Ant colony optimization approach to digital comparative holography through traveling salesman problem

M. HOSSEIN AHMADZADEGAN*, M. KINNUNEN, T. FABRITIUS
Department of Electrical Engineering, Optoelectronics and Measurement Techniques Laboratory, University of Oulu Oulu, Finland

Digital comparative holography is an essential mechanism used for working on verifying the body or contortion of two corresponding entities with varying micro architecture. Ant Colony Optimization (ACO) is a paradigm for designing meta-heuristic algorithms for combinatorial problems of optimization. The vital characteristic of ACO algorithms is the combination of a priori information about the structure of a promising solution with a posteriori information about the structure of previously obtained good solutions. The Traveling Salesman Problem (TSP), given a list of nodes and the distances between each node pairs, describes the shortest possible route that visits each node exactly once and returns to the originating node. The TSP has been successfully deployed with ACO to explain and justify many existing optimization issues. Here in this research work, it has been demonstrated how the joint ACO-TSP notion can be used for optimization purposes in digital comparative holography's context.

(Received October 14, 2014; accepted November 13, 2014)

Keywords: Digital comparative holography, Ant colony optimization, Traveling salesman problem, Plane mirror

1. Introduction

Digital comparative holography (DCH) is a method in which comparative holography joins with digital holography [1]. When it comes to comparative holography the conjugated contortions of the master object are reconstructed and the test object is set at light. The observation is carried out in the genuine illumination direction. The distinguished advantage of comparative digital holography compared with conventional comparative holographic interferometry is that the holograms of all states can be kept and later on rebuilt independently from each other. Therefore no more reference waves are desired for a separate coding of the diverse holograms. This property of digital holography leads to the reduction of technical needs for comparative measurements to a large extent. In computer science and operations research, the ant colony optimization algorithm (ACO) is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs. This algorithm is a member of the ant colony algorithms and among methods of swarm intelligence; moreover it can lead to some meta-heuristic optimizations. Initially proposed by Marco Dorigo in his research works [2][3], the first algorithm was aiming to seek for an optimal path in a graph, according to the ants behavior searching a path between their colony and a food source. The original idea has since modified for solving a much wider class of numerical related issues, and therefore, various problems have come up, drawing on different aspects of the ant's behavior. In the natural world, ants choose randomly, and after figuring out where the food is, come back to their colony while leaving pheromone trails. In case other ants come to know such a path, they most likely will not continue travelling randomly, but instead the left trail would be followed, returning and reinforcing it if they eventually find food. Over time, however, the pheromone trail begins to evaporate, therefore diminishing its attractive strength. The more time it takes for an ant to travel down the path and back again, the more time the pheromones have to evaporate [2]. A short path, by comparison, gets crossed over more regularly and therefore the pheromone amount and its density becomes higher on shorter paths than longer ones. Pheromone evaporation also has the advantage of avoiding the convergence to a locally optimal solution [3]. If there were no evaporation at all, the paths chosen by the first ants would tend to be excessively attractive to the following ones. In that case, the exploration of the solution space would be constrained. Therefore, when one ant figures out a good path from the colony to a food source, other ants are more likely to follow that path, and positive feedback finally results in all the ants' following a single path. The idea of the ant colony algorithm is to mimic this behavior with "simulated ants" walking around the graph representing the problem to solve. The traveling salesman problem (TSP) is a well-known optimization problem in operations research and is of great importance in other fields due to its widespread application in diverse issues. In this problem a salesman starts to move from an arbitrary node called node depot and returns after visiting n nodes so that each node is visited just once. The objective is to find the shortest minimum cycle. Although TSP has been considered in the research arena since the 1920, this issue nowadays is receiving much attention by researchers and scientists [4].

The chief reason is that the TSP belongs to non-deterministic polynomial problems in nature. It implies that it needs a non-polynomial time complexity at runtime to produce a solution.

2. Digital Comparative holography

In DCH, for measuring the body of an entity the illumination wavelength is changed between taking the two holograms. The transmission of this digital hologram to a test location in Fig. 1 can be done by any data transfer medium. At Fig. 1 the hologram is fed into a Liquid Crystal Display (LCD) as spatial light modulator. A laser rebuilds the hologram optically in Fig. 1. The observation is performed from the original illumination direction.

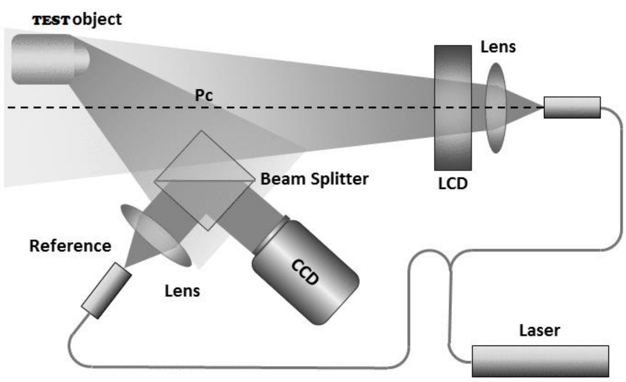

Fig. 1. Digital comparative holography [4]. Illumination of the test entity with the conjugated wave front of the master.

