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Implementation of a Modified SQI for the Preprocessing of Magnetic Flux Leakage Signal

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A modified SQI method using magnetic leakage flux (MFL) signal for underground gas pipelines' defect detection and characterization is presented in this paper. Raw signals gathered using MFL signals include many unexpected noises and high frequency signals, uneven background signals, signals caused by real defects, etc. The MFL signals of defect free pipelines primarily consist of two kinds of signals, uneven low frequency signals and uncertain high frequency noises. Leakage flux signals caused by defects are added to the case of pipelines having defects. Even though the SQI (Self Quotient Image) is a useful tool to gradually remove the varying backgrounds as well as to characterize the defects, it uses the division and floating point operations. A modified SQI having low computational complexity without time-consuming division operations is presented in this paper. By using defects carved in real pipelines in the pipeline simulation facility (PSF) and real MFL data, the performance of the proposed method is compared with that of the original SQI

Keywords : modified SQI, complexity, magnetic flux leakage, gas pipeline, pipeline defects

1. Introduction

There is more than 500,000 km of gas pipelines globally. For extra safety, all gas pipelines should be examined regularly. The well-known examination methods include magnetic flux leakage (MFL), ultrasonic, electromechanical acoustic transducer (EMAT), etc. Because couplants are required for ultrasonic-based methods, MFL- and EMAT-based methods are used to detect the defects' detection and characterization of underground gas pipelines [1, 2].

The MFL-based method is dealt in this paper. It uses specially designed MFL PIGs (pipeline inspection gauges), as presented in Fig. 1(a). In general, MFL pigs consist of permanent magnets, brushes, several sensors including hall sensors, eddy-current sensors and gyroscopes, and data acquisition systems. Hall sensor signals are mainly used to detect and characterize pipeline defects. In defects or metal losses of pipelines, the flux from permanent magnets is leaked out, as shown in Fig. 1(b), and the leakage flux is detected using hall sensors. Hall sensors detect leakage flux in three directions: axial, radial and circumferential. In the case of Fig. 1(a), 192 sensor triplets are used around the PIG.

MFL signals include many unwanted noises and high frequency signals, uneven background signals, signals caused by real defects, etc. MFL signals of defect free pipelines mostly consist of two kinds of signals, uneven low frequency signals and uncertain high frequency noises. Leakage flux signals caused by defects are added in the defects regions. Investigation on three signals is needed in order to guarantee a good inspection performance.

There are many approaches to detect and characterize defects using MFL signals. Among them, Han *et al.* [3] and Kim *et al.* [4, 5] apply their algorithms to real MFL PIGs, as illustrated in Fig. 1(a). Han *et al.* [3] propose a DCT-based detection algorithm of defects for underground pipelines. They attempt to detect the defects' position using DCT-based high pass filters and align the base levels of every hall sensor. Kim *et al.* [4, 5] use the SQI to detect and characterize the defects. They use Gaussian filter as the smoothing filter; SQI is then automatically aligned to its base level of 1. However, SQI requires a

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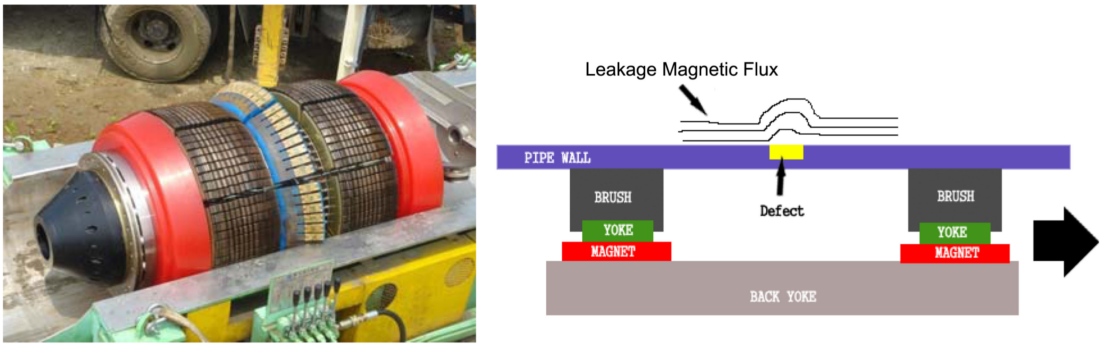


(a) MFL-PIG (b) Principle of the MFL method

Fig. 1. (Color online) MFL PIG and the principle of the MFL method [2].

time-consuming division operation using floating point numbers. In this paper, we try to reduce the computation time using simple addition/subtraction operations in order to embed the SQI module in a PIG.

This paper is organized as follows. In section 2, the MFL signals and conventional SQI [6] are explained. A modified SQI is presented in section 3 and the experimental results are given in section 4.

