Development of a Digital Recording System for Automation of Class A Evaporation Pan Measurement

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ABSTRACT

Adapting a sensor for automation of pan evaporimeters will increase reliability and accuracy of evaporation measurements especially in areas where data reliability is questionable. This research was aimed at developing and calibrating a digital recording (water level sensing device) system for use with Class A pan. A simple quadratic equation (calibration curve) was fitted between the sensor's recorded depth and manually recorded depth ($R^2 > 0.98$; $F = 4388$; $P < 0.0001$). The system performance was evaluated on the basis of its accuracy in measuring water depth when compared with readings from manual observations. Two accuracy parameters, correlation coefficient (R) and mean bias error (MBA) were used to indicate this accuracy. A high $R > 0.97$ and MBA of 0.19 mm/day was obtained between the digital sensor values and manual readings of pan evaporation for the months of March while $R > 0.97$ and MBA of 0.15 mm/day was estimated for the month of April. The high correlation coefficient between pan evaporation values from digital sensor and the Manual method is an indication of the accuracy and sensitivity of the developed digital recording system for Class A pan evaporation measurement. The result of this study offers an opportunity for a near real-time evaporation measurement.

Keywords: Pan evaporation, automation, irrigation scheduling, sensor, climate, Nigeria

1. INTRODUCTION

Accurate measurements of environmental variables such as rainfall, runoff, soil moisture, evaporation rates, minimum and maximum temperatures, etc., are essential aspect of agrometeorologial research that is important in agricultural related issues. Evaporation is an important climate element as it affects both plant and animal life and is a major factor in man's comfort and well-being (Purvis, 2006). Design of irrigation systems and scheduling of irrigation requires information on evaporation rates to the atmosphere as well as transpiration from plants. Evaporation pans can be used to indicate the rate of crop water use (Smajstrla et al., 2000). Data from evaporation pans are a great tool to study climate and this has been done by several researchers (Brutsaert and Parlange, 1998**;** Linacre, 2004; Liu et al., 2004; Roderick and Farquhar, 2004) Pan Evaporation is a measurement that combines or integrates the effects of several climate elements: temperature, humidity, solar radiation, and wind (Allen et al., 1998; Al-Ghobari, 2000).

Of the many avenues for water loss, evaporation remains the most important in most part of Nigeria. However, routine measurement of evaporation in Nigeria still suffers from poor coverage and non-uniform instrumentations (Owonubi and Olorunju, 1991). Some weather stations include measurements of the evaporation from a US Class-A pan as recommended by the Federal Department of Meteorology in Nigeria. But most places are without such measurements, and, even where there is a pan, the measurements may be smeared by poor maintenance, leading to errors due to leaks, the growth of algae in the water, an incorrect water level, weed-growth nearby, un-reliable attendants, and so on.

Recently, precision agriculture technologies have made significant advances in the area of irrigation scheduling, especially in developed countries, where equipment for continuous monitoring of climatic conditions is now available to help producers determine how much water to apply and when to apply it. Phene (1992) and Phene (1995) showed that frequent measurement of evaporation rates from an automated Class A evaporation pan can accurately estimate ET and be used as an irrigation scheduling tool. Key to Phene's work is the finding that ET data is more accurate when the water level in the pan is measured hourly making it possible for real-time irrigation scheduling of crops with an automated pan evaporation system.

However, Investments in such espensive automated system is more risky in the cash-strained economic realities of African farmers. Therefore, the use of electronic level sensors for automation of pan evaporimeter has been given little or no attention in this region. This project stems from the need for a more accurate method of measuring evaporation as well as better estimate of crop water use. Availability of automated system will minimize the incidence of human error in the measurement of evaporation from the pan evaporimeter and provide avenue for real-time irrigation scheduling. Therefore, the objective of this study was to develop and calibrate a cheap electronic device for water level measurement for use with Class A pan.

