Journal of Scientific & Industrial Research
Vol. 82, October 2023, pp. 1091-1099
DOI: 10.56042/jsir.v82i10.2613

Evaluation of Ultrasonic Sensor for Flow Measurement in Open Channel

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Received 02 November 2021; revised 26 July 2023; accepted 28 August 2023

Accurate measurement of flow depth in an open channel on a real-time basis is the prime factor leading to more accurate quantification of discharge by the flow measuring device. The aim of present study was to evaluate the ultrasonic sensors (*viz.* HC-SR04 and JSN-SR04T) for depth of flow and corresponding discharge rate measurement in irrigation channel of canal command. The effect of ambient temperature on ultrasonic sensors was also investigated for irrigation channel hydraulic response measurement. It was observed that the performance of calibrated and temperature compensated sensors was better than the uncalibrated ones. Moreover, the performance of JSN-SR04T was better with mean absolute deviation (MAD: 0.21 ± 0.01cm), root mean square error (RMSE: 0.82 ± 0.01) and mean absolute percentage error (MAPE: 0.46 ± 0.09) compared to HC-SR04 sensor with MAD (0.36 ± 0.07), RMSE (0.43 ± 0.08) and MAPE (1.54 ± 0.82), respectively. Hence, JSN-SR04T ultrasonic sensor was used in the developed sensing system for the measurement of flow depth. It was observed that the system measured flow rate when compared with the observed flow resulted in prediction error estimate MAD (0.13 ± 0.05 lps), RMSE (0.16 ± 0.05) and MAPE (2.09 ± 1.16) and coefficient of determination (R^2: 0.99) for flow rate ranging from 2 to 20 lps. Overall, the study resulted in the development of a novel and economically viable open channel digital flow sensing system to measure discharge rate passing through the flume. The developed sensing system will assist stakeholders in enhancing surface irrigation water use efficiency in canal commands.

Keywords: Agriculture, Command area, Irrigation channel, Surface irrigation, Water use efficiency

Introduction

Out of 68 Mha of irrigated area in India, about 88% is under surface irrigation and the irrigation sector uses 80% of the Country's water resource.[1] Moreover, the irrigation water demand is projected to increase by 30% by 2030 and 50% by 2050 from the present level.[2] Therefore, it becomes imperative to enhance the irrigation water use efficiency from the present level of 30–35% in canal command of the Country.[3] All these calls for the creation of infrastructure to store water and supply of measured irrigation water as per crop water demand in surface irrigation which is prevalent in canal commands of the Country. Quantifying the amount of irrigation water distributed and utilized by individual users will ensure an equitable allocation, fostering a balanced distribution of available water resources and promote conservation of this invaluable resource.[4] Employing real-time water measuring devices to monitor water usage enables farmers to enhance irrigation efficiency and increase agricultural water productivity. Furthermore, in order to establish an effective on-farm water management plan, it becomes essential to accurately measure and quantifies the amount of water delivered to the fields.[1] When water is excessively applied, the surplus water seeps or percolates below the crop's root zone, providing no additional benefit to the crop. An estimate is that 40 percent or more of the water diverted for irrigation is wasted at the farm level through either deep percolation or surface runoff.[5] Conversely, inadequate water supply, particularly during crucial growth stages of the crop, can lead to decreased crop yield.[6] Hence, precise water measurement empowers on-farm irrigation decision-makers with essential information to optimize the use of irrigation water, while also minimizing any potential adverse environmental effects. In situations where water availability from a specific source is limited, measuring the flow rate at different points in the system and quantifying the water delivered to farmers' fields becomes imperative. In India and abroad, different types of flumes such as Parshall flume, long throated flume and cut-throat are being used for the measurement of open channelflow.

In India, permanent structures of Parshall and cut-throat flumes are commonly installed in various types

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of channels within canal commands. These flumes provide reasonable accuracy in flow measurement, but they have a significant drawback as only measure the instantaneous discharge rate and lack a mechanism to quantify the volume of water supplied to the field over a specific period of time.[1] Indeed, the flow rate in open channels is subject to fluctuations over time, and any changes in the flow rate will directly impact the total volume of water delivered to the farmland. As a result, accurately measuring and accounting for these variations becomes essential to ensure efficient water management and equitable distribution among users. The available literature on flow measurement in irrigation channels reveals a lack of affordable flow depth sensing systems for open channels.

