Application Research on The Equipment Measuring Sludge Thickness in Coalmine Channel

X.G. QIU
The Institute of Computer Science
Xi'an University of Science and Technology
Xi'an,China
Email:439767454@qq.com

Y.S. FANG
The Institute of Computer Science
Xi'an University of Science and Technology
Xi'an,China
Email:601247867@qq.com

***Abstract*—For solving the problem of measuring sludge thickness in coalmine channel,the paper discusses a new measuring method based on the difference of penetration when light spread in different medium.The method combines computer science,sensor technology,data communication technology,which measures sludge thickness in coalmine channels effectively,and the problem that water flow is larger than reality owe to the existence of sludge in coalmine channels will be solved.The method has the advantage of low price and high accuracy.This paper emphasis the system architecture,hardware design and data processing algorithm in the equipment,which has very practical guiding value in project applications.**

Key Words-Sludge Thickness Measurement; Coalmine; SCM; Light

I. INTRODUCTION

Because of the particularity of coalmine environment,there are many precipitates such as dusts,sand and mud in coalmine channels.With the changes in water flow,these substances will accumulate in the sunken or uneven places,and lead to sludge deposition phenomenon,with the problems of water level rising,water flowing faster at the same time.Currently,there have been some measuring methods and equipments which focus on the open channel discharge and flow,they all use the important parameter 'water level' during computing processes,for example,when computing the discharge in the open channel cross section,we usually get the discharge values after measuring the average flow and then multiply it with cross-sectional area of open channel.However,because of concrete conditional limit, we do not usually take the situation into account that water level has already been raised,the water flow will be larger than reality and it may lead to potential risks in some related projects.So an effective measuring method is needed in sludge thickness measurement in practice.Nowadays,the main measuring methods aiming at this problem including:①Ultrasonic inspection.this method is based on the basic time difference theory and the character that ultrasonic will reflect at the interface of different medium,water level will be calculated after we get the time intervals from the moment ultrasonic waves are sent out to the moment reflected waves are detected,and sludge thickness can be got indirectly by calculating.However,ultrasonic waves have the problems of large blind area and it is hard to set ultrasonic probes suitably above the coalmine channels,so this method has some limitations in practice.②Capacitive inspection.Capacitive sensors have the features of high sensitivity and fast reaction rate,because water and sludge have different dielectric constant in theory,sensors can get sludge thickness by comparing the dielectric constant's difference between water and sludge.But in practice,this method also has some disadvantages:when the moisture capacity in sludge reaches a certain degree,dielectric constants in water and sludge are nearly the same,it is very hard to distinguish water and sludge,so the measuring results are not accurate at all.This paper summarizes current implements and research situations of sludge thickness measurement in coalmine channels,and puts forward a new kind of measuring method based on the theory that light penetrates differently in different medium,it

really increases the measuring accuracy.

II. Measuring Principle

Photoelectricity,it refers to the phenomenon when light reach objects,it will trigger some changes in the electrical properties of objects and currents may appear.In industrial applications,photoelectric devices are usually used,they transfer light signals to electrical signals,and then electrical signals are often handled by computers or some other controlling devices.The new method proposed in this paper is based on photoelectricity and penetration difference of light in different medium,concrete measuring principle is shown in Fig. 1.The measurement equipment is equipped with light launching circuit board and light receiving circuit board,which separately finish the work of light launching and receiving.To guarantee accuracy,these two circuit boards are set parallelly in the distance of one centimeter from one to another, shell,water,air and sludge can normally fill up the space between the two boards.

