Applied Soft Computing Journal 73 (2018) 153–177

Contents lists available at ScienceDirect

Applied Soft Computing Journal

journal homepage: www.elsevier.com/locate/asoc

Artificial ants and fireflies can perform colour quantisation

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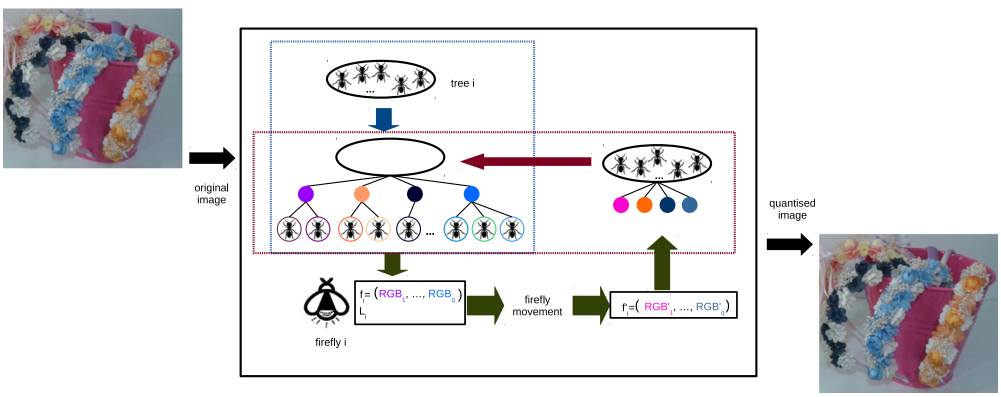
GRAPHICAL ABSTRACT



HIGHLIGHTS

- A colour quantisation method is proposed.
- The method combines artificial fireflies and artificial ants.
- The quantised image improves with the iterations of the algorithm.
- The method requires few iterations to obtain good results.
- This method generates better images than some well-known colour quantisation methods.

ARTICLE INFO

Article history:
Received 5 December 2017
Received in revised form 9 June 2018
Accepted 13 August 2018
Available online xxxx

Keywords:
Colour quantisation
Artificial ants
Ant-tree algorithm
Firefly algorithm
Clustering

ABSTRACT

Several methods based on the behaviour of biological systems have been proposed during the last years to solve a wide range of problems. Ant algorithms and Firefly algorithms are two methods of this type.

The Ant-Tree for Colour Quantisation algorithm was recently proposed to quantise colour images. It is a clustering-based method which creates a tree structure where the pixels of the image are grouped in subtrees according to their similarity. A threshold value determines if the similarity is sufficient to associate a pixel to a subtree. The computation of that threshold includes a parameter in (0, 1], whose value must be set taking into account the number of colours of the quantised image. Since this parameter influences the quality of the final image, it is recommended to perform several tests with different values of that parameter and then select the best result. In order to reduce the influence of said parameter and improve the resulting image, this paper proposes to combine the Ant-Tree for Colour Quantisation algorithm with the Firefly algorithm.

Computational experiments show that the new method generates better images than some popular colour quantisation methods such as Median-cut, Octree, Neuquant, Wu's method or the Variance-based method.

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https://doi.org/10.1016/j.asoc.2018.08.018

1. Introduction

Colour quantisation aims to find a small set of representative colours of an image, in such a way that the image can be represented with these colours without significant loss of quality.

Let us consider an image with n pixels, $\{p_1, \ldots, p_n\}$, represented by the amount of red, green and blue colours: $p_i = (R_i, G_i, B_i)$, where each colour takes integer values between 0 and 255. The colour quantisation process includes two operations. First, a quantised palette which includes the set of selected colours must be defined: $C = [c_1, c_2, \ldots, c_q]$, where each element c_k is a colour, $c_k = (R_k, G_k, B_k)$, and q is the size of the palette. Once the quantised palette has been defined, it is used to associate a new colour with each pixel of the original image, in order to obtain the quantised image. Since the objective of the process is to reduce the colours of the image, the value q is much smaller than the size of the palette used to define the original image.

Colour quantisation is a task by itself and it is also an auxiliary operation for other methods commonly applied to images, such as compression [1–4], segmentation [5,6], texture analysis [7,8], or content-based image retrieval [9–12].

Garey et al. demonstrated that finding the optimal palette is an NP-complete problem [13]. For this reason, several heuristic methods have been proposed to solve the colour quantisation problem, including methods related to the field of artificial intelligence, such as the swarms of particles. The swarm-based algorithms are inspired by the behaviour observed in some groups of animals (such as birds, fish, ants or other insects), and they have been applied to solve problems of different types.