Measurement of flow in an open irrigation channel either at a given time or continuously is an essential requirement not only to prevent wastage of water but also to increase the water use efficiency at the farm level.[5,7] In a standard continuous measuring system, the components typically include a primary flow device, a flow sensor, a transmitter, a flow recorder, and a totalizer. The primary flow device serves as the core of this system, generating predictable hydraulic responses corresponding to the depth of flow passing through it.[8] This enables the system to obtain instantaneous flow measurements. To measure the specific hydraulic responses produced by the primary flow device and transmit them to the recording system, a flow sensor is essential. Various types of sensors are available, such as ultrasonic transmitters, floats, pressure transducers, capacitance probes, differential pressure cells, electromagnetic cells, and more. The sensor signal is typically converted through mechanical, electromechanical, or electronic means into flow units, which are then recorded directly on a chart or transmitted to a data logger for storage. Systems equipped with a recorder usually include a flow totalizer that provides real-time display of the total flow. This comprehensive setup ensures accurate and continuous flow measurement in the system. Additionally, there is currently no device that integrates sensing mechanisms with a digital display unit to provide instant flow rate readings over time in irrigation channels.[1] Further research and development in this area are required to address these limitations and improve the effectiveness of flow measurement in irrigation practices. Considering the aforementioned context, this study aims to develop a digital open channel flow rate sensing system using a non-contact ultrasonic sensor and evaluate its performance in real field situations.

Materials and Methods

In the present investigation, a microcontroller-based flow depth sensing system with a data logger was fabricated for the measurement and recording of flow parameters in the irrigation field channel. Component of the developed sensing system is Arduino Mega microcontroller, HC-SR04 and JSN-SR04Tultrasonic sensors, DHT11 temperature sensor, LCD (liquid crystal display) RTC (real-time clock) module, and SD card module with SD card as shown in Fig. 1.

Arduino Mega Microcontroller

The Arduino Mega is a prototyping platform based on the ATmega processor, and it utilizes the C++ language as the development environment for creating software applications. The Arduino Mega is indeed equipped with the ATmega 2560 processor.[9] The Arduino board operates autonomously without requiring a constant connection to a computer. It can be programmed to respond to commands from the computer via various software interfaces or process data acquired from input channels. The Arduino Mega is programmable using the Arduino Integrated Development Environment (IDE) software, enabling users to upload code and execute programmed tasks autonomously.

Real-Time Clock (DS3231) Module

The Real-Time Clock (RTC) module is an important component of integrated circuits responsible for accurately tracking the current time and date. In data logging systems, the RTC module

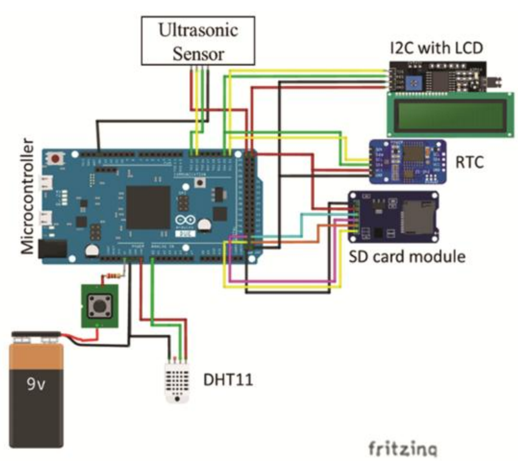

Fig. 1 — Circuit diagram of developed depth-flow measuring sensing system.

plays a critical role in ensuring precise timekeeping. This accuracy is essential for effectively correlating parameter values with their respective timestamps during display or recording. It ensures that the logged data is well-organized and can be correctly interpreted in relation to time. The RTC was used to display the time of measurement and recording in the developed data logger.[10]

Micro SD Card Module

The micro-SD card adapter is a module that functions as a micro-SD card reader. It is equipped with the Serial Peripheral Interface (SPI) and a file system driver, along with a microcontroller system. These components work together to enable the micro-SD card's capability to read and write various data files efficiently.[11]

I^2C or I2C Interface

I2C, which stands for Standard Inter-Integrated Circuit bus, is a serial data protocol that facilitates communication between devices using a master and slave relationship. The I2C protocol requires only two physical wires, allowing data to travel in a single direction at any given time.[11] The communication signals in I2C are Serial Data (SDA) and Serial Clock (SCL). With these two signals, I2C supports serial communication of 8-bit data bytes, 7-bit device addresses, and control bits, all while using just two wires. This simplicity makes I2C a cost-effective and straightforward option for hardware implementation.

