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Small-target leak detection for a closed vessel via infrared image sequences

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ABSTRACT

This paper focus on a leak diagnosis and localization method based on infrared image sequences. Some problems on high probability of false warning and negative affect for marginal information are solved by leak detection. An experimental model is established for leak diagnosis and localization on infrared image sequences. The differential background prediction is presented to eliminate the negative affect of marginal information on test vessel based on a kernel regression method. A pipeline filter based on layering voting is designed to reduce probability of leak point false warning. A synthesize leak diagnosis and localization algorithm is proposed based on infrared image sequences. The effectiveness and potential are shown for developed techniques through experimental results.

1. Introduction

With the rapid development of industrial automation and progress of science technology, the requirements of leak detection on industrial equipments are very important in the field of aerospace, automotive engines, power and medicine [1]. Actually, air-tightness is an important factor for products quality, so the study of leak detection technology becomes much deeper with the growing air-tightness requirement of industrial manufacturing than before [2]. Because of the advantages on fast response and non-contact measurement, leak detection technologies on infrared thermal images are used widely [3]. Although fruitful results on leak detection technologies are found in recent publications, there is still a lot of space for further investigation.

It is known from experiments that the temperature in a leak point is different from others in surface of the test vessel [5]. The leak point is seen as a small target point in an infrared image obtained by an infrared thermal imager [6]. Therefore, both small target detection and image filter are two key technologies for leak detection methods via infrared images [4]. However, some random small points are always mistaken for false targets in a single-frame image [7]. Fortunately, a frame sequence technology is effective to overcome the single-frame image drawbacks [8]. To reduce influences of heavy clutter, a complex background suppression is presented for infrared small target detection in [9]. A kernel-based nonparametric regression method is proposed for clutter removal in infrared small-target detection applications in [10]. A homogeneous background prediction algorithm is given for detection of point targets in [11]. A separable convolution template background prediction method is presented for infrared small target detection in [12]. An adaptive learning to pipeline filter has been applied in the area of frame sequence image processing [13]. An infrared small targets detection method of mobile pipeline filter is proved in [14]. Moreover, a pipeline filter algorithm based on movement direction estimation is proposed in [15]. The performance of layering voting target detection is analyzed in [16]. However, to the best of our knowledge, the study on detection of infrared small dim targets in the field of leak detection has not been investigated yet.

Both the leak detection system in [4] and adaptive kernel regression approaches in [18] are effectively to improve the quality of leak detection for a single-frame infrared image [19]. However, there is a lot of space to be improved in leak diagnosis and localization. Firstly, marginal information affects some detection results usually when the surface shape of detected objects is irregular. Secondly, false warning with undetected and error-detected leak points happens sometimes due to influence of noise and surroundings. That is, if the threshold of leak points is not appropriate, the rate of false warning will increase, and workpieces without leaks may be regarded as leak workpieces. To solve these problems, a leak detection method of differential background prediction based

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on kernel regression (DBPKR) is introduced in this paper. The problem on DBPKR is important and challenging in both theory and practice, which motivated us to carry on this research work.

In this paper, a leak diagnosis and localization algorithm based on infrared image sequence is proposed. We combine DBPKR method with improved pipeline filter method to introduce a new leak point detection method on the basis of infrared image sequences. That is, both the DBPKR method and pipeline filter based on layering voting method are developed to a synthesize algorithm. This method can eliminate marginal information effectively and reduce the rate of false warning and improve the detection success rate. Some experimental results are given to illustrate the effectiveness of the algorithm.

2. Problem statement and preliminaries

2.1. Experimental system

The experimental model of leak localization system includes three important parts: pneumatic control circle, position driven, infrared image acquisition and processing. The diagram of pneumatic circuitry term in the experiment is shown in Fig. 1.

The leak diagnosis and localization model used in the experiment of this paper is shown in Fig. 2.

2.2. Mathematical model of infrared image

The gray value of infrared image pixel shows the temperature of the vessel surface correspondingly. The image acquired by infrared camera is named an original infrared image.

