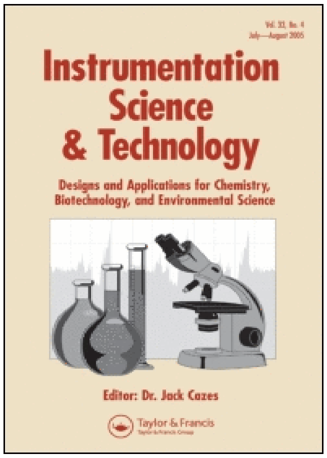

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A New High Precision Pluviometer System

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Abstract: The water present at the Earth's surface is explained by the hydrologic cycle concept. Precipitation in the form of rain, snow, or hail is the most important parameter of the hydrologic cycle. In order to evaluate the water budget in a basin that receives water by precipitation, it is necessary to quantify this precipitation. Based on the knowledge of the amount of precipitation, one may estimate how much of this water infiltrated to the soil or was added to the runoff, these parameters being of high importance for designing hydraulic structures. Agricultural activities, too, are planned on the basis of precipitation data. This kind of information is also of great interest nowadays for understanding and predicting the effects of a possible worldwide event, the global heating which directly affects the environment by land degradation and even desertification of very large areas. On the other hand, real-time functioning pluviometers play important roles on the prediction or warning systems for geologic hazards like inundation or avalanches.

This study deals with the construction of a simple, precise, highly economical, and automated pluviometer where the level of the precipitated water is measured with sensors. These sensors achieve the automated tasks to determine the initiation time of the precipitation and also to detect the level of the water column with the help of a simple electronic circuitry. The meter also comprises two electrical solenoid valves used to open and shut off the instrument. The working system uses an electronic card processed by a microcontroller, a time chip, and an EEPROM. The addition of a GPRS-RS232 inverter will provide a very cheap manner of communication on the Internet basis, and data will be transferred continuously each time precipitation is detected.

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Among the advantages of such a measurement system, the most important is its ability to inform the user on the precipitation conditions immediately and in detail for even the farthest stations. This will give the user the time to collect and interpret data so as to immediately intervene, if necessary.

Keywords: Pluviometer, Hydrology, Environmental monitoring, Climate

INTRODUCTION

Solid or liquid state waters coming from the atmosphere to the land are called precipitation. Pluviometers or rain gauges are the instruments that are used to measure the quantity of water (rain, sleet, snow, or hail) precipitated on a unit surface on land. This information is used 1) primarily on determining the water budget in basins and, consequently, on estimating how much of the precipitated water infiltrates (groundwater) to the ground or runs off (streams, rivers); 2) on predicting the floods and landslides that occur during and after heavy rains; 3) on agricultural, and 4) forestry applications; 5) global heating is a worldwide process mostly mentioned in recent studies as a serious risk for our planet. It is reasonable to expect variations in precipitations if temperatures are globally increasing at the surface of the earth. Measuring the precipitation and comparing the results with older data will be an indirect evidence to argue for global heating, whereas the precipitation data is of crucial value when studying the processes associated with land degradation.

Two types of pluviometers are widely used.[1–7] In the first type, named Weighting Rain Gauge, the weight of the precipitated water accumulated on a collecting surface (tray, bucket, etc.) is measured. In a second type, most widely used, the water collection apparatus, namely a Tipping Bucket Rain Gauge, mechanically discharges its contents once a certain water level is reached, and a mechanical counter is used to know the number of buckets discharged and the quantity of water collected. This type of gauge has the major disadvantage that the tipping of the bucket takes some time ($\sim$0.5 s), during which an amount of rainfall becomes unmeasured. To eliminate this effect, smaller buckets or calibrated/compensated gauges found applications, but the new versions also suffer form the difficulty of measuring the water that remains in the bucket. It appears that the existing gauges are not near to measuring the “true rain” (term used in Reference [2] see also references cited therein). There are also other tools used to estimate the height of the column of the precipitated water, using different sensors (capacitive, optical, acoustical).[4,5] Output of data from the meter is done either by user intervention or by sending data by communication means using cables, wireless systems, telephone, etc. In recent applications, systems that allow both possibilities are preferred.

In this account, we present a new rain gauge with higher accuracy with regard to the stability at the collection level, as well as the precision by which the precipitated solid/liquid state water is measured. The gauge may be used in hydrological domains for both nearby and remote applications, since data obtained may be extracted manually or transferred by e-mail and/or short messages.

