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Development and Calibration of a Digital Recording System for Automation of Runoff Measurement

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Abstract: Field runoff estimation by the use of integrated circuit (ICL7106) digital converter is a new concept of surface water flow measurement in the sub-Saharan Africa. 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 Vr 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 7500 ml to 42000 ml 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.

Key words: Analog, catchmant, digital, electronic sensor, runoff and storage tank

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 accelerated erosion and encourage 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 and Nwosu, 1995).

Consequently, Duley (1986) reported that the major loss of phosphorous in runoff water was through eroded sediments, while Roger (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 damages and losses that accompany runoffs after rainfalls, its determination on cropped field in the tropical environment is mostly 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.

MATERIALS AND METHODS

Construction of Runoff-Metre and Installation: The rectangular runoff meter was made from metal sheet (18 gauge), 1m 1m 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. The runoff meter was installed at a depth of 10 cm into the soil, leaving about 20 cm height above the soil surface. 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 was made of galvanized steel of 2.5 cm diameter and 50 cm length, the purpose for which is to discharge the collected runoff into the runoff storage tank of dimension 0.60 m x 0.60 m x 0.30 m. The cover and base of the storage tank was tightly sealed to prevent any leakage through the system (Fig. 1). The digital sensing device was appropriately installed in other to bring together an unprecedented combination of high accuracy, versatility and true result.

In the absence of rainfall, artificial testing and calibration were carried out. Water was gently and continuously applied into the runoff meter in form of shower until the cease of infiltration and the start of runoff from the catchment. 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 was converted to digital readout by analog to digital (A/D) converter (i.e. liquid crystal display).

Digital sensing device:

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 10mW
- No additional active circuit required
- Evaluation kit available

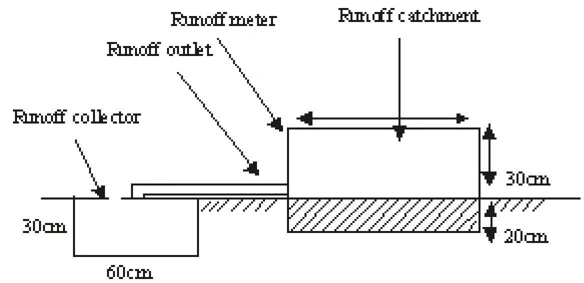

Fig 1: A section of the runoff meter installed on the field

General description of the sensor: The intersol ICL7106 is of high performance, low power 3½-digit analog to digital (A/D) converter. All the necessary active devices were contained in a single complementary metal-oxide semiconductor (CMOS), including seven segment decoders, display drivers, reference, and a clock. The ICL7106 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 10µV, input bias current of 10pA maximum, and roll-over error of less than one count. Also, 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 components and a display (Fig. 2). 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 (Ri,). This varying voltage was converted to digital readout by A/D converter.

Components Selection:

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 is 0.682v. Instead of dividing the input down to 200 mV, the input voltage was directly used and V_r = 0.341v selected. Suitable value for integrating resistor and capacitor would be 120kw and as a reference a nominal +2 or -2 volt and analog full-scale integration swing was selected.

