Design of nuclear radiation level gauge based on normalized LMS filtering correction

WU Zuo-peng, WANG Xiao-peng, WU Xu

(*School of Electronic and Information Engineering, Lanzhou Jiaotong University, Lanzhou 730070, China*)

Abstract: In the measurement of liquid level in industrial site environment, noise interference can affect the measurement accuracy. In order to improve the measurement accuracy of liquid level in the viscous state, a nuclear radiation level measurement system based on the least mean square (LMS) filtering correction method is designed. The system uses STM32F103 as the control core and adopts HART bus HT1200M chip for remote signal transmission and reception. The adaptive LMS algorithm can be used for more accurate filtering, calculating iterative weight vector, updating weighted coefficient, effectively removing system measurement noise and improving the measurement accuracy. The results show that the nuclear radiation level gauge based on normalized LMS can correct the measurement system accuracy in adaptive rules, improve the measurement accuracy to meet the requirements of industrial field environment for liquid level measurement and enhance the industrial automation control degree.

Key words: least mean square (LMS); nuclear radiation method; self-adaptive algorithm; weighted coefficient updating; level gauge

CLD number: TP273 **Document code**: A

Article ID: 1674-8042(2019)02-0103-06 **doi**: 10.3969/j.issn.1674-8042.2019.02.001

0 Introduction

The liquid level as one of the main parameters of modern industrial automation, employing liquid level sensor to measure liquid level is the most common method that used in industrial control, and the common types of liquid level sensors include float level sensor[1], static pressure level sensor[2], ultrasonic liquid level sensor[3] and optical fiber liquid level sensor[4]. The float liquid level sensor has complex installation and low reliability. Static pressure level sensor is influenced greatly by medium density and temperature. The ultrasonic liquid level sensor is easily affected by the temperature and density of the propagating medium and the absorption of liquid also leads to the increase of the measurement error. The mechanical transmission parts of the optical fiber level sensor make the failure rate increased and the installation complex.

In this paper, a nuclear radiation level measurement system based on least mean square (LMS) filtering correction[5] is designed. The measurement method is a typical non-contact measurement mode. Compared with other liquid level measurement technology, it has the characteristics of good stability, high accuracy, corrosion resistance and high cost performance.

The system adopts STM32[6] as the control core and adhibits radioisotopes to radiate γ ray during the decay process. The intensity of the radiation changes after the rays pass through the liquid. The system measures the thickness of the medium by measuring the intensity of the radiation through the medium, and then measures the liquid level. The signal transmission and reception based on HART bus HT1200M chip can be employed to realize real-time remote measurement. Weight vectors[7] are iterated and weight coefficients[8] are updated through adaptive LMS filtering algorithm, so the measurement results are corrected by eliminating noise interference in the measurement environment and the accuracy of liquid level measurement is improved.

Received date: 2019-01-23

Foundation items: National Natural Science Foundation of China (Nos. 61761027, 61261029)

Corresponding author: WU Zuo-peng (852119655@qq.com)

1 System design

1.1 Overall design of system

The system puts the nuclear radiation measurement technique to measure the liquid level and the whole system diagram is shown in Fig. 1.

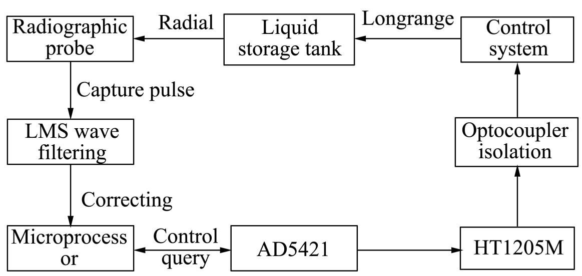

Fig. 1 General system block-diagram

Ray probe receives from the emission source through the medium ray capture pulse. Capture pulse is captured by STM32 microprocessor and it will convert the capture pulse frequency to the corresponding level. Microprocessor gets adaptive LMS filtering based on current results. After that, the liquid level value is sent back to AD5421 through the SPI port and converted to the corresponding 4—20 mA current to transmit the HART bus. The control system reads the data from the bus and analyzes the height of the liquid level to control the electric valve for adjusting the feed.