Recently, an ant-based algorithm, called Ant-tree for Colour Quantisation (ATCQ), was proposed by Pérez-Delgado [14]. This method generates good results compared to some well-known colour quantisation methods. It adapts the Ant-tree algorithm, which is a clustering method that mimics the behaviour of some species of real ants that connect among themselves to avoid obstacles [15]. ATCQ associates an artificial ant to each pixel of the image to be quantised and defines groups of similar ants. The ants are organised in a tree structure to which they connect progressively. To connect an ant to a subtree of the structure, the similarity between that ant and the subtree must be bigger than a threshold. The value of this threshold is computed as a function of a parameter which must be set before the algorithm is applied. Experimental results presented in [14] showed that this parameter influences the solution and it must be carefully selected to obtain a good quantised image.

When the literature related to colour quantisation is analysed, it is observed that some solution methods combine other existing methods to improve the overall result; some examples appear in [16–20]. Based on this idea, it was analysed the possibility of combining the ATCQ algorithm with another algorithm, in order to obtain a method that generates better quantised images than ATCQ and with less dependence on a poor selection of the previously mentioned parameter. To achieve this goal, it is interesting to use a method that can consider several solutions and select the best of these solutions; among the methods with this possibility, the Firefly algorithm was selected. It should be noted that another important characteristic of the resulting method is the execution time, which must be competitive with other colour quantisation methods.

The Firefly algorithm was proposed by Yang [21], based on the social behaviour of natural fireflies. This method was designed to solve optimisation problems, and it has been applied to several problems, such as scheduling problems [22,23], continuous optimisation [24], clustering and classification [25], forecasting [26], or image processing [27–29]. Related to the image processing area, Jitpakdee et al. applied fireflies to colour quantisation [30]. They combined the Firefly algorithm with the K-means algorithm in a two-stage operation: first, the Firefly algorithm was applied to obtain a solution to the problem; next, the K-means algorithm was used to improve the result obtained by the fireflies. The results published showed that the proposed method reached solutions a little better than K-means and Firefly algorithms applied independently.

Unlike the solution proposed in [30], which applies two methods sequentially, this article proposes to combine the operations of Firefly algorithm and ATCQ algorithm. Moreover, ATCQ is used instead of K-means since the results reported in [14] show that ATCQ generates better results than K-means when applied to colour quantisation.

The proposed algorithm not only allows to improve the results of the ATCQ algorithm but also defines a method to apply the Firefly algorithm to perform colour quantisation. Computational results show that this swarm-based algorithm generates better results when combined with the ATCQ algorithm.

The rest of the paper is organised as follows. First, Section 2 briefly describes some well-known colour quantisation methods. Then, the ATCQ and the Firefly algorithms are described. Next, Section 5 presents the proposed algorithm, combining ants and fireflies. Section 6 shows some computational experiments and the paper ends with the conclusions.

2. Colour quantisation methods

The methods proposed to solve the colour quantisation problem can be classified into splitting methods and clustering-based methods.

Methods of the first group apply a recursive division of the colour space until q regions are obtained, and they take the representative colour of each region as a colour for the quantised palette. Some methods which apply this technique are Median-cut [31], Variance-based method [32], Binary splitting [33], Octree [34], and Wu's methods [35,36].

The Median-cut method divides the colour space into rectangular boxes and the centroids of these boxes define the palette. Each iteration selects the box containing the largest number of pixels and splits it along the longest axis at the median point. In this method, each colour of the quantised palette represents approximately the same number of pixels in the original image.

The Variance-based method applies the same idea as Median-cut, but it divides the box with the largest weighted variance. The splitting axis is the one with the least weighted sum of projected variances and the splitting point is the one that minimises the marginal squared error.

The Binary splitting method is based on the Variance-based method, although it selects the box with the largest distortion, the axis with the largest variance and the point corresponding to the projection of the centroid to such axis.

The Greedy orthogonal bipartitioning method proposed by Wu is similar to the Variance-based method, but in this case the selected box is divided along the axis that minimises the sum of the variances of both sides [35]. The same author proposed another method that applies dynamic programming [36]. This method sorts the colours along their principal axis and divides the colour space with respect to this ordering; then, the resulting constrained optimisation problem is solved by dynamic programming.

The Octree method builds a tree where the leaves represent the colours of the image. Next, it processes the tree from the leaves to the root, merging the leaves until the number of colours is reduced to q.

Clustering-based methods divide the pixels of the image into clusters or groups according to the similarity of those pixels; each cluster is represented by a single colour in the quantised