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RESEARCH ARTICLE

Applications of Swarm Intelligence

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Abstract— The inherent intelligence of swarms has inspired many social and political philosophers, in that the collective movements of an aggregate often derive from independent decision making on the part of a single individual [1].

Key Terms: - ACO-Ant Colony Optimization; PSO-Particle Swarm Organization; ABC-Ant Based Control; FOC-Field Oriented Controller; GA-Genetic Algorithm; SCL-Simple Competitive Learning

I. INTRODUCTION

Swarm intelligence is the discipline that deals with natural and artificial systems composed of many individuals that coordinate using decentralized control and self-organization.[1]

Swarm intelligence is the emergent collective intelligence of groups of simple autonomous agents. Here, an autonomous agent is a subsystem that interacts with its environment, which probably consists of other agents, but acts relatively independently from all other agents. The autonomous agent does not follow commands from a leader, or some global plan.

Swarm intelligence has a marked multidisciplinary character since systems with the above mentioned characteristics can be observed in a variety of domains.

Two of the most important algorithms are:

Ant colony optimization

Ant colony optimization or ACO is a class of optimization algorithms modeled on the actions of an ant colony. Artificial 'ants' - simulation agents - locate optimal solutions by moving through a parameter space representing all possible solutions. Real ants lay down pheromones directing each other to resources while exploring their environment. The simulated 'ants' similarly record their positions and the quality of their solutions, so that in later simulation iterations more ants locate better solutions. [2] One variation on this approach is the bees algorithm, which is more analogous to the foraging patterns of the honey bee [1].

Particle swarm optimization

Particle swarm optimization or PSO is a global optimization algorithm for dealing with problems in which a best solution can be represented as a point or surface in an n-dimensional space. Hypotheses are plotted in this space and seeded with an initial velocity, as well as a communication channel between the particles [3][4]. Particles then move through the solution space, and are evaluated according to some fitness criterion after each timestamp. Over time, particles are accelerated towards those particles within their communication grouping which have better fitness values. The main advantage of such an approach over other global minimization strategies such as simulated annealing is that the large numbers of members that make up the particle swarm make the technique impressively resilient to the problem of local minima [1].

In this study we will learn about some of the major applications of swarm intelligence.

II. SWARM INTELLIGENCE ROUTING

A. AntNet

In the AntNet[5] algorithm, routing is determined by means of very complex interactions of forward and backward network exploration agents ("ants"). The idea behind this sub-division of agents is to allow the backward ants to utilize the useful information gathered by the forward ants on their trip from source to destination. Based on this principle, no node routing updates are performed by the forward ants. Their only purpose in life is to report network delay conditions to the backward ants, in the form of trip times between each network node. The backward ants inherit this raw data and use it to update the routing table of the nodes [2].

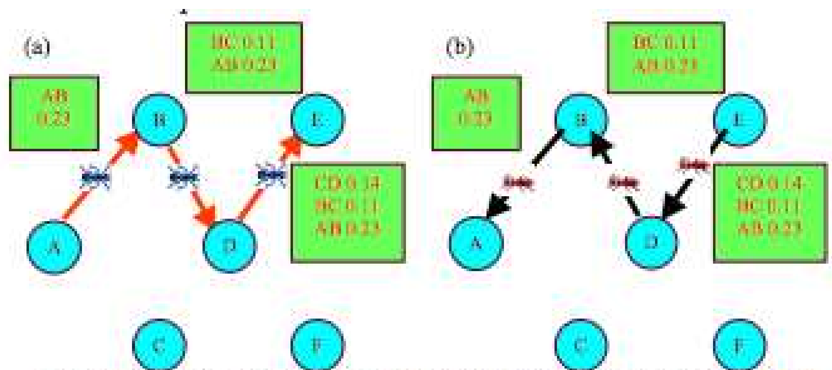

Fig. 1. (a) Forward ant movement (b) Backward ant movement [2]

B. Ant-Based Control

Ant-based Control (ABC)[6] is another successful swarm intelligence based algorithm designed for telephone networks. This algorithm shares many key features with AntNet, but has important differences. The basic principle shared is the use of a multitude of agents interacting using stigmergy. The algorithm is adaptive and exhibits robustness under various network conditions. It also incorporates randomness in the motion of ants. This increases the chance of discovery of new routes. In ABC, the ants only traverse the network nodes probabilistically, while the telephone traffic follows the path of highest probability [2].

