Abstract— This paper is presented a gravitational motivated algorithm for image segmentation. In this method the image is mapped into a feature space that has features of location and color. By traveling strategy of gravitational search algorithm, GSA, the masses travel in feature space to find similar regions and segmented the image by region growing using operation of merging. Similar regions are defined in feature space, so in image this yield to regions that are similar and semi-compact and may be discontinuous in image.

Index Terms— Color image segmentation, Feature space, Gravitational Search Algorithm, Gravitational Clustering.

I. INTRODUCTION

Image segmentation is an important process in many image/video processing and computer vision applications. The principle goal of image segmentation is to partition an image into several regions. Segmentation is very important in image processing and computer vision applications, such as object recognition [1],[2], color reduction [3], content based image retrieval [4], cell segmentation [5] and etc.

Image segmentation methods are divided into three categories of techniques [6],[7]: feature based, image domain based and physics based techniques. Feature based techniques use one or more features to segment images. Clustering based and histogram based methods belong to this category. Image-based techniques exploit spatial information and consider continuity or discontinuity of image. Region based, and edge based image segmentation methods are famous subclasses in this category. Physical based techniques use physical model accounting for reflections properties of colored mater [6].

In the clustering based methods an iterative clustering technique like the well-known C-means algorithm, fuzzy C-means algorithm or other variants of these algorithms is used to partition an image into \( C \) clusters [7]. Recently, there has been a great interest in using heuristic based clustering algorithms in image segmentation and other related fields. Most heuristic algorithms are inspired by natural and/or biological phenomena. Ant-based clustering is one of interesting clustering techniques which widely used in image segmentation [2], [3], [8].

Gravity based clustering is a natural based clustering technique inspired by the theory of Newtonian physics [9], [10], [11], [12]. To the best of our knowledge only a variant of this clustering approach has been adopted for color image segmentation [13]. In this method, a Markovian model of the gravitational clustering in RGB space is used for color image segmentation.

In this article, a novel image segmentation algorithm based on theory of gravity is presented. Moving equations are based on gravitational search algorithm, GSA [14]. The proposed method uses color information to partition the image to homogenous regions. Moreover, to achieve compact regions the spatial information of pixels is also considered as a feature and will be used in the segmentation process. Therefore, the proposed method benefits from the advantages of clustering techniques as well as region growing based ones. However, regions obtained by this method are somewhat compact, better than those of pixel based clustering methods and not fully compact like region growing methods.

The distinct characteristics of the proposed segmentation method are as follows: a) This is a gravitational based method and uses GSA to traveling in feature space. By the method of GSA, particles move in feature space and find similar regions. b) This is a feature based image segmentation algorithm while uses the spatial information of pixels to result in compact regions.

The rest of the paper is organized as follows. A review on related work and a brief introduction to the law of gravity is presented in section 2. The proposed gravitational segmentation algorithm is introduced in section 3. Experimental results are presented and discussed in section 4 and finally in section 5 the paper is concluded.

II. BACKGROUND

Newton's law of universal gravitation says all objects attract each other with a force of gravitational attraction. The force of gravitational attraction between two objects is directly dependent upon the masses of both objects and inversely proportional to the square of the distance which separates their centers. Newton's conclusion about the magnitude of gravitational forces is summarized as Eq. 1.
where \( F_{ij} \) is the magnitude of gravitational force between two objects \( i \) and \( j \) and \( M_i \) is the mass of object \( i \). \( G \) is the universal gravitational constant and \( r \) is the distance separating the objects’ center. Fig. 1 shows Newton’s law of universal gravitation.

\[
F_{ij} = \frac{G M_i M_j}{r^2}
\]

(1)

Inspired by Newtonian law of gravity, gravitational clustering algorithm is first proposed in [9] and has been studied in [10]-[13].

In [13] a Markovian model of the gravitational clustering in RGB space is used for color image segmentation. In [10] a clustering method based on the notion of a force of attraction between each pair of points has been presented. In [11] the GRIN algorithm, an incremental hierarchical clustering algorithm based on the gravity theory is presented to construct clustering dendrograms. The mass of a cluster is the number of its data instances. GRIN algorithm works in four phases: initial phase, incremental phase, insert operation and split operation.

It should be noted that the law of gravity has been used in some other fields. In [14] a swarm based meta-heuristic gravitational search algorithm, GSA, for real-valued (continuous) function optimization is proposed. In GSA a set of agents called masses are introduced to find the optimum solution by simulation of Newtonian laws of gravity and motion.

III. PROPOSED METHOD

In this paper, an unsupervised segmentation algorithm for color images based on gravitational law is presented. The proposed algorithm contains 2 stages, called traveling and merging. In traveling operation stage, agents move in the feature space under influence of gravitational force so that they find other similar agents. In merging operation stage, the regions of points are merged with the closest neighbors. When two or more points are merged into a one cluster, the mass of the resulting cluster will be a summation of point's masses. So, the mass of a cluster is the number of its data instances.

First of all, image is mapped into a feature space in which the masses walk to find similar regions. Feature space includes five dimensions. Each pixel deals with a location in the space. The first 2 dimensions indicate the location of pixels. The next 3 dimensions are related to the RGB color definitions of pixels. The five dimensions of each agent are shown in Eq. 2.

\[
Z_i = (x_i, y_i, r_i, g_i, b_i)
\]

for \( i = 1, 2, ..., N \)

At the beginning, each pixel is assigned to a particle with unit mass. By traveling operator, objects move under gravitational force of the other objects. The number of agents is decreased per iterations by merging operation. Agents are the representatives for regions and the color of agents is the color of regions.

