Experimental study for determine Manning´s coefficient of open channels by means of ultrasonic sensors

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Highlights

- Straightforward approach for determine Manning´s roughness coefficient.
- Good efficiency of low cost apparatus for flow monitoring purposes in experimental channels.
- Great appreciation of the flow regime influence for determine Manning´s roughness coefficient.

Introduction

The direct determination of the effective roughness coefficient of artificial canals (*n*) is a very important procedure used in different hydraulic applications, yet is rarely performed as involves experimental tests resulting in budget increase, use of apparatuses and relative high deadlines. In small experimental channels, there is also the concern to obtain the best possible readings of free-water surface of different cross sections from predefined data of run-off flow, flow and bed slope channel in order to obtain parameter *n*.

The consequence for poorly conducting the estimation of the channel roughness parameter will derive in the underestimation of the water flow, floods and flooded areas which consequently might be inconsistent with reality. Thus, the *n* parameter constitutes a non-constant variable that depends on the channel depth flux up to the six power (Boyer, 1954), and that can also be determined by applying other types of methodological approaches (Limerinos, 1970; Ramesh et al., 2000; Wilson et al., 2002).

Hence, one of the approaches used for determining the free surface of a fluid submitted to different flow regimes and, consequently, the *n* parameter, is by the use of ultrasonic sensors in the Arduino platform, which constitute the main focus of the present paper. Limitations on the degree of precision, accuracy, time of readings as well as recording of depth level data measured by the ultrasonic sensor and Arduino were also evaluated.

Methodology

The artificial open channel used for the experimental tests is located in the Hydraulic Laboratory of the School of Civil and Environmental Engineering of the Federal University of Goiás (UFG), in the city of Goiânia, Brazil, with 4.0 m of useful length, adjustable bed channel slope from 0 – 35%, rectangular cross-section of 0.20 x 0.40 m, side walls of transparent glass and bottom of acrylic material (Figure 1).

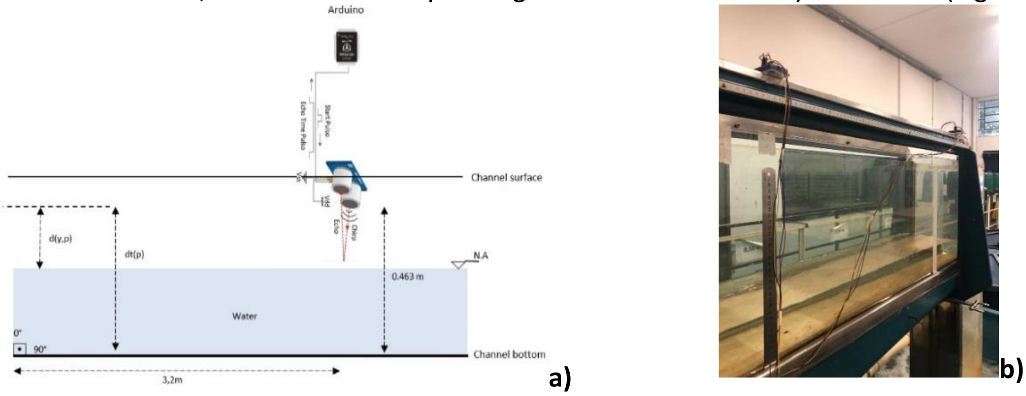

Figure 1. Representation of the equipment used for the experimental study of artificial open channel: a) schematic geometry; b) physical model.

A total of 15 experimental tests were carried out at different slope and flow configurations, where measurements of the level of free-water surface for uniform flow regime of were made by using ultrasonic sensors for Arduino (electronic and automatic method) and graduated millimetre ruler (manual method).
Five different channel inclination configurations were adopted: 0.0055, 0.0089, 0.0133, 0.0144 and 0.0288 m m^{-1}. The adopted slopes were checked and measured using Topcon optical level, AT-B4A model, in five stages by taking readings at a horizontal distance of 0.90 m. Consequently, for each slope, three different flow rates were used: 10, 15 and 20 l s^{-1}. Due to the oscillation of the hydraulic pump used in the artificial channel, the minimum and maximum values measured for the subsequent calibration of the Manning roughness coefficient were adopted.
The ultrasonic sensor used was the HC-SR04 model (Figure 2a). For the control and storage of the measures of flow depth obtained from the sensor, an open-source Arduino platform (board) of the MEGA 2560 type was used, which has a built-in ATmega2560 microcontroller, 54 pins of digital inputs and outputs, 16 analogue inputs and 4 ports of serial communication (Figure 2b). The card was powered directly through the computer's USB port, without a voltage regulator.

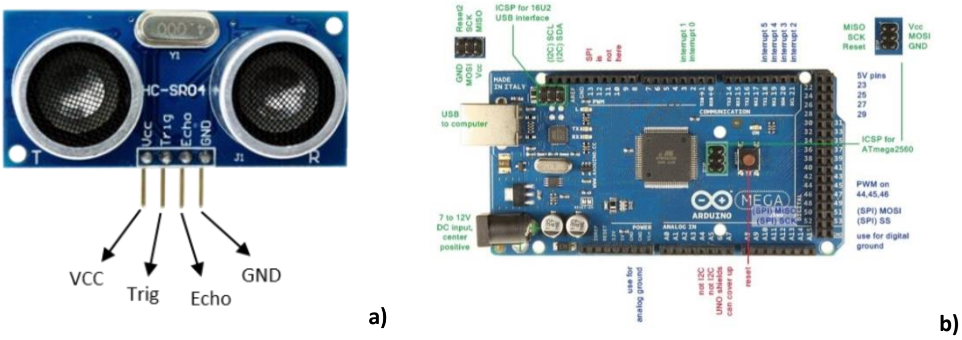

Figure 2. Electro-electronics devices used: a) ultrasonic sensor HC-SR04; b) Mega Arduino board.

