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Original paper

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

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ABSTRACT: Accurate tracking of open-water evaporative losses is increasingly important, with anticipated climate shifts toward more prolonged and more severe droughts. Adapting a sensor for the automation of pan evaporimeters will increase the reliability and accuracy of evaporation measurements, especially in areas where data reliability is questionable. This research is aimed at designing, fabricating and testing a Class A pan digital recording (water level sensing device) system for laboratory use. The system includes a mobile app for monitoring and retrieving logged data, a logger system and user interface, an online database, and water level sensor monitoring. Along with sensors and a router, this system will be developed using the MCU ESP32 Micro-controller. When compared to results from manual observations, the system's accuracy in monitoring water depth will be used to assess its performance. This study's findings should make it possible to assess evaporation almost instantly.

Keywords: Evaporation, Evaporimeter, Evapotranspiration, Automation, Irrigation water management, Smart Agriculture

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INTRODUCTION

The Class A Evaporation pan is utilized to measure water movement from the surface of the soil. It is regularly assembled on a wooden platform set on the ground in an open area. The pan is filled with water and presented to address an open waterway. The pan is filled to the datum in the fixed-point gauge. The evaporation rate can be measured by hook gauge or by refilling to the datum in the fixed-point gauge.

Accurate measurements of ecological factors, for example, precipitation, overflow, soil moisture, evaporation rates, minimum and maximum temperatures, and so on are a fundamental part of agrometeorological research that is significant in agricultural-related issues. Evaporation is a significant environmental component as it influences both plant and creature life and is a central point in man's solace and prosperity (Purvis, 2006). Plan of irrigation frameworks and booking of irrigation requires data on evaporation rates to the air as well as happening from plants. Evaporation pans can show the pace of crop water use (Smajstrla et al., 2000). Information from evaporation pans is great tool for studying climate, and this has been done by a few specialists (Brutsaert and Parlange, 1998; Linacre, 2004; Liu et al., 2004; Roderick and Farquhar, 2004). Evaporation Pan is a measurement that consolidates or incorporates the impacts of a few environmental components: temperature, dampness, sun-powered radiation, and wind (Allen et al., 1998; Al-Ghobari, 2000).

Of the numerous avenues for water loss, evaporation is foremost in Nigeria. In any case, routine measurement of evaporation in Nigeria actually experiences setbacks in coverage and non-uniform instrumentations (Owonubi and Olorunju, 1991). A few weather stations incorporate measurements of the evaporation from a US Class-A pan, as suggested by the Government Division of Meteorology in Nigeria. Be that as it may, most places are without such measurements, and, even where there is a pan, the measurements might be spread by unfortunate support, prompting blunders because of releases, the development of green growth in the water, a mistaken water level, weed-development close by, un-dependable orderlies, etc.

As of late, precision agriculture advancements have made considerable advances in irrigation scheduling, particularly in developed nations, where hardware for consistent observing of climatic circumstances is presently accessible to assist producers with deciding how much water to apply and when to apply it. Phene (1992) and Phene (1995) showed that continuous measurement of evaporation rates from an automated Class A evaporation pan could precisely gauge ET and be utilized as an irrigation planning device. The key to Phene's work is observing that ET information is more precise when the water level in the pan is estimated hourly, making it feasible for continuous irrigation booking of crops with a robotized pan evaporation framework.

However, Investments in a such expensive automated system is riskier in the cash-strained economic realities of African farmers. Therefore, the use of electronic level sensors for automation of pan evaporimeters has been given little or no attention in this region. This work stems from the need for a more accurate method of measuring evaporation as well as a better estimate of crop water use. The availability of an automated system will minimize the incidence of human error in the measurement of evaporation from the pan evaporimeter and provide an avenue for real-time irrigation scheduling.

Accurate measurements of environmental variables such as rainfall, runoff, soil moisture, evaporation rates, minimum and maximum temperatures, etc., are essential aspect of agrometeorological 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).

Irrigated agriculture utilizes massive sum of water. Subsequently, a significant liability lies with irrigation directors to utilize the water productively. A massive amount of water is lost as evaporation and transpiration from the fields. Evaporation and transpiration typically co-occur, and it is difficult to isolate the two cycles. To coordinate the irrigation supply with request, an assessment of the evapotranspiration is expected to be finished with proper techniques, which can give sensibly great exactness. FAO introduced two distributions to portray different models for assessing crop water prerequisites (Doorenbos and Pruitt, 1977; Allen et al., 1998). In view, of the new improvement in information acquisitions, and methods to show soil water crop cooperation, the choice of fitting model necessities the comprehension of the capacities and limits of each accessible model. In this section, survey is finished, of the more significant part of the broadly utilized strategies accessible to gauge reference evapotranspiration, because of environment information. Focuses to be considered for the determination of fitting strategy are additionally proposed.

