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Harmony search algorithm for image reconstruction from projections

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ABSTRACT

Image reconstruction from projections is an important problem in the areas of microscopy, geophysics, astrophysics, satellite and medical imaging. The problem of image reconstruction from projections is considered as an optimization problem where a meta-heuristic technique can be used to solve it. In this paper, we propose a new method based on harmony search (HS) meta-heuristic for image reconstruction from projections. The HS method is combined then with a local search method (LS) to improve the quality of reconstructed images in tomography. The two proposed methods (HS and hybrid HS) are validated on some images and compared with both the filtered back-projection (FBP) and the simultaneous iterative reconstruction technique (SIRT) methods. The numerical results are encouraging and demonstrate the benefits of the proposed methods for image reconstruction in tomography.

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1. Introduction

Image reconstruction from projections is an important problem that has been handled by a large number of scientists. This technical has found widespread application in many scientific fields, including microscopy, geophysics, astrophysics and medical imaging [1–3].

Let us consider a set of measures produced by unknown object, image reconstruction from projections is an inverse problem that consists in finding the original object from its projections. The problem is also ill-posed because the solution could be unique, could not exist, or different solutions could exist for the same problem [4].

The X-ray computed tomography (CT) is the most familiar application of image reconstruction from projections. The *X* scanners are used in different areas such as medical routine, metallurgy, material structure analysis and others [5]. The principle of CT has expanded to other physical phenomena that X-rays as radioactive emission (tomographic emission to a single photon (SPECT) or positron emission tomography (PET)), ultrasound, microwave, electrical impedance and magnetic resonance imaging (MRI).

The problem of image reconstruction from projections is an important problem in tomography. Several methods for image reconstruction are proposed in CT. Among them, we mention the following ones: filtered back-projection method (FBP) [6], algebraic reconstruction techniques (ART) [7], maximum likelihood expectation maximization (MLEM) [8] and simultaneous iterative reconstruction technique (SIRT) [9]. However, till now there is no method able to give satisfactory results. Other iterative methods were recently proposed as model-based iterative reconstruction (MBIR) [10] or iterative reconstruction in image space (IRIS) [11].

Some researchers [12,13,1,14–18] consider this problem as an optimization problem where the aim is to minimize a certain objective function referred to the projections.

The meta-heuristic is a kind of methods that have been used with success in solving several optimization problems in many search areas such as geophysics, astrophysics, medical imaging and microscopy [19–22]. However, to the best of our knowledge, there are only a few researches on tomographic reconstruction by using meta-heuristics based approaches. We can cite, for example the genetic and fly algorithms for tomographic reconstruction [23,17,13,14,16]. These methods are till now in the experimental stage. Nonetheless, it is possible to further improve the reconstruction.

The aim of the current work is to open a new field by using harmony search based meta-heuristic in image reconstruction. Further, we hope to improve the quality of reconstruction and find a method able to solve efficiently the considered problem of image reconstruction. First, we propose a new method based on harmony search (HS) meta-heuristic for image reconstruction in tomography. Then, we combine HS with a local search method (LS) to enhance the performance for image reconstruction with low

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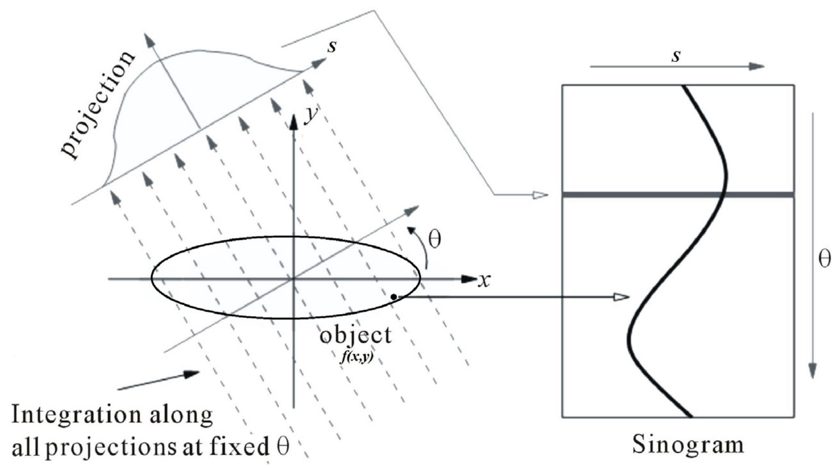

