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Projective sampled pattern matching method for the defect recognition in conductive materials

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Abstract

Previously, we have proposed the sampled pattern matching method in order to search for the current distributions in the biological objects from the local magnetic fields. Further, this method has been successfully applied to the defect identification problems from the local electric potential measurements.

In this present paper, we propose the simple implemented techniques of our sampled pattern matching method to improve the accuracy of the defect identifications.

1. INTRODUCTION

In order to protect the accidents of the aircraft, iron bridge, and nuclear reactor, crack or defect recognition is of paramount importance technology. Therefore, various nondestructive testing methodologies, e.g. the eddy current testing, X-ray computed tomography, ultrasonic imaging and electrical potential method, have been exploited and utilized. Among these methods, the electrical potential method requires a relatively simple device and measurement [1,2].

Previously, the current distributions in human heart as well as brain have been successfully estimated from the local magnetic fields by the sampled pattern matching (SPM) method [3,4]. The SPM method has been exploited for solving the inverse source problems also applicable to the defect recognition problems, i.e. medium parameter identification problems.

Denoting C as a system matrix, it is possible to write $\mathbf{CX=Ys}$ as a discretized electric current flowing system equation of a conducive material having defect or crack. This system equation can be modified into $C_0\mathbf{X}=(C_0-C)\mathbf{X}+\mathbf{Ys}$, where C_0 is a system matrix without defect or crack. This means that the vector $\mathbf{X}(=C^{-1}\mathbf{Ys})$ is composed of the two input vectors $\mathbf{Y}$ and $\mathbf{Ys}$. The vectors $\mathbf{Y}$ and $\mathbf{Ys}$ are the equivalent field source vector $\mathbf{Y}=(C_0-C)\mathbf{X}$ caused by the defect or crack; and externally impressed field source vector $\mathbf{Ys}$, respectively. Thus, the defect or crack recognition problems can be reduced into the equivalent source vector $\mathbf{Y}$ searching problems. Obviously, this equivalent source vector $\mathbf{Y}$ depends on the vector $\mathbf{X}$. Further, this vector $\mathbf{X}$ is a function of the externally impressed field source vector $\mathbf{Ys}$. Thereby, the equivalent source vector $\mathbf{Y}$ can be expressed as a function of the impressed field source vector $\mathbf{Ys}$, i.e. $\mathbf{Y}=f(\mathbf{Ys})$. Introducing this functional relationship into our SPM method leads to the following advantages: this method requires a quite low CPU resource compared with those of the original SPM method because the SPM process has to be carried out only to the vectors satisfying the relationship $\mathbf{Y}=f(\mathbf{Ys})$; relatively highly accurate solutions can be expected, because one of the characteristics of solution vector $\mathbf{Y}$ is known; and changing the direction of vector $\mathbf{Ys}$ reaches the correct solution vector $\mathbf{Y}$ similar to the computed tomography. This new method is called the projective sampled pattern matching (PSPM) method because the functional relation between **Y** and **Ys** is that the direction of vector **Y** depends on the known vector **Ys**. In the present paper, we examine the characteristics of PSPM method. As a result, we propose here the simple implementation techniques to improve the accuracy of PSPM method.

2. THE PROJECTIVE SAMPLED PATTERN MATCHING METHOD

2.1. Basic equations

As described above, the original system equation is written down in a following form:

$$C_0 \mathbf{X} = \mathbf{Y} + \mathbf{Ys}, \tag{1}$$

where Co is *m* by *m* square matrix; **X**, **Y** and **Ys** are the *m*-th order column vectors. Taking the inverse matrix of C_0 and multiplying it to (1) yields

$$\begin{aligned} \mathbf{X} &= C_0^{-1}\mathbf{Y} + C_0^{-1}\mathbf{Ys} \\ &= C_0^{-1}\mathbf{Y} + \mathbf{X}_0 . \end{aligned} \tag{2}$$

where $\mathbf{X}_0\,(=C_0^{-1}\mathbf{Ys})$ is a vector without defect or crack. Subtracting $\mathbf{X}_0$ from (2), we can get

$$\begin{aligned} \mathbf{X}_d &= \mathbf{X} - \mathbf{X}_0 \\ &= C_0^{-1}\mathbf{Y}. \end{aligned} \tag{3}$$

Generally, it is difficult to measure the entire difference vector $\mathbf{X}_d$ in (3) so that we can only obtain a part vector $\mathbf{X}_p$ of $\mathbf{X}_d$. This yields a system equation of the defect or crack recognition problem. Namely, denoting *n* as a number of measured points, we have

$$\begin{aligned} \mathbf{X}_p &= D\mathbf{Y}, \\ &= \sum_{i=1}^{m} y_i \mathbf{d}_i , \end{aligned} \tag{4}$$

where D and $\mathbf{X}_p$ are the *n* by *m* partial matrix in C_0^{-1} and measured difference vector with order *n*. The y_i and $\mathbf{d}_i$ in (4) are the i-th element of **Y** and i-th column vector in D, respectively.