As it can be observed the chief positive point of comparative digital holography compared with conventional comparative holographic interferometry is that the holograms of all states can be stored safely and at a required moment become reconstructed independently from each other. Therefore no additional reference waves are needed for the separate coding of the holograms [5].

3. Ant colony optimization

Ant colony optimization (ACO) is one of the most popular algorithms in the research field of swarm intelligence. ACO has been inspired by the behavior of real ants seeking a path between their colony and a source of food as in Fig. 2.

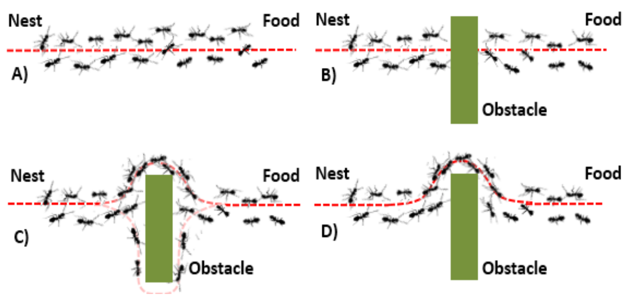

Fig. 2. (A) Real ants follow a path between the nest and a food source; (B) An obstacle appears on the path: Ants choose whether to turn left or right with equal probability; (C) Pheromone is deposited more quickly on the shorter path; (D) All ants have chosen the shorter path [6].

While walking between their colony and the food source, ants deposit pheromones along the paths they move. The pheromone level on the paths increases with the number of ants passing through and decreases with the evaporation of pheromone. As time passes, shorter paths attract more pheromone. Consequently, pheromone intensity helps ants to identify shorter paths to the food source. The first version of ACO called Ant System (AS) aimed at searching for an optimal path between two nodes.

4. Traveling salesman problem

The TSP is a special case of the travelling purchaser problem. In the theory of computational complexity, the decision version of the TSP where, the length L is given, the issue is to verify if the graph has shorter available tours than L, belongs to the class of NP-complete problems. Therefore, it can happen that for any algorithm, the worst-case running time in case of the TSP increases hyper-polynomially with the number of nodes. The problem was first formulated in 1930 and is one of the most intensively studied problems in optimization. It is used as a benchmark for many optimization methods. Even though the issue is computationally intricate, a vast number of precise methods are available in such a way that some examples having several thousands of nodes can be settled smoothly and even problems possessing millions of nodes can be mitigated and approximated within a tiny fraction of 1% [7]. The TSP has numerous applications even in its initial formulation, like in logistics, planning and the microchip manufacturing corporations. With small modifications, it emerges as a sub-problem in various cases like DNA sequencing. When it comes to these applications, the concept which the node implies, for instance, soldering points customers or DNA fragments, and the concept distance represents travelling times or cost, or a similarity measure among DNA fragments. In several applications, extra constraints like limited resources or time windows can be imposed. The TSP can be formulated as an integer linear program [8-10].

We label the nodes with the numbers 0... n and define:

$$x_{ij} = \begin{cases} 1, & \textit{the path goes from Node i to Node j} \\ 0, & \textit{otherwise} \end{cases}$$

For i = 1... n, let Ui be an artificial variable, and finally take Cij to be the distance from node i to node j. Then TSP can be written as the following integer linear programming problem:

$$min \sum_{i=0}^{n} \sum_{j \neq i, j=0}^{n} c_{ij} x_{ij}$$

$$0 \leq x_{ij} \leq 1 \qquad i,j = 0, \cdots, n$$

$$u_i \in Z \qquad i = 0, \cdots, n$$

$$\sum_{i=0, j \neq i}^{n} x_{ij} = 1 \qquad j = 0, \cdots, n$$

$$\sum_{j=0, j \neq i}^{n} x_{ij} = 1 \qquad i = 0, \cdots, n$$

$$u_i - u_j + n x_{ij} \leq n - 1 \quad 1 \leq i \neq j \leq n$$

The first set of equalities requires that each node be reached at from exactly one other node, and the second set of equalities requires that from each node there is a departure to exactly one other node. The last constraints enforce that there is only a single tour covering all nodes, and not two or more disjointed tours that only collectively cover all nodes.

5. Results and discussion

In the holographic system, one can control the aperture through which the light travels. In order to start with the process of analysis, primarily we denote two moments of time being t0 and t1. The delay between t0 and t1 is set to be not very short to cause problems with the effect of multiple reflections/scatterings. The reason for choosing two moments is twofold. First of all two moments reflect different moments and therefore they are independent from each other. Secondly at each specific moment a certain action takes place and this enables the analysis to take place smoother. Moreover the results can be distinguished easier.