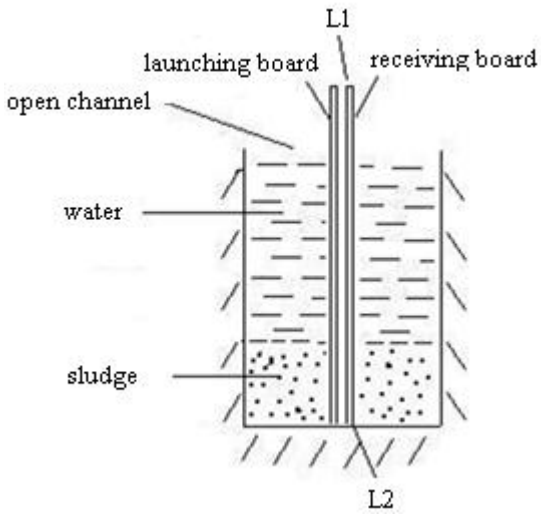

Fig. 1 Measuring schematic diagram

Light penetrates differently in different medium.For light with same intensity,the distance they spread are very different,and the absorbed energies are also different.So,light intensities that the receiving board receives are surely different.According to the principle shown in Fig. 1,the substances from the top to the bottom in coalmine channels are air,water and sludge,light has the strongest penetration ability in the air,and the weakest in sludge.When the light-emitting diodes on the light launching circuit board are lighten at the same time or in proper order with same light intensity,the light intensities received by the receiving board show apparent gradual weaken trend from the top to the bottom(L1 to L2).An apparent sudden changing phenomenon will take place at the interface of different medium,as shown in Fig. 2. Phototransistors are driven differently by different light intensities they receive,and they will generate diverse electrical signals.The new method proposed in this paper calculates sludge thickness in coalmine channels according to this character.

According to the results in the research,blue light with short wavelength has stronger penetration ability.So The new method choose blue light as the color of light source to enlarge the distance light spread in water.

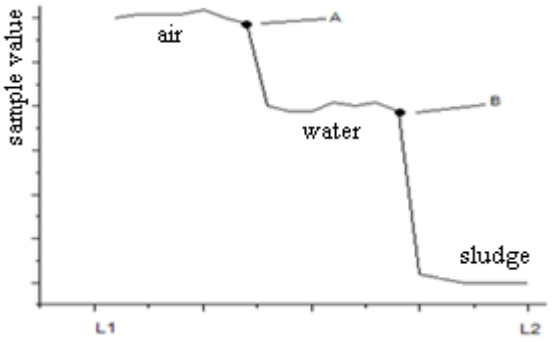

Fig. 2 Sample values' changing trend in ideal state

As shown in Fig. 2,sampled light values in the same medium remain stable in ideal state,the values are largest in the air and smallest in sludge.Because the penetration ability of light in water is weaker than that in the air,so at the interface of air and water,an apparent falling point will emerge in all the sampling values got by the light receiving board---Point A.As the same,a second falling point will emerge at the interface of water and sludge---Point B.We can get the concrete location of A and B on the receiving board by means of processing the sampled values,and continue to calculate the water level and sludge thickness to finish the task of measuring sludge thickness in coalmine channels.

III. BASIC STRUCTURE OF THE MEASURING INSTRUMENT

As shown in Fig. 3,the measuring instrument is

composed of light launching circuit board,light receiving circuit board,sensor motherboard and terminal motherboard.

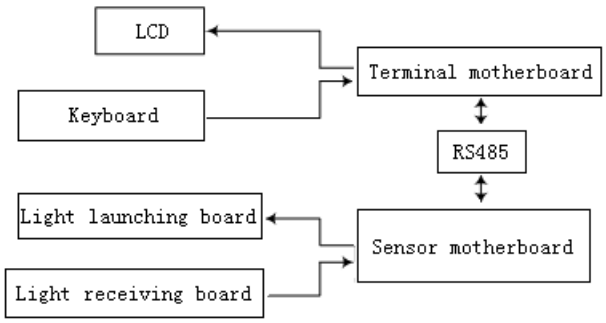

Fig. 3 Basic structure of the instrument

1) Light launching circuit board

The board consists of 448 light-emitting diodes and some related periphery circuits,these light-emitting diodes are placed on the board in a straight line with the same distance from one to another(As shown in Figure 1 from L1 to L2) ,the launching circuit board receives controlling signals emitted by sensor motherboard,controlled by programs,it lightens one light-emitting diode or all the diodes in a sample period.

2) Light receiving circuit board.

The board consists of 448 phototransistors and some related periphery circuits,each phototransistor corresponds to a light-emitting diode on the launching board.When a light-emitting diode is lightened,the corresponding phototransistor on the receiving circuit board is driven differently based on the light intensity received,the sensor motherboard calculates received sample values and ascertain sludge thickness.

3)Sensor motherboard.

This board takes SCM as the core,including some periphery circuits.To satisfy the small volume and low power consumption requirements in coalmine environment,MSP430F5438 ,one of MSP430 series SCM produced by TI is selected as the controlling unit,its normal working voltage is 3.3 volts,the highest frequency is 32MHZ, a 12-bits AD unit is embedded into the chip,making it easy for the receiving board to sample values.The periphery circuits consist of some related logic device aiming at light-emitting diodes on the launching board and phototransistors on the receiving board.There are also standard RS-485 interfaces that can guarantee the light receiving board communicate with other terminals or computers.

4) Terminal motherboard.

It has the functions of data storage,display and human-machine interaction.