1.2 Measurement principle of nuclear radiation method

The intensity of the ray varies with the thickness (or height) of the medium when it passes through the liquid level. The transmission intensity of ray decreases with the increase of the thickness of the medium layer. The radiation source increases with the thickness of the medium, and the intensity is exponential decay. The relation is

$$H = H_0 e^{-\mu T}, \tag{1}$$

where H_0 is incidence intensity, μ is the absorption coefficient of the medium to the radiation, T is the thickness of medium, H is the radiographic strength passing medium. According to the above function, by measuring the radiation intensity H after passing the medium, the thickness of the medium and the height of the liquid level can be obtained. The emission source radiate through the measured level and is received by the receiver, which is composed of a receiving probe, a photomultiplier tube and a preamplifier circuit. The ray is absorbed by the scintillation counter and the stronger the radiation is, the more the current pulse number is. The schematic diagram of the measurement principle of the nuclear radiation method is shown in Fig. 2.

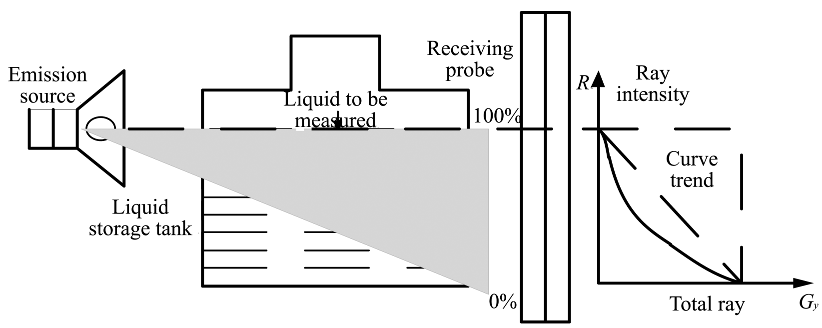

Fig. 2 Principle of nuclear radiation method

2 Hardware design

2.1 Overall hardware design of system

To count the output and acquired pulse signals of the radio receiver accurately, the ARM7 STM32 processor is used for the liquid level meter. The processor has a high precision pulse acquisition function and the system block diagram is shown in Fig. 3.

When the radiation pass through the measured liquid level, the radiation is received by the pulse receiving circuit, which is composed of scintillator, photomultiplier tube and preamplifier circuit. The stronger the radiation is, the more the number of current pulses is. The upper computer is used to display the operating interface. The HART module can communicate with the instrument and the external information exchange interface for remote communication.

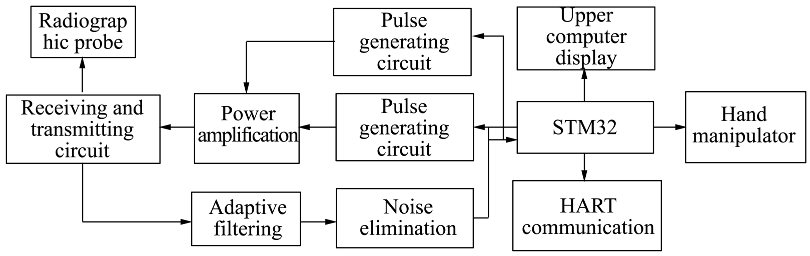

Fig. 3 Overall hardware block diagram

2.2 HART bus communication

The HART bus communication module needs to set up the information of liquid level, liquid level data, calibration parameters and so on. It can convert the height of the measurement liquid into 4—20 mA standard, analogize current loop signal output. The HART communication module is mainly composed of STM32 processor, HT1200M and AD5421. The structure block diagram of the HART communication module is shown in Fig. 4.

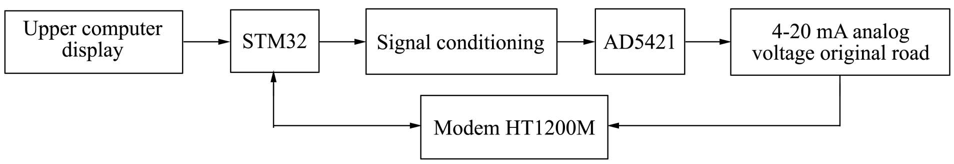

Fig. 4 HART bus communication

STM32 is connected through the universal serial transceiver module UART to HT1200M. After communicating and demodulating the signal, it can communicate with HART handheld device, measure data and modify parameters.

3 Software design

3.1 Overall system process

The software design mainly includes system initialization, capture, pulse counting, noise elimination, reading count and result display function. The system flowchart is shown in Fig. 5.

