Zeitschrift für Bewässerungswirtschaft

Journal of Applied Irrigation Science

ISSN 0049-8602

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2009

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First published in: *(Copyrights apply)*
Journal of Applied Irrigation Science, Vol. 44, No. 2 /2009, pp 177 - 185.

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Zeitschrift für Bewässerungswirtschaft, 44. Jahrg., Heft 2 /2009, ISSN 0049-8602 **Seiten 177 - 185**

Development and calibration of a digital recording system for automation of runoff measurement

J. T. Fasinmirin

Keywords
Runoff, digital, sensor, analog, storage tank

Abstract
The measurement of surface water flow (runoff) by the use of integrated circuit (ICL7106) digital converter is a new concept of runoff measurement in Nigeria. It is a very efficient, low power analog to digital (A/D) converter. A runoff collector of area $1m^2$ and depth 30 cm was constructed, and a discharge pipe of 2.5 cm diameter and length 60 cm connects the runoff collector to the runoff storage tank, 30 cm x 30 cm x 30 cm in dimension. Both the runoff collector and the storage tank were made of metal sheet (18 gauge).

The active devices used for the construction of the digital sensing device include decoders, display driver, reference resistor, a clock, sensor, liquid crystal display (LCD) and lCL7106. The lCL7106 was designed to interface with a liquid crystal display (LCD), which includes a back-plane drive. This digital recording system was designed to measure the amount of runoff that flow into the runoff storage tank through the discharge pipe, such that the resistor sensed runoff according to the level of water in the tank. The sensor divides the reference voltage (V_r) in ratio to the value of resistance (R_1). This varying voltage is now converted to digital readout by A/D converter with respect to liquid crystal display (LCD).

The equipment was calibrated with the aid of standard measuring cylinder (1000 ml). It was observed that runoff within the range 1.12 to 96.00 litres could be adequately measured using the digital device. This research development is useful in weather forecasting, flood studies and hydrological analysis in natural science studies.

1. Introduction

FOTH (1990) defined agricultural runoff as the surface water leaving farm fields because of excessive precipitation, irrigation, or snow melt. In the early 20th century, there was considerable concern about erosion of farm field caused by rainfall washing away valuable topsoil from the field and resulting in loss of productivity. With the passage of the Federal water pollution control Act Amendment of 1972, the potential for pollution of surface water from agricultural runoff was officially recognized and an assessment of the nature and extent of such pollution was mandated (BAILEY, 1995).

Runoff is not an important detecting agent rather it is an overland flow, which can be regarded as an efficient transporter of sediments (OZARA, 1991). The relationship between the precipitation and runoff is usually influenced by the various storm and basin characteristic, while the storm and basin characteristic (rainfall depts., duration and intensity) provides the surplus water known as runoff, the basin characteristic (size and shape of the watershed, slope and surface culture of the watershed) generates the materials and sediments that may be referred to as pollutants (BEASLEY, 1992).

Hence the increased volume of overland flow due to heavy rainfall pattern, deforestation and urban development accelerates erosion and encourages land degradation and water pollution (LAL, 1986). HAMMER et al. (1980) stated that the degradation is reflected by undesirable amount of inorganic chemicals, organic compounds or biological indicators that render water and the soil unfit for beneficial uses. ARILESERE (1996) reported that degradation of land encompassed the soil and vegetation as well as the water resources all of which are closely related; while SMITH (1981) noted that with an intense storm on bare soil, the level of erosion, sedimentation, flooding, nutrients losses and environmental degradations are usually high; erosion carries away the eroded materials to the down-stream where they are deposited causing pollution of land and water surfaces. Runoffs and eroded materials from agricultural lands are usually rich, containing nutrients, pesticides, residues and fertilizer (SANGODOYIN et al., 1995).

Consequently, DULEY (1986) reported that the major loss of phosphorous in runoff water was through eroded sediments, while ROGERS (1984) stated that the eroded sediment from corn land were richer in nitrogen and phosphorous than the original soil. Therefore the total nutrient losses in the runoff water can be said to be proportional to the surfaces runoff (KOWEL, 1992). Despite the magnitute and severity of damages and losses that accompany runoffs after rainfalls, its determination on cropped field in the tropical environment it is predominantly still carried out manually with the aid of measuring cylinders. This method is not only very strenuous; it is also very inaccurate in most cases. This research therefore was aimed at designing a digital electronic sensor for measuring soil and water losses through the process of over land flow.

