# Development of Self-recording Real-time Monitoring System of Soil Erosion

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*Abstract*—**This article develops tipping-bucket self-recording real-time monitoring system of district soil erosion monitoring and solves the problem of long-term automatic monitoring at fixed point. It adopts the water body measurement method with simple and reliable mechanical structure, with low cost and no personnel participating. It also reduces the artificial error in measurement data. The measurement data is recorded in SD memory card by control circuit, carrying on the real-time monitoring of soil erosion condition.**

*Keywords*—*water body measurement, real-time monitoring, mechanical structure*

## I.    INTRODUCTION

Due to the special physiofigureic condition and the development of urbanization, manufacturing and mining industries, the surface disturbance and vegetation deterioration have made China among the countries of the most serious state of soil erosion. Soil erosion monitoring is indispensible in ecological construction of soil conservation. The soil erosion monitoring network should be automated and informationized to form fast and convenient system of data collecting, transportation, processing and publishing, also to realize dynamical monitoring and scientific evaluating of soil erosion, which will provide evidence for ecological construction of soil conservation and national macroscopic decision. Soil conservation monitoring is the combination of macroscopic monitoring and microscopic monitoring. Microscopic monitoring is field observation for soil erosion and corresponding measurement and prevention by setting up ground monitoring site and equipments. For a long time, the general measurement method for sediment concentration in flow-water is the traditional "drying method", which is of long measuring period, cumbersome process, great labor intensity and can not monitor well the sediment dynamic process. So it is becoming more urgent to solve the problem of measuring the sediment concentration fast and accurately[1,2].

In soil conservation automatic monitoring field, foreign products are more advanced, with high integration level, high automation level, and of course high price. The HDS3000 systematized technique with integration of software and hardware produced by Switzerland Leica company and the LPM-2K 3-d laser scanning modeling system produced by Austria Riegl company are of important application in soil conservation ecological project, conversion of cropland to forest, fast monitoring of soil conservation, and monitoring of slope and channel soil loss amount, etc[3,4]. But they are not able to get the best accuracy for monitoring result of soil loss amount and sediment concentration in water flow. What is more, the equipment price is rather expensive, around ＄180,000 per set. It is only suitable for large river valley institution but not applicable for wide spread subsidiary monitoring sites.

## II.    MEASUREMENT PRINCIPLE OF TIPPING-BUCKET SELF-RECORDING

Tipping-bucket self-recording soil erosion real-time monitoring system measures flowing water continuously by the moment balance principle, taking the tipping-bucket water meter as core component. Then it records and analyses the water volume, mass and density and records the interval time between two measurements to calculate the flow rate.

### A.    Measurement method based on the volume

The most direct way to test the water body density ρ is to get the ratio of M and V by obtaining the water volume V and mass M. To simplify the question and reflect the sediment concentration in water body meanwhile, here we divide the water body into sections of same volume and measure the mass M.
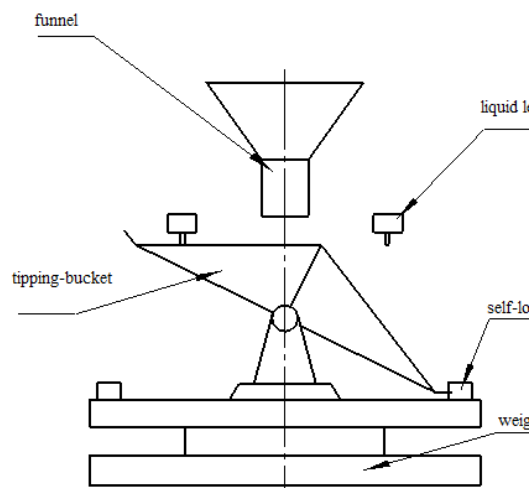


Figure 1.    Measurement principle of tipping-bucket self-recording

The advantage of tipping-bucket water measurement is that the moment increases gradually during the water body collection period, which drives itself turn over. In this situation, the collection—measurement—turn over-collection process will be continuous and cycling, with less artificial intervention. The mechanical structure principle of tipping-bucket self-recording is as shown in Figure 1.

The mechanical structure is divided into three parts from the function: water collection part, weighing part and self-locking part. The water collection part is to collect water containing sediment by fixed volume. It is composed of funnel, tipping-bucket and liquid level switch. The tipping-bucket contains two rooms of the same at left and right, between which is a partition board. By the moment function, one room goes up and collects the water containing sediment; the other room goes down and pours out the water containing sediment which is collected by last time. In initial state, the tipping-bucket leans to the down room to keep it stable at the site shown in the figure. As the water containing sediment increases in up room, its center of gravity moves towards the left side shown in the figure. Up to a specified time, the center of gravity moves to the left side of the center line and produces the anticlockwise moment of rotation, which makes the tipping-bucket tending to turn over. Self-locking part is applied to restrict its turning over to keep water containing sediment of fixed volume. The tipping-bucket turns over only when the liquid level reaches the liquid level switch, triggers the electromagnet, pulls back the iron core and releases the tipping-bucket. Then the tipping-bucket right room still goes up to collect water containing sediment for measurement. When the tipping-bucket turns over, the weighing part records the mass of water with sediment when the liquid level switch is triggered.