C. AntHocNet

AntHocNet's design is inspired by ACO routing algorithms for wired networks. It uses ant agents which follow and update pheromone tables in a stigmergic learning process. Data packets are routed stochastically according to the learned tables. An important difference with other ACO routing algorithms is that AntHocNet is a hybrid algorithm, in order to deal better with the specific challenges of MANET[7] environments. It is reactive in the sense that nodes only gather routing information for destinations which they are currently communicating with, while it is proactive because nodes try to maintain and improve routing information as long as communication is going on [2].

III. SWARM ROBOTICS

Swarm robotics is a field of multi-robotics in which large numbers of robots are coordinated in a distributed and decentralized way. Large number of simple robots can perform complex tasks in a more efficient way than a single robot, giving robustness and flexibility to the group.

The collective behaviours of social insects, such as the honey-bee's dance, the wasp's nest-building, the construction of the termite mound, or the trail following of ants, were considered for a long time strange and mysterious aspects of biology. Researchers have demonstrated in recent decades that individuals do not need any representation or sophisticated knowledge to produce such complex behaviours. In social insects, the individuals are not informed about the global status of the colony. There exists no leader that guides all the other individuals in order to accomplish their goals. The knowledge of the swarm is distributed throughout all the agents, where an individual is not able to accomplish its task without the rest of the swarm.

Social insects are able to exchange information, and for instance, communicate the location of a food source, a favourable foraging zone or the presence of danger to their mates. This interaction between the individuals is based on the concept of locality, where there is no knowledge about the overall situation. The implicit communication through changes made in the environment is called stigmergy. Insects modify their behaviours because of the previous changes made by their mates in the environment. This can be seen in the nest construction of termites, where the changes in the behaviours of the workers are determined by the structure of the nest.

Organisation emerges from the interactions between the individuals and between individuals and the environment. These interactions are propagated throughout the colony and therefore the colony can solve tasks that could not be solved by a sole individual. These collective behaviours are defined as self-organising behaviours. Self-organisation theories, borrowed from physics and chemistry domains, can be used to explain how social insects exhibit complex collective behaviour that emerges from interactions of individuals behaving simply. Self-organisation relies on the combination of the following four basic rules: positive feedback, negative feedback, randomness, and multiple interactions.[3]

IV. CROWD CONTROL

Crowd control focuses on creating a realistic smooth and flexible motion for virtual human beings by utilizing the computational facilities provided in Particle swarm optimization (PSO).

In particular, we present a uniform conceptual model based on particle swarm optimization (PSO) to simulate the motion of all persons in a crowd according to the analogy between a swarm and a crowd. A person can be considered as a particle, which would like to find a way to reach the best solution.

Although PSO does possess some characteristics of the crowd behavior, it is still incompatible with the use for crowd control. Firstly, the particle in PSO is absolutely free to fly through everywhere in the given multidimensional space. However, the environment for a crowd may have obstacles, and the pedestrians in the crowd must avoid collisions, including the collision with the given obstacles and the collision with the fellow pedestrians, where other pedestrians can be considered as dynamic obstacles. These dynamic obstacles are not predictable and may appear and disappear in the environment at any moment.

Steps followed by Particle swarm optimization:

Initial

Set the position and the velocity of each particle.

Evaluate

Compute the objective value by the objective function.

Update PBLS

Update the PBLS of each particle by its objective value.

Update PBGS

Update the PBGS in the swarm.

Update Velocity and Position

Update the velocity and the position of each particle.

BLS: Best local solution
BGS: Best global solution

Particle swarm optimization (PSO) is an optimization paradigm proposed in the field of evolutionary computation for finding the global optimum in the search space. The concept of PSO is easy to comprehend, and the mechanism is easy to implement. The ability of PSO to reach the position of the optimum creates the possibility to automatically generate non-deterministic paths of virtual human beings from one specified position to another. On the other hand, if the target is the best position, the movement of a person is a process to find a walkable path to the destination. For these essential reasons, we propose the model to work with the original PSO for path creation. [4]

V. INVERSE HEAT CONDUCTION PROBLEM

Solution of the inverse problem is much more difficult than solution of the direct heat conduction problem in which the initial and boundary conditions are known, only the temperature must be found. The Artificial Bee Colony and Ant Colony Optimization algorithms can be used for minimizing the functional representing the crucial part of approach leading to the solution of the inverse heat conduction problem consisting in heat flux reconstruction.

In the inverse heat conduction problem with boundary condition of the third kind to be analyzed the distribution of temperature needs to be determined and the form of heat transfer coefficient appearing in boundary condition of the third kind reconstructed.

An important part of the procedure is minimization of the functional expressing the errors of approximate results.