3. Material and method

3.1 Construction of runoff metre

The rectangular runoff metre was made from metal sheet (18 gauge), 1 m x 1 m x 0.3 m in dimension, it was designed and constructed with the top and the base opened for exposure to the effect of sunlight, precipitation and infiltration into the soil. This runoff collector carries overland flow from its catchments and discharge into the runoff storage tank (RST) through a discharge pipe that links the collector to the

runoff storage tank. The discharge pipe is made of galvanized steel with a diameter of 2.5 cm diameter, directing the collected runoff into the runoff storage tank. The storage tank has the dimensions 0.60 m x 0.60 m x 0.30 m. The cover and base of the storage tank is tightly sealed to prevent any leakage through the system as shown in Figures 1.

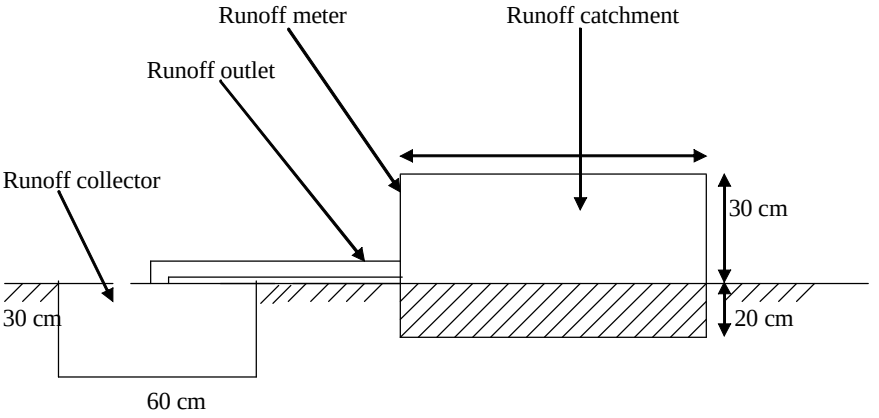

Figure 1:
A cross section of the runoff meter installed on the field

3.2 Digital sensing device

3.2.1 Features

The features of the digital sensing device include

– Guaranteed zero reading for 0 volt input
– True polarity at zero for precise null deflection
– 1 pA input current
– True differential input and reference
– Direct display drive- no external components required –LCD ICL7106
– Low noise – less than 15µV
– Chip clock and reference
– Low power dissipation – typically less than 10 mW
– No additional active circuit required
– Evaluation kit available

3.2.2 General description of the sensor

The intersol (IC7106) is of high performance, low power 3½-digit analog to digital (A/D) converter. All the necessary active devices are contained on a single CMOS,

including seven segment decoders, display drivers, reference, and a clock. The IC7106 was designed to interface with a liquid crystal display (LCD) and includes a back plane drive (COX, 1988).The digital device ICL7106- brings together an unpredicted combination of high accuracy, versatility and true economy. High accuracy like auto – zero to less than 10 µV, input bias current of 10 pA maximum and roll-over error of less than one count. The versatility of true differential input and reference is useful in all systems, but gives the designer an uncommon advantage when measuring lead cells strain gauges and other bridge-type transducers. And finally the true economy of single power supply operation (ICL7106) enable a high performance panel meter to be built with the addition of only 7 passive component and a display (Figure 2).

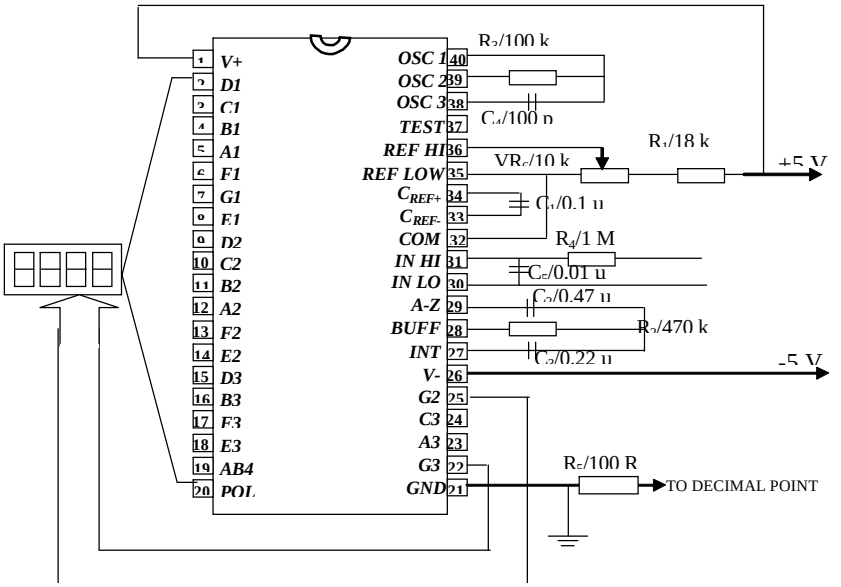

Figure 2:
The ICL7106 with Liquid Crystal Display (LCD)

