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Optimisation of Engineering Systems With the Bees Algorithm

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ABSTRACT

This article describes the Bees Algorithm in standard formulation and presents two applications to real-world continuous optimisation engineering problems. In the first case, the Bees Algorithm is employed to train three artificial neural networks (ANNs) to model the inverse kinematics of the joints of a three-link manipulator. In the second case, the Bees Algorithm is used to optimise the parameters of a linear model used to approximate the torque output for an electro-hydraulic load system. In both cases, the Bees Algorithm outperformed the state-of-the-art in the literature, proving to be an effective optimisation technique for engineering systems.

KEYWORDS

Bees Algorithm, Engineering Systems, Hydraulic Motor, Intelligent Optimisation, Machine Learning, Robot Manipulator

1. INTRODUCTION

The Bees Algorithm (D.T. Pham, Ghanbarzadeh, et al. 2006a; D.T. Pham and Castellani 2009b) is related to several other nature-inspired population-based optimisation procedures, such as evolutionary algorithms (EAs) (Fogel, 2000) and swarm intelligence (SI) (Kennedy, 2006). Whilst EAs rely on competition amongst agents to evolve the population's fitness, SI mostly models cooperation in social insects. Moreover, standard EAs rely on centralised population selection, mating, and replacement procedures, whereas SI prescribes a fully decentralised population structure, self-organisation, and distributed intelligence. Similarly, to the SI approach, the Bees Algorithm relies on the cooperation of the artificial bees to discover the optimal solution. However, the Bees Algorithm has a centralised control structure to allocate the sampling opportunities in the search space. For this reason, the Bees Algorithm lies at the intersection between the EA and SI approaches.

2. THE BEES ALGORITHM

The Bees Algorithm is a nature-inspired optimisation method based on the foraging behaviour of honey bees. A number of agents (scout bees) are used to explore randomly the solution space, looking

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for regions of high fitness. The regions (sites) of highest fitness are further searched by forager bees which carry out local exploitative search. The Bees Algorithm repeats cycles of global (random) and local search until an acceptable solution is discovered, or a given number of iterations have elapsed.

The Bees Algorithm makes no assumption on the nature of the solution space, such as its derivability or continuity (Pham and Castellani, 2009b). For this reason, it is applicable to a wide range of continuous and combinatorial problems. Henceforth, unless explicitly stated, continuous optimisation problems will be considered.

Many variants of the BA have been developed, with variations in the way the bees are recruited, when and how a site is abandoned, and other key aspects of the algorithm. A recent survey (Hussein, Sahran, and Abdullah, 2017) suggests a classification of the Bees Algorithm in three different branches: one referred to as the Basic Bees Algorithm (BBA) by several authors (Pham, Castellani, and Fahmy, 2008; Packianather, Landy, and Pham, 2009; Pham and Castellani, 2009b; Yuce et al., 2013), where different sites are searched using a fixed search scope radius; one also considering a reduction (shrinking) of the scope of the local search shrinking-based BA (ShBA) (Pham, Ghanbarzadeh, et al., 2006a), and one regarded as the Standard BA (SBA) (Castellani, Pham, and Pham, 2012; Pham, Pham, and Castellani, 2012), including neighbourhood shrinking and site abandonment.

2.1. Bees Foraging Process in Nature

In a bee colony, a portion of the population explores the environment surrounding the hive in search for food (Von Frisch, 2014). These scouts look for patches of flowers where pollen or nectar is easily available and rich in sugar. Upon their return to the hive, the scouts unload the food they collected. Scouts that discovered a high-quality flower patch communicate to idle foragers the position of their find through a ritual called the waggle dance (Seeley, 2009). The duration of the waggle dance depends on how the scout rated the patch: highly rated patches are advertised via long dances, which attract a large number of free foragers (Seeley, 2009). Once the waggle dance is terminated, the scout returns to the food source for further foraging. The foragers that joined a scout in harvesting food from a flower patch, may as well waggle dance once they return to the hive, thus calling in more workers on the food source. Thanks to this autocatalytic mechanism, a bee colony is able to exploit efficiently the most profitable food sources (Tereshko and Lee, 2002).

2.2. The Algorithm

Without loss of generality[1], let us consider a minimisation problem $f\left(U\right) \rightarrow R^{+}$ defined over the n-dimensional continuous parameter space $U = \left\{x \in R^{n}; max_{i} < x_{i} < min_{i}, i = 1,\ldots,n\right\}$. The function $f\left(U\right)$ (*fitness function*) may feature constraints on the parameters, and defines a measure of the 'cost' of each solution $x = \left\{x_{1} \ldots x_{n}\right\} \in U$. The aim of the optimisation task is to find the solution $\mu \in U$ of minimal cost (i.e. maximal fitness):

$$f\left(\mu\right) \leq f\left(x\right)\left(\forall x \in U\right) \quad (1)$$

The standard procedure of the Bees Algorithm was outlined by (Pham and Castellani, 2009a), and is sketched in Figure 1.

At the beginning of the search, ns artificial scout bees are randomly initialised. Each scout lands on a candidate solution x, and evaluates its fitness. After the initialisation phase, a number of optimisation cycles are iterated.

At the beginning of each cycle, the $nb \leq ns$ scouts that visited the locations (solutions) of highest fitness perform the waggle dance. In the Bees Algorithm, the waggle dance is implemented