Evapotranspiration is the combined process through which water is lost by evaporation from the soil surface and the crop by transpiration. The crops require a fixed quantity of water to meet the water losses through evapotranspiration, for bumper crop production under standard conditions. Allen et al. (1998) in FAO-56 crop evapotranspiration (ETc), under standard conditions refer to crops that are disease-free, well fertilized. They are grown in large fields, under optimum soil water with excellent management and environmental conditions, to attain full production, under the given climatic conditions. ETc measurement is not easy and requires sophisticated, expensive equipment, and trained research personnel with varied range of systems.

Lanthaler (2004) reported measuring evapotranspiration using lysimeter. Phene et al. (1990); Cammalleri et al. (2010); Allen et al. (2011) and Evett et al. (2012) illustrated that evapotranspiration data, could be obtained from varied range of measurement systems, which included lysimeters, eddy covariance, Bowen ratio, scintillometry, sap flow, satellite-based remote sensing, direct modeling, and soil water balance, such as gravimetric, neutron probes, electromagnetic types of soil sensors, and time domain reflectometry etc.

Direct measurement techniques are not feasible for estimating evapotranspiration in large irrigated area. Mostly they are used for research purposes by trained personnel. Evapotranspiration is generally estimated, by using different methods, which requires measurements of climatological parameters.

Empirical and temperature based methods

Pan evaporation method

Evaporation pan measured the collective impact of temperature, radiation, wind, and mugginess on evaporation from a specific vast water surface. Cuenca (1989), an Allen et al. (1998) used evaporation pan information to change evaporation from the free-water surface with pan coefficient to assess expected evapotranspiration. This method showed that wrong representation of pan climate and nearby environment, could cause mistakes in the assessment of crop water utilize around give or take 40%.

Temperature based methods

Hedke (1924), Blaney and Morin (1942, Lowry and Johnson (1942), Thornthwaite (1948), Blaney - Criddle (1950, 1962), Phelan (1962), and Doorenbos and Pruitt, (1977) created strategy for regions, where accessible climatic information covered air temperature information as it were. A System for changing month to month k qualities, as a component of air temperature, will be created, is known as the SCS Blaney Criddle strategy. The Researcher included other meteorological factors to develop further a gauge of likely evapotranspiration, prevalently known as FAO, Blaney-Criddle strategy. Doorenbos and Pruitt, (1977) reasoned that the radiation technique would be more solid than Blaney Criddle in tropical areas, on little islands, or at high altitudes even if measured sunshine or cloudiness data were available.

The empirical and temperature-based methods have been used for estimating evapotranspiration for a more extended periods, i.e. monthly or weekly.

Radiation Methods

Evapotranspiration occurs only when energy is available, and hence estimation of solar radiation can give a better estimation of ET, by using the Energy Balance equation, which includes Rn (radiation from sun and sky), G (heat to ground), H (heat to air). Makkink (1957), Turc (1961), Jensen-Haise (1963), and Hargreaves-Samani (1985) proposed a formula for estimating ET from air temperature and sunshine or cloudiness or solar radiation. The Makkink equation will be the base of the following FAO 24 Radiation method. Despite of sufficient energy available, ET could be less due to aerodynamic resistance in the form of Wind speed and Humidity. As, for the atmosphere’s ability to remove water vapour, an 'aerodynamic' strength also plays a crucial role.

Combination Methods

Penman (1948, 1963) used the Bowen proportion standard. He determined a blend condition by combining two terms, one (radiation) term, which will be for the energy expected to maintain evaporation from the untamed water surface, and revitalizing burst of energy (and dampness) term for the environment's capacity to eliminate water fume, a 'streamlined' strength. Different scientists proposed alterations in the Penman condition. Wherein, Monteith (1965, 1981) stretched out Penman's fundamental idea to plants and cropped regions. Clerical and Taylor (1972) improved Penman's situation for moist conditions. Doorenbos and Pruitt (1975, 1977) changed the Penman technique with an updated breeze capability term, and a change for mean climatic information, for assessing reference crop ET. Wright (1982) changed the first Penman condition and adjusted 1982 Kimberly-Penman condition. Kizer et al. (1990) grew the hourly evapotranspiration expectation model, by aligning the Penman condition for a horse feed reference crop.