Both swarm intelligence algorithms are useful for solving the considered problem; they give satisfying results for small numbers of individuals as well as for relatively small numbers of iterations. However, taking into account the number of calculations indispensable to obtain good results, which indicates the velocity of working of the algorithms, the ant algorithm appears to be slightly more efficient in solving this kind of problem. The number of iterations in the ACO algorithm execution, implying the number of direct heat conduction problems to be solved, is smaller by half in comparison with the ABC algorithm [5].

VI. INVERSE ANALYSIS IN CIVIL ENGINEERING

Applications to Identification of Parameters and Design of Structural Material Using Mono or Multi-Objective Particle Swarm Optimization

Many engineering applications suffer from the ignorance of mechanical parameters. It is particularly true when soil model is necessary to assess soil behaviour. Nevertheless, it is not always efficient to directly assess the values of all the parameters in the case of soil mechanics.[6]

Considering structural mechanics, also worked to propose an optimal design of a truss pylon respecting the stress constraints of the elements but it is not an easy task to solve considering the number and loading of the structure. Inverse analysis is an efficient solution to reach these aims. This technique becomes more and more popular thanks to the increase of the computing capabilities. Computing costs have decreased and allow to handle complex optimization problems through meta heuristic methods for example to identify the solution of the problem like the mechanical parameters of a behaviour model of a soil to define the best section of the beams composing a truss structure or to optimize wood-plastic composite mechanical properties designed for decking and taking into account the environmental impact during the life cycle of the product. [7]

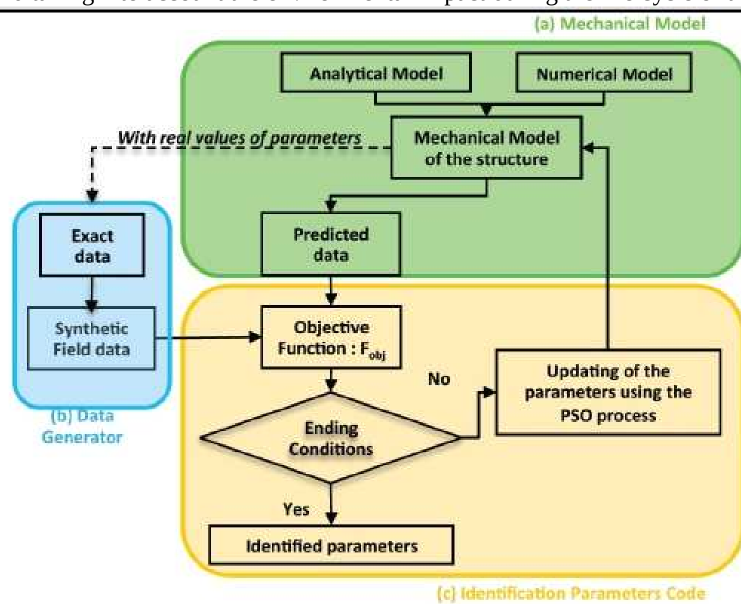

Fig. 2 [7]

The PSO algorithm is blind to the real physics, and can be easily adapted to a wide variety of engineering problem. Thus is used to solve structural problem and material problem in civil engineering.

The main issue is the definition of a relevant objective function, which describes the goal to reach (mimic the physical field measurement at best in the first case, minimize a multi-objective function in the second one).

The PSO can be used either for mono-objective or for multi-objective problems. The quick convergence of the PSO to the solution of the problem and its capabilities to be blind to local minimum shows that this algorithm is particularly appropriate for solving such kind hard optimisation problems.

Thanks to its simplicity of use, the PSO can be combined with more sophisticated computations (like for instance finite element computations, which are used, as a "slavecode", in the direct model) [8].

VII. APPLICATIONS IN ELECTRIC MACHINES

Particle Swarm Optimization (PSO) has potential applications in electric drives. The excellent characteristics of PSO may be successfully used to optimize the performance of electric machines in many aspects.

A field-oriented controller can be made based on Particle Swarm Optimization. In this system, the speed control of two asymmetrical windings induction motor is achieved while maintaining maximum efficiency of the motor. PSO selects the optimal rotor flux level at any operating point. In addition, the electromagnetic torque is also improved while maintaining a fast dynamic response. A novel approach is used to evaluate the optimal rotor flux level by using Particle Swarm Optimization. PSO method is a member of the wide category of Swarm Intelligence methods (SI). There are two speed control strategies field-oriented controller (FOC), and FOC based on PSO. The strategies are implemented mathematically and experimental. The simulation and experimental results have demonstrated that the FOC based on PSO method saves more energy than the conventional FOC method.

Another application of PSO for losses and operating cost minimization control is for the induction motor drives. These strategies are based on PSO and are called maximum efficiency strategy and minimum operating cost Strategy. The proposed technique is based on the principle that the flux level in a machine can be adjusted to give the minimum amount of losses and minimum operating cost for a given value of speed and load torque.