IV. HARDWARE DESIGN

A. Light launching Circuit

The light launching circuit board generates all the used light during measuring process,there are 448 light-emitting diodes on the board with the same distance from one to another,every eight diodes are linked to one logic controlling unit,so there are 56 units in all.Fig. 4 shows concrete controlling principle.

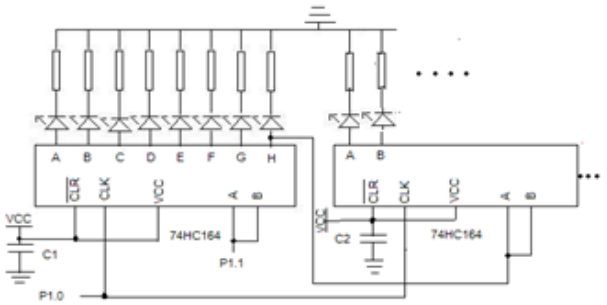

Fig. 4 Light-emitting controlling circuit diagram(part)

74HC164 is the device controlling logic,it is a kind of 8-bit shift register with serial input and parallel output.Port P1.0 is regarded as the clock signal,when it changes from low level to high,one bit of a byte is shifted to the right.Port P1.1 is regard as the serial data input.The time sequence signals on P1.0 and P1.1 are shown in Fig. 5.

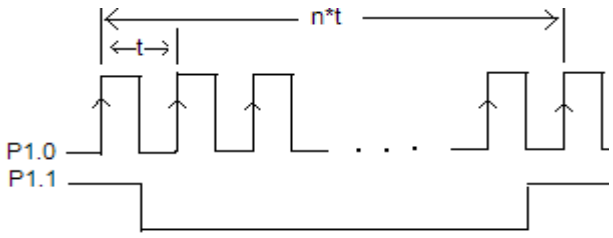

Fig. 5 Serial Input logic time sequence diagram

As shown in Fig. 5,port P1.0 is linked to clock signal input terminal CLK,port P1.1 is linked to the serial data input terminals,A and B.74HC4051 does ‘and operation’ on A and B.SCM generates square wave

signals on port P1.0，whose signal period(t) is 0.5 second.The results of experiment showed that this signal period guarantees all the phototransistors on light receiving circuit board can sample light intensity values smoothly.Port P1.1 is set to high level at the first rising edge of port P1.0,and set to low level before the second rising edge arrives,the low level keeps n clock signal periods.This controlling logic guarantees that there is only one light-emitting diode lightened and moving to one side in a sampling cycle.The light launching circuit board drives each light-emitting diode and generates the same light intensity to let the light receiving board sample values.

The input voltage of light launching circuit board is 5 volt,it is converted to 3.3 volt by the voltage conversion device LM1117-3.3 to guarantee the light launching circuit board work normally.

B. Light receiving Circuit

Light receiving circuit board' duty is to sample light intensity values generated by the light-emitting diodes on the light launching board.there are 448 phototransistors on the receiving board with the same distance from one to another and Each one corresponds one light-emitting diode on the light launching board to sample light intensity.Similar with the light launching board,each eight analog signals are linked to an analog-selection switch.SCM gates one analog signal in a time,converting it to digital signal through the embedded AD unit of MSP430, and then,processing and storing it.The concrete controlling logic is shown in Fig. 6.

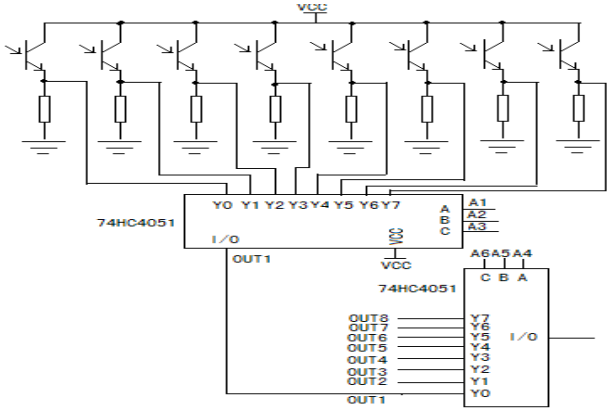

Fig. 6 Light sampling circuit diagram(part)

As shown in Fig. 6,each phototransistor is driven differently according to the light intensity it samples.Those driven with large degree will generate large emitter currents and high voltage when the currents flow through resistances.Conversely,those driven with small degree will generate small emitter currents and low voltage when the currents flow through resistances.When the light intensity is very weak,a phototransistor is not driven at all,the sampled voltage value is nearly 0;when the light intensity is very strong ,a phototransistor is fully driven and the sampled voltage is equal to VCC(3.3 volts).