2.2. Sampled pattern matching (SPM) method

If a point *h* in the target region takes the maximum of:

$$\gamma_i = \mathbf{X}_p^T \cdot \mathbf{d}_i / [\,|\mathbf{X}_p|\,|\mathbf{d}_i|\,],\ i=1,2,\cdot,m, \tag{5a}$$

then *h* is called the first pilot point. If a point *g* takes the maximum of:

$$\gamma_{h,j} = \mathbf{X}_p^T \cdot (\mathbf{d}_h + \mathbf{d}_j) / [\,|\mathbf{X}_p|\,|\mathbf{d}_h + \mathbf{d}_j|\,],\ j=1,2,\cdot,m;\ j \neq h, \tag{5b}$$

then *g* is called the second pilot point. Similar process to (5a) or (5b) is continued up to the *n*-th pilot points. Thus, the element y_i in the vector **Y** has been assumed to

$$y_i = \begin{cases} 1, & \text{if i is a pilot point,} \\ 0, & \text{if i is not a pilot point,} \end{cases} \tag{6}$$

$i=1,2,\cdots\cdots,m.$

Pilot point solutions of (6) mean that the magnitude of solution y_i, i=1~m, in (4) is represented by the spatial concentrating rate of unit input.

2.3. Projective Sampled Pattern Matching (PSPM) Method

The SPM method is applicable to the inverse problems that the solution vector **Y** is not a function of the known function **Ys**, i.e.

$$\mathbf{Y} \neq f(\mathbf{Ys}). \tag{7}$$

However, if a relationship

$$\mathbf{Y} = f(\mathbf{Ys}), \tag{8}$$

is established, then the SPM processes are carried out only to the vectors $\mathbf{d}_i$ $(i=1,2,\cdots,m)$ satisfying the relationship (8). This method is called *the projective sampled pattern matching (PSPM) method.*

The PSPM method has the following features:

1) low cpu resource,
2) relatively highly accurate solutions,
3) changing the projective angles with $\mathbf{Y_s}$ reaches the correct solution vector,
4) the pilot point solutions are available if the known vector $\mathbf{X_p}$ encloses a target area.

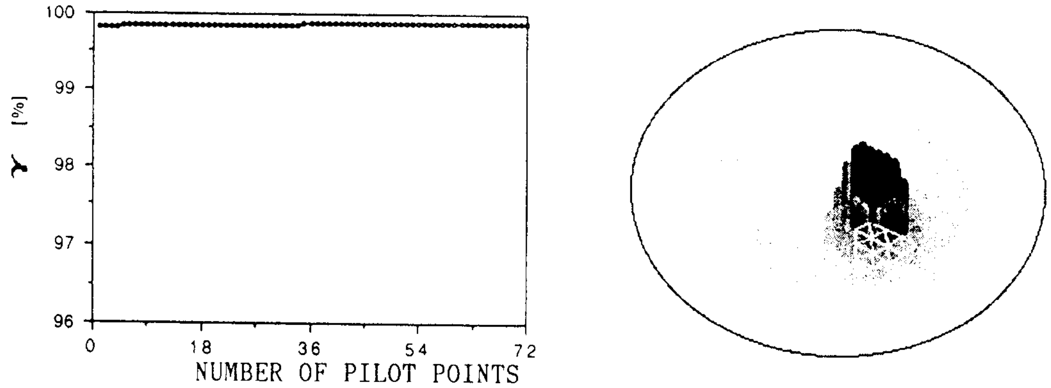
A curve obtained by plotting the pattern matching rate γ in (5a) or (5b) versus the pilot points reveals

1) if the curve monotonously increases in accordance with the addition of pilot points then the target area has single defect or indistinguishable plural defects,
2) if the curve has a deflection point then the object has the plural defects. In this case, each of the plural defects can be distinguished by shrinking the target area or removing the pilot points up to the first peak value of γ. This is because the pilot points up to the first peak value of γ provide the globally good pattern matching vectors common to the entire defects.