EXPERIMENTAL

The automated rain gauge system developed in this study is illustrated schematically in Figure 1. We hereafter present its working principles.

At the beginning of the precipitation, the system initiates the measurement process when the rainwater reaches the main sensor (MS). This first signal causes the microcontroller to open the solenoid valve 1 (SV1) to ensure the rainwater to flow to the measurement bottle. This process is interrupted when the water rises to a certain level, detected by a fixed sensor (CS) on the bottle. At this time, the microcontroller closes the SV1, and opens a second valve (SV2) that discharges the known quantity of rainwater collected in the bottle out of the system and records this quantity in its memory. These operations are repeated until the precipitation ends and, at each discharge of the measurement bottle, the microcontroller renews the

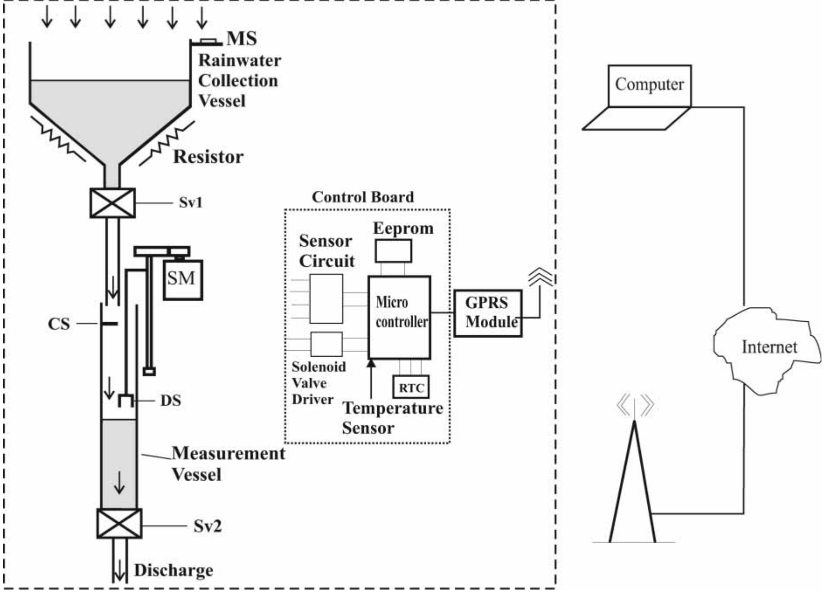

Figure 1. Schematic diagram of the automatic pluviometer system.

recordings. If rainwater does not reactivate the sensor CS for more than 5 minutes, the microcontroller considers this as the end of the precipitation, sends starting/ending time and quantity information to the external EEPROM that records the information. The system remains in standby state waiting for the next precipitation.

System Components

Rain Water Collection Vessel

The size of the water collecting vessel is one of the parameters that affect the sensibility of the measurement systems used to determine the precipitation quantities. If this size is small and if precipitation occurs in windy conditions, the collection is not efficient and the results contain errors. In larger sizes and in heavy rain cases, the speed of the tipping bucket to discharge the water remains small relative to the precipitating water; this induces measurement errors. In our case, the size of the water collection vessel, except for small sizes, does not influence the measurement sensibility. Even in case of heavy rains, the whole collected sample can be measured and, therefore, any size may be selected for the vessel. The present gauge uses a commercial funnel with a collection surface of 283.3 cm^2. If required, a larger vessel may be installed; this will not have any negative effect on the system function.

Measurement Vessel

A second parameter that affects the measurement results in pluviometer systems is the size of the measurement vessel. The quantity of water that remains in the vessel after the precipitation ends is another source of error. To minimize this error in tipping bucket pluviometers, the size of the measurement vessel, which is also the collection vessel, is maintained the smallest possible. But, at heavy rain precipitations, the speed by which the bucket comes back to its initial position to collect water remains small compared to the velocity of the rain to fill the bucket and errors up to 10% are estimated to occur.

In the present study, we use a measurement vessel of 30 mL volume. In conventional systems, this remaining part corresponds to the error of the measurement. If the precipitation is high, this amount may be considered as negligible but, in small quantities of precipitation, the error will be considerable. To overcome this, the remaining water is measured using a new, high sensitivity, electro-mechanical level detection system.[6] In this system, a simple stepper motor provides vertical displacements to contact electrodes to sense a liquid level. The number of steps executed by the motor is determined by a microcontroller that calculates the depth of the water present in the measurement vessel.

