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# Ultrasonic temperature distribution reconstruction for circular area based on Markov radial basis approximation and singular value decomposition

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ABSTRACT

Temperature distribution reconstruction is of critical importance for circular area, and an ultrasonic technique is investigated to meet this demand in this paper. Considering the particularity of circular area, algorithm based on Markov radial basis approximation and singular value decomposition is proposed, while ultrasonic transducers layout and division of measured area are properly designed. The reconstruction performance is validated via numerical experiments using different temperature distribution models, and is compared with algorithm based on least square method. To study the anti-interference, various noises are adding to the theoretical value of time-of-flight. Experiment results indicate that the proposed algorithm can reconstruct temperature distribution with higher accuracy and stronger anti-interference, while without the problem of algorithm based on least square method that its reconstructions will lose much temperature information near the edge of measured area.



## 1. Introduction

Temperature distribution is important in industrial applications related to burning or heating, as it can reflect the equipments' running state, then help to develop control strategy and ensure safety operation. Moreover, it is also used as powerful reference information for studying combustion technology, thus to design combustion systems [1–3]. Conventional intrusive methods of thermocouples and thermal resistances may cause problems with reliability and security in severe environment, and their single-point measurement will lead to insufficient of information [4–6]. The infrared temperature measurement is nonintrusive method, but it is just suitable for surface temperature and also accompanied with the limitation of single-point measurement [5,6]. In some power plants, the flame monitoring devices enable operators to judge current combustion state from some flame characteristics. Unfortunately, there exists uncertain influence of subjective factors, and it cannot provide quantitative temperature information [7]. The CCD camera technique utilizes radiation theory to construct temperature distribution image. However, its continuous working performance and maintenance will become problems in terrible environment [8].

As an emerging nonintrusive technique, ultrasonic temperature measurement has advantages of wide measuring temperature range, strong environmental adaptability, well real-time and continuous working ability [1,3,7–13]. Temperature distribution reconstruction using this technique is an inversion process, which depends greatly on reconstruction algorithm. Many algorithms have been proposed, such as algorithm based on least square method [14,15], algorithm based on interpolation and iterative [16], and algorithm based on RBF neural network [17]. However, due to problems of practicability like low accuracy, long time consumption, or poor applicability, they are seldom used in practice.

Among the existing algorithms, only the earliest one based on least square method has been used in circular measured area, and others are just emerging in rectangular situations. However, there is a great demand for temperature distribution reconstruction for circular area in practical applications. For example, the temperature monitoring areas of power plant boilers as well as other industrial furnaces are circular in fact. Again, most of large-scale gas tanks are cylindrical, thus their cross sections are also circular. Though algorithm based on least square method is simplest with quickness, the results it reconstructed will lose much temperature information near the edge of measured area, while

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with low reconstruction accuracy. Especially for circular measured area, these poor phenomena are even worse when compared with rectangular area.

In this paper, algorithm based on Markov radial basis approximation and singular value decomposition is proposed to reconstruct temperature distribution for circular area, which can gain remarkable performance with proper transducer layout and division of measured area. To compare with algorithm based on least square method under the same conditions, numerical experiments are designed while considering measurement errors of time-of-flight. Experiment results indicate that our proposed algorithm can obtain higher reconstruction accuracy, stronger anti-interference, and without the problem of losing temperature information near the edge of measured area.

## 2. Theoretical basis

Ultrasonic temperature measurement technique is based on the temperature dependence of ultrasound velocity, i.e., ultrasound velocity in an exact medium is a function of temperature. Take gaseous environment for example, ultrasound velocity is directly proportional to the square root of temperature, described as:

$$c = \sqrt{\kappa \frac{R}{M_g} T} = B\sqrt{T} \tag{1}$$

where $c$ is the ultrasound velocity, $T$ is the gas absolute temperature, $R$ is the universal gas constant, while $\kappa$ and $M_g$ are the ratio and average molecular weight of the gas, respectively. As $\kappa$, $M_g$ and $R$ are fixed constants for the specific gas, they may be replaced by a constant coefficient $B$.