In traveling stage, some of the objects search the feature space. The searching approach is based on the Gravitational Search Algorithm, GSA, which explained in details in [14]. GSA has been proposed motivated by gravitational law and laws of motion [14]. In order to compute the agent acceleration, The forces of a set of heavier masses which applied on any agent are put into gravity law (Eq. (3)). The computation is followed by calculation of agent acceleration using law of motion (Eq. (4)). The next velocity of an agent is then calculated by addition of the current acceleration to a fraction of current velocity (Eq. (5)). The new position is then calculated using Eq. (6).

\[
\text{Force}_{ij}(t) = \sum_{j \in \text{Kset}, j \neq i} \text{rand}_j G(t) \frac{M_j(t) M_i(t)}{R_{ij}(t)^2} (Z_{ij}^d(t) - Z_i^d(t))
\]

(3)

\[
a_i^d(t) = \frac{\text{Force}_{ij}(t)}{M_j(t)}
\]

(4)

\[
\text{vel}_{ij}^d(t + 1) = \text{rand}_j \times v_i^d(t) + a_i^d(t)
\]

(5)

\[
z_i^d(t + 1) = z_i^d(t) + v_i^d(t + 1)
\]

(6)

Where \( \text{rand}_i \) and \( \text{rand}_j \) are random numbers in the interval [0, 1] with uniform distribution. \( \varepsilon \) is a small value, and \( R_{ij}(t) \) is the Euclidean distance between two agents \( i \) and \( j \) defined as \( R_{ij}(t) = \left\| Z_i(t) - Z_j(t) \right\| \). Kset is a set of \( K \) agents which apply forces on the \( i \)'th agent and pull it. In GSA, the gravitational constant, \( G \), is assigned to an initial value, \( G_0 \), and will be reduced by time (Eq. (7)):
In merging stage every two objects \(i \) and \(j \) which are closer than a predefined threshold \( \theta \) are merged into one cluster representative object, \( Z_q \). The location, mass and velocity of the new object \( \{i, j\} \) are calculated using Eqs. (8-10).

\[
Z_q = \frac{M_i Z_i + M_j Z_j}{M_i + M_j} \quad (8)
\]

\[
M_{\{i,j\}} = M_i + M_j \quad (9)
\]

\[
V_{\{i,j\}} = \frac{M_i V_i + M_j V_j}{M_i + M_j} \quad (10)
\]

Applying the merging operator, the number of agents is decreased during iterations.

The pseudo-code of the proposed gravitational segmentation algorithm is presented in fig. 2.

- Mapping: Map pixels of image into feature space.
  \( Z = \{Z_1, Z_2, ..., Z_C : Z_i \text{ is cluster representative} \} \), containing all pixels at the beginning.
- Repeat until reaching to the maximum number of iterations or receiving a specified number of regions:
  a) Traveling: For every \( Z_i \in Z \) calculate \( v_i \) and the new position of \( Z_i \) based on GSA.
  b) Merging: Every two pairs \( Z_i, Z_j \in Z \) which are closer than a predefined threshold are merged to new \( Z_q \). \( Z_i \), \( Z_j \) are removed from \( Z \) and \( Z_q \) is added as the cluster representative of all pixels belonged to \( Z_i \) and \( Z_j \).

IV. RESULTS

In this section, segmentation results of the proposed method are evaluated on some test images. The proposed approach has been tested on more than 100 images taken from public image segmentation databases. In this paper, 4 images are selected to evaluate the efficiency of the proposed algorithm. Tested images are shown in fig. 3. The size of each tested image is \( 256 \times 256 \). Statistical region merging method, SRM [15], is selected as a base for comparison. In [15] segmentation was done by region growing using statistical information of images.

Experimental results are presented in fig. 4. In table 1, numerical results that are number of regions and PSNR are reported. PSNR is one of most popular evaluation methods that is widely used to evaluate the perceived quality of compressed images. Moreover, in this report we use an evaluation function to serve as the quantitative benchmarks. This benchmarks aim at finding a better tradeoff between homogeneity of a region and the total segment number [16]. The goal of segmentation is to achieve more homogeneity within regions while keeping a reasonable segment number [17]. These function give a larger values for segmentation methods that form too many regions and having non-homogeneous regions.

Using the merging operator, the number of agents is decreased during iterations.

The pseudo-code of the proposed gravitational segmentation algorithm is presented in fig. 2.

\[
e_j^2 = \sum_{R_j} (I - \hat{I})^2 \quad (11)
\]

\[
Q = \frac{1}{1000S_I} \sqrt{C} \sum_{j=1}^{C} \left[ \frac{e_j^2}{1 + \log N_j} + \left( \frac{N(S_j)}{S_j} \right)^2 \right] \quad (12)
\]
The proposed method is similar to region growing methods but regions are defined in feature space. So, continuous regions in feature space, may be non-continuous in image. By this effect, we can find regions that are discontinuous and semi-compact in image. In images, some objects may be divided by the other objects into some parts. By region growing methods, these objects are segmented into multiple regions. But by search based method in feature space, one can find the breakdown objects in fewer regions, as traveling in the feature space, the agents find similar regions which may be discontinuous in the image.

And also, in images that contain complicated details, fewer numbers of regions is reached. This may be beneficial in some machine vision applications.

V. CONCLUSION

In this paper, an unsupervised segmentation of color images is presented based on a gravitational motivated algorithm. The proposed algorithm is a gravitational merging method that segment images by region growing in feature space. Applying this method, divided objects segmented with fewer regions than those created by traditional region growing methods. Although the regions may be discontinuous in image, they will be continuous in feature space, but this effect is not as pixel-based method.

REFERENCES