Control Card

In this study, the PIC 16F877 (peripheral interface controller) produced by the MicroChip Company is used as microcontroller for processes associated with system control, measurement, and data transfer operations. A schematic drawing of the control card is presented in Figure 2.

To precisely determine the measurement times, the DS1302 RTC clock chip, a product of the Dallas Semiconductor Company, is added to the circuit. To store the data collected, we use an external EEPROM, the 24LC256 of the Microchip Company.

The electronic circuit linked with the fluid level detecting sensor is designed by Tony Van Roon, available from the Internet site (fluid-level detector, http://www.uoguelph.ca/~antton/circ/sensor3.htm). The reason we use this circuit is that AC current is used at detection to prevent the electrodes from electrolytic corrosion. The detector works efficiently, even if the water contains small quantities of dissolved ions. In the present study, pure nickel wires are used as electrodes. The system comprises three sensors. The main sensor (MS) has the mission to sense the initiation of the

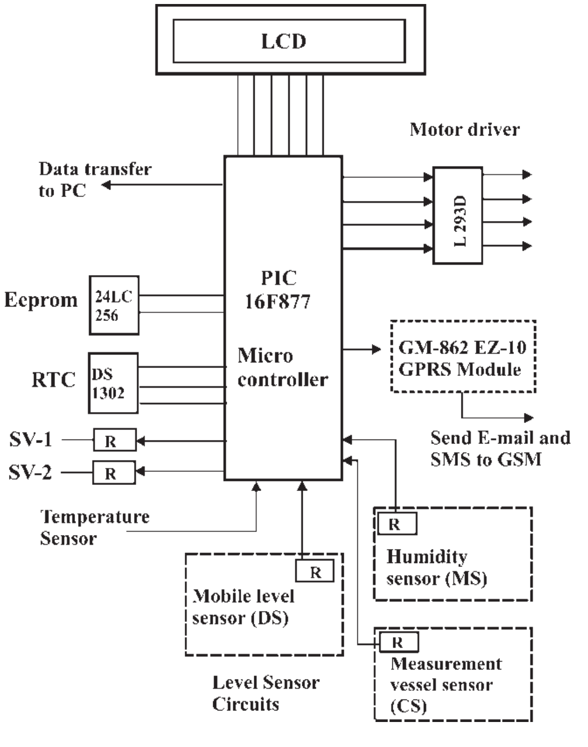

Figure 2. Schematic diagram showing the control card of the automated pluviometer.

precipitation; it reactivates a relay and informs the microcontroller that precipitation begins. It is from this point that the software loaded to the microcontroller begins to be executed. The second level sensor (CS) is fixed to detect a 30 mL volume in the measurement vessel. When water coming from the collection vessel reaches the level of the CS, a relay connects +5 V to a pin of the PIC 16F877. The pin logic becomes 1, meaning that the microcontroller now is informed that the measurement vessel is full and it accomplishes two operations on two different valves: it closes the valve SV1 to stop the measurement vessel to be supplied in rainwater and opens the valve SV2 to evacuate the water collected in the measurement vessel. The number of closures the valve SV2 experienced is recorded by the microcontroller and will be used in the calculation of the quantity of precipitation.

The third sensor (DS) is used in the moving part of the level detection system for the determination of the water quantity that remains in the measurement vessel at the end of the precipitation.

To drive the bipolar stepper motor, the integrated circuit L293D is used. There are three ways for the system to communicate the measurement data. Two of them are possible if the user is nearby. In this case, using the buttons on the LCD display, one may execute direct readings, where precipitation data recorded in the EEPROM can be seen from the most recent data to the older ones, progressively at each button touch. Another way to retrieve the data is by means of a portable computer linked with the pluviometer, where the data stored in the EEPROM memory is transferred to the computer in a few seconds.

We use the EZ–10 module of the TELIT Company that includes GM–862 GPRS chip for on-line data communication. At the end of the precipitation period and in the function of the intensity of the precipitation, the measurement results are sent to a known e-mail address or as a short message (SMS) to a known GSM telephone. The e-mail mode will be used for small precipitation quantities whilst, during heavy rain, the SMS message is sent to inform a user about the possible risks the event entails for the region considered.

Software

The microcontroller PIC 16F877 is programmed using the PicBasic Pro compiler developed by Micro Engineering Labs for the PICMicro controllers.

The flow chart of the software compiled for the microcontroller is presented in Figure 3. The software comprises the following main points.