*B. Weighing balance principle*

The key procedure and the difficult point of system monitoring is to correctly measure the mass of water with sediment of fixed volume (hereinafter named as "mass"). We can see from the figure that the measure result G value equals to the measurement Gt value. The weighing principle is shown in Figure 2. the single weighing sensor is adopted to measure the Gt value to simplify the mechanism. During the collection of water containing sediment, Gt value produces offset value e from the center in horizontal direction along with the increasing of water volume, which makes the weighing platform producing clockwise rotation trend shown in figure. The static friction in vertical direction between weighing platform and fixed flange is eliminated by ball bearing contact. The measuring point of weighing sensor falls on the geometric center line of weighing platform as shown (a). (b) is the force analysis figure of weighing platform. From the figure, we can see that the direction finding force of weighing platform is always the force couple m'(N，N'), whichever side the offset value deviates to. The function of Gt with eccentricity can be decomposed into Gt' acting on geometric center of weighing platform and the torque m in the opposite of m' shown in Figure (c). From the figure we can see that the equilibrium condition balancing the weighing platform is:

$$P = -G_t' = -G_t \quad (1)$$
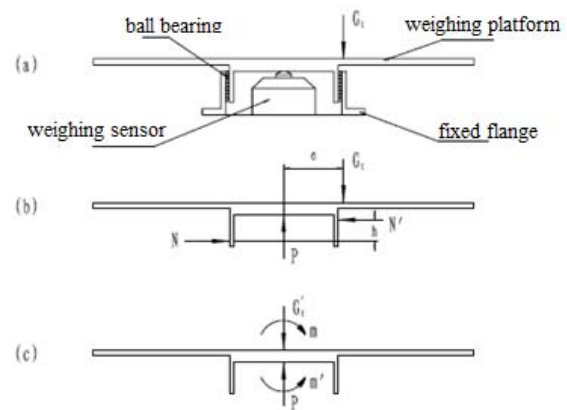$$m = -m' = -G_t \cdot e \quad (2)$$



Figure 2.   Weighing balance principle

Minus sign means the opposite direction. P is the force measured by weighing sensor. So, the formula (1) is force balance condition and the precondition for measuring the weight correctly; Formula (2) is the moment balance condition.

*C. System working process*

The working process of tipping-bucket self-recording real-time monitoring system of soil erosion is a cycling logic, including collecting of water containing sediment, measuring, pouring away the water, collecting again.
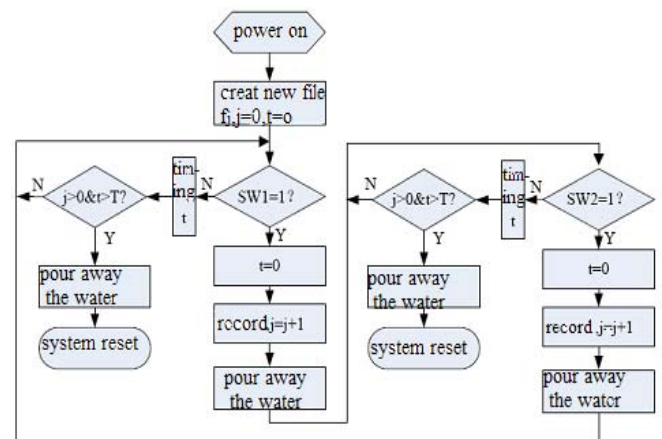


Figure 3.   System working flow chart

The system enters into timing recording situation when it is initialized or SW1 and SW2 are triggered.

In addition, it also includes the program post processing of original data. The system working process is shown in Figure 3.

New storage file $f_i$ is established in SD memory card when the system is power on. fi stores the data collected during one rainfall process. The system is always in waiting

condition and records the waiting time t before the water containing sediment is collected. When the tipping-bucket begins to collect water containing sediment and the water level reaches the liquid level switch, the liquid level switch closes, say SW1=1. SW1 only represents the liquid level switch condition corresponding to the tipping-bucket room collecting water containing sediment for the first time. "1" means closed. After SW1 is closed, reset the timer, say t=0. Meanwhile the measured weight G is recorded into file fi. The record frequency is j=j+1. After the record is finished, the system triggers the electromagnetic mechanism. The tipping-bucket rotates and the water containing sediment is poured out. Then the next collection and record process begins, say SW2=1, which is the same with SW1 situation. With constant water flow, the system keeps cycle working. It records data once the tipping-bucket rotates till the SW1 and SW2 not be triggered for a long time.