Particle swarm optimization (PSO) is a population based stochastic optimization technique influenced by the social behaviour of bird flocking or fish schooling. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles [9].

VIII. APPLICATIONS IN SOFTWARE ENGINEERING

Software testing is an important and valuable part of the software development life cycle.

Due to the time and cost constraints, it is not possible to test the software manually and fix the defects. Thus the use of test automation plays a very important role in the software testing process. [10]

Meta-Heuristic algorithms have been applied to three areas of software engineering: test data generation, module construction and cost/effort prediction.

The process of test data generation involves activities for producing a set of test data that satisfied a chosen testing criterion. [11]

Requirements for test case generation:

- Transformation of the testing problem into a graph.
- A heuristic measure for measuring the "goodness" of paths through the graph.
- A mechanism for creating possible solutions efficiently and a suitable criterion to stop solution generation.
- A suitable method for updating the pheromone.

Current research into the ACO is still at a nascent age. More potentially beneficial work remains to be done, particularly in the areas of improvement of its computation efficiency. [12]

IX. IMAGE SEGMENTATION

Image segmentation plays an essential role in the interpretation of various kinds of images. Image segmentation techniques can be grouped into several categories such as edge-based segmentation, region-oriented segmentation, histogram thresholding, and clustering algorithms (Gonzalez & Woods, 1992). The aim of a clustering algorithm is to aggregate data into groups such that the data in each group share similar features while the data clusters are being distinct from each other. There are a number of techniques, developed for optimization, inspired by the behavior of natural systems (Pham & Karaboga, 2000). Experimental results showed that swarm intelligence can be employed as a natural optimization technique for optimizing both K-means and SCL (SIMPLE COMPETITIVE LEARNING) algorithms.

The K-means algorithm often fails to realize clusters since it is heavily dependent on the initial cluster centers. The ACO-K-means and PSO-K-means algorithms provide a larger search space compared to the K-means algorithm. By employing these algorithms for clustering, the influence of the improperly chosen initial cluster centers will be diminished over a number of iterations. Therefore, these algorithms are less dependent on randomly chosen initial seeds and are more likely to find the global optimal solution.

SI can help SCL find the global optima using the same parameter set and learning rate as those used in the SCL and recognize the clusters where the SCL fails to do, in some cases. This can be advantageous since for SCL to find the global optima the learning rate should be adjusted in the course of experimentation [13].

X. DATA MINING

Data mining and particle swarm optimization may seem that they do not have many properties in common. However, they can be used together to form a method which often leads to the result, even when other methods would be too expensive or difficult to implement. A new clustering method based on PSO is proposed and is applied to unsupervised classification and image segmentation. [14]

The PSO-based approaches are proposed to tackle the color image quantization and spectral unmixing problems. Visual data mining via the construction of virtual reality spaces for the representation of data and knowledge, involves Particle swarm optimization (PSO) combined with classical optimization methods. This approach is applied to very high dimensional data from microarray gene expression experiments in order to understand the structure of both raw and processed data. [15]

Cluster analysis has become an important technique in exploratory data analysis, pattern recognition, machine learning, neural computing, and other engineering. The clustering aims at identifying and extracting significant groups in underlying data. [16]

The basic mechanism underlying this type of aggregation phenomenon is an attraction between dead items mediated by the ant workers: small clusters of items grow by attracting workers to deposit more items. It is this positive and auto-catalytic feedback that leads to the formation of larger and larger clusters. The general idea for data clustering is that isolated items should be picked up and dropped at some other location where more items of that type are present.

Therefore, various swarm intelligence algorithms can be used together to form a method which often leads to the result, even when other methods would be too expensive or difficult to implement [17].

XI. CONCLUSION

The complexity of an ant colony or the beautiful sight of a large swarm of birds surprises with the simplicity of the underlying rules. With ant colony optimization and particle swarm optimization two algorithms have been created which can solve difficult computational problems efficiently, while still beeing easy to understand. As there is a wide variety of swarm behaviors in nature, there is a great chance we will see more algorithms and systems modeled after social insects and other social animals.

The challenge in designing such systems will be to define the correct rules for the interaction of the individuals, as it is not immediately evident which rules lead to the desired behavior of the swarm.

Swarm intelligence is a very active and exciting research field. As our technical systems become increasingly complex, swarm intelligence algorithms – which consist of many simple parts – become more and more useful as a solution to difficult computational problems. As the algorithms are parallel in nature, they are well adapted for the use on parallel hardware. On coming processor generations – which will feature a growing number of parallel processing units – this may lead to very efficient implementations of these algorithms [18].

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