1. At the beginning, the clock chip, the external EEPROM, and serial connections are described.
2. The microcontroller enters the main loop where, at 100 millisecond time intervals, the main sensor is continuously questioned to know if a precipitation starts. At the same time, it asks the temperature sensor if the

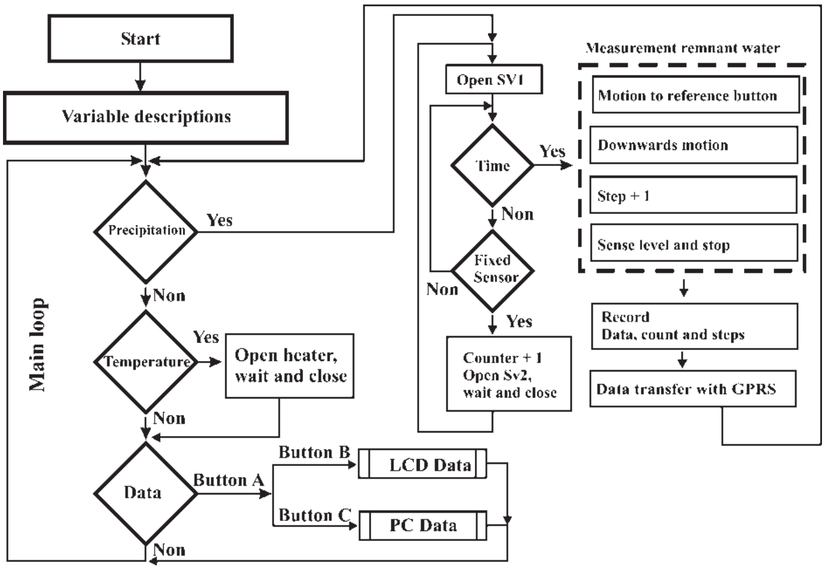

Figure 3. Flow chart of the microcontroller.

ambient temperature is less then 0°C and controls whether the manual data collection button is reactivated.

3. When the rainwater sensor (MS) sends the signal that precipitation begins, the microcontroller initiates the measurement process. To do this, it first opens the solenoid valve SV1 by energizing the associated relay to supply the measurement vessel by rainwater. Once this vessel fills upon the signal sent by the sensor CS, the microcontroller closes the SV1, opens the SV2, and waits for the determined time period for the evacuation of the vessel. At the same time, the counter variable set for the measurement is increased by one. Again, the SV1 is opened to let the rainwater fill the measurement vessel up to the level CS, etc., and all these operations are repeated until the time interval when the last signal sent by CS exceeds 5 minutes. This is considered by the system as the end of the precipitation, and the program switches to the measurement operation of the quantity of water that remains in the measurement vessel.
4. To achieve this measurement, the electro-mechanical level detection system enters into operation. The microcontroller first commands the stepper motor to move the detection part upwards to reach the reference button. The reference button sends a signal to the microcontroller that stops the moving part and takes into account that the part is positioned at the reference point. Afterwards, the stepper motor works in the opposite direction, i.e., downwards, until the detection electrodes contact the level of the water that remains in the measurement vessel. Between the reference point and the contact point, the step counter is

increased by one integer at each step the motor executes. Once the contact is established, the motor is stopped, and counter variables of the steps and the SV2 closures are recorded together with date/time parameters in the external EEPROM. The remnant water is evacuated from the pluviometer and the measurement operation finishes.

5. The collected data is sent to the e-mail address of a user by means of the GPRS module, and the system waits for the next precipitation.
6. Another process accomplished within the main loop is the temperature control of the ambient air. If the temperature sensor sends the information that the temperature decreases below 0°C, the microcontroller energizes a relay which has the mission of heating the water collection vessel by means of power resistors and to maintain its temperature above 0°C. This also gives the pluviometer the opportunity to achieve measurements in times where the collection vessel is filled by snow or hail that will be melted due to heating.
7. As explained previously, there are two other ways to extract data from the meter. Briefly, the user may prefer to read the results from the LCD display, or data stored in the EEPROM can be transferred by the user to a portable computer by a serial connection in a very short time period.

TESTS AND RESULTS

Tests executed on the automated pluviometer are explained in the following.

Tests on the Measurement Vessel

As the precision of the pluviometer is dependent on how precise the measurements are done at the measurement vessel, the repeatability of the measurements at this level is checked. The level sensor (CS) in the vessel is fixed and the moving part has detected the water level in 20 successive measurements. Results and statistical values derived are given in Table 1. The arithmetical mean was 30.19, with a standard deviation of 0.08.