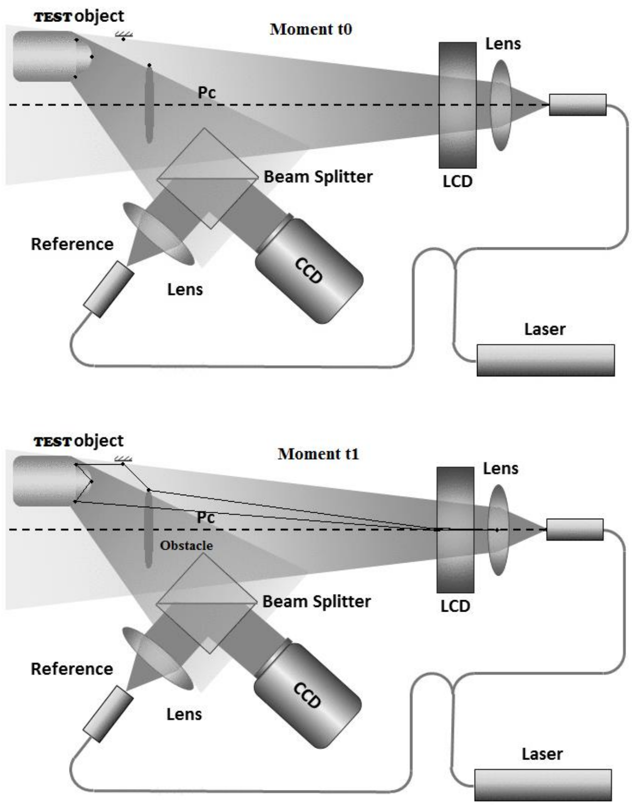

Fig. 3. Experimental digital comparative holographic setup represented in moment's t0 and t1.

Now let us pass on to the initial system setup, obtained results and their relevant analysis. First of all we focus on the moment t0. At this moment one can observe the initial DCH setup. As it can be seen, in order to apply the ACO mechanism in our optical system we locate an opaque obstacle being rough on the edges in front of the illumination direction situated between the laser light and the test object. As a result of this we actually engineer the light's travelling path. Also the blocked photons will be absorbed by the obstacle. Thus in this manner as it can be confirmed, the ACO has been simulated. Before starting the real simulation it should be added that above the test object there is a horizontal plane mirror located with a measured angle so that the light would be reflected to the body of the test object entirely and keep the beams of light safe and away from deviation. Further on we go to the moment t1. At this moment we turn on the lasers light. The beams of light travel the path and touch the edge of the opaque obstacle. Some get blocked and the remaining beams get reflected by the plane mirror on different surface locations of the test object as it can be seen in Fig. 3. Then the light gets back to the observer and where the light initially originated. As one can agree the ACO notion has been applied so that for this specific optical setup the shortest path would be selected which correctly imitates the ACO notion. As explained earlier for describing the phenomenon we utilize the TSP approach now. Therefore as it can be observed, at moment t1, the light travels the path distinguished by the dark dots one by one and never passes from a dot twice. Therefore this exactly resembles the TSP where the shortest path is determined by a salesman going from one node to another and coming back but not visiting any node twice. Thus we have created a setup with optimal optical characteristics and explained and defined the phenomenon with the successful joint couple being the ACO-TSP. This setup can be useful in specific application where it is required to fix the illumination direction and block some beams from travelling or deviation.

6. Conclusions

Digital comparative holography is an important method that provides the possibility of a contortion checkout of two corresponding entities. Thus by the help of its deployment the main parameters can be changed and therefore in this manner it facilitates the situation for a comparative analysis. Utilization of this method has made it possible to compare various entities in far situated locations by interferometric sensitivity. In this research paper, we have taken a novel approach by using the ant colony optimization theory to transfer the image obtained by comparative holography in three-dimensional form as usual but fix the setup so that the shortest path would be selected. Further on, the TSP together with ACO has been deployed to describe and explain the phenomenon and how the light behaves in such similar situations. This operation enables us to investigate the test object and the behavior of the light by the aid of the travelling salesman problem. Eventually by analyzing the obtained results, we have provided an alternative way through which ACO-TSP can be deployed to describe the behavior of light and facilitate the shortest path selection, justification and description.

Acknowledgment

The authors should express their gratitude toward the Oulun Yliopiston Apteekin Rahasto fund, the Kaute Foundation, Finnish Foundation for Technology Promotion and University of Oulu for supporting this research work and providing the necessary funding and means for performing the tests and their respective analysis. In addition to this, the authors and scientific community are indeed grateful to U. Schnars and W. Jueptner for providing excellent insights and materials in the field of digital holography.

References

[1] W. Osten, T. Baumbach, S. Seebacher, W. Jüptner, in Proceedings of 4th International Workshop on Automatic Processing of Fringe Patterns. Akademie, pp 373-382, Berlin, 2002.
[2] M. Dorigo, C. Blum, Theoretical Computer