Allen et al. (1998) utilized the condition an hourly premise with the rs term, having a consistent worth of 70 s m-1 throughout constantly. They suggested the FAO-56 Penman Monteith technique as the sole standard strategy, for deciding reference evapotranspiration environments, mainly when information is accessible. Allen (2000) created the REF-ET program, which gave normalized reference evapotranspiration computations in various time ventures, for more than 15 strategies generally utilized, like Pan Evaporation, Temperature techniques, Radiation strategies, and Mix techniques.

Allen (2002) compared the seasonal reference evapotranspiration estimated by ASCE standardized Penman-Monteith, with 1982 Kimberly Penman and found the differences to be low.

Walter et al. (2005) developed a standardized reference evapotranspiration equation, which could be applied to two types of reference surfaces, alfalfa and clipped grass, for daily and hourly calculation time steps. The ASCE Standardized Reference Evapotranspiration Equation based on the FAO-56 Penman-Monteith equation was developed by the ASCE-EWRI task committee with aforesaid purpose. The equation is also recognized as the ASCE-EWRI standardized Penman-Monteith equation. Allen et al. (2006) reviewed the functioning of the FAO-PM method, using surface resistance parameter rs = 70 sm-1 in hourly time step, while using a constant rs = 50 sm-1 during day, and rs = 200sm^{-1} during night for hourly period.

MATERIALS AND METHODS

Design consideration

The Development of a Digital Recording System for Automation of Class a Evaporation Pan Measurement was carried out according to the functional blocks namely:

(i) Power supply unit
(ii) mobile app interface
(iii) Logger System (microcontroller section) and user interface

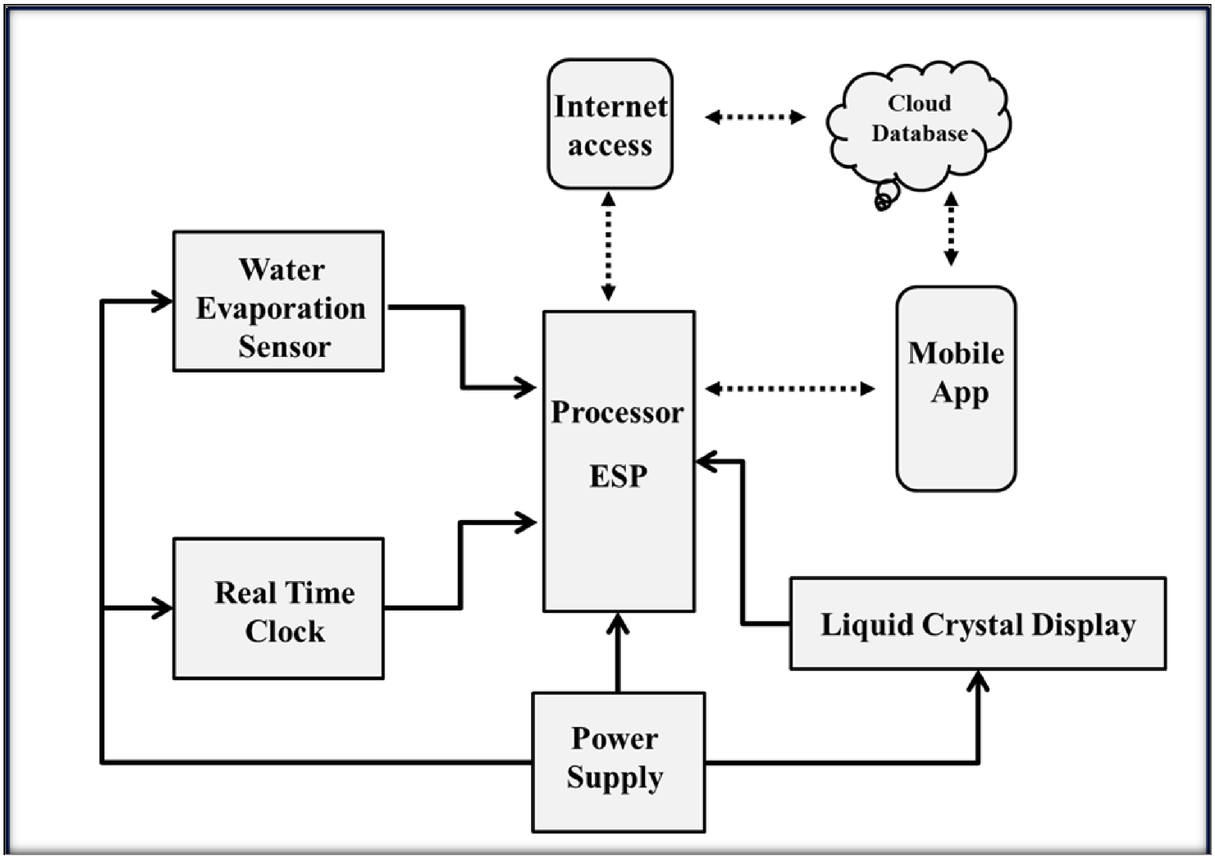


Figure1: Block diagram of Evaporation real time monitor and logger system.