Liquid-Crystal Display

Liquid Crystal Display (LCD) screen is an electronic display module that finds a wide range of applications. One common variant is the 20 × 4 LCD display, which serves as a basic module and is widely used in various devices and circuits. The display has 16 pins in a single row. To get the display working, the Inter-Integrated Circuit (I^2C) interface was used to minimize the wire connection from 16 to 4 numbers. A liquid-crystal display was used for the display of the instantaneous upstream depth of flow, discharge rate and amount of water flow over a period of time.

DHT 11 Temperature Sensor

The DHT11 is a digital humidity and temperature sensor that provides a calibrated digital signal output for both temperature and humidity measurements.[12] It combines a resistive sensor for humidity and NTC (negative temperature coefficient) temperature measurement components. The sensor is integrated with a high-performance 8-bit microcontroller to process and transmit the temperature and humidity data accurately. The use of a temperature sensor assists to understand the propagation of sound waves by the ultrasonic sensor because the sound wave in air is temperature dependent.[12–14]

Working Principle of Ultrasonic Sensors

Ultrasonic sensors used to measure distance or depth are specifically designed for non-contact measurements. They typically consist of a transmitter and receiver, or a transceiver, which enables the sensor to both transmit and receive ultrasonic sound waves. The transducer generates high-frequency, inaudible acoustic waves in a specific direction through the vibration of its element. When these waves hit an object and rebound, the transducer detects the echoed signal. The sensor is ideal for accurately measuring distances between both moving and stationary objects.[15] The sensor determines the distance from the object by measuring the time taken between the emission of the initial sound burst and the reception of the echo, a parameter known as the Time of Flight (ToF).[16] ToF results in relatively long response times for a single measurement, as the distance to an object is determined by the time interval between sending the signal and receiving the echo. To achieve contactless distance measurement, the device relies on the target to reflect the pulse back to itself. For this reflection to occur accurately, the target must have the appropriate orientation, specifically perpendicular to the direction of pulse propagation. In this study, two ultrasonic sensors namely HC-SR04 having separate transmitter and receiver, and other JSN-SR04T having a single unit were used and the schematic diagram of these two sensors is presented in Figs 2 (a & b), respectively.

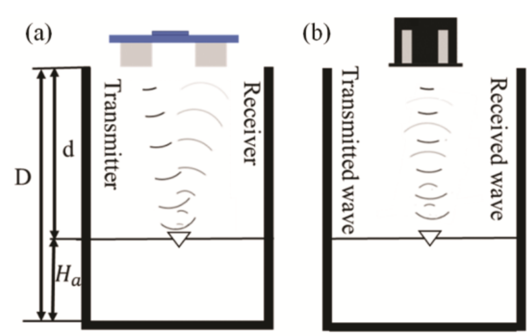

Fig. 2 — Working principle of ultrasonic sensors (a) HC-SR04 (b) JSN-SR04T; where, H_a= Depth of flow (cm), D = Depth between sensor and channel bottom (cm), and d = Depth between sensor and water surface (cm)

The accuracy of ultrasonic sensors might be affected or hindered by environmental conditions.[16] It can be temperature compensated for better results.[13] At 0℃, the speed of sound waves in air is approximately 331.46 m/s. With each 1°C rise in air temperature, the speed of sound increases by about 0.607 m/s, and conversely, it decreases with a decrease in temperature.[12,13] As a result, in hot weather, the reported distance measured by ultrasonic sensors will be relatively shorter, while in cold weather, it will be comparatively greater. The distance is estimated by using the equation[13,17] (Fig. 2), given by:

$$D = c.t/2 \qquad \ldots (1)$$

Where d = distance from sensor to the target, c = speed of sound waves in the air, t = ToF of ultrasonic pulses

The distance measured is of three types.[13] Actual distance D (cm) is measured manually.