As R is varying according to the level of water in the tank, it divides the reference voltage (2v) in ratio to the value of internal resistance (R_i,). This varying voltage is then converted to digital readout by A/D converter.

3.5 Component value selection

The component selected includes integrating resistor, integrating capacitor, auto zero capacitor, reference capacitor, Oscillator components, and reference voltage.

3.6.1 Reference voltage (Calibration)

The analog input required to generate full-scale output (200 counts) is $V_{in} = 2V_r$. Thus, for the 200 mV and 2.000-volt scale, V_r should equal 100 mV and 1 volt, respectively. However, in much application where the A/D is connected to a transducer, there exists a scale factor other than unity between the input voltage and the digital reading. For instance, in a weighing system, the voltage from the transducer was 0.682 v. Instead of dividing the input down to 200 mV, input voltage was used directly and V_r = 0.341v selected. Suitable value for integrating resistor and capacitor would be 120 kw and as a reference a nominal +2 or -2 volt and analog full-scale integration swing was selected.

3.6.2 Auto- zero and reference capacitor

The size of the auto-zero capacitor has some influence on the noise of the system. For 200 mV full scale, where noise is mostly experienced, 0.47 µF capacitor was selected. On the volt scale, a 0.47 µF capacitor increases the speed of recovery from overload and is adequate for noise on this scale. Reference capacitor gives good results in most application. However, where a large common mode voltage exists (i.e. the reference low is not at analog) and a 200 mV scale is used, a higher value reference capacitor may be required to prevent roll over error. Generally 1.0 µF will hold the rollover error to 0.5 count in this instance.

3.6.4 Oscillation components

For all ranges of frequency, a 100 Ω resistor is recommended and the capacitor was selected from the equation F= 45/RC for 48 kHz clock (readings in s^{-1}), C= 100 pF = 0.22 µF. This makes the system slightly quieter with + 5 volts supplies. Another advantage of this system occurs when a digital reading of zero is desired for V not equals to zero.

3.6.5 Integrating resistor and capacitor

Both the buffer amplifier and the integrator have a class A output stage with 10 µA of quiescent current. They can supply 20µA of drive current with negligible non-linearity. The integrating resistor was large enough to remain in this very linear region over the input voltage range, but small enough that undue leakage requirements are not placed on the printed circuit (PC) board.

The integration capacitor was selected to give the maximum voltage swing that ensures tolerance build-up will not saturate the integrator swing (approx. 0.3 volt. from either supply) in IC7106 while using the analog common.

4. Results and discussions

4.1 Performance test and calibration of runoff meter

In the absence of rainfall, artificial testing and calibration were carried out. Water was poured into the runoff meter, which was installed at a depth of 10 cm into the soil, leaving about 20 cm height above the soil surface. The discharge pipe was installed carefully with the runoff storage tank (RST). The digital sensing device was appropriately installed in other to bring together an unprecedented combination of high accuracy, versatility and true result. While pouring water into the runoff catchments, in the first instance, no runoff occur for the first few minutes which shows that all the water had infiltrated into the soil. When infiltration into the soil had been satisfied, runoffs started in the runoff storage tank (RST) until the end of the experiment.

Immediately runoff gets into the RST, resistor becomes varying and as the resistance varies according to the level of water in the tank; it immediately divides the references voltage (2v) in ratio to the value of resistor R. This varying voltage is now converted to digital readout by analog to digital (A/D) converter (i.e. liquid crystal display). It was also noticed that rainfall with high intensity and long duration produced high level runoffs, while the precipitation inform of dew produces little or no runoff.