2. MATERIAL AND METHODS

2.1 Description of class A pan

A Class A evaporation pan is cylindrical with diameter of approximately 121 cm and 25 cm deep. Usually was made of twenty-two (#22) gauged galvanized metal sheet and mounted on an open frame with its bottom 15 cm above the ground. A typical Class A pan evaporimeter is shown in Figure 1. The pan rests on a carefully leveled, wooden base and is often enclosed by a chain link fence to prevent animals drinking from it. Evaporation is measured daily as the depth of water (in mm) evaporates from the pan. The measurement day begins with the pan filled to about 5 cm from the pan top. At the end of 24 hours, enough water is added, in measured increments, to again fill the pan to initial level from its top. If precipitation occurs in the 24-hour period, it is taken into account in calculating the evaporation. Sometimes precipitation is greater than evaporation, and measured increments of water must be dipped from the pan.

Figure 1. A typical class A evaporation pan (www.novalynx.com)

2.2 General description of the digital sensor

The direct display drive (ICL7106) is a high performance, low power 3½ digit analog to digital converter. All the necessary active devices are contained on a single CMOS, including seven segment decoders, display drivers, reference and clock. The ICL7106 was designed to interface with a liquid crystal display (LCD) and include a back plane drive (Cox, 1988).

The digital device, ICL7106 brings together a combination of high accuracy, versatility and low-cost; high accuracy like auto-zero to less than 10µv, zero drift to less than 1Nu/c, input bias current of 10 pA maximum, and roll over of less than one count. The versatility of true differential input and reference is useful and advantageous when measuring load cells, strain gauges and other bridge-type transducers. The true economy of a single power operation (7106) enables a high performance panel meter to be built with the addition of only seven (7) passive components and a display. The resistance (R) varies according to the level of water in the pan. It divides the reference voltage (2v) in ratio to the value of the internal resistance (R_i). This varying voltage is now converted to digital readout by the A/D converter. The schematic representation of the ICL7106 is shown in Figure 2.