74HC4051 is a eight-channel selection switch,which gates one channel in Y0 to Y7 according to the state of A,B and C,and then,transporting the analog value to the port I/O.A1,A2 and A3 are address-selection pins to select the current selected phototransistor to receive light intensity,A4,A5 and A6 are pins to select first-level switch 74HC4051.To the light receiving circuit board,it needs 56 first-level switch and 7 second-level switch.By address decoding,light receiving circuit board can sample each voltage value generated by the current flow through the below resistance,and send it to sensor motherboard to process.

C AD Conversion

After sensor motherboard receiving the sampled values transmitted from the light launching board,it has to convert these analog signals to digital ones that SCM can process.This measuring instrument proposed in the paper uses MSP430F5438 as the controlling unit,it has 12-bit embedded AD unit,so it can finish all the AD operation without any other device.The positive electrode (VR+) of reference voltage is linked to VCC,the negative electrode (VR-) is linked to the ground.AD output range is from 0 to 0FFFH,When input voltage is higher than VR+,the output is 0FFFH,and when input voltage is lower than VR-.the output is 0.

V DATA PROCESSING

Software controls the light launching board to generate light and let light receiving circuit board receive light intensity at the same time.Software put all the sampled values in buffer,preprocessing the values and calculating silt thickness at last.Data processing has a great effect on the final accuracy.

A Data Preprocessing

Water environment in coalmine channels is relatively complex,there may be dusts,particles and some impurities in it,these substances will weaken the penetration ability of light and make each phototransistor receive light with different intensities,many signal burrs will appear on the data curve.The practical situation differs from ideal state and causes many problems in calculation.To guarantee accuracy,software take the method of moving average filter to preprocess data.

Algorithm description:software put the sampled values,whose total quantity is N,into the program buffer.The length of program buffer is N.And then,a sliding window is used to process the data,whose length is m.In the initial state,The left side of the sliding window and buffer[0] are in accord,variant i is equal to 0.Starting from the initial state,software calculates the average value of sampled values in sliding window and assign it to buffer[i],after that,the sliding window moves right one unit,variant i increases by one.Software will not stop this process and do it again and again until the right side of the sliding window reaches the max array subscript of buffer[ ].The concrete formula is:

$$buffer[i]=\frac{1}{m}\sum_{j=1}^{m-1}buffer[i+j],m\neq 0,i=0,1,...,N-m \qquad (1)$$

According to measuring principle above,the key of calculating sludge thickness is to determine the location of point B.During the experiment,we found that the method of moving average filter will make point B deviated to the right.In order to solve this problem,during this data processing progress,software goes on a moving average filter to the opposite direction immediately after one filter to the normal direction.After this process,point B returns to its original position.

B. Determining sludge surface

The key of calculating silt thickness is to determine the silt surface,point B in Fig. 2.According to the analysis above,the received light intensities will change obviously at the interface of water and silt.To characterize this phenomenon and determine the interface,software take local-derivation method,successfully showing the changing rate of sampled values.Let slop[ ] be the array storing values which have experienced the course of local-derivation,and the concrete equation is as follows:

$$slop[i]=\frac{buffer[i]-buffer[i-1]}{\Delta s} \qquad (2)$$

among them,i=1,2,3,...N.N is the total number of light-emitting diodes or phototransistor; Δs represents the constant distance from one phototransistor to another;buffer[ ] stores sampled values which have been preprocessed.

Each local derivative can be obtained by equation (2).Buffer[ ] and Δs is determined by hardware design,SCM does 12-bit AD operation,output range is from 0 to 0FFFH.Due to Δs is small in value,the calculation results may be very large and it is hard for SCM to process.To guarantee the accuracy,software does some improvements on equation (2),a new one is as follows:

$$slop[i]=\frac{buffer[i]-buffer[i-1]}{\Delta s'} \qquad (3)$$

among them,variant i and buffer[ ] are same in meaning and value range,but $\Delta s'$ changes a little:

$$\Delta s'=\frac{buffer[i]+buffer[i-1]}{2} \qquad (4)$$

All the local-derivation values are stored in array slop[ ] by equation (3),and the value at the interface of water and sludge will be the highest,software can get this value's array subscript(i_{max}) by traversal algorithm.And then,software can continue to get sludge thickness with the help of i_{max}.