Calibration curves based on linear regression equation are shown in Figure 4.5 a while Figure 4.5 b showed calibration curve based on a quadratic model. A summary of the calibration statistics is presented in Table 1. Results showed that the sensor readings are almost linear with the manual observation with $R^2 > 0.94$ in both cases. The quadratic calibration curve showed a better fit with $R^2 > 0.98$. All the models are highly significant at $P < 0.0001$. Although linear fit showed high accuracy with their R^2 not statistically different from that of the quadratic model, the values of standard error (0.150 mm) is higher making it less acceptable to the non-linear equation which has *SE* of 0.079 mm. Linear model starting from the origin is theoretically favoured since no negative runoff depth was observed. Given the foregoing, calibration curve based of the quadratic model was adjudged best and then adopted for this electronic water level sensor.

The performance was further validated by measuring runoff simultaneously with the sensor and manually for the months of March and April. Runoff obtained from digital sensor conversion using the quadratic calibration equation were very similar to values from manual measurement as shown Figures 4.5a and 4.5b, for March and April, respectively. The variation between both the manual and digital datasets was quite small. *MBE* for the month of March and April were 0.19 mm and 0.15 mm, respectively and the correlation coefficients were very high ($R > 0.97$) for both datasets.

Table 1:
Summary of calibration statistics

S/N	Model	#Overall Statistics		
		R^2	Standard error	Sig. level
1	Linear	0,9448	0,150	< 0.0001
2	Quadratic	0,9869	0,079	< 0.0001

#R^2 is coefficient of determination; SE is standard error of estimates

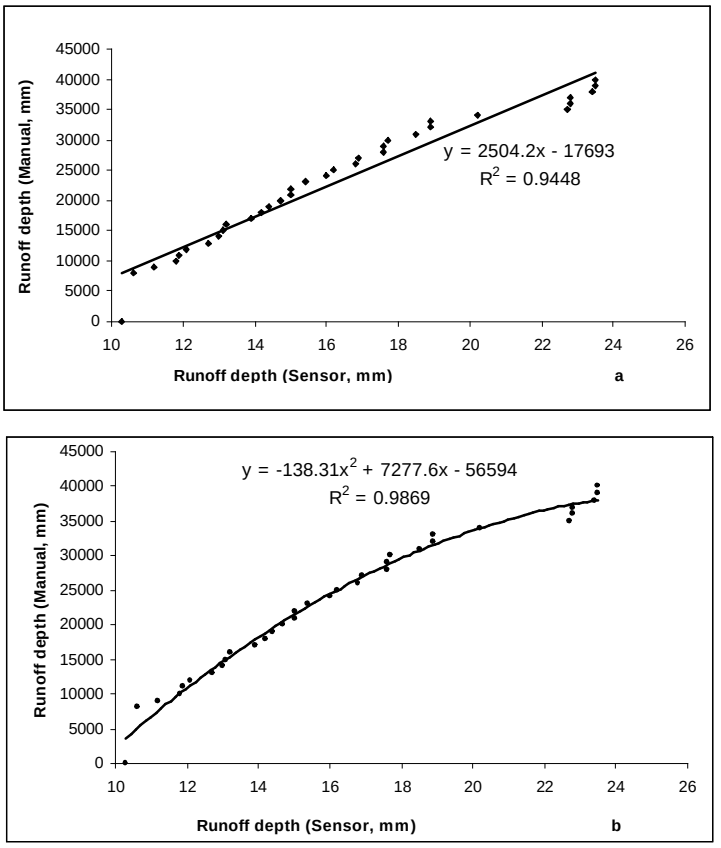

Figure 3:
Calibration curves for digital sensor (a) Linear fitted (solid line) and (b) Quadratic fitted

5. Conclusion

The design analysis, and construction of digital sensing devices for runoff measurement has been presented. It consist of runoff catchment's box (basin), runoff storage tank ((RST), discharge pipe, digital devices such as ICL7106 analog to digital converter, resistor, liquid crystal display (LCD), sensor (floater), Pressure hose, 6F 2.29V battery, among others. All the materials used for the fabrication were sourced locally. The calibration is done such that the initial reading was 11.2 litres (minimum) and 96 litres (maximum) reading for accurate measurement. The use of digital ICL7106 analog to digital converter for measuring the amount of runoff at all period of time brings together an accuracy, versatility and economical method of estimating runoff.

Notations	**Meanings**
RST	Runoff Storage Tank
LCD	Liquid Crystal Display
pA	picoAmpere(s)
µA	microAmpere(s)
µV	microVolt
mW	milliwatts
IC	Integrated Circuits
C	Capacitance
R	Resistance
R_i	Internal Resistance
V_r	Reference Voltage
V_{in}	Input Voltage
Ω	ohm
KHz	kilohertz
µF	microFarad
pF	picoFarad
mV	milliVolt

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