Fig. 1. Example of process of measuring projections and recording as sinogram [28].

resolution [18]. The two proposed methods are compared with FBP analytical method which is till now largely implemented in CT clinical routine [24,25] and with the iterative technique SIRT.

The rest of the paper is organized as follows: Section 2 presents a background on some basic principles of reconstruction from projections with an overview of standard methods for reconstruction in tomography. Section 3 details the proposed approaches for image reconstruction from projections. Section 4 gives experiments and some numerical results. Finally, we conclude in Section 5 and give some future works.

2. Background

Tomography is an imaging technique that permits to visualize the internal structure of an object. Tomography is performed in two steps. The first step is the process of data acquisition for recording projections. The set of angular projections is called *sinogram*. This *sinogram* is used in the second step to reconstruct the image. There are two main groups of reconstruction methods: the analytic and the iterative reconstruction methods.

The aim of this section is to give a background on basic principles of tomographic reconstruction followed by a brief description of standards methods applied in this field.

2.1. Basic principles of reconstruction from projections

The first step in tomography is the data acquisition process that can be modeled by Radon transform [5]. This transform converts a 2D function *f(x,y)* to 1D projection following a Cartesian coordinates (s,θ) [15]. In continuous cases, projections $P(s,\theta)$ with s the distance between each point crossed by the projection ray and the center of θ angle, such as (1), is to measure the integral of an infinite domain of all points (x, y) of the function or the object $f(x, y)$ [26,27]. These points contribute in P projection such as (2).

$$s = x\cos(\theta) + y\sin(\theta) \tag{1}$$

$$P(s,\theta) = \int_{-\infty}^{+\infty} f(x, y)dv \tag{2}$$

The set of these projections acquired at different angles θ are recorded into a certain format so-called *sinogram*. A *sinogram* is simply the 2D array of data containing the projections. Each column of the sinogram corresponds to the set of acquired projections for the same radial value s at different angles.

The two images depicted in Fig. 1 explain the process of data acquisition. The left image corresponds to the acquisition of the projections from the objects and the right one corresponds to projections collected as sinogram.

By analogy, in the discrete case, Radon transform is the sum of the values of all pixels (x, y) that contribute in each projection P_i as given in formula (3); r_{ij} is the value of pixel contribution j at the projection P_i; f_j is the value of this pixel [29].

$$P_i = \sum_{j=1}^{m} r_{ij} f_j \tag{3}$$

Added to this transform, John Radon has proved in 1917, that the reconstruction of the object from its projections is possible and could be exact if we have an infinite number of projections, and in reality it is impossible [30].

The reconstruction step is to back-project for each (x, y) the value of the projection at θ angle in which (x, y) is crossed by the ray of projection.

$$i = x\cos(\theta) + y\sin(\theta) \tag{4}$$

$$f'_\theta(x, y) = p_\theta(i) \tag{5}$$

The back-projection of all projections can be given as

$$f'(x, y) = \int_0^{\Pi} p_\theta(i)d\theta \tag{6}$$

By analogy, in discrete case the back-projection is computed such that

$$f'(x, y) = \sum_{\theta=0}^{\Pi} p(i, \theta) \tag{7}$$

With f' is the reconstructed object.

In overall, the image reconstruction in tomography can be summarized into two main steps:

1. Produce the projections from the image. The projections are collected as sinogram mode, see Fig. 2.
2. From these projections (sinogram) we reconstruct the image [5], see Fig. 3.

Several methods for image reconstruction are studied in CT. These methods can be divided into two main categories: analytical and iterative methods. The next subsection gives an overview on some well-known standard methods for image reconstruction in tomography.

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