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Application of artificial neural network and genetic programming models for estimating the longitudinal velocity field in open channel junctions

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ABSTRACT

Estimating the accurate longitudinal velocity fields in an open channel junction has a great impact on hydraulic structures such as irrigation and drainage channels, river systems and sewer networks. In this study, Genetic Programming (GP) and Multi-Layer Perceptron Artificial Neural Network (MLP-ANN) were modeled and compared to find an analytical formulation that could present a continuous spatial description of velocity in open channel junction by using discrete information of laboratory measurements. Three direction coordinates of each point of the fluid flow and discharge ratio of main to tributary channel were used as inputs to the GP and ANN models. The training and testing of the models were performed according to the published experimental data from the related literature. To find the accurate prediction ability of GP and ANN models in cases with minor training dataset, the models were compared with various percents of allocated data to train dataset. New formulations were obtained from GP and ANN models that can be applied for practical longitudinal velocity field prediction in an open channel junction. The results showed that ANN model by Root Mean Squared Error (RMSE) of 0.068 performs better than GP model by RMSE of 0.162, and that ANN can model the longitudinal velocity field with small population of train dataset with high accuracy.

1. Introduction

Channel junctions have special importance in environmental and hydraulic engineering where two or more rivers or river tributaries are connected. Their flow structure has considerable significance in measurement results, scouring problems, sediment transport, wastewater treatment facilities and river modeling in the regions of confluence. Due to the interaction between the main and branch flows, they have a completely 3D behavior and a number of important flow phenomena involved in this concept. For many years, a considerable number of experimental studies have been carried out to clarify and predict the profile of these complex flows. These studies demonstrate that it is difficult to determine the hydraulic flow pattern in an open channel junction. Taylor [1] was the first to study the open channel junction flow. In an experiment on a rectangular horizontal channel with junction angles of 45 and 135°, the author presented a 1D analytical model to predict tributary channel depth upstream of the junction. Webber and Greated [2] implemented the method of conformal mapping to define a theoretical flow pattern throughout the junction region. Lin and Soong [3] presented a 1D model to predict the energy loss in a confluence in terms of discharge ratios in lateral channel to total inflow. The authors considered the energy loss occurring in the confluence as a result of boundary friction loss and turbulent mixing loss.

Using conformal mapping technique Modi et al. [4] studied the flow in rectangular channel junction and presented equations to calculate the stagnation point and the size of separation zone by ignoring the energy loss. Best and Reid [5] analyzed the effect of junction angle and discharge ratio on separation zone dimensions. The authors concluded that by increasing the junction angle and discharge ratio, the length and width of separation zone increase. Ramamurthy et al. [6] designed a model to predict the depth of flow in open channel junctions in terms of discharge ratio of lateral channel to total inflow. The authors concluded that for discharge ratio of 0.23 to 0.6, the lateral momentum transfer is linearly relative to the discharge of branch channel and mean velocity of the main channel. Using a laboratory model on an acute angled confluence Biron et al. [7] examined the effect of discordance in bed elevation between main and tributary channels on flow characteristics of open channel junctions. The authors reported that bed elevation discordance can

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change the location of mixing layer between the flows, fluid upwelling at the downstream of confluence and consequently the size of the separation zone. Chung-Chieh et al. [8] studied the separation zone and the contraction of the flow as it passes through the separation zone. The authors indicated that the energy and momentum correction coefficients at the maximum flow constriction are related to the inverse of the upstream to downstream discharge ratio of the main channel. Weber et al. [9] conducted a laboratory study on flow characteristics in a 90° channel junction to measure the velocity field in different hydraulic conditions and provide comprehensive information about its hydraulic flow patterns. This extensive measurement study has provided a benchmark experimental data set for validation purposes. By using an acoustic Doppler velocimeter Wang et al. [10] studied experimentally the three-dimensional flow behavior in a 30° angle junction flume. The authors concluded that a channel confluence flow can be divided into several zones including a zone of separation, the maximum and minimum velocity regions and a shear plane developed between the two combining flows downstream of the confluent channel.

By improving the speed of computers in the past decade, numerical methods came to characteristically predict the open channel junction problem. Studies conducted by using computational fluid dynamic are the most common numerical methods used in hydraulic engineering fields [11–16]. Because of their great ability to analyze complex problems, soft computing methods have been widely used for various problems in recent years. One of the most common soft computing methods is neural network. This method has been extensively used in various hydraulic engineering problems such as discharge capacity of lateral weirs [17], scour depth prediction, flow characteristics in different open channels [18–21], rainfall modeling [22–24], combined open channel flow [25] and sediment transport [26–28]. In recent years, genetic programing (GP) has been pronounced as a new strong technique to solve a wide range of modeling problems in hydraulic engineering such as velocity prediction in compound channels [29], rainfall-run-off modeling [30–33], sediment modeling [34–38], soil analyzing [39], open channel characteristics [40], etc. GP is an exploratory evolutionary modeling technique that automatically solves problems without requiring the user to specify the form of the solution. The easy-to-use and explicit form of this method has made it popular among soft computing techniques.