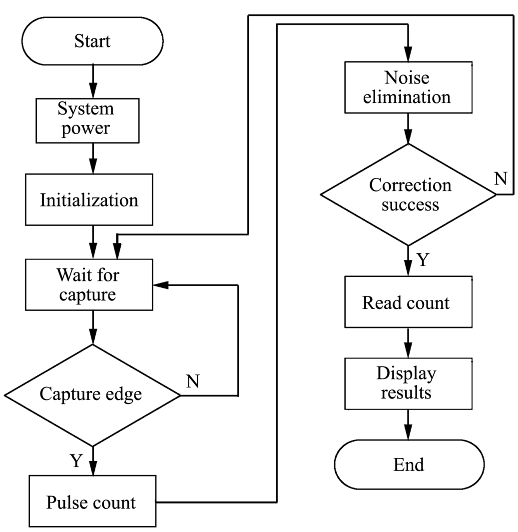

Fig. 5 Overall system flow chart

For ensureing the input pulse waveform distortion, the pulse output by the ray receiver is reshaped by the plastic circuit and input to the STM32. After the pulse edge is captured by STM32, the pulse is counted. When the measurement system is filtered, the reading count is performed to calculate the liquid level and the related parameters.

3.2 LMS adaptive filtering de-noising

In the actual measurement environment, because the installation level of the nuclear radiation level gauge is restricted by the structure of the liquid storage tank, the radiation can not completely avoid the influence of the liquid level gauge structure and the liquid level measurement contains noise, so the measurement result is not accurate.

The system is self-adaptive to adjust the liquid level. The system searches in the negative direction of the weight value gradient. According to the input signal, the gradient vector is estimated and weight coefficient is updated, and finally the optimal weight and the LMS adaptive filtering algorithm are achieved.

But when the $X(k)$ is large, the filter of the LMS algorithm will suffer from the amplification of the gradient noise. The filter of the normalized LMS algorithm can be adopted to overcome this difficulty.

The normalized LMS algorithm has a faster convergence rate because it uses a variable convergence factor when the instantaneous output error is minimized. To make the speed of convergence faster, the variable convergence factor μ_k is used in the updated equation of the LMS algorithm. The function can be expressed as

$$\boldsymbol{w}(k+1) = \boldsymbol{w}(k) + 2\boldsymbol{\mu}_k \boldsymbol{e}(k)\boldsymbol{x}(k) = \boldsymbol{w}(k) + \Delta\widetilde{\boldsymbol{w}}(k), \tag{2}$$

where $\boldsymbol{w}(k)$ is the filter coefficient vector, $\boldsymbol{x}(k)$ is the input signal of the filter, and vector $\boldsymbol{e}(k)$ is the error signal.

In the process of normalization, the selection of $\boldsymbol{\mu}_k$ must be aimed at achieving faster convergence. The possible way to achieve it is minimizing the instantaneous square error. The starting point of this method is that the instantaneous square error is a better simple estimate of the mean square error (MSE). The instantaneous squared error $e^2(k)$ is given by

$$e^2(k) = \boldsymbol{d}^2(k) + \boldsymbol{w}^{\mathrm{T}}(k)\boldsymbol{x}(k)\boldsymbol{x}^{\mathrm{T}}(k)\boldsymbol{w}(k) - 2\boldsymbol{d}(k)\boldsymbol{w}^{\mathrm{T}}(k)\boldsymbol{x}(k), \tag{3}$$

where $\boldsymbol{d}(k)$ is the desired response. The function can be written as

$$\Delta e^2(k) \triangleq \tilde{e}^2(k) - e^2(k) = -2\Delta\widetilde{\boldsymbol{w}}^{\mathrm{T}}(k)\boldsymbol{x}(k)\boldsymbol{e}(k) + \Delta\widetilde{\boldsymbol{w}}^{\mathrm{T}}(k)\boldsymbol{x}(k)\boldsymbol{x}^{\mathrm{T}}(k)\Delta\widetilde{\boldsymbol{w}}(k). \tag{4}$$

Make the $\boldsymbol{\mu}_k$ value of $\dfrac{\partial \Delta e^2(k)}{\partial \boldsymbol{\mu}_k} = 0$ as

$$\boldsymbol{\mu}_k = \frac{1}{2\boldsymbol{x}^{\mathrm{T}}(k)\boldsymbol{x}(k)}, \tag{5}$$

and $\boldsymbol{\mu}_k$ takes the above value to make $\Delta e^2(k)$ negative. So it corresponds to the minimum point of $\Delta e^2(k)$.

