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A novel evolutionary algorithm inspired by the states of matter for template matching

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ABSTRACT

Template matching (TM) plays an important role in several image processing applications such as feature tracking, object recognition, stereo matching and remote sensing. The TM approach seeks the best possible resemblance between a sub-image, known as template, and its coincident region within a source image. TM has two critical aspects: similarity measurement and search strategy. The simplest available TM method finds the best possible coincidence between the images through an exhaustive computation of the Normalized Cross-Correlation (NCC) value (similarity measurement) for all elements in the source image (search strategy). Unfortunately, the use of such approach is strongly restricted since the NCC evaluation is a computationally expensive operation. Recently, several TM algorithms that are based on evolutionary approaches, have been proposed to reduce the number of NCC operations by calculating only a subset of search locations. In this paper, a new algorithm based on the states of matter phenomenon is proposed to reduce the number of search locations in the TM process. In the proposed approach, individuals emulate molecules that experiment state transitions which represent different exploration–exploitation levels. In the algorithm, the computation of search locations is drastically reduced by incorporating a fitness calculation strategy which indicates when it is feasible to calculate or to only estimate the NCC value for new search locations. Conducted simulations show that the proposed method achieves the best balance in comparison to other TM algorithms considering the estimation accuracy and the computational cost.

1. Introduction

Template matching (TM) is employed to measure the degree of similarity between two image sets that are superimposed, one over the other. TM is one of the most important and challenging subjects in digital photogrammetry, object recognition, stereo matching, feature tracking, remote sensing and computer vision (Brunelli, 2009). It relies on calculating the degree of similarity between the image under examination and the template image for each position. Thus, the best matching is obtained when the similarity value is maximized.

Generally, template matching involves two critical aspects: similarity measurement and search strategy (Hadi, Mojtaba, & Hadi, 2009). The most used matching criterion is the Normalized cross-correlation (NCC) which is computationally expensive and represents the most consuming operation in the TM process (Krattenthaler, Mayer, & Zeiler, 1994).

The full search algorithm (Rosenfeld & VanderBrug, 1977; Tanimoto, 1981; Uenohara & Kanade, 1997) is the simplest TM algorithm that can deliver the optimal detection with respect to a maximal NCC coefficient as it checks all pixel-candidates one at a time. However, such exhaustive search and the NCC calculation at each checking point, yields an extremely computational expensive TM method that seriously constraints its use for several image processing applications.

Recently, several TM algorithms, based on evolutionary approaches, have been proposed to reduce the number of NCC operations by calculating only a subset of search locations. Such approaches have produced several robust detectors using different optimization methods such as Genetic algorithms (GA) Dong et al. (2011), Particle Swarm Optimization (PSO) Liu, Duana, & Deng, 2012; Wu et al., 2009 and Imperialist competitive algorithm (ICA) Duan, Xu, Liu, and Shao (2010). Although these algorithms allow reducing the number of search locations, they do not explore the whole region effectively and often suffers premature convergence which conducts to sub-optimal detections. The reason of these problems is the operators used for modifying the particles. In such algorithms, during their evolution, the position of each agent in the next iteration is updated yielding an attraction

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towards the position of the best particle seen so-far (Adra & Fleming, 2011; Chen, Low, & Yang, 2009). This behavior produces that the entire population, as the algorithm evolves, concentrates around the best particle, favoring the premature convergence and damaging the particle diversity.

Every evolutionary algorithm (EA) needs to address the issue of exploration–exploitation of the search space. Exploration is the process of visiting entirely new points of a search space whilst exploitation is the process of refining those points within the neighborhood of previously visited locations, in order to improve their solution quality. Pure exploration degrades the precision of the evolutionary process but increases its capacity to find new potential solutions. On the other hand, pure exploitation allows refining existent solutions but adversely driving the process to local optimal solutions. Therefore, the ability of an EA to find a global optimal solution depends on its capacity to find a good balance between the exploitation of found-so-far elements and the exploration of the search space (Tan, Chiam, Mamun, & Goh, 2009). So far, the exploration–exploitation dilemma has been an unsolved issue within the framework of EA.

In this paper, a novel nature-inspired algorithm, called the states of matter search (SMS) is proposed for solving the TM problem. The SMS algorithm is based on the simulation of the states of matter phenomenon. In SMS, individuals emulate molecules which interact to each other by using evolutionary operations based on the physical principles of the thermal-energy motion mechanism. Such operations allow the increase of the population diversity and avoid the concentration of particles within a local minimum. The proposed approach combines the use of the defined operators with a control strategy that modifies the parameter setting of each operation during the evolution process. The algorithm is devised by considering each state of matter at one different exploration–exploitation rate. Thus, the evolutionary process is divided into three stages which emulate the three states of matter: gas, liquid and solid. At each state, molecules (individuals) exhibit different behaviors. Beginning from the gas state (pure exploration), the algorithm modifies the intensities of exploration and exploitation until the solid state (pure exploitation) is reached. As a result, the approach can substantially improve the balance between exploration–exploitation, yet preserving the good search capabilities of an evolutionary approach.