During the experiment, the original infrared image with small target leak points consists of three components: background, target points and noise. Infrared background is mainly shown as low frequency information whose gray value changes slowly with a continuous distribution in space and a strong correlation between pixels. The small leak targets and noise are mainly shown as high frequency information, which present as isolated spots without correlation with the background in the image. Let

$$K = \{(x,y) | 1 \leqslant x \leqslant V, 1 \leqslant y \leqslant W\}$$

denote the pixel coordinates of the original infrared image, where V and W are two integral numbers which denote the height and width, respectively. The original infrared image is described by the following functional model

$$f(x,y) = f_T(x,y) + f_B(x,y) + f_N(x,y) \quad (1)$$

where $f(x,y)$ is the gray value of a pixel (x,y) at the original infrared image, $f_T(x,y)$ is the gray value of a pixel at the region of targets, $f_B(x,y)$ is the gray value of a pixel at the background, $f_N(x,y)$ is the gray value of random noise.

In the following, a synthesize diagnosis and localization algorithm will be given to eliminate the background component $f_B(x,y)$ and $f_N(x,y)$, and to get the leak targets $f_T(x,y)$ in model (1).

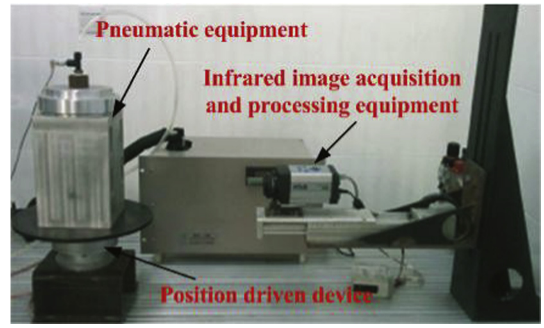

Fig. 2. Leak diagnosis and localization experimental model.

2.3. Kernel regression method

In [4], a nonparametric statistical regression model which is used in this paper is given as

$$g_i = m(z_i) + \varepsilon_i, \quad z_i = [x_i, y_i], \quad i = 1, 2, \ldots, N$$

where g_i is the image gray, (x_i, y_i) is the spatial coordinates, $m(z_i)$ is the regression function to approximate the complex background, ε_i is an interference which is uncorrelated with $m(z_i)$, N is the total number which is used to estimate the regression model. Note that ε_i is a Gaussian random variable with zero mean.

The nonparametric regression is used to deal with background component with complexity fluctuation. The local expansion of regression function $m(z_i)$ will be used when z is near the sample z_i. That is, the values of regression function at any points can be estimated. By the Taylor series, a local signal representation of function $m(z_i)$ is given as

$$m(z_i) = m(z) + \{\nabla m(z)\}^T (z_i - z) + \frac{1}{2}(z_i - z)^T \{\mathbf{H} m(z)\}(z_i - z) + \cdots \quad (2)$$

where ∇ is a gradient operator and $\mathbf{H}$ is a Hessian operator. Furthermore, (2) is also rewritten as

$$m(z_i) = \beta_0 + \beta_1^T (z_i - z) + \beta_2^T vech\{(z_i - z)(z_i - z)^T\} + \cdots \quad (3)$$

where β_0 is the interest pixel value $m(z)$, and

$$\beta_1 = \left[\frac{\partial m(z)}{\partial x} \; \frac{\partial m(z)}{\partial y}\right]^T$$

$$\beta_2 = \left[\frac{\partial^2 m(z)}{2\partial x^2} \; \frac{\partial^2 m(z)}{\partial x \partial y} \; \frac{\partial^2 m(z)}{2\partial y^2}\right]^T$$

Moreover, the half-vectorization operator $vech(\cdot)$ is given as follows

$$vech\left\{\begin{bmatrix} a & b \\ b & c \end{bmatrix}\right\} = [a \quad b \quad c] \quad (4)$$

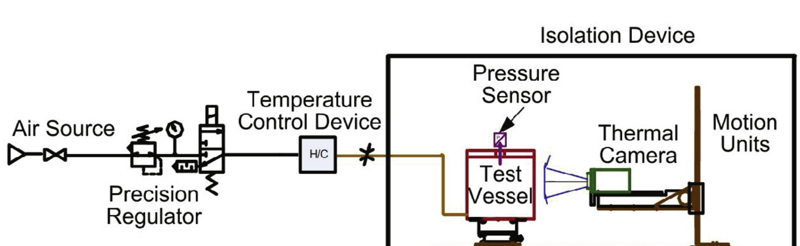

Fig. 1. The diagram of pneumatic circuitry term.