Using a variable convergence factor, the equation of the normalized LMS algorithm can be defined as

$$\boldsymbol{w}(k+1) = \boldsymbol{w}(k) + \frac{\boldsymbol{e}(k)\boldsymbol{x}(k)}{\boldsymbol{x}^{\mathrm{T}}(k)\boldsymbol{x}(k)}. \tag{6}$$

The designing principle of an adaptive de-noising system is shown in Fig. 6.

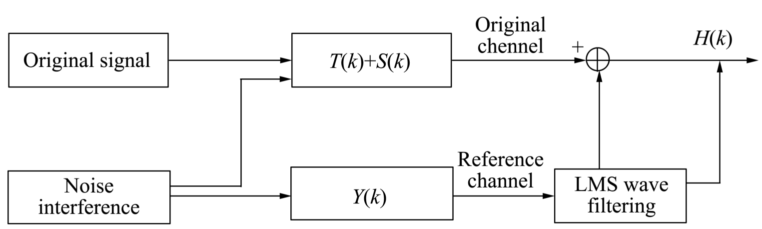

Fig. 6 Principle diagram of LMS adaptive filtering

The system has two input channels, one channel includes the original signal $T(k)$ and signal irrelevant noise $S(k)$, which is called the original input channel, and the input signal is $T(k)+S(k)$; Another route is not related to the original signal $T(k)$ and the noise is associated with noise $S(k)$ and $Y(k)$, which is called the reference input channel. According to adaptive filtering characteristics, the noise $Y(k)$ is automatically adjusted by LMS adaptive filtering, the estimation signal can be expressed as

$$A(k) = \hat{Y}(k). \tag{7}$$

The system output error signal $H(k)$ is the difference between the original signal and the reference signal, as

$$H(k) = T(k) + S(k) - Y(k). \tag{8}$$

Assuming that the upper signals $T(k)$, $S(k)$ and $Y(k)$ are stationary, the MSE is obtained, and the result is

$$E[H^2(k)] = E[T^2(k)] + E[S(k) - \hat{Y}(k)^2] + 2E[T(k)]E[S(k) - Y(k)]. \tag{9}$$

The adaptive filtering process is minimum for $E[H^2(k)]$. The $E[T^2(k)]$ represents the output power of the original signal, which has nothing to do with the LMS adaptive filter. Because the input signal source and the noise source are not correlated, the result is 0, the mean square error $E[H^2(k)]$ is the smallest, and the second value of the formula is the smallest. So

$$E[H^2(k)]_{\min} \Leftrightarrow E[S(k) - Y(k)]_{\min}. \tag{10}$$

In line with Eq. (7), Eq. (10) can be written as

$$H(k) - T(k) = S(k) - Y(k). \tag{11}$$

Under the adaptive LMS criterion, $E[S(k) - \hat{Y}(k)^2]$ is the smallest and $E[S(k) - T(k)^2]$ is minimized. LMS adaptive filtering output $A(k)$ is approximated to $Y(k)$. The output $H(k)$ of the equivalent system is approximated to the $T(k)$, thus the system output signal $T(k)$ is the best estimate which plays a role in suppressing noise.

4 Data test and error analysis

In order to verify the measurement accuracy of liquid level meter, regular rectangular liquid storage tank is used to test data. The standard value before and after the LMS filtering method is compared with the measured value liquid level, the measurement results are shown in Tables 1 and 2.

Table 1 LMS precorrection liquid level measurement data

Standard value (mm)	Measured value (mm)	Error (mm)	Relative error (%)
800.0	808.6	+8.60	1.10
550.0	542.7	−8.30	1.51
690.0	680.9	−9.10	1.31
630.0	640.4	+10.40	1.65
525.0	536.0	+11.00	2.10
639.0	628.4	−10.60	1.66
450.0	461.1	+11.10	2.50
850.0	861.5	+11.50	1.35
840.0	828.3	−10.70	1.30
910.0	900.4	−9.60	1.11
940.0	929.6	−10.40	1.11
915.0	904.3	−10.70	1.12
920.0	908.7	−11.30	1.22
855.0	844.3	−10.70	1.25
750.0	739.2	−10.80	1.44

Table 2 LMS corrected liquid level measurement data

Standard value (mm)	Measured value (mm)	Error (mm)	Relative error (%)
800.0	803.8	+3.80	0.48
550.0	548.7	−1.30	0.44
690.0	688.9	−1.10	0.16
630.0	630.4	+0.40	0.059
525.0	526.0	+1.00	0.18
639.0	638.4	−0.60	0.087
450.0	451.1	+1.10	0.24
850.0	851.5	+1.50	0.18
840.0	838.3	−1.70	0.20
910.0	908.4	−1.60	0.18
940.0	939.6	−0.40	0.042
915.0	914.3	−0.70	0.076
920.0	918.7	−1.30	0.14
855.0	854.3	−0.70	0.081
750.0	749.2	−0.80	0.11