Distance without temperature compensation D_1 (cm) which is measured by the sensor

$$D_1 = [(33146)\ t10 \qquad \ldots (2)$$

Distance with temperature compensation D_2 which is also measured by the sensor

$$D_2 = [(33146 + 60.7\,T)\ t\ 10^{-6}/2] \qquad \ldots (3)$$

where, D_1 = distance between sensor and target measured by the sensor without temperature compensation (cm); D_2 = distance between sensor and target with temperature compensation (cm); t = round trip/ToF of ultrasonic pulses (micro second); and T = ambient temperature (℃).

Principles of Flow Rate Measurements in Open Channels

Open channel flow measuring devices employ either the orifice or the weir principle and each device is adapted to be used in specific locations. Furthermore, the ideal flow measuring device would be simple to operate, inexpensive to construct, and free from working parts, require little maintenance, provide accuracy in its measurement, not affected by silt, sand or floating trash, and require minimal head loss in the channel. The discharge becomes a function of only a single flow depth point which is measured in the upstream section when the critical depth occurs in the downstream section.[18–20] The discharge remains independent of the downstream depth variations as long as the flow passes through the critical depth in the downstream section. This condition is known as free flow conditions. The discharge equation[1] for free-flow conditions is given as:

$$Q = \alpha H_a^{\beta} \qquad \ldots (4)$$

Here, Q = discharge rate (lps), H_a = head or depth of flow in upstream (cm), α = coefficient and β = exponent.

The values of α and β of the flow measuring device were determined from the experiment conducted at flume testing facility at WTC, ICAR-IARI, New Delhi. The PROC NLIN (Non-linear) procedure of Statistical Analysis System (SAS-9.4) software was used to develop the relationship between depth of flow (H_a) and corresponding discharge rate or flow rate (Q). The Marquardt method used by NLIN procedure was used to estimate the coefficient (α = 0.119) and exponent (β = 1.721) having the smallest sum square error (SSE).

Mounting Height of Ultrasonic Sensors for the Flow Measuring Device

The height for placement of sensors from the channel bottom will depend on the angle of field of view i.e., ultrasonic sensor sound waves (θ). The maximum height of sensor (H) can be obtained from the H = $B/2$) x Tan($\theta/2$), pertaining to channel width (B = 30 cm)[1] and angle of field of view (θ °)[(13)] (Fig. 3). Therefore, the maximum height of placement of sensor should be 56 cm from channel bottom and if placed at a height more than 56 cm, then the ultrasonic wave field of view will not touch the channel bottom and will be unable to measure small depth of water flowing in the channel. Moreover, the threshold values of HC-SR04 and JSN-SR04T sensors

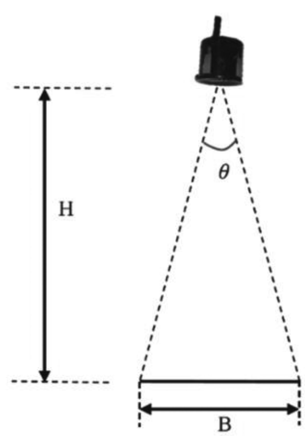

Fig. 3 — Field of view of ultrasound waves of JSN-SR04T ultrasonic sensor

are 2 and 20 cm respectively.[13,17] Therefore, sensors were calibrated and evaluated in application range viz. 10, 20, 30, 40 and 50 for HC-SR04 and 25, 30, 35, 40 and 45cm for JSN-SR04T, respectively.

Calibration of Ultrasonic Sensor

It is always desirable to calibrate the electronic sensing system to ensure the acquisition of data in line with the real experimental situations. In the experiment, the sensors were fixed at known height and the variation of room temperature was undertaken by using a room heater. Data of the distance measured by both calibrated and un-calibrated sensors were recorded in the data logger under different temperature settings varied as 20, 21,... to 40°C. Subsequently, the calibration factor was developed and actual distance measured for discharge measurement. Such investigation assists in the selection of more accurate and reliable sensors for depth flow sensing systems. Subsequently, the depth flow sensing system was tested for flow depth measurement at different operating depths in the open field channel located at the research farm of Water Technology Centre (WTC), ICAR-IARI, New Delhi.