The ultrasonic sensor used was positioned at the top of the channel, in an acrylic template, at a distance of 3.20 m from the beginning of the channel. The location of the inlet flow was considered to be as the beginning of the channel (Figure 1a). The position of these instruments was defined as the result to be the point of the channel with greater stability of the uniform flow and also with not influenced of free fall at the bottom of the channel.
The measurements of the water level surface along the experimental model, for both adopted instruments, were used to determine the Manning's roughness coefficient, and the results were subsequently compared. After completion of all tests and measurement the respective water column levels, the data were processed in Microsoft R in order to determine and validate the different methods used to obtain the Manning roughness coefficient.

Results and discussion

From the 15 experimental tests (Figure 1b) with different set configurations, it was possible to determine and statistically evaluate the Manning's roughness coefficient of the experimental channel (Table 1).
By comparing the two methods for determine the water surface level in the channel, for the flow regime applied, and by considering the different bed channel slopes and flow rates assumed, it was find out that no significant differences in the measures were obtained, with 6.2% being as the greatest differences that was observed. Tests 4 and 11 were considered as outlier. However, although these two tests presented significant differences, from the water level point of view, the effective roughness values are extremely close, with only 2.2% difference (Table 1), which may be related to the instability of operation of the motor-pump machine used in this artificial channel.
Regarding also to the data presented in Table 1, it is presumed that the biggest errors occurred for the lowest flow rates that were applied, mainly for the flow of 10.0 l s^{-1}. This might be justified by the difficulty of reading small levels of water depth, both by the ultrasonic sensor (problems with the angle of reading and reflection of the fluid), and the graduated ruler (parallax error), i.e. inaccuracy of readings.

Another significant factor, taking into account the results presented in Table 1, are the low standard deviations obtained, extremely close considering extremely close considering the very different level of accuracy of the two methods used.

Table 1. Summary of the different setting configuration of experimental tests carried out in the artificial channel, results of the Manning's roughness coefficient by different methods used and statistical indexes.

Test n°	S_0 (m m^{-1})	Q (l s^{-1})	h (m)		Measurement difference		Manning's coefficient	
			Ruler	Sensor	(m)	(%)	Ruler	Sensor
1	0.0055	10.18 10.29	0.075	0.0710	0.004	5.33%	0.01381 0.01367	0.01280 0.01266
2		15.04 15.15	0.085	0.0817	0.003	3.88%	0.01111 0.01102	0.01052 0.01044
3		20.20 20.50	0.103	0.1070	0.004	3.88%	0.01071 0.01056	0.01127 0.01110
4	0.0089	10.18 10.29	0.0408	0.0509	0.010	24.75%	0.00735 0.00727	0.01015 0.01004
5		15.07 15.16	0.065	0.0652	0,000	0.31%	0.00972 0.00966	0.00976 0.00970
6		20.50 20.64	0.083	0.0807	0.002	2.77%	0.01003 0.00996	0.00965 0.00959
7	0.0133	10.08 10.10	0.044	0.0449	0.001	2.05%	0.01014 0.01012	0.01044 0.01042
8		15.22 15.40	0.059	0.0556	0.003	5.76%	0.01026 0.01014	0.00942 0.00931
9		20.04 20.19	0.070	0.0687	0.001	1.86%	0.00991 0.00984	0.00966 0.00959
10	0.0144	10.25 10.43	0.039	0.0377	0.001	3.33%	0.00868 0.00853	0.00826 0.00811
11		15.06 15.24	0.053	0.0474	0.006	10.57%	0.00925 0.00914	0.00787 0.00778
12		20.05 20.20	0.067	0.0633	0.004	5.52%	0.00970 0.00963	0.00895 0.00889
13	0.0288	10.06 10.17	0.034	0.0319	0.002	6.18%	0.01019 0.01008	0.00926 0.00916
14		15.07 15.36	0.046	0.0442	0.002	3.91%	0.01065 0.01045	0.01004 0.00985
15		20.36 20.42	0.056	0.0565	0.001	0.89%	0.01047 0.01044	0.01061 0.01058
						Average	**0.01008**	**0.00986**
						Standard deviation	**0.13%**	**0.12%**

Conclusions and future work

The feasibility of using the ultrasonic sensor and Arduino platform in the process of determination and calibration of the Manning's roughness coefficient for artificial channels was proved by the identification of small errors (less than 6.2%). Other than that, the consistency on the estimation of the average value of roughness coefficient (n = 0.01) compared to the roughness characteristics of the main material as it is the artificial channel as well as the easiness of operation of the instruments used with also a low financial cost expenditure.

Better precision and accuracy of the results could be achieved in future studies with the development of a flow control and stabilization system provided by a hydraulic pump; facilitating the measurement of the water level from the graduated ruler for different flow regimes and, from the ultrasonic sensor point of view, noise filtering (due to the high frequency of operation).

Finally, with the improvement of the monitoring system here presented, its use and applicability can be extended to other practical situations involving urban drainage systems.

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