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

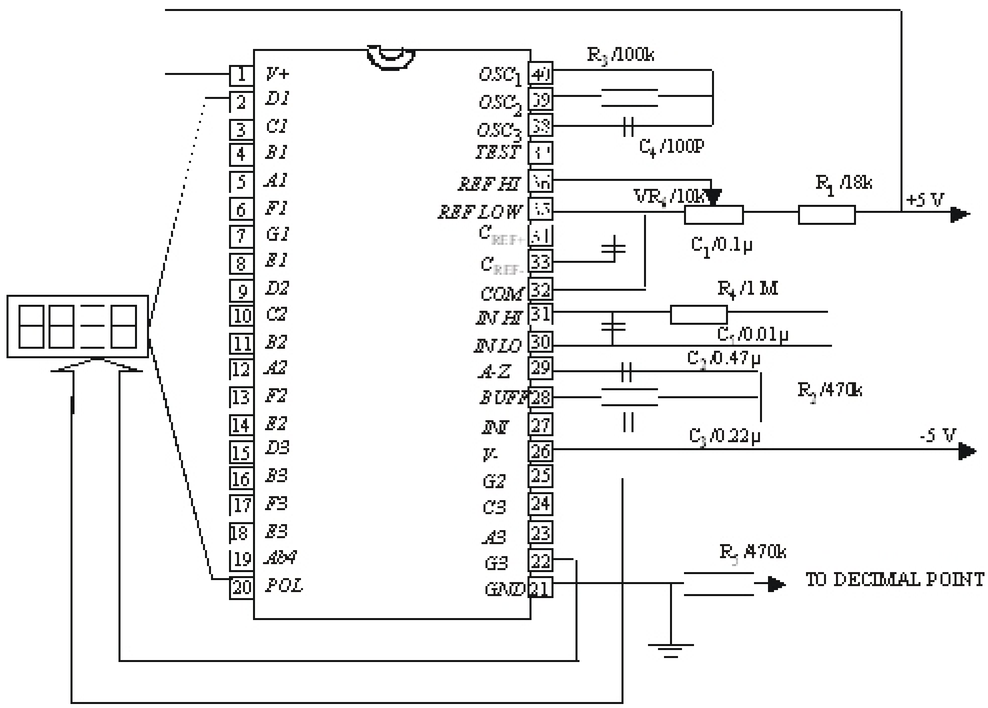

Fig. 2: The ICL7106 with Liquid Crystal Display

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 voltage is not at analog) and a 200mV 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.

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 20 μA of drive current with negligible non-linearity. The integrating resistor was high 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 ICL7106 while using the analog common.

Statistical Analysis: Runoff data obtained from both the digital runoff meter and cylinder measurements were subjected to statistical analysis and the corresponding coefficients of determinations from linear and quadratic models were generated. The standard error SE from the linear and quadratic models was determined to suggest which of the model is best under the prevailing soil and climate condition.

RESULTS AND DISCUSSION

Performance Test and Calibration of Runoff Meter: The result of the calibrations carried out on the runoff sensor equipment is presented in Fig. 3–6. The sensor reading increases with increase in water depth in the runoff storage tank. However, water depth from zero to 7499 ml in the runoff storage tank (RST) was not enough to lift the sensor arm and hence, no sensor measurement was recorded until the 7500 ml depth of water in the tank. The corresponding sensor measurement at the instance of 7500 ml was 8002.1 ml, while at the 40000 ml level; the sensor reading was 41083.85 ml during the first calibration exercise. The minimum and maximum sensor readings during the second calibration were 7965 and

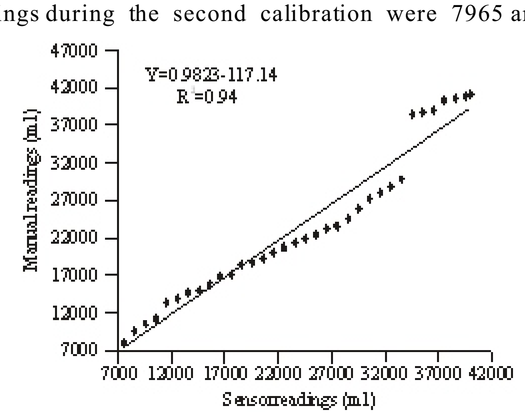

Fig 3: Runoff curve during the Ist calibration of the digital sensor (linear fit)

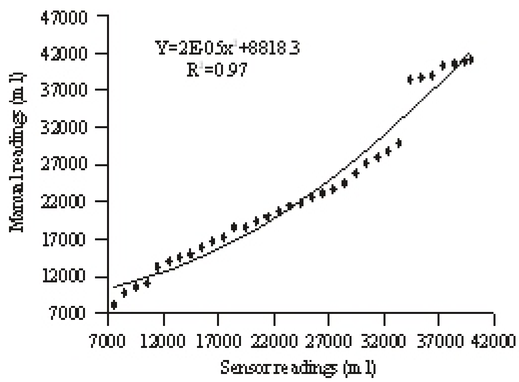

Fig. 4: Runoff curve during the Ist calibration of the digital sensor (quadrartic fit)

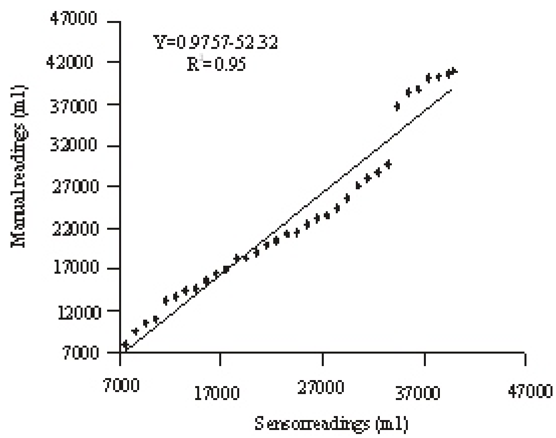

Fig. 5: Runoff curve during the second calibration of the digital sensor (linear fit)