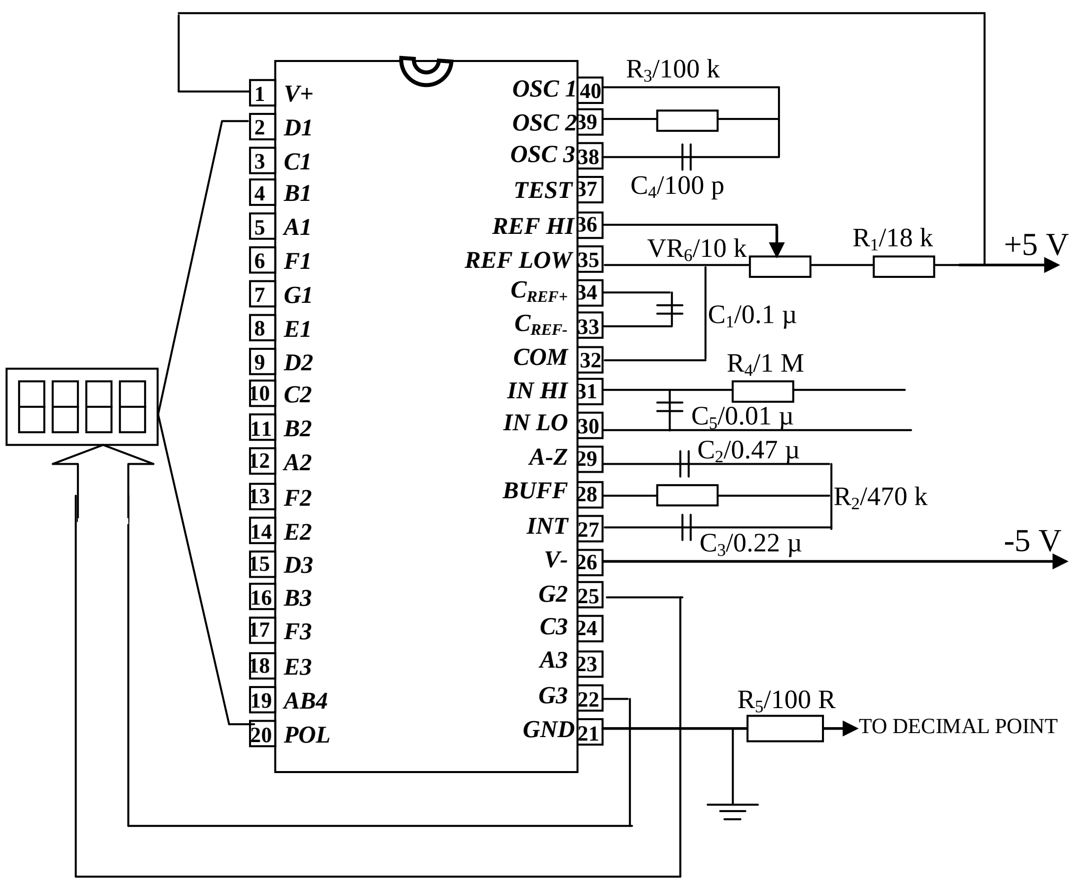

Figure 2: The ICL7106 with liquid crystal display

An internal digital ground is generated from a 6v zener diode and a large P-channel source follower in the digital section of the ICL7106. This supply is made stiff to absorb the relative large capacity currents where the back plane (BP) voltage is switched. The BP frequency is the clock frequency divided by 800 dings per second (Cox, 1991), this s a 60Hz square wave with nominal amplitude of 5v. The segments are drives at the same frequency and amplitude are in phase with BP when "OFF", but out of phase when "ON". In all cases negligible DC voltage exists across the segments.

A circuit was built, as shown in Figure 3, and connected to pin 38 of the ICL7106 in order to generate a stable reference voltage for the divider (sensor). The entire system was powered by two 9-volt batteries. The first battery provided power to the circuit while the second powered the LCD and provided the reference voltage. The sensor being a resistive-type acted as a voltage divider. Initially, the pan is at zero level and the entire system is having a voltage of 2 volts across it, which is the reference voltage, and the output at the display end is 00.0. As water level in the pan decreases due to evaporation, the arm of the sensing device moves and this movement accentuates a slider moving across a coil of thin wire. The resistance in the coil varies according to the position of the slider and thus the movement of the slider causes a change in resistance, which in turn causes the voltage across the system to change. The ICL7106 being an A/D (Analog to Digital) converter then converts the new voltage from electrical impulses to a digital display.

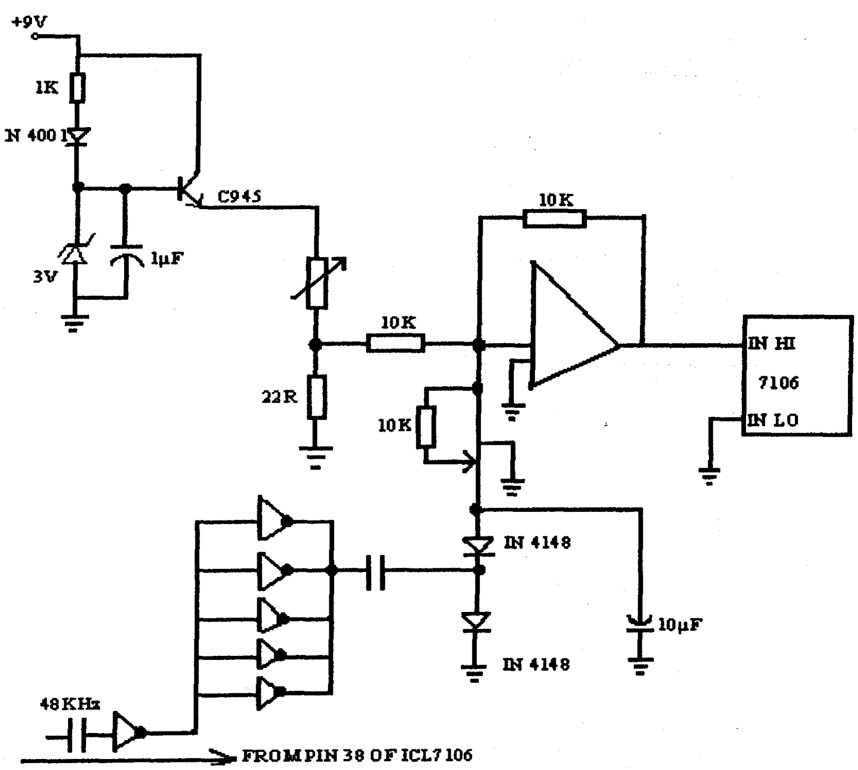

Figure 3: The built and connected circuit

2.3 Calibration procedures for the digital sensor

The calibration procedure is as follows:

i. The pan was filled to its maximum allowable level (zero level) where the reading on the LCD was 0.00
ii. The water level in the pan was gradually reduced by 1 mm pan depth for every 2.5cm^3 of water removed from the pan and the LCD output taken at each 1 mm depth.
iii. The results obtained were plotted on a graph and a calibration curve fitted between manual and sensor readings of water depth in the pan.

2.4 Performance evaluation

The performance of the developed digital sensor was evaluated to ascertain its accuracy and sensitivity in measuring pan evaporation (*Ep*). The digital values obtained were first converted using the calibration equation and then compared with the *Ep* values obtained from manual measurements for the months of March and April 2005. Statistical analysis, to determine the degree of associations between data obtained from sensor and manual readings are correlation coefficient (*R*) and mean bias error (*MBE*). These were used to indicate the sensor accuracy. *MBE*, which quantifies the bias of the measurements, was computed as:

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(Ep_i^* - Ep_i) \qquad (1)$$

where Ep_i^* is the sensor value and Ep_i is the manual value. *MBE* should be close to zero for unbiased sensor reading, while the value of *R* explains the degree of associations between the measurements. Correlation *R* ranges from 0 to 1 and the closer to unity the better.

3. RESULTS AND DISCUSSION

Calibration curves based on linear regression equation are shown in Figure 5A while Figure 5B 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 $R^2 > 0.96$ 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 both linear fits showed high accuracy with their R^2 not statistically different from that of the quadratic model, the values of standard error (0,111 mm and 0,150 mm) are higher making them inferior to the non-linear equation which has *SE* of 0.079 mm. Linear model starting from the origin is theoretically preferred over the other since no negative water depth was observed. However, this equation will lead to high errors especially at water depth below 2.5 mm as revealed by the scatter points away from the trend line of Figure 5A (dashed line). Given the foregoing, calibration curve based of the quadratic model was adjudged best and then adopted for this electronic water level sensor.

Table 1: Summary of calibration statistics

S/N	Model	#Overall Statistics		
		R^2	Standard error	Sig. level
1	Linear with intercept	0,9796	0,111	< 0.0001
2	Linear without intercept	0,9613	0,150	< 0.0001
3	Quadratic	0,9897	0,079	< 0.0001

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

The performance was further validated by measuring *Ep* simultaneously with the sensor and manually for the months of March and April. *Ep* obtained from digital sensor conversion using the quadratic calibration equation were very similar to values from manual measurement as shown Figures 5 and 6, 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/day and 0.15 mm/day, respectively and the correlation coefficients were very high (R > 0.97) for both datasets.