Design of the power supply unit

The circuit comprises of several digital and analog components which require different operating voltages. The digital components work with +5volts, the ESP32 IC works with a voltage of +15volts. Therefore, for a perfect operation of our circuit, we will require operating voltages namely +5volts (Figure 1).

The power supply is comprised of a regulator which provide all the required DC voltages. C1 is an input capacitor while C2 is an output capacitor. The regulator used is a fixed voltage regulators which do not require any external component settings to regulate the output voltages. They are namely: 7805 for +5volts output voltage and 7812 for +12volts output voltage

However certain calculations must be made to determine the input and output capacitances.TR1 is a step-down center tapped transformer, it steps down the voltage from the ac mains from the typical 220 volts (AC) to two 15 volts (AC) output. BR1 is a full wave bridge rectifier arrangement. It rectifies the stepped down AC voltage to a dc level which has a peak value shown below.

$$Vpeak = Vsec \times 1.414 \quad (1.0)$$

$$Where\ Vpeak = 15 \times 1.414 = 21.21\ volts$$

However, the second half of the supply will give an equal but opposite voltage magnitude of -21.21 Volts. C3 are the input filter capacitors, whose value can be derived from the expression below.

$$Vripple = I/(f \times C) \quad (2.0)$$

Where

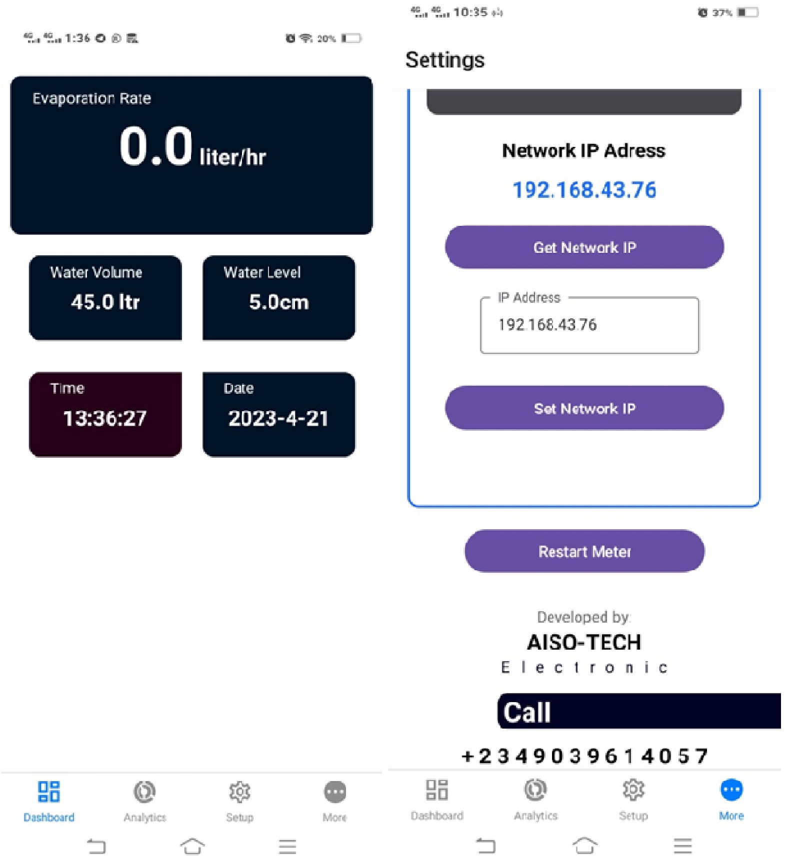
V_{ripple} = the ripple voltage
I = the maximum current drawn by the circuit
F = the frequency
C = the value of the input capacitance

A stiff design rule is to ensure that the ripple voltage is at least a third of the peak input voltage

This implies that $Vripple = Vpeak / 3$ (3.0)
= 21.21 / 3 $= 7.07\ volts$

The maximum current the circuit can draw is limited to the maximum current the regulators can supply, which is1.5Amps (ref. www.alldatasheet.com/ texas instrument/regulators).