Performance Error Statistics

In developing the proposed sensing system, the accuracy of the results is determined by four statistical error parameters *viz.*MAD (mean absolute deviation), RMSE (root mean square error), MAPE (mean absolute percentage error) andR^2 (coefficient of determination).[21,22] Equations for statistical error parameters are given below.

$$\text{MAD} = \frac{\sum_{i=1}^{n}\left|x_{pred_i}-x_{true_i}\right|}{n} \quad \ldots (5)$$

$$\text{MAPE}=\frac{100\%}{n}\sum_{t=1}^{n}\left|\frac{x_{pred_i}-x_{true_i}}{A_t}\right| \quad \ldots (6)$$

$$\text{RMSE}=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{pred_i}-x_{true_i}\right)^2} \quad \ldots (7)$$

$$R^2 = \frac{\sum_{i=1}^{n}\left(x_{pred_i}-\overline{x_{pred}}\right)\left(x_{true_i}-\overline{x_{true}}\right)^2}{\sum_{i=1}^{n}\left(x_{pred_i}-\overline{x_{pred}}\right)^2\left(x_{true_i}-\overline{x_{true}}\right)^2} \quad \ldots (8)$$

where, n is the number of observations, $x_{true}$and x_{pred} are observed and predicted value, respectively, $\overline{x_{true}}$ and $\overline{x_{pred}}$ are the mean values of observed and predicted data, respectively.

Results and Discussion

Accurate measurement of flow depth in an open channel on a real-time basis is the prime factor leading to more accurate quantification of discharge by the flow measuring device. Moreover, the depth of flow in an open channel is a highly variable phenomenon and properly calibrated sensors would capture accurate flow depth in the channel. In this study, two ultrasonic sensors *viz.* HC-SR04 and JSN-SR04T were calibrated with and without temperature compensation for the measurement of flow depth. Subsequently, the sensing system developed with a digital display unit and data loggerwas used for calibration and testing of ultrasonic sensors.

Performance Statistics of HC-SR04 Ultrasonic Sensor

The performance of the HC-SR04 sensor was evaluated with and without temperature compensation. The sensor was fixed at 10, 20, 30, 40, and 50 cm height above the target. A comparison of the actual distance and distance measured by the sensor without calibration and temperature compensation is presented in Table 1. The statistical parameters *viz.* MAD, RMSE and MAPE of HC-SR04 sensor were beyond the acceptable limit without temperature compensation as compared to temperature compensation pertaining to both non-calibrated and calibratedsituations (Table 1). It was observed that the distance measured with sensor was less than the actual distance and the MAD was 3.04 ± 0.22 cm. Moreover, the distance measured withsensor without calibration and with temperature compensation was alsoless than the actual distance with MAD 2.76 ±

Table 1 — Performance Error Statistics of HC-SR04 Ultrasonic Sensor

	Observed depth (cm)					MAD	RMSE	MAPE
	10	20	30	40	50			
T_1	7.36 ± 0.17	17.19 ± 0.10	27.03 ± 0.09	37.41 ± 0.18	47.42 ± 0.28	3.04 ± 0.22	3.07 ± 0.23	13.97 ± 9.21
T_1T	6.88 ± 0.15	16.84 ± 0.17	27.41 ±0.23	36.79 ± 0.40	46.91 ± 0.36	2.76 ± 0.16	2.82 ± 0.15	12.36 ± 7.58
T_2	9.93 ± 0.23	20.06 ± 0.21	29.96 ± 0.25	40.01 ± 0.12	50.19 ± 0.17	0.46 ± 0.05	0.92 ± 0.02	1.73 ± 0.93
T_2T	9.87 ± 0.83	19.69 ± 0.81	30.02 ± 0.85	39.78 ± 0.78	50.13 ± 0.89	0.36 ± 0.07	0.43 ± 0.08	1.54 ± 0.82

Figure indicates- mean ± standard deviation, T_1- Non-calibrated sensor, T_2- calibrated sensor, T- temperature compensated sensor, MAD-mean absolute deviation (cm), RMSE- root mean square error, MAPE-mean absolute percentage error (%)

0.16 cm. Moreover, the calibrated sensor without temperature compensation could measure the distance in close agreement with the actual distance but with a lower MAD of 0.46 ± 0.05 cm. Nonetheless, the sensor reading with calibration and also with temperature compensation was very close to the actual distance with MAD value of 0.36 ± 0.07 cm. The RMSE (0.43 ± 0.08) and MAPE (1.54 ± 0.82) values were the least amongst all for the calibrated and temperature compensated ultrasonic sensor.