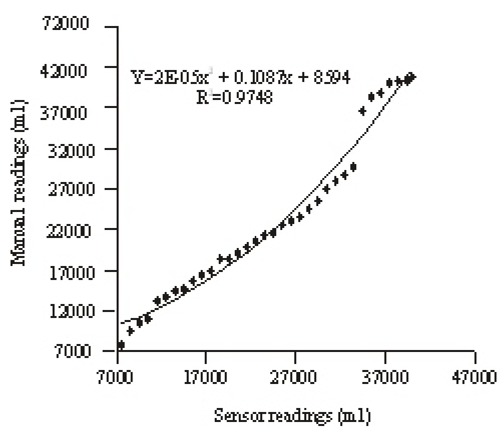

Fig. 6: Runoff curve during the second calibration of the digital sensor (quadrartic fit)

40945.76 ml, respectively. The coefficients of variation (CV) of sensor readings during the first and second calibrations were 42.82 and 42.58%, respectively, comparatively with the lower coefficient of variation (41.41 %) obtained under the cylinder measurement.

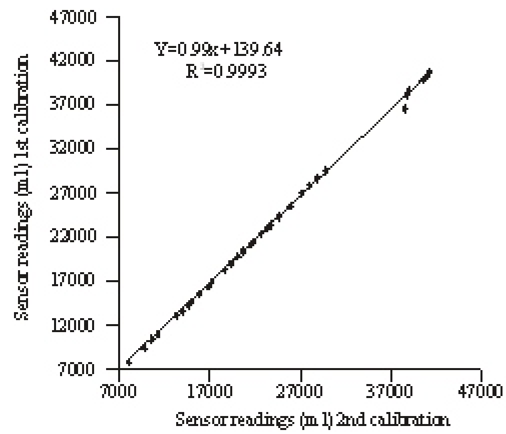

Fig. 7: Regression curve of the 1st and 2nd calibration of the digital sensor

However, the difference in CV is not significant at $p < 0.05$.

A regression of the cylinder and the sensor readings during the first calibration suggest that there were no significant difference at the $p = 0.05$ and $p = 0.01$. However, the difference were highly significant at $p < 0.0001$, with r (Pearson) = 0.97 from the linear fit (Table 1). However, the quadratic fit gave a slightly higher Pearson coefficient of correlation (r) = 0.98. Similar observations were recorded during the second calibration. The linear and quadratic fits gave r = 0.97 and 0.98, respectively.

The relationship between observed sensor readings during the first and the second calibrations gave a high coefficient of determination $r^2 = 0.99$ (Fig. 7), which almost approach unity.

The regression plot so obtained reflects the consistency level of the sensor equipment in the measurement of runoff. Re-sampling t-test of the first and second calibrations in ten simulations showed that the measured general average and deviation were 23397.01 ml and ± 95.13, respectively. The statistically simulated general average and deviation were 24097.43 ml and ± 79.61, respectively.

CONCLUSION

The design analysis, and construction of digital sensing devices for runoff measurement has been presented. It consist of runoff catchment 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 was performed such that the initial water level in the runoff storage tank must reach 7500 ml to activate the sensor. The use of digital ICL7106 analog to digital

Table 1: Summary of calibration statistics for the manual and sensor measurements

	1st calibration			2nd calibration		
Statistics	Manual		Sensor	Manual		Manual
Minimum (ml)	7500		8002.1	7500		7965
Minimum (ml)	40000		41083.85	40000		40945.76
CV%	41.41		42.82	41.41		42.58
SE	1703.58		1721.82	1703.58		1705.18
r^2		0.94			0.95	
r(Pearson)		0.97*			0.97*	
(p)		<0.0001			<0.0001	
RE		Y=1440.12+0.962X			Y=1246.86+0.974X	

converter for measuring the amount of runoff at all period of time brings together an accuracy, versatility and economical method of estimating runoff.

Nomenclatures:

ICL7106	Integrated Circuit 7106
A/D	Analog to Digital
CMOS	Complementary meta-oxide Semiconductor
V_r	Reference Voltage
R_i	Internal Resistance
LCD	Liquid Crystal Display
PC board	Printed Circuit Board
C	Capacitance
V_{in}	Input Voltage
RST	Runoff Storage Tank

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