Table 1. Results of tests on the measurement vessel

Measurement values					Statistics	
30,14	30,14	30,12	30,07	30,26	Mean value	30,19
30,20	30,25	30,20	30,25	30,14	Standard deviation	0,08
30,18	30,10	30,07	30,35	30,32	Minimum value	30,06
30,27	30,27	30,15	30,06	30,17	Maximum value	30,35

Remnant Water (Mobile) Level Sensor Calibration Results

Calibration and tests are done on the level detection sensor used to quantify the water remaining in the measurement vessel.

First, the number of steps the motor executes when the level electrodes leave the reference button to contact the water level is determined. To do this, the measurement vessel is filled with water up to the CS sensor level. The system is energized to move the level electrodes upwards until the moving part enters in contact with the reference button, followed by the downward motion of the mobile sensor that senses the liquid level. At this last motion, the number of steps is determined.

In a second procedure, the calibration graph of the measurement vessel is drawn. For this purpose, the mobile sensor is pushed downward for a known number of steps (2,000, 4,000, 6,000, 8,000, 10,000, and 12,000) with respect to the fixed sensor (CS). The software is programmed to ensure that the vessel is filled with corresponding volumes of water. This quantity of water present in the vessel is taken to another dry vessel with known tare, and is weighed. This operation is repeated 5 times for each different step number calibration. Results obtained are presented in Table 2. Using these figures, the graph of the remnant water is drawn in Figure 4. As suggested by the graph, a very high coefficient of correlation is obtained.

Quantification Process

The measurement process comprises various operations explained previously once the precipitation begins. When 5 minutes separate the last contact of the rainwater with the fixed sensor, the remnant water is also measured. After these operations, the microcontroller initiates the calculation of the water precipitated. In the first step, the number of evacuations the measurement vessel experienced is multiplied by the 30.19 mL value. Secondly, the remnant water is computed using the number of steps determined and the slope of the

Table 2. Calibration results of the mobile sensor

Number of steps executed downward from the fixed sensor						
0	2000	4000	6000	8000	10000	12000
Level of the fixed sensor 30,19	26,32	21,77	17,93	13,64	8,94	4,83
	26,37	21,72	17,87	13,59	8,96	4,86
	26,34	21,76	17,88	13,57	8,89	4,84
	26,27	21,68	17,89	13,61	8,86	4,80
	26,31	21,72	17,91	13,56	8,82	4,78
	26,32	21,73	17,90	13,59	8,89	4,82

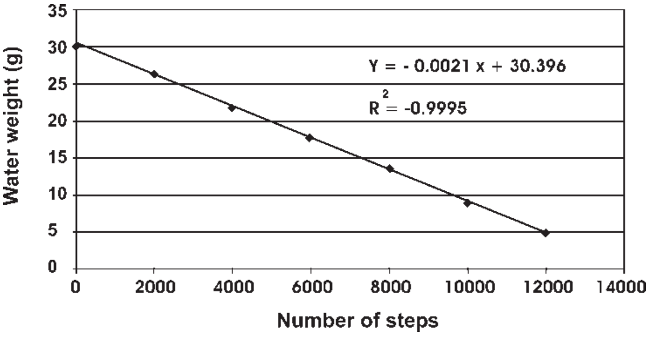

Figure 4. Calibration graph mobile detection sensor.

Table 3. Results of measurement tests

A weighted water (g)	Number of vessels	Water weight from vessels (g)	Number of steps for the remnant water	B Measured weight (g)	Remnant water weight (g)	Relative error (A–B)/A*100 (%)
85,64	2	60,38	2547	85,43	25,05	0,245815
85,54	2	60,38	2557	85,41	25,03	0,152207
85,48	2	60,38	2549	85,42	25,04	0,070241
85,52	2	60,38	2563	85,39	25,01	0,152243
85,49	2	60,38	2572	85,37	24,99	0,140565

calibration graph. The two numbers are added, and the result is multiplied by a constant characteristic with the rainwater collection vessel to quantify the precipitation in grams per cm square. These results are saved in the external EEPROM.

After the measurement operation, data is send to the address(es) previously defined, by e-mail and/or by SMS to a GSM number.

Measurement Tests

Five consecutive tests are executed to check the consistency of the measurement operations. To do this, the collection vessel was filled with a certain quantity of water that is measured by the pluviometer. At the end of each measurement, the water measured is taken in a dry vessel with known tare to know the weight of water measured. As seen in Table 3, the relative errors between the two sets is less than 0.25%, showing that the system is able to work with a relatively high sensitivity.

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