Performance of JSN-SR04T Ultrasonic Sensor

Similarly, the performance of the JSN-SR04T sensor was evaluated with and without calibration and temperature compensation. The resolution of JSN-SR04T sensor was 20 cm so the sensor was fixed at 25, 30, 35, 40, and 45 cm from the target. The performance error statistics of the sensor in the measurement of distance compared with actual distance before and after calibration and temperature compensation, are presented in Table 2. It was observed that the performance of JSN-SR04T ultrasonic senor was the best after calibration and temperature compensation in which the sensor measured distance was very close to the actual distance with MAD of 0.21 ± 0.01 cm and all statistical parameters were the least under calibrated and temperature compensated situation.

The non-calibrated JSN-SR04T sensor measured distance was lower than the actual distance as that of HC-SR04. Therefore, it can be inferred that the non-contact ultrasonic sensor should be calibrated before use. Overall, based on these experimental findings, it was observed that both HC-SR04 and JSN-SR04T ultrasonic sensors without calibration measured the distance less than the actual distance. Moreover, it was observed that calibrated sensors measured the distance close to the actual. However, the statistical error parameters *viz.* MAD, RMSE, and MAPE of JSN-SR04T ultrasonic sensor were less than the HC-SR04 ultrasonic sensor (Tables 1 & 2) indicating its efficacy in measurement over HC-SR04 sensor. Similar results of HC-SR04 sensor were reported by Găşpăresc & Gontean.[23] Besides this, the measurement error was 0.75% with calibrated JSN-SR04T sensor as compared to manual measurement[24], reduced in error from 3.77% to 17.19% without temperature compensation to 0.03 to 9.89% with temperature compensated for uncalibrated HC-SR04 sensor[13], uncalibrated sensor accuracy not to the desired level, while accuracy of the ultrasonic sensor was increased beyond the specifications as 0.4 mm with the calibrated with real time ambient temperature compensated sensor.[25] In practice, the sensing system only compensates for errors caused by temperature. The temperature sensor can be integrated with sensing system to measure the ambient temperature in real-time and compensate the sound velocity value accordingly.[17] Therefore, it can be concluded that the ultrasonic sensors need calibration before real applications. Nonetheless, the JSN-SR04T sensor was observed to be better than HC-SR04 due to its ease of installation, water proof coating, and accuracy.

Development of the Digital Sensing System for the Flow Measuring Device

The JSN-SR04T ultrasonic sensors were further integrated with other electronic gadgets of the sensing system. The 3D printed casing encompassing all gadgets besides the ultrasonic sensors and the integrated circuitry is shown in Fig. 4. Moreover, the depth of flow *vs* discharge relationships of the flow measuring device was embedded in the

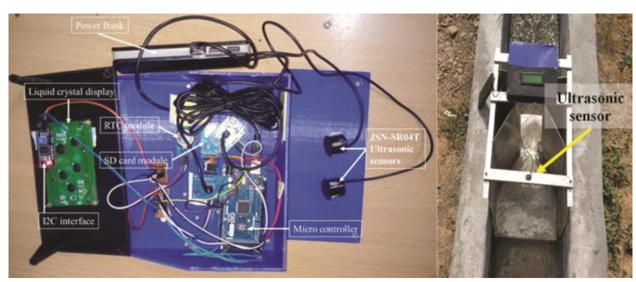

Fig. 4 — Digital sensing system with ultrasonic sensors and other electronic gadgets enclosed in a 3D-printed casing (left) and flow measuring device with sensing system (right)

Table 2 — Performance Error Statistics of JSN-SR04T Ultrasonic Sensor

	Observed depth (cm)					MAD	RMSE	MAPE
	25	30	35	40	45			
T_1	22.44 ± 0.12	27.40 ± 0.10	32.62 ± 0.38	37.48 ± 0.10	42.48 ± 0.29	2.52 ± 0.07	2.55 ± 0.08	7.53 ± 1.70
T_1T	23.29 ± 0.05	28.32 ± 0.06	33.37 ± 0.03	38.26 ± 0.06	43.32 ± 0.20	1.77 ± 0.04	1.87 ± 0.03	5.09 ± 1.06
T_2	24.60 ± 0.17	29.57 ± 0.12	39.56 ± 0.14	34.55 ± 0.12	44.58 ± 0.28	0.44 ± 0.02	0.48 ± 0.03	1.31 ± 0.22
T_2T	25.00 ± 0.05	29.93 ± 0.05	34.95 ± 0.05	39.94 ± 0.07	44.99 ± 0.06	0.21 ± 0.01	0.82 ± 0.01	0.46 ± 0.09