The frequency of a full wave rectified voltage is normally



Evaporation Rate 0.0 liter/hr

Water Volume 45.0 ltr

Water Level 5.0cm

Time 13:36:27

Date 2023-4-21

Settings

Network IP Adress 192.168.43.76

IP Address 192.168.43.76

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Figure 2: Mobile App interface of the logger.

twice the input frequency of 50Hz i.e $2 \times 50Hz = 100Hz$

Substituting for f, V_{ripple} and I in the above equation yields

$$C = I / f \times (Vripple) = 1.5 / (100 \times 7.07) = 2121.64\,\mu F$$

Nearest preferred value for the input capacitances = 2200µF

C2 is the output capacitance; its function is to improve the transient response of the DC output voltages. It is typical to have an output rise time of about 50µsec for a micro-controller circuit. The rise time is dependent on the output capacitance and the output equivalent resistance of the voltage regulator.

To obtain a minimum rise time of 50µsec, we will design with reference to the voltage of least absolute value, which is 5volts. The equivalent output resistance for a 5volts fixed regulator, which can supply a maximum current value of 1.5

Amps is given as $R_{out} = 5 / 1.5 = 3.3\Omega$

$$Output\ rise\ time = R_{out} \times C2 \qquad (4.0)$$

Therefore C2 = 50µsec / 3.3Ω = 15.15µF

Nearest preferred value = 10µF; Therefore C1 = 10µF

The fixed voltage of +12 volts and +5 volts can be derived by placing the fixed regulators 7812 and 7805 respectively at the cathode ends of the bridge rectifier

Design of the android mobile app user interface

The Mobile App was design with android studio which as a user interface that allows one to calibrate the logger, settings network IP address for communication with the router, setting and resetting log interval time and also monitor the evaporation rate with the App (Figure 2).

Design of the Logger System (Microcontroller Section)

The logger system is the heart of the entire system.