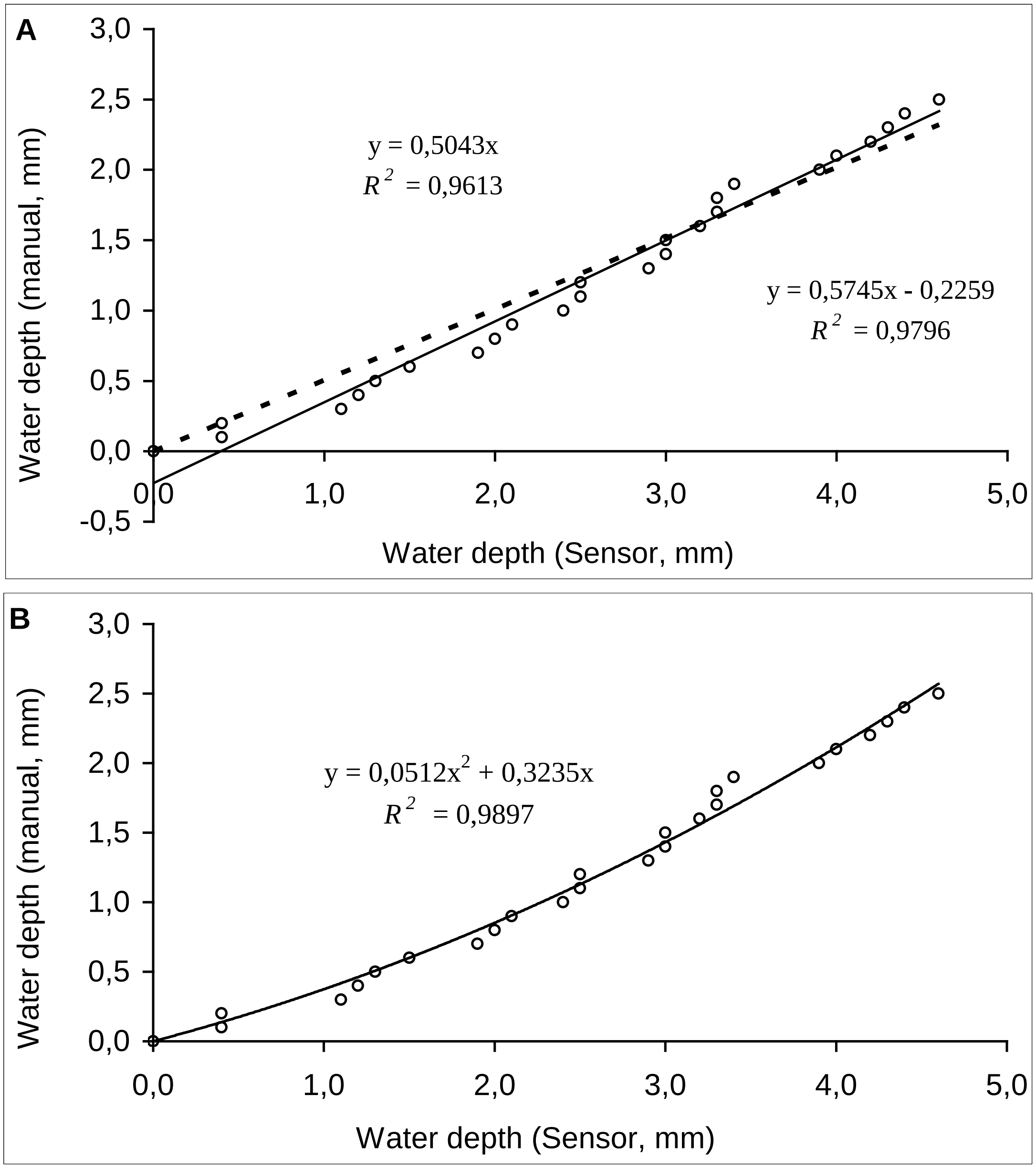

Figure 4: Calibration curves for digital sensor (A) linear fits with intercept (solid line) and without intercept (dashed line); and (B) quadratic fit without intercept.