Figure indicates- mean ± standard deviation, T_1- Non-calibrated sensor, T_2- calibrated sensor, T- temperature compensated sensor, MAD-mean absolute deviation (cm), RMSE- root mean square error, MAPE-mean absolute percentage error (%)

microcontroller for displaying the flow rate, volume, and time of flow in the open channel.

Performance evaluation of flow measuring sensing system

The developed sensing system mounted on an open channel flow measuring device was validated under varying depths of flow in the open channel. The depth of flow was measured by the JSN-SR04T ultrasonic sensor and the corresponding discharge rate (flow rate) was displayed in the digital system as per the rating curve equation of head-discharge relationship embedded in the microcontroller with a coefficient ($\alpha = 0.119$) and exponent ($\beta = 1.721$) (Eq. 4). However, the average actual flow rate of three replications was measured in the collection tank buried near the field channel at the downstream side of the measuring device. The average discharge rate of thirty successive readings was taken as recorded in the sensing system. The sensor measured depth of flow observed flow rate, and estimated flow rate of thirty successive readings of sensing system under different depths of flow was presented in Figs. 5 (a & b), respectively. It was observed that the developed depth-flow sensing system precisely measured the depth of flow (DoF) and corresponding flow rate as shown in Fig. 4b.

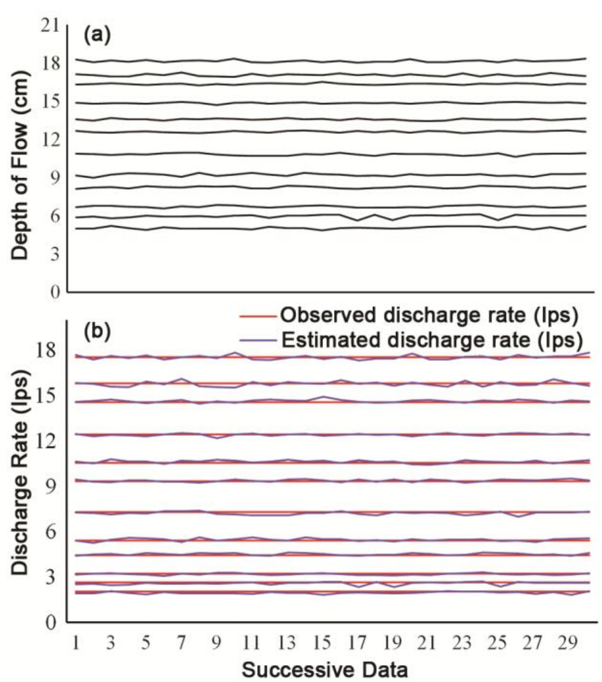

Fig. 5a — Sensor measured depth of flow (cm) in open channel; & b) Observed and estimated discharge rate (lps) in the open channel

Prediction error statistics parameters *viz.* MAD, RMSE, and MAPE pertaining to the performance of the sensing system is presented in Table 3. It was observed from Table 3 that the MAD, RMSE, and MAPE decreased with an increase in flow depth and corresponding flow rate. The MAD, RMSE, and MAPE for the experimented flow rates were 0.13 ± 0.05, 0.16 ± 0.05, and 2.09 ± 1.16, respectively. However, The MAPE of all experimented flow rates (≥ 2.5 lps) was less than 5. The coefficient of determination (R^2) was 0.99 as shown in Fig. 6. Different flow measuring devices reported to operate with an accuracy of approximately ± 5%.[1,26,27] Nevertheless, a select few have demonstrated the