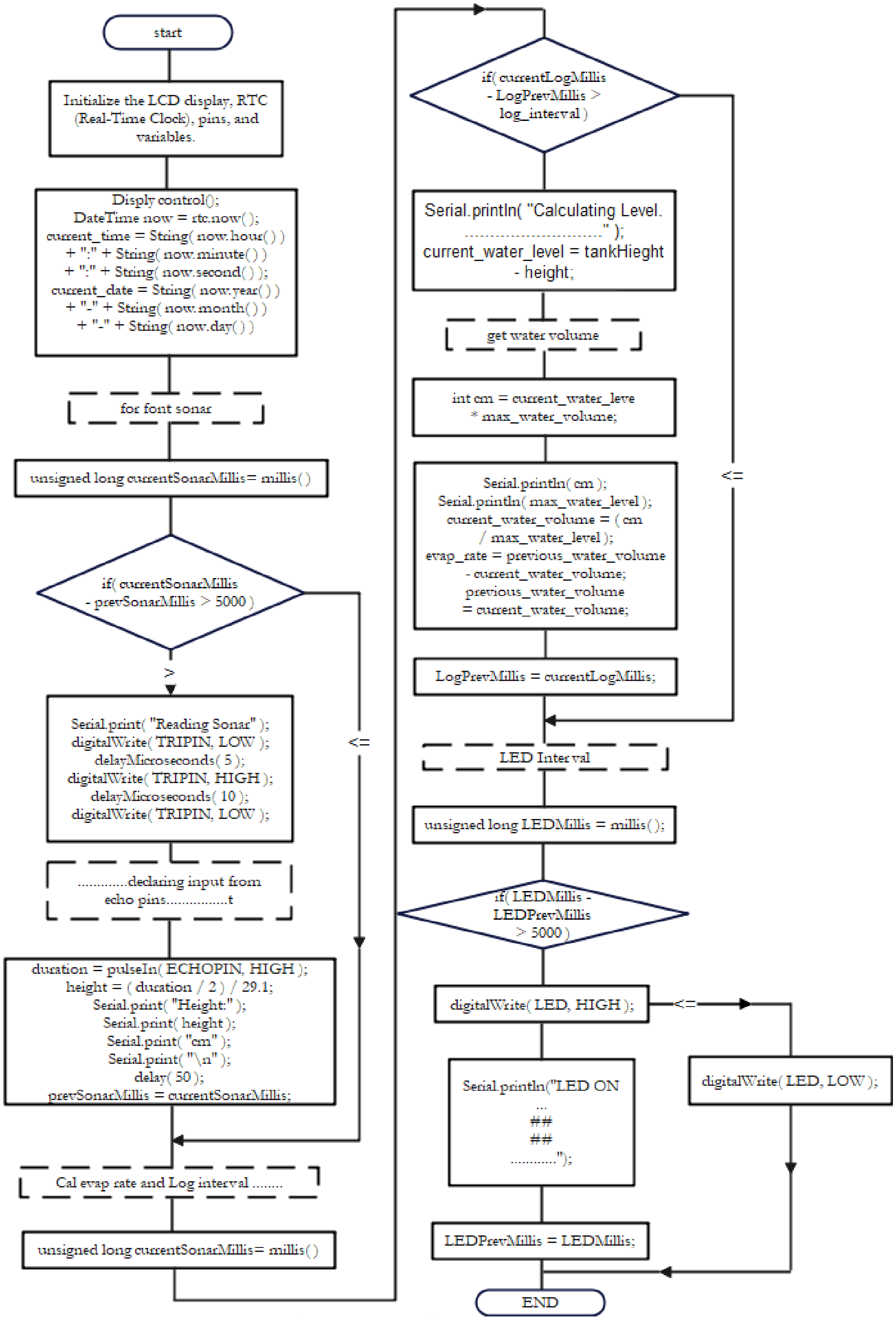


Figure 3: Flow chart diagram of the design of the digital logger system.

It coordinates all the actions between the block because it consists of the following: Microcontroller, LCD, DS1307 RTC and ultra sonic sensor. The microcontroller used is an Arduino ESP32 and it is driven by internal program. The following flowchart has adopted to realize he entire design (Figure 3).

The Design of the Evaporation 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

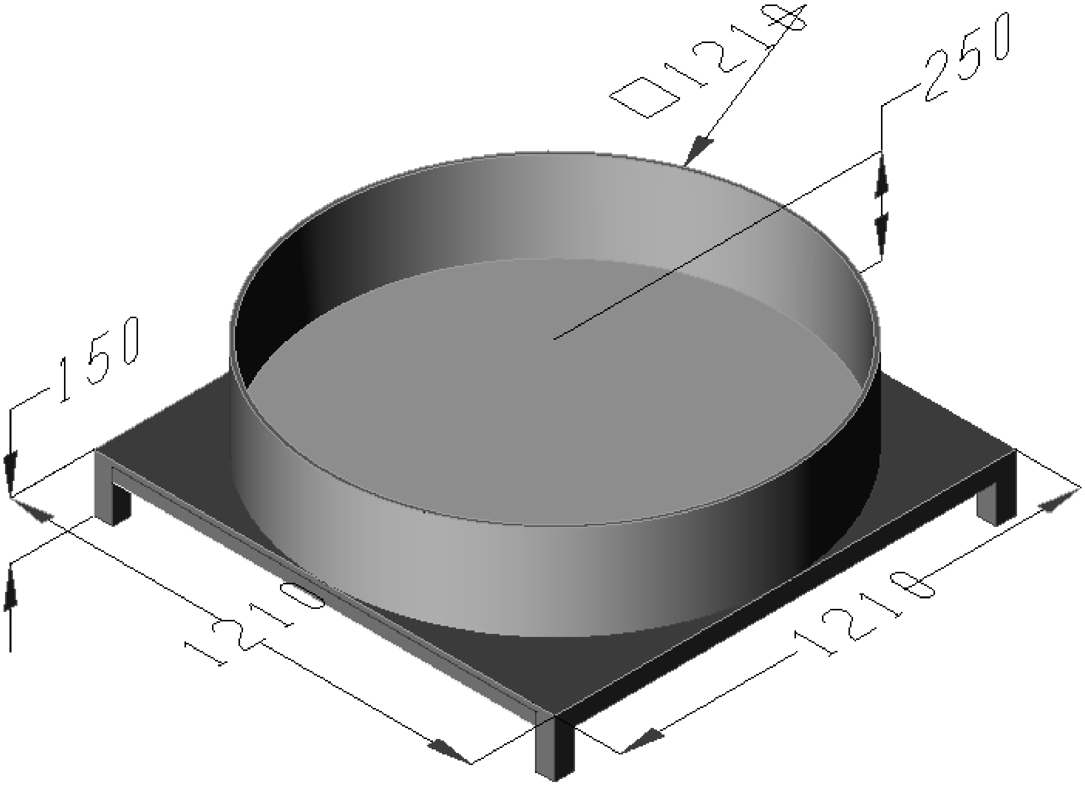


Figure 4: 3D view of evaporation pan

above the ground. A typical Class A pan evaporimeter is shown in (Figure 4). 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.

RESULTS AND DISCUSSION

After, design and construction of the digital evaporation logger system with its evaporation pan.