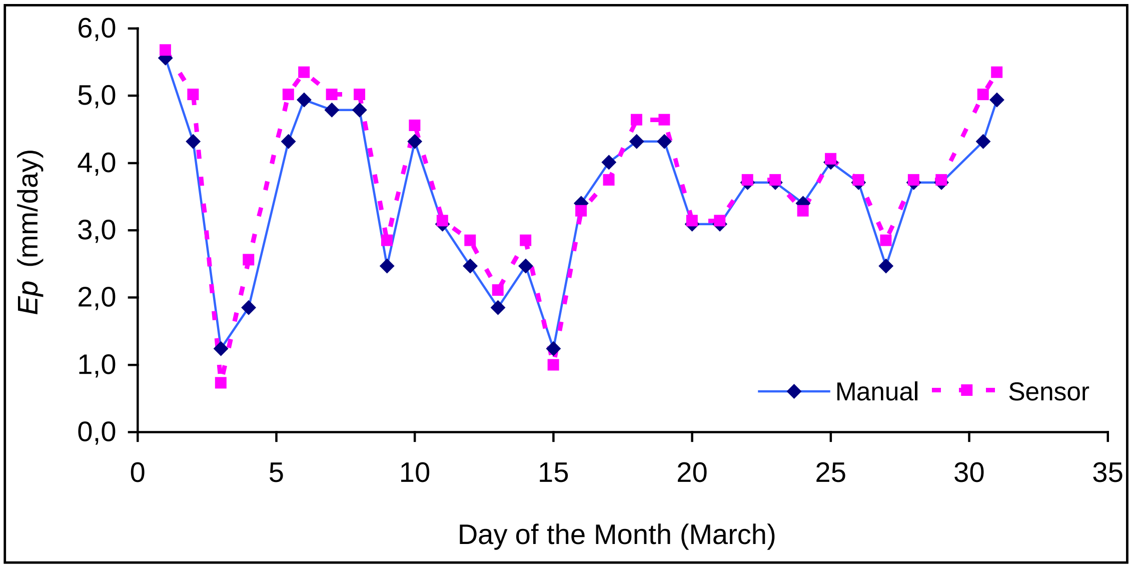

Figure 5. Pan evaporation (*Ep*) measured with digital sensor and manually in the month of March 2005.

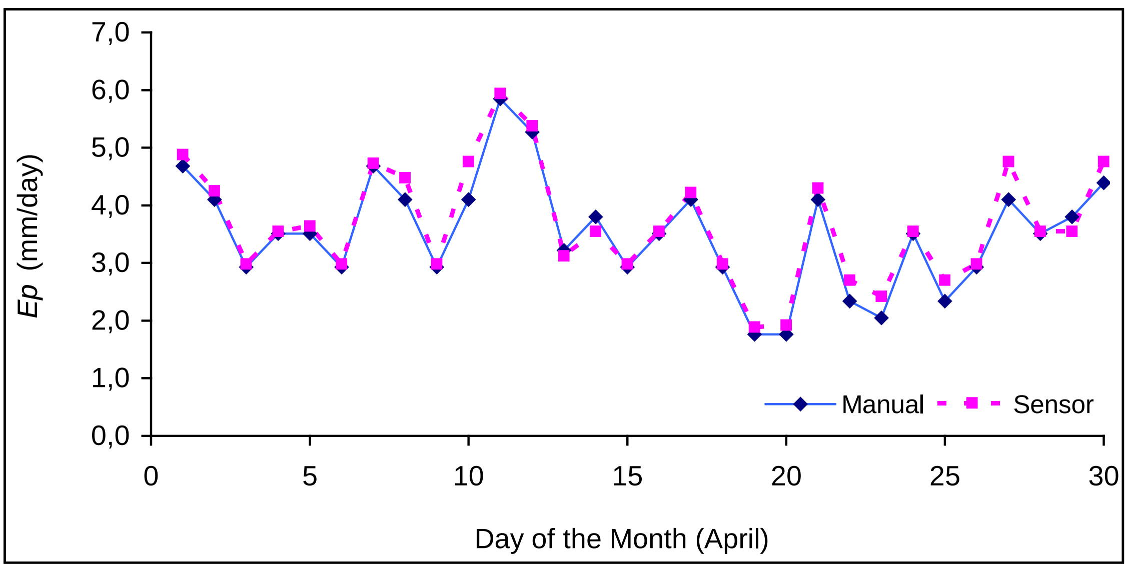

Figure 6. Pan evaporation (*Ep*) measured with digital sensor and manually in the month of April 2005.

4. CONCLUSION

A digital electronic device was developed and calibrated for use in evaporation measurement with Class A pan evaporimeter. A quadratic calibration curve of the form:

$$Ep = 0.0512\mathrm{Ep_s}^2 + 0.3235\mathrm{Ep_s} \pm 0.079, \qquad R^2 = 0.989 \qquad (2)$$

was fitted for the digital sensor. Where *Ep* is the actual pan evaporation and Ep_s is the sensor reading. Observations from two months of experimentation indicated that the digital device has a high degree of accuracy, easy to use and reduces the time spent on field when compared with manual method. The digital water level sensor presented offers opportunity for near real-time measurement of evaporation and/or possibility of remote logging. However, improvement is required especially to incorporate an automatic re-fill mechanism to the present design.

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