The aim of this study is to predict the continuous longitudinal velocity profile of open channel junction by using discreet coordinates of each point and discharge ratio of main to tributary channel. A Levenberg–Marquardt ANN model and a GP model were designed for predicting the longitudinal velocity field. The accuracy of both ANN and GP models was compared by using laboratory results. Various percents of train data were used to investigate the ability of each model in modeling the longitudinal velocity field with small population of samples. New formulations were obtained by GP and ANN models, respectively.

2. Experimental model

In this paper, experimental results of Weber et al. [9] and were used for ANN and GP validation. The channel junction consisted of a direct main channel and one tributary channel that were connected together in a 90° angle. The width of the tributary and the main channel (b) were equal with a value of 0.914 m. All distances were normalized by the channel width ($W=0.914$ m); the non-dimensional coordinates were called $x^*=x/W$, $y^*=y/W$ and $z^*=z/W$. Fig. 1 shows a schematic plan of the channel that was used in experimental study. In this figure, the positive x-axis direction was considered to be on the upstream side of the main channel, the positive y-axis direction inside of the main channel and the positive z-axis direction, upward in the vertical direction.

The upstream main and tributary channel flow were denoted by Q_m and Q_b, respectively. The total channel flow $Q_t=Q_m+Q_b$ and the discharge ratio were considered as $q^*=Q_m/Q_t$ (Table 1).

In the experimental study, the total channel flow (Q_t) and depth of tail water (Y_t) were held constant. Constant depth of tail water (Y_t) and width of main channel (W) lead to a constant tail water cross section area (A_t). Considering this constant total channel flow (Q_t) and tail water cross section area (A_t) and using the downstream average velocity equation ($V_t=Q_t/A_t$) we can conclude that downstream average velocity (V_t) remains constant.

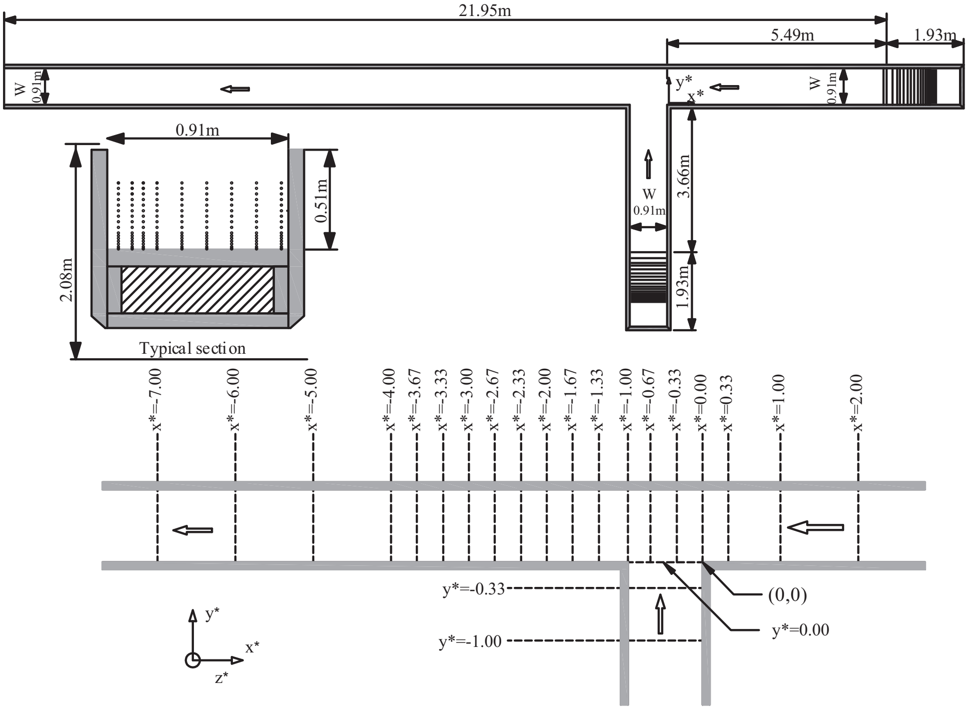

Fig. 1. Laboratory model [9] and sampling places along channel width and cross section.