2.4. Examples

We chose the two dimensional electric potential method as the examples. The derivation of the system equation is described in detail in the Ref. [1].

Figure 1(a) shows one of the γ versus pilot points curves. Obviously, this curve monotonously increases in accordance with the addition of pilot points, so that the target area has single defect. In fact, the result of PSPM method shows the single defect as shown in Fig. 1(b).

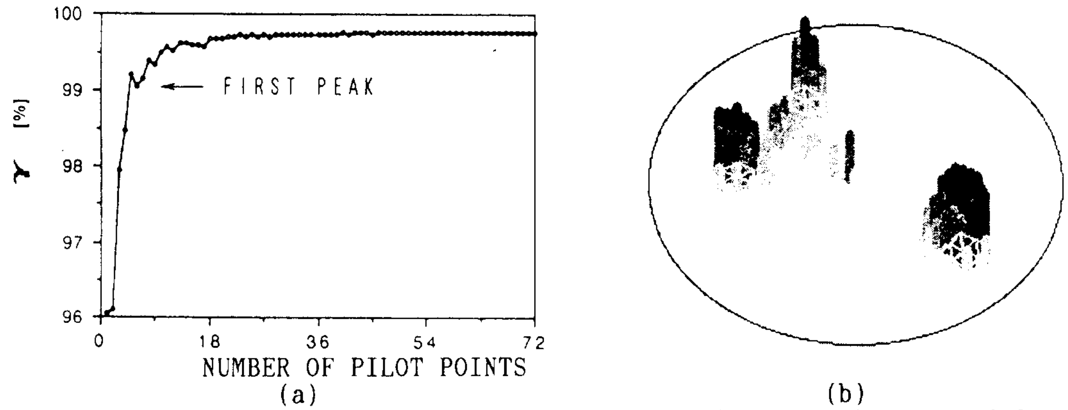


(a) (b)

Fig.1 Single defect recognition by measuring the electric potential around a target area. (a) γ vs. pilot points, and (b) recognized defect. The number of subdivision $m=1801$, and the number of measured points $n=72$. The direction of the externally impressed current input vector $\mathbf{Y_s}$ was changed 72 times with 5 degree subdivision.

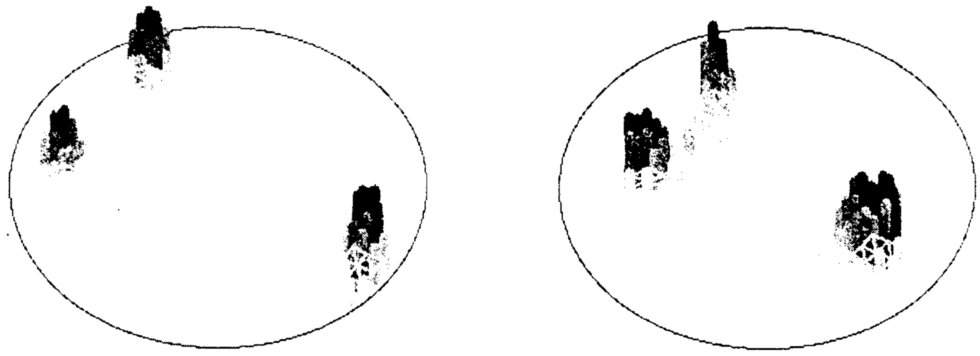
Figure 2(a) shows one of the γ versus pilot points curves. Obviously, this curve has a deflection point, so that the target area has the plural defects. In fact, the result of PSPM method shows the plural defects as shown in Fig. 2(b).

Figure 3(a) shows an improved plural defect recognition by shrinking the target area, and Fig. 3(b) shows the other improved plural defect recognition by removing the pilot points up to the first peak of γ.



(a) (b)

Fig.2 Plural defects recognition by measuring the electric potential around a target area. (a) γ vs. pilot points, and (b) recognized defect. The number of subdivision m=1801, and the number of measured points n=72. The direction of the externally impressed current input vector **Ys** was changed 72 times with 5 degree subdivision.



(a) (b)

Fig.3 Improved plural defect recognition. (a) Improvement by shrinking the target area, (b) improvement by removing the pilot points up to the first peak.

3. CONCLUSION

As shown above, we have examined the PSPM method and proposed the methods of improvement for the plural defect recognition problems. Examples have demonstrated that the plural defect recognition is dramatically improved by our method.

4. REFERENCES

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