C Calculating sludge thickness

As shown in Fig. 2,the max array subscript corresponds to L1,the min array subscript corresponds to L2,sludge thickness can be got by the equation as below:

$$thickness=(447-i_{max})*\Delta s \qquad (5)$$

Δs has the same meaning as the introduction above.

VI TEST AND ANALYSIS

According to the measuring principle description

above,after finishing all the hardware and software design,a series of stimulation experiments are conducted to test the accuracy.

The Concrete method and experimental experiment:water environment in coalmine channels is stimulated in the experiment,water velocity keep 0.75 meter per second,water environment is muddy and there is much sludge depositing at the bottom of experimental channel.During the experiment,the light launching circuit board and the receiving circuit board are parallelly placed in the environment,sludge thickness values will be displayed on the sensor motherboard and researchers record them.

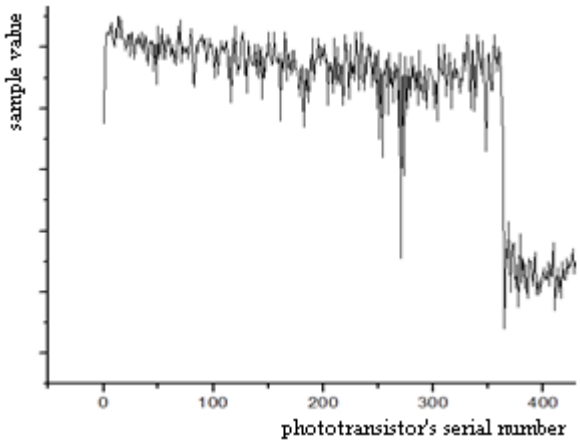

Fig. 7 Original sampling value curve

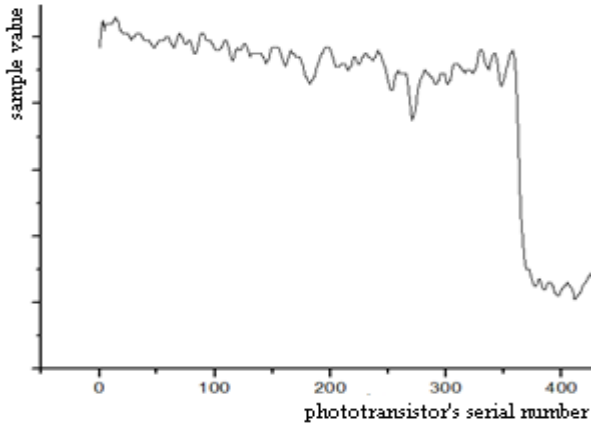

Fig. 8 Filtering effect curve

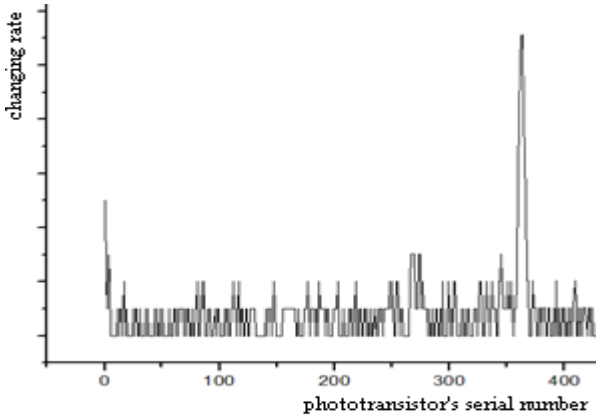

Fig. 9 Changing rate curve

Concrete processing effect of one set of data is shown from Fig. 7 to Fig. 9.The real sludge thickness is 0.105m,measured value is 0.108m,error is 0.003m.researchers change sludge thickness artificially and repeat the experiment process,measured data are listed as below:

Table 1 measurement data

Number	Real/m	Measure/m	Error/m
1	0.035	0.037	0.002
2	0.051	0.055	0.004
3	0.073	0.069	0.004
4	0.095	0.092	0.003
5	0.117	0.119	0.002
6	0.124	0.129	0.005
7	0.139	0.137	0.002
8	0.158	0.155	0.003

From the data listed in Table 1,the max error is no more than 0.005 meter,which satisfy the accuracy requirement in coalmine applications.

VII CONCLUSION

For solving the problem of measuring sludge thickness in coalmine channels,the paper proposes a practical and feasible measuring method and develops a new measuring instrument.This new method takes sensor technology,microcontroller technology as the core,and uses appropriate data processing algorithm, making all the final measuring results scientific,accurate,reliable,which satisfy the measuring

precision requirements in coalmine channels.

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