Judging from the time variable set by timer, we can know whether one record process (rainfall process) is finished or not.

It is clear to zero till the system is reset or triggered again. The system presupposes the time fixed value T as the judgment whether one record period is finished or not: In the record perod-- j>0, if t<T, it means the record period is not finished; If t≥T, it means the record period is finished. The electromagnetic lock opens and the water containing sediment collected by the last time is poured out. The system is reset and new record file is established to wait for another new rainfall record process.
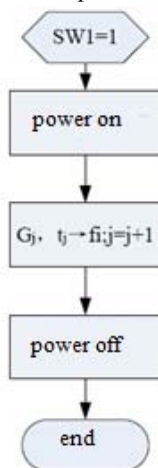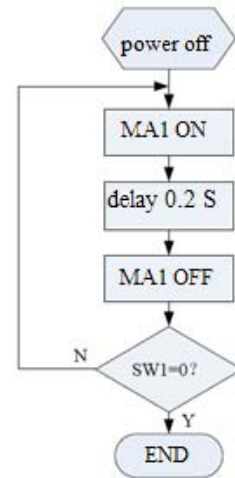


Figure 4.  Flow chart of data record



Figure 5.  Flow chart of pouring away the water

The system adopts 24V battery. To save energy, all the electromagnet, weighing sensor and active devices in circuits are provided power only when they receive the trigger signal. They are in dormant situation when waiting. The record and pouring water process is shown in Figure 4 and 5. To ensure the tipping-bucket turn over successfully, the system triggers the electromagnetic lock by multiple pulse till the tipping-bucket turns over.

III.    MECHANICAL STRUCTURE OF MONITORING DEVICE

The mechanical structure of tipping-bucket self-recording monitoring system of soil erosion includes four parts: supporting frame, tipping-bucket mechanism, weighing mechanism and self-locking mechanism.
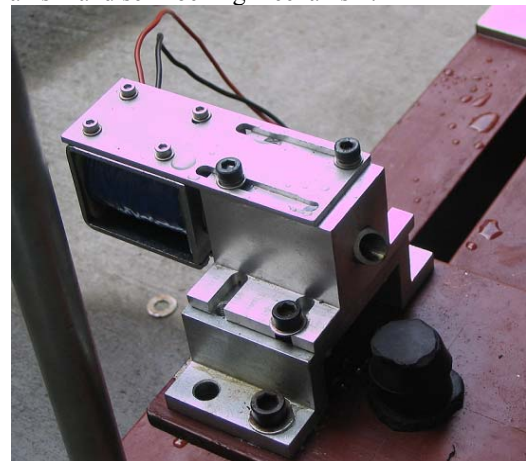


Figure 6.  Mechanical structure appearance

Figure 7.    Magnetic lock structure

Figure 6 is the whole profile drawing of the mechanical structure. Figure 7 is the profile drawing of electromagnetic lock. Figure 8 is the assembly drawing of whole mechanism structure.

From the figure, we can see that the tipping-bucket is the core components and it revolves around the fixed center in certain angle range (determined by the stop bolt). Two liquid level switches and two electromagnetic locks cooperate to control the turning over movement. The electromagnetic lock is normally closed. The electromagnetic lock core ejects by the spring and locks the tipping-bucket at fixed position when it is loss of power. The lock core is pulled back by electromagnetic force and releases the tipping-bucket when it is electrifying. The weighing mechanism achieves the function described in Figure 2.

## IV.    ELECTRICAL CONTROL SYSTEM

The electrical control system achieves two functions: firstly, it makes all moving components acting coordinately to achieve the goal of collecting water containing sediment continuously. So the system movement control is switch control. Secondly, the electrical control system needs to supply electricity for active devices in time to guarantee the measured data recorded correctly and timely. Then it stores the measured data in sequence to prepare for the post processing.

The electrical control system adopts MSP430 series MCU produced by TI company as controller to achieve the above functions with low power consumption. MSP430 series MCU is a kind of powerful MCU with super low power consumption.

The combinations of MSP430 series MCU, power conversion chip and signal amplification chip makes up the electrical measurement and control system. Large capacity SD memory card is adopted as memorizer, to gain large capacity storage space and to be convenient for taking down

and carrying around, which improves the data sharing performance. Figure 9 and 10 are the principle diagram and actual picture separately.