However, one particular difficulty in applying any EA to real-world problems is about its demand for a large number of fitness evaluations before delivering a satisfying result. Fitness evaluations are not always straightforward in many applications as either an explicit fitness function does not exist or the fitness evaluation is computationally expensive. Furthermore, since random numbers are involved in the calculation of new individuals, they may encounter same positions (repetition) that have been visited by other individuals at previous iterations, particularly when individuals are confined to a finite area.

The problem of considering expensive fitness evaluations has already been faced in the field of evolutionary algorithms (EA) and is better known as fitness approximation (Jin, 2005). In such approach, the idea is to estimate the fitness value of so many individuals as it is possible instead of evaluating the complete set. Such estimations are based on an approximate model of the fitness landscape. Thus, the individuals to be evaluated and those to be estimated are determined following some fixed criteria which depend on the specific properties of the approximate model (Jin, 2011). The models involved at the estimation can be built during the actual EA run, since EA repeatedly samples the search space at different points (Branke & Schmidt, 2005). There are many possible approximation models which have been used in combination with EA (e.g. polynomials Zhou, Ong, Nguyen, & Lim, 2005, the kriging model (Ratle, 2001), the feed-forward neural networks that includes multi-layer Perceptrons (Lim, Jin, Ong, & Sendhoff, 2010) and radial basis-function networks (Ong, Lum, & Nair, 2008).

In this paper, a new algorithm based on SMS is proposed to reduce the number of search locations in the TM process. The algorithm uses a simple fitness calculation approach which is based on the Nearest Neighbor Interpolation (NNI) algorithm in order to estimate the fitness value (NCC operation) for several candidate solutions (search locations). As a result, the approach can not only substantially reduce the number search positions (by using the SMS approach), but also to avoid the NCC evaluation for many of them (by incorporating the NNI strategy). The proposed method achieves the best balance over other TM algorithms, in terms of both estimation accuracy and computational cost.

The overall paper is organized as follows: Section 2 holds a description about the SMS algorithm. In Section 3, the fitness calculation strategy for solving the expensive optimization problem is presented. Section 4 provides backgrounds about the TM process while Section 5 exposes the final TM algorithm as a combination of SMS and the fitness calculation strategy. Section 6 demonstrates experimental results for the proposed approach over standard test images and some conclusions are drawn in Section 7.

2. States of matter

The matter can take different phases which are commonly known as states. Traditionally, three states of matter are known: solid, liquid, and gas. The differences among such states are based on forces which are exerted among particles composing a material (Ceruti & Rubin, 2007).

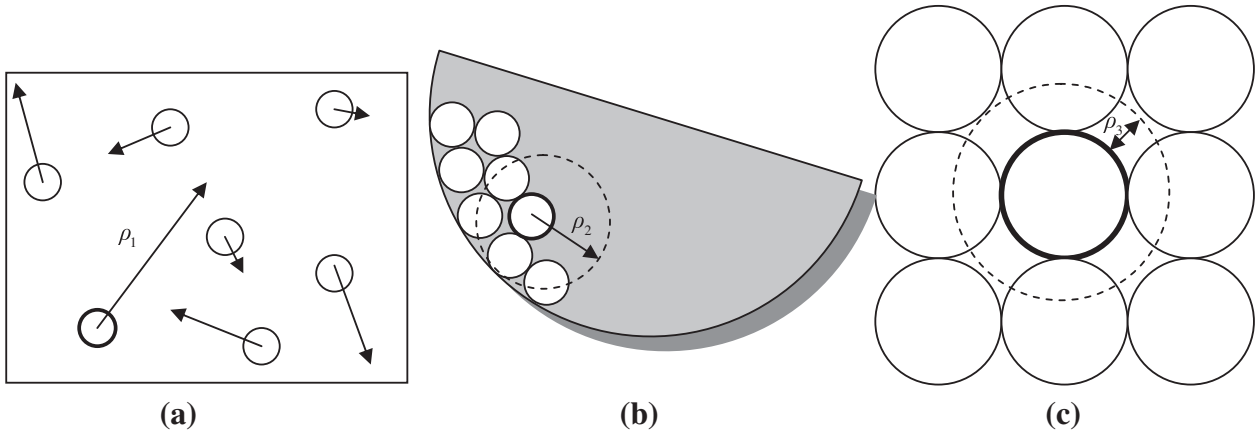

Fig. 1. Different states of matter: (a) gas, (b) liquid, and (c) solid.