Procedure

(i) The evaporation pan was mounted on an open field on a stand 15cm above the ground.

(ii) The ultrasonic sensor was mounted on the evaporation pan and then connected to the logger system via a coaxial cable.

(iii) The evaporation logger system was turned on and the following setup was carried out using the android interface application from a mobile phone which interfaces with the logger system through a router.

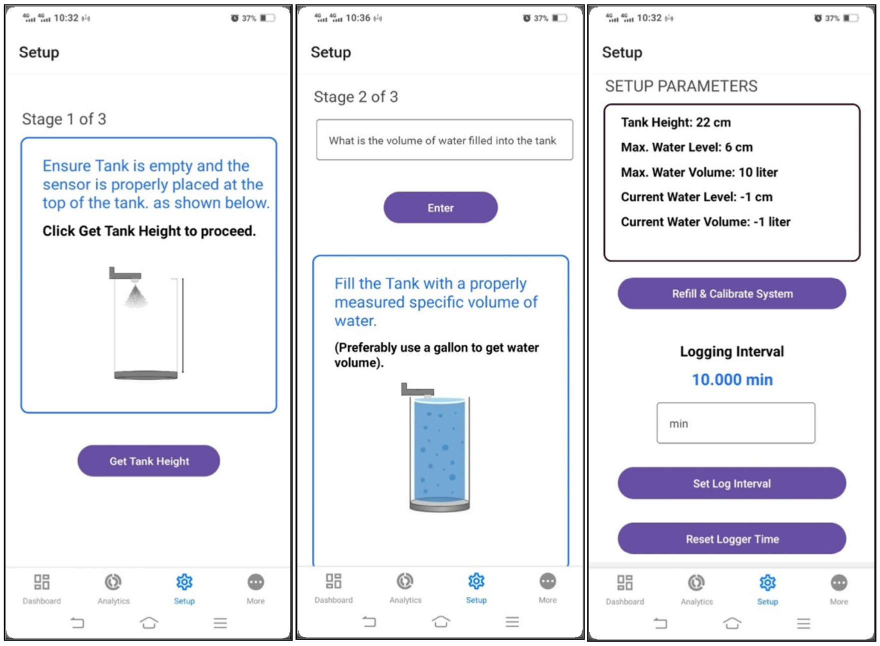
(iv) Water was poured into the evaporation pan to height of 60mm and the sensor having the capability to determine the current height of the water.

(v) The logger system was set to logging data obtained from the sensor every 1 hour when evaporation takes place.

(vi) Due to the time when test was carried out the following reading was obtained as the water level in the evaporation pan changes during evaporation.

The performance of the digital system 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 2023 (Figures 5-8). 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, will be computed as:

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



Setup

Stage 1 of 3

Ensure Tank is empty and the sensor is properly placed at the top of the tank. as shown below.

Click Get Tank Height to proceed.

Setup

Stage 2 of 3

What is the volume of water filled into the tank

Fill the Tank with a properly measured specific volume of water.

(Preferably use a gallon to get water volume).