In the condition of noisy environment, fifteen groups of liquid level data are continuously measured. In Table 1, minimum error of liquid level is 8.30 mm, minimum relative error is 1.10%, noise interference is consistent with the inherent defect of the liquid level meter. Table 2 adopts the proposed adaptive LMS filtering method for iterative weight vector and renewal of weight coefficient. Under the adaptive rule, the maximum error of the liquid level is 3.80 mm, the maximum relative error is 0.48%, and the precision is 99%. The measurement accuracy can meet the requirements of industrial measurement and field control, and it can set and measure the remote liquid level parameters.

5 Conclusion

A nuclear radiation level measurement system based on LMS filtering correction is designed, which can be employed for the liquid level measurement in environment of high temperature, high pressure, high viscosity and highly toxic. The measurement results can be corrected, the system can effectively remove measurement noise and realize real-time remote measurement, parameter setting and correction of liquid level. The field tests show that the radiometric level meter corrected by the LMS filtering method can eliminate the noise interference of the positive measurement system under the adaptive rule and improve the measurement accuracy. The liquid level meter can meet the requirements of the industrial field environment for the liquid level measurement and improve the degree of related industrial automation.

References

[1] Xing Y G, Wang Z, Liu Z J, et al. Underwater acoustic signal data acquisition system based on submersible. Measurement and Control Technology, 2015, 34(2): 59-61.

[2] Zhang N, Huang Y, Li J S. Research on the measurement method of physical location meter. Journal of Metrology, 2008, 29(3): 104-106.

[3] Liu H, Zhao J Y. Design of level measurement based on variable frequency oscillation method. Instrument Technique and Sensor, 2014, (11): 53-55.

[4] Li J N, Yang X Z, Gao J, et al. Research on the design method of two kinds of adaptive nonlinear filters. Chinese Journal of Scienctific Instrument, 2005, 26(8): 374-377.

[5] Glover J R. Adaptive noise cancellation is used for sinusoidal interference. IEEE Acoustics and Signal Processing, 1977, 25(6): 484-492.

[6] Liang Y M, Liu D, Zhao Y. Temperature signal processing of the furnace chamber of CZ single crystal furnace based on adaptive noise cancellation. Control Theory and Application, 2011, 28(1): 94-100.

[7] Liang Y M, Liu D, Ren P, et al. Diameter tracking in

pulling of crystals based on adaptive notch filtering. Chinese Journal of Scientific Instrument, 2010, 31(7): 1441-1447.
[8] Torrea D, Ghinamo G, Detoma E, et al. Analysis of the accuracy of indoor GNSS measurements and positioning solution. In: Proceedings of the European Navigation Conference-Global Navigation Satellite Systems, ENC-GNSS, 2008: 22-25.

基于归一化 LMS 滤波校正的核辐射法液位计设计

吴作鹏，王小鹏，吴　旭

（兰州交通大学 电子与信息工程学院，甘肃 兰州 730070）

摘　要： 在工业现场环境对液位的测量中，噪声的干扰会影响测量精度。为提高粘稠状态下液位测量精度，设计了一种基于归一化最小均方误差(LMS)滤波方法校正的核辐射法液位测量系统。以 STM32 为控制核心，利用基于 HART 总线 HT1200M 芯片进行数据传输与接收，归一化 LMS 滤波算法能够进行更精确的滤波处理，计算系统迭代权矢量，进行权系数更新，有效消除系统液位测量噪声，提高液位测量精度。测试数据表明，归一化 LMS 滤波方法校正的核辐射法液位计在自适应规则下能够消除测量系统噪声干扰，提高液位测量精度，液位计能够满足工业现场环境对液位测量要求，能够提高相关工业自动化程度。

关键词： 最小均方误差；核辐射法；自适应算法；权系数更新；液位计

引用格式： WU Zuo-peng, WANG Xiao-peng, WU Xu. Design of nuclear radiation level gauge based on normalized LMS filtering correction. Journal of Measurement Science and Instrumentation, 2019, 10(2): 103-108. [doi: 10.3969/j.issn.1674-8042.2019.02.001]