A simplest ultrasonic temperature measurement instrument is composed by one ultrasonic transmitter mounted on one side and one ultrasonic receiver mounted on the other side along the same path. The transmitter is used to transmit ultrasonic signal, while the receiver is responsible for detecting the signal. As distance $L$ between them is known, average temperature of the path can be calculated from Eq. (2) when time-of-flight $t$ is measured:

$$T = \left(\frac{L}{t}\right)^2 \frac{1}{B^2} \tag{2}$$

This single-path measurement is just suitable for situations with uniform temperature, but not fit for complex situations with non-uniform temperatures. Fortunately, temperature distribution can be reconstructed using appropriate reconstruction algorithm with multiple ultrasonic transducers (including transmitters and receivers) properly installed [10–12,14–17]. Fig. 1 shows the typical transducer layouts and effective ultrasound paths between the transducers, of square and circular areas, respectively. Here, the

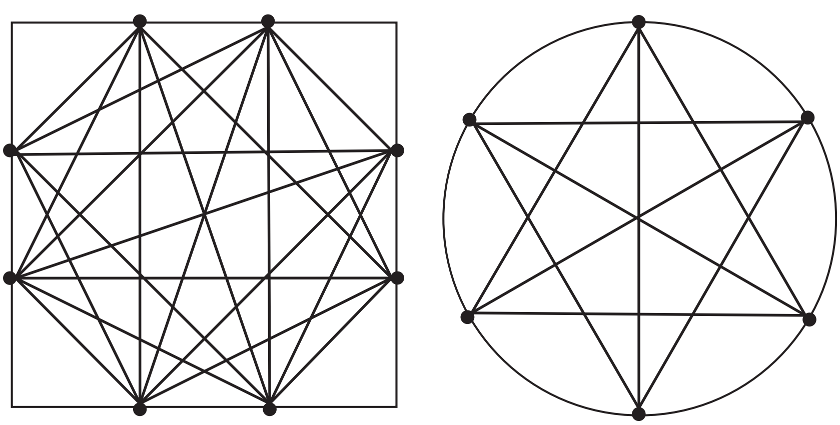


**Fig. 1.** Transducer layouts and effective ultrasound paths. (a) Square area. (b) Circular area.

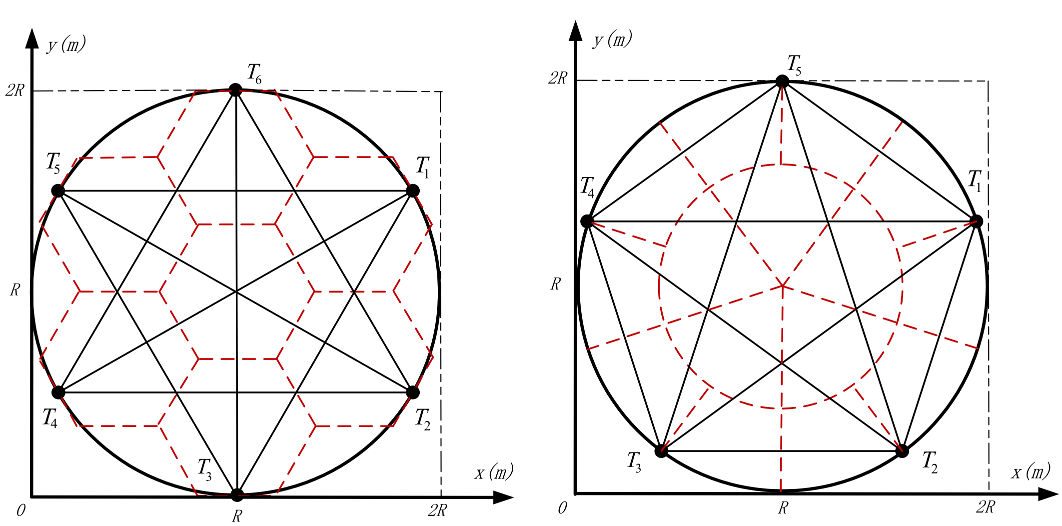


**Fig. 2.** Transducer layouts and divisions of measured area for circular situations. (a) Algorithm based on least square method. (b) Our proposed algorithm.