2. MFL Signals and SQI

The MFL method is a nondestructive inspection technique which detects the leakage flux of pipelines using hall sensors during MFL PIG floats inside the magnetized pipelines. Leakage flux varies according to the thickness of pipe walls. Due to the fact that the thickness of pipe walls is reduced in the case of defects or metal losses, there is an increased in leakage flux compared to defect free regions. By analyzing the leakage flux, defects can be detected and characterized.

In general, MFL PIGs equipped with many triplet hall sensors around the PIG and triplet is aligned to three orthogonal directions: axial, radial and circumferential. MFL PIGs move using gas pressure and maneuver through the pipelines made of steel. Once it has been installed, external control of PIGs is impossible. During the maneuvering, many unexpected circumstances may arise, of which many influence the sensing signals. Even though all the sensors are calibrated in advance, it does not guarantee that the calibration is kept on arrival.

SQI is a good preprocessing of MFL signals because it automatically aligns each signal, except it requires the time-consuming floating point division. SQI uses its signal itself to process the signal and does not need any extra information. Originally, SQI is used for face and gesture recognition due to its novel characteristic to reduce shadow and uneven lighting effects. Kim *et al.* [4, 5] tried to use SQI preprocessing in order to detect and characterize defects.

SQI can be characterized as the "original image divided by low-pass filtered image of original image," as shown in the two-dimensional SQI of Eq. (1). A low-pass filtered image is implemented by using the weighted Gaussian filters.

$$Q = \frac{I}{\hat{I}} = \frac{I}{F \times I}, \tag{1}$$

where

$$F(i,j) = W(i,j) \cdot G(i,j)$$

$$G = \frac{1}{2\pi\sigma^2} e^{\frac{(x^2+y^2)}{2\sigma}}.$$

Weight matrix W, as shown in Eq. (2), has a value of 0 or 1 depending on the surrounding values; hence, it determines to pass or block the Gaussian smoothing effect.

$$W(i,j) = \begin{cases} 0, & I(i,j) < Mean(I_\Omega) \\ 1, & otherwise \end{cases}, \tag{2}$$

where

$Mean(I_\Omega)$: Mean of the kernel (kernel size: Ω).

To consider more of the surrounding values, the weight matrix is modified, as shown in Eq. (3). In Eq. (3), M_1 represents the total number of pixels whose value is greater than the mean value of the kernel; that is, $\#\{(i, j) | I(i,j) > Mean(I_\Omega), (i,j) \in \Omega\}$.

$$W(i,j) = \begin{cases} \sim W(i,j), & M_1 < \dfrac{\Omega}{2} \\ W(i,j), & otherwise \end{cases} . \tag{3}$$

By Eq. (2) and (3), a low-pass filtered image is acquired and SQI is obtained by the original image divided by the low-pass filtered image.

3. Modified SQI for Real-time Implementation

A modified SQI is presented in this section for real-time implementation by reducing the computational complexity of the original SQI. By analyzing many years' MFL data, it is found that there exists high frequency noise between −5 and 5 gauss even in the no defect regions. For real-time implementation, the original SQI in Eq. (1) is modified to Eq. (4). Basically, SQI emphasizes high frequency components; thus, a modified version of it uses the subtraction of the original image to a low-pass filtered image, as conveyed in Eq. (4).

$$Q_{tmp} = I - \widehat{I} . \tag{4}$$

Modified SQI also considers the high frequency noise of defect-free pipelines; the final modified SQI is given in Eq. (5), where δ represents the boundary of high frequency noise of defect-free pipelines. In this research, δ is empirically selected as 5.

$$Q_M = \begin{cases} 0 & |Q_{tmp}| < \delta \\ Q_{tmp} - \delta & Q_{tmp} \geq \delta \\ Q_{tmp} + \delta & Q_{tmp} \leq -\delta \end{cases} . \tag{5}$$

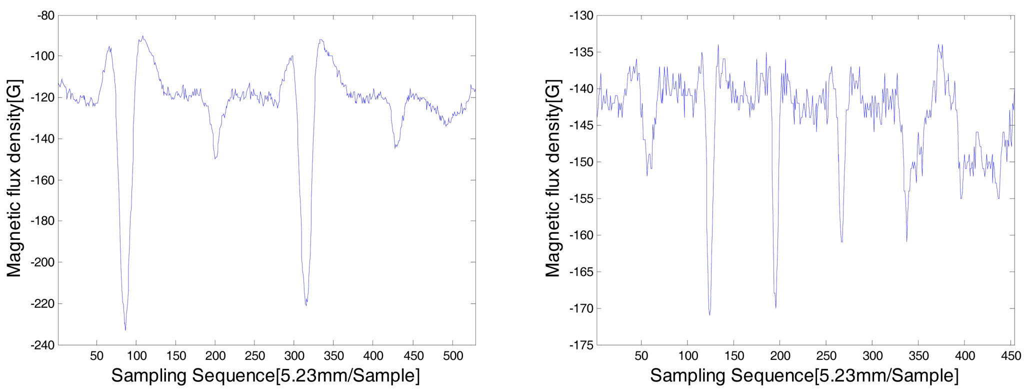
Further, Eq. (2) is modified to Eq. (6) in order to consider the broader local information rather than the kernel and $I_{section}$, which represents a weld-to-weld section of pipelines.