## V.    SYSTEM EXPERIMENT AND CONCLUSION

Figure 11 is the comparison result of water containing sediment measured by the system and the actual value. From the measurement result we can see that the data obtained by the measurement system varies according to the actual data and reflects the change tendency of sediment content in water. This indicates that the measurement system can correctly measure and monitor the soil erosion situation in rainfall process. The weighing mechanism principle and system control principle conforms to actual requirement.

From the figure we also see deficiency of the measurement system. The measured data still have
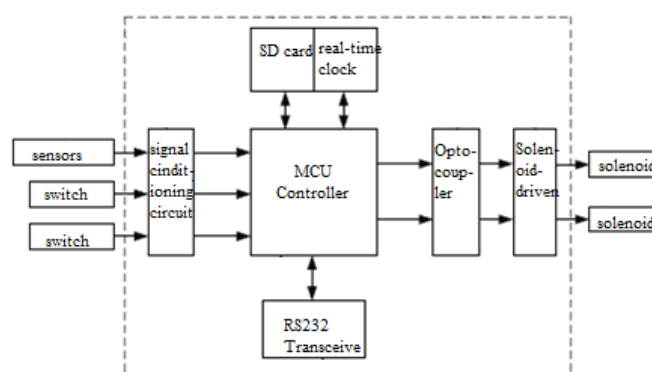


Figure 9.  Principle diagram of electrical control system



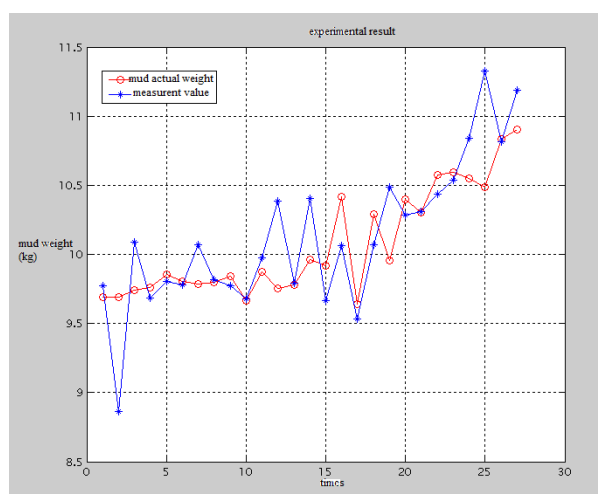Figure 10. Actual picture of electrical control system

Figure 11.  Measurement result of system monitoring

random error. Some individual data shows obvious error. In the following work we need to complete

these jobs from software and hardware system: (1) Improve weighing mechanism and increase the structure stability to gain more accurate result in single measurement. (2) Add filtering function in hardware circuit or control program to lower down the external uncertain interference.

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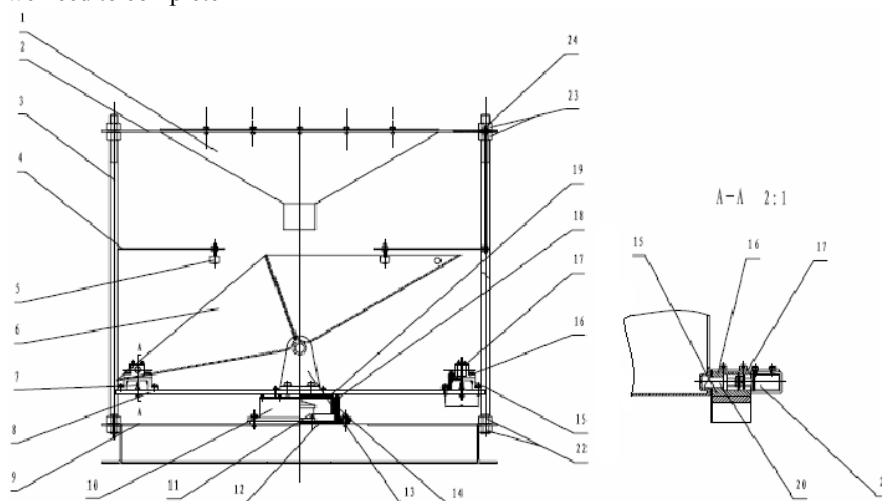


Figure 8.   Mechanical structure assembly diagram
1-funnel 2-upper frame 3-strut 4-liquid level switch holder 5liquid level switch 6-tipping-bucket 7-stop bolt 8-process frame 9-pedestal 10-flange 11-weighing sensor 12-frame plate 13-bearing bracket 14-ball bearing 15-electromagnetic lock bracket 16-electromagnetic lock pedestal 17- electromagnetic lock bracket 18-dust shutter 19-weighing platform 20- electromagnetic lock core 21-electromagnet 22-set nut 23-adjusting nut