Setup

SETUP PARAMETERS

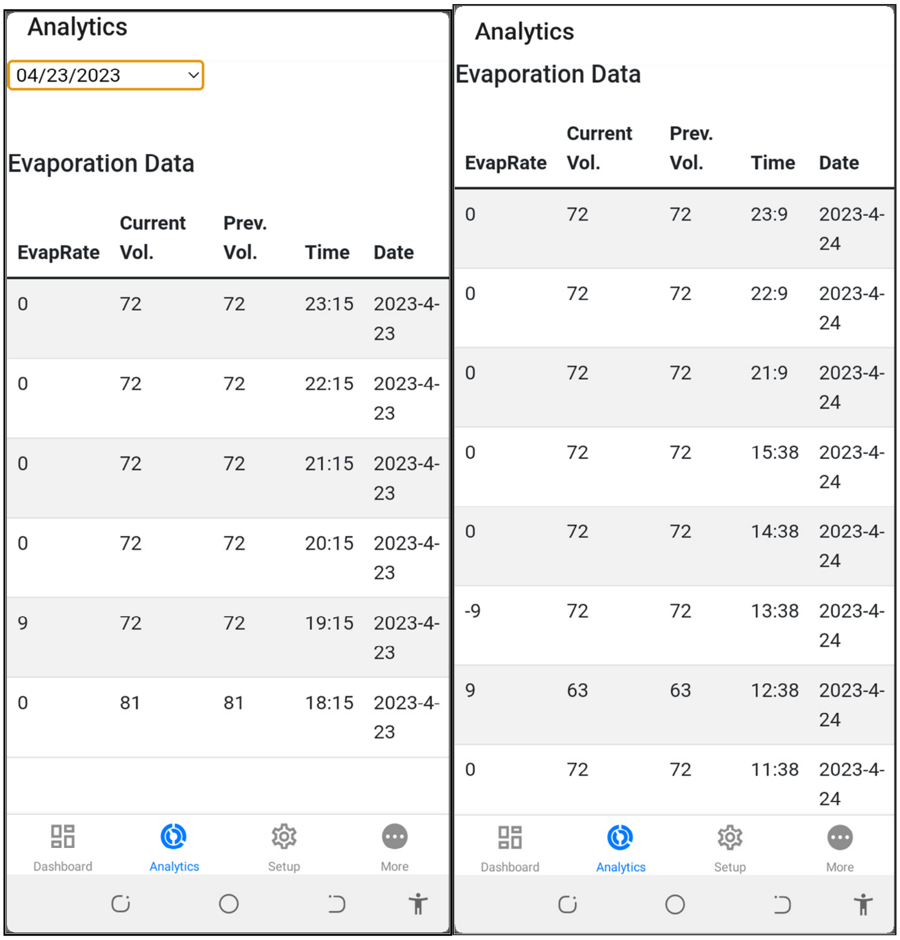
Tank Height: 22 cm
Max. Water Level: 6 cm
Max. Water Volume: 10 liter
Current Water Level: -1 cm
Current Water Volume: -1 liter

Logging Interval

10.000 min

min

Figure 5: Mobile app. GUI of evaporation logger app.



Analytics

04/23/2023

Evaporation Data

EvapRate	Current Vol.	Prev. Vol.	Time	Date
0	72	72	23:15	2023-4-23
0	72	72	22:15	2023-4-23
0	72	72	21:15	2023-4-23
0	72	72	20:15	2023-4-23
9	72	72	19:15	2023-4-23
0	81	81	18:15	2023-4-23

Analytics

Evaporation Data

EvapRate	Current Vol.	Prev. Vol.	Time	Date
0	72	72	23:9	2023-4-24
0	72	72	22:9	2023-4-24
0	72	72	21:9	2023-4-24
0	72	72	15:38	2023-4-24
0	72	72	14:38	2023-4-24
-9	72	72	13:38	2023-4-24
9	63	63	12:38	2023-4-24
0	72	72	11:38	2023-4-24

Figure 6: Result obtained from data logger mobile app.

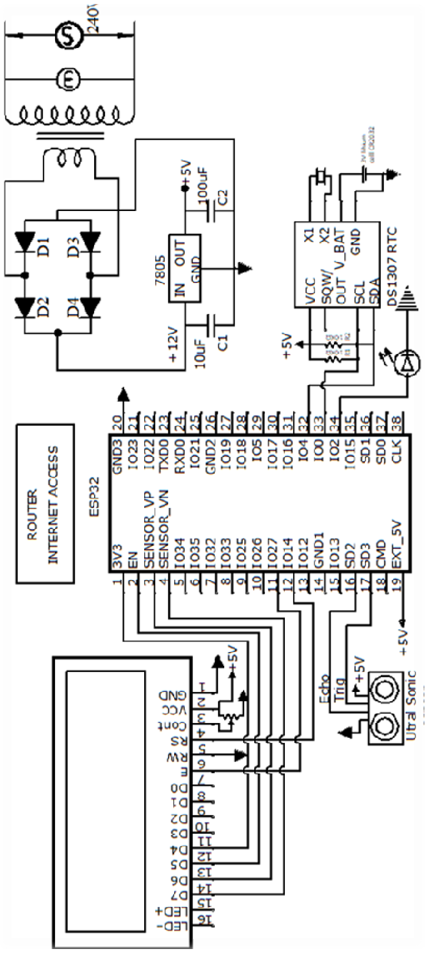


Figure 7: Circuit diagram of the Digital evaporation pan logger system.

Figure 8: 3Dview of digital evaporation pan with logger.

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.

Conclusion

1. More accurate data show evaporation rate was obtained as compared to manual data obtained. Especially a period when evaporation rate is rapid
2. The system design and constructed can be use for laboratory purposes to obtain evaporation rate.
3. The system enables a mobile monitoring of evaporation rate from any remote area since data obtained are sent to the internet through a router
4. They system will require constant power supply to enable effective evaporation rate data collection at real time.
5. The accuracy and effectiveness of the system will depend on highly sensitive ultrasonic sensor to sense very minimal change in water level in the pan.

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