$$W(i,j) = \begin{cases} 0, & I(i,j) < Mean(I_{section}) \\ 1, & otherwise \end{cases} . \tag{6}$$

4. Experiments and Result

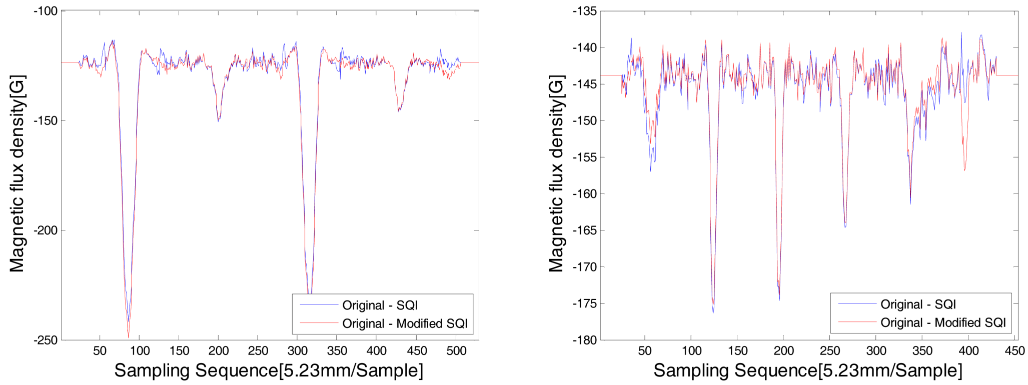
To verify that the modified SQI shows a similar result to the original SQI, real data measured from pipelines in PSF is used in this paper. Fig. 2 shows some of such data. Fig. 2(a) indicates the measured data from a pipeline having 4 defects. The defects are carved in different sizes and placed with constant distances. Fig. 2(b) shows the measured data from pipelines with 5 defects and 1 bend. The last lower lobe is a signal acquired by a leaned PIG due to the inertia during maneuvering inside the bend region.

The preprocessed signals are presented in Fig. 3. Fig. 3(a) shows the preprocessing result of Fig. 2(a) and Fig. 3(b) for Fig. 2(b). As shown in the figure, modified SQI having a lower computational complexity and easier hardware realization demonstrates a similar result to the original SQI, except for the bend region. Because it shows a similar result with the original SQI, all the conventional detection and characterization algorithms based on SQI can be used without modification using the modified SQI. Table 1 summarizes the execution time for SQI and modified SQI. It is obvious that the modified SQI take approximately half the time to preprocess the raw MFL signal.



(a) Pipeline signal with 4 defects (b) Pipeline signal with 5 defects and a bend

Fig. 2. (Color online) Two MFL raw signals.



(a) Defect characterization of Fig. 2(a) (b) Defect characterization of Fig. 2(b)

Fig. 3. (Color online) Preprocessed signals using SQI and the modified SQI.

Table 1. Comparison of execution time of SQI and modified SQI.

	SQI	modified SQI
Fig. 2(a)	0.4680	0.2340
Fig. 2(b)	0.4060	0.2180

5. Conclusion

A modified SQI-based preprocessing of MFL signals are presented in this paper. MFL is widely used as a non-destructive evaluation signal for underground gas pipelines' defect detection and characterization. However, raw signals gathered using MFL PIGs include many unexpected noises and high frequency signals, uneven background signals, signals caused by real defects, etc. SQI is a useful tool to gradually remove the varying backgrounds; yet, it uses the division and floating point operations. The low computational complexity version of SQI is suggested in this paper. The division operation in SQI is substituted with subtraction; moreover, a hard limiter is applied to reduce the high frequency noise. For the real MFL signals, it is found that the modified version and original SQI show similar results.

Future works include embedding the modified SQI to real MFL PIG and the ILI (In-Line Inspection) system, on-the-fly defect detection and characterization, light-weight MFL PIG implementations, etc. Further, algorithms of defect detection and characterization for weld regions, which lead to many defects in pipelines, should be developed.

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