Table 3 — Performance error statistics of developed sensing system

Q_{obs}	Q_{est}	MAD	RMSE	MAPE
2.03 ± 0.05	1.94 ± 0.06	0.11	0.12	5.16
2.62 ± 0.03	2.57 ± 0.06	0.08	0.11	3.09
3.20 ± 0.12	3.18 ± 0.05	0.10	0.12	3.10
4.44 ± 0.09	4.49 ± 0.07	0.10	0.12	2.14
5.39 ± 0.07	5.45 ± 0.14	0.09	0.12	1.75
7.27 ± 0.22	7.21 ± 0.05	0.18	0.21	2.41
9.33 ± 0.15	9.36 ± 0.07	0.13	0.16	1.38
10.53 ± 0.17	10.61 ± 0.10	0.16	0.19	1.49
12.43 ± 0.21	12.4 ± 0.06	0.14	0.16	1.14
14.55 ± 0.35	14.62 ± 0.09	0.26	0.30	1.77
15.79 ± 0.03	15.76 ± 0.16	0.14	0.16	0.86
17.53 ± 0.02	17.52 ± 0.14	0.12	0.14	0.66
Average		0.13 ± 0.05	0.16 ± 0.05	2.09 ± 1.16

Figure indicates- mean ± standard deviation, Q_{obs}- observed discharge rate (lps), Q_{est}= Estimated discharge rate (lps), MAD- mean absolute deviation (lps), RMSE- root mean square error, MAPE-mean absolute percentage error (%)

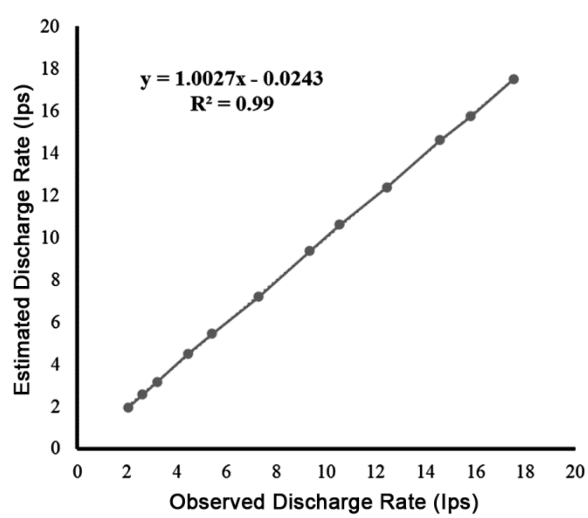

Fig. 6 — Observed *vs.* estimated discharge rate by the sensing system

capability to measure flow with a higher precision, achieving an accuracy as ±1% under controlled laboratory conditions.[27] These findings highlight the diversity in accuracy levels among flow measuring devices, emphasizing the importance of selecting the appropriate instrument for specific applications. Therefore, the developed depth-flow sensing system is capable of measuring the flow rate and total flow volume delivered over the period of time to surface irrigated farms with acceptable accuracy.

Conclusions

Accurate irrigation water measurement saves water and enhances agricultural productivity. An attempt was made in this study to develop an open channel flow sensing system for the measurement of irrigation water supplied to agricultural farms. The effect of ambient temperature on non-contact HC-SR04 and JSN-SR04T ultrasonic sensors were investigated for open channel hydraulic response measurement. Results indicated that the calibrated and temperature compensated ultrasonic sensor performed better than non-calibrated non-temperature compensated sensors. The JSN-SR04T sensor was observed to measure the depth of flow in close agreement with the actual depth of flow with MAD 0.21 ± 0.01 cm as compared to the HC-SR04 ultrasonic sensor (MAD 00.36 ± 0.07 cm). Besides this, the developed sensing system using JSN-SR04T sensor measured the flow rate (lps) with MAD (0.13 ± 0.05 lps), RMSE (0.16 ± 0.05), MAPE (2.09 ± 1.16), and R^2 (0.99) for flow rate ranging from 2 to 20 lps. The device displayed and stored data pertaining to discharge rate and total flow volume in a given time span, which is useful for irrigating farmland as per the surface irrigation schedule. Overall, the study resulted in the development of a new, innovative, economically viable, and technically sound flow-depth sensing system to measure discharge rate and volume of water passing through an openfield channel for enhancing water productivity in surface irrigation.

Acknowledgment

Authors wish to acknowledge the financial assistance to undertake research under the sub-project of "Hub and Spoke model (DIC: 24-596)" funded by MHRD, GoI, in collaboration with IIT, Kanpur and operational at Division of Agricultural Engineering, ICAR-IARI, New Delhi.

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