 – turbulence zone behind the obstacle

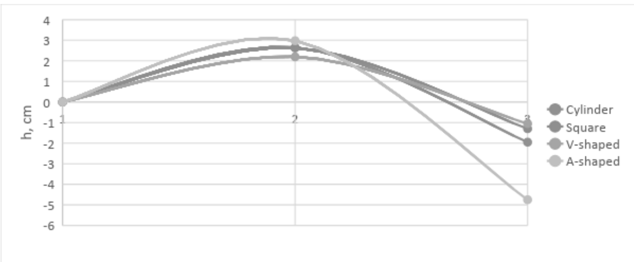


Fig. 4. Experimental results of water level differences for different shapes of obstacles

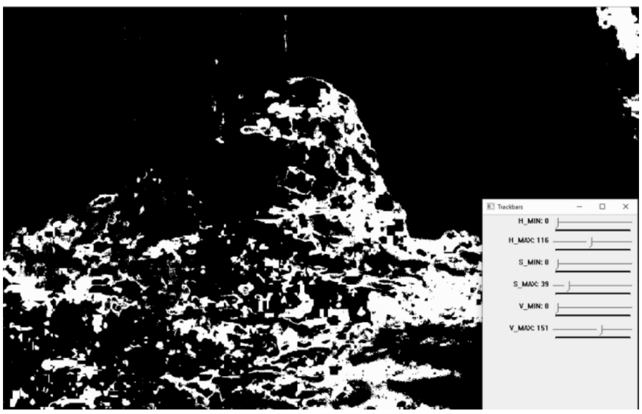


Fig. 5. Processed and filtered image of incident wave

Also, during the experiment, a preliminary test was performed to investigate technical capability of image capturing and processing. To do that, a few photos were taken for further software testing and setup. The resulting image (Figure 5) was processed using a threshold filter to select the contours of the incident wave in relation to the free surface. Based on that, authors confirmed expediency of using the optical method for obtaining the measurement information.

To visualize hydrodynamic processes occurring around the selected obstacle, a re-simulation was conducted in the Solidworks environment. According to the results of modeling, in front of the obstacle there was a separation of the flow into two parts - the ascending, which appears on the surface in the form of an incident wave and descending, resulting in the vortex at the bottom of an obstacle. Investigation of the downstream part of the flow is important for hydraulic engineering and research on bridge support erosion, but since this study is aimed at measuring the flow velocity, the further direction of research is connected with the ascending part of the stream (incident wave). The simulation results are shown in Figure 6.

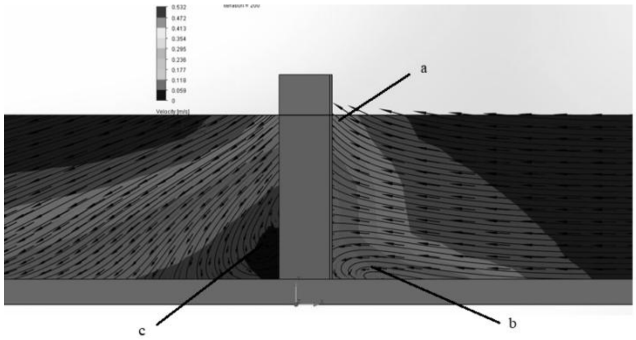


Fig. 6. Modelling of flow around the obstacle SolidWorks: a – incident wave, b – downflow, c – vortex behind the obstacle

To confirm the existence of a dependence between the height of the incident wave in front of the obstacle and flow velocity in the open stream, repeated experimental studies with the selected obstacle were conducted. A pre-selected body of A-shaped form was placed in a channel of rectangular shape with known geometric sizes.

During the research, measurements of the flow velocity and height of the free surface of water were made. The formation of turbulence zones around the obstacle was observed, in particular - two zones of significant difference in water level in front of and behind the obstacle. Measurements were made at the water velocity in the channel from 0.21 m/s to 0.55 m/s, which is a typical value for plain rivers. As the speed increased, an increase in the size of the turbulence zones and the height of the water level changes around the obstacle were observed. Based on the experimental data authors determined dependence of the incident wave height on the speed of water in the open channel for the selected obstacle. The given experimental data are obtained for the selected obstacle, and are approximated by a polynomial: $y = 48.29x^3 - 56.552x^2 + 35.419x - 4.6681$ with determination coefficient $R^2 = 1$ (Figure 7).

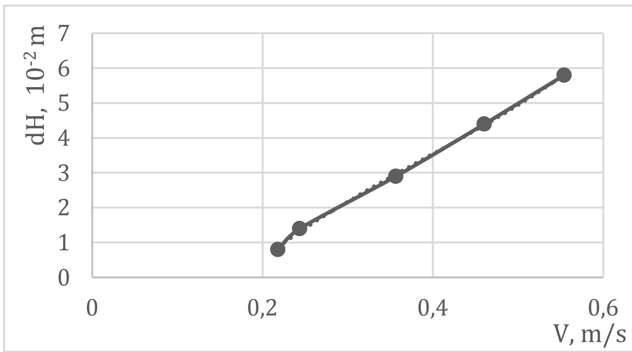


Fig. 7. Experimental dependence between incident wave height and flow velocity

Also, during experimental research, created measurement complex was tested. It consists of the webcam that was installed both in front and next to the obstacle, which allows real-time photo and video shooting of hydrodynamic processes occurring near an artificial obstacle (Figure 8), and the server that processed the received visual information using developed software.

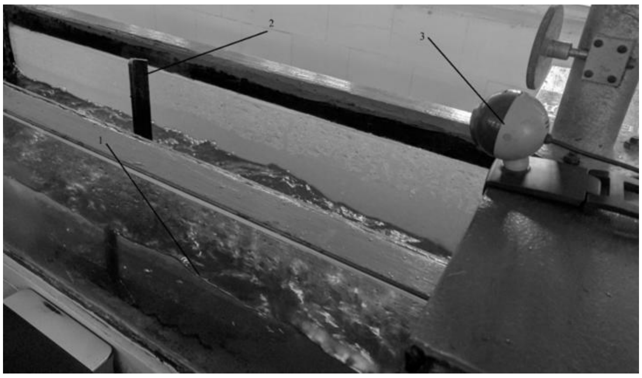
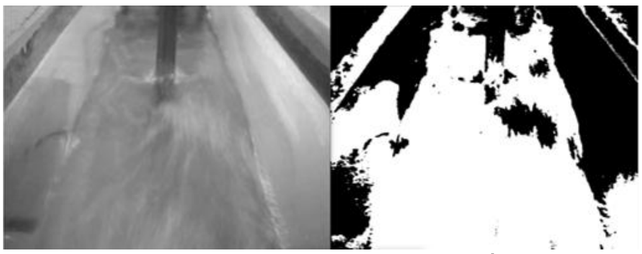


Fig. 8. Image capturing of incident wave: 1 – rectangular channel, 2 – artificial obstacle, 3 – camera

OpenCV library and CodeBlocks environment were used to collect and process image and video data. The developed software uses threshold filters with the ability to manually adjust, which is appropriate for changes in light levels and color of a stream. The image processing was carried out in several steps: first, the necessary part of the image, which contains the incident wave, was cut out. Next, the color model of the image was converted from RGB (red, green, blue) to HSV (hue, saturation, value). The convenience of this method is to simplify getting measurement results, since the converted image contains only two colors, which are converted into binary values. After the image conversion, a threshold filter is applied using the ability to manually adjust the maximum and minimum threshold values for each component of the color model. When conducting the experiment, the manual settings of threshold filter were changed in real time, on a video stream for previously unprepared environment. In order to reduce the visual noise during automatic measurements, there may be a need to install additional light sources or use bright water coloring, but during semi-automatic measurements, the resulting images can be sent to the server for further analysis and processing. Figures 9 and 10 show the original and filtered image at different camera positions.



a b

Fig. 9. Captured images of the incident wave: a) original image, b) filtered image

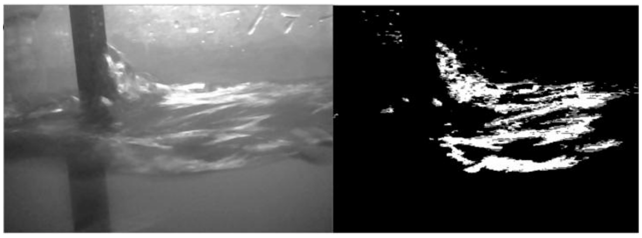


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Fig. 10. Captured images of incident wave by camera placed beside the obstacle: a) original image, b) filtered image

Based on the results of experiments authors created remote monitoring system of flow velocity in open channels. Technical implementation is based on the Raspberry Pi 3B microprocessor platform based on the ARM architecture. Its advantages are: availability of hardware parts, the ability to scale, the convenience of configuring, and use of open-source and free software repositories.

On the platform, the Apache Web server, the SSH server and the FTP server based on the Vsftpd module were configured, and the video capturing capability was implemented with the Motion module. Combination of these protocols and applications allows not only to transmit measurement data remotely but also to remotely reconfigure the device, send control signals to any other elements connected to the server. The system used a client-server architecture, but it was decided to abandon the client part as a separate application, since it allows you to measure or make changes to the system only from individual clients and a limited number of devices. Therefore, a Web-SCADA system was created based on html, php, javascript, which allows access from anywhere in the world and from any device that has a browser.

Technical implementation of the Web-SCADA system is based on the use of Dynamic DNS technology, since the SCADA web-page is stored on a microprocessor platform that is connected to the Internet via a router. Port forwarding was configured when accessed via HTTP port 80, which allows you to access the page not only from the local network but from anywhere in the world.

2. Conclusion

As a result of experimental studies, the dependencies between the hydrodynamic parameters of the turbulence zones around the semi-immersed artificial obstacles in the open stream and the velocity of water and were discovered. Based on the results of the experiment, a combined hydrodynamic-optical measurement method was developed and a technical implementation of the measuring complex in the form of a server and Web-SCADA system was created, allowing remote reliable operational monitoring of the measurement parameters.

Further research is planned to investigate measuring the velocity distribution not only in height but also in the width of the flow profile as well as measuring the profile of the channel, for switching from measuring the velocity to measuring the flow in open stream.

Bibliography

[1] Budz O. P.: Hydrology. NUWEE, Rivne 2008.

[2] Ostapiv V. V., Pindus N. M., Chekhovskyi S. A.: Criteria for vortex flow meter bluff body form optimization. Information Processing Systems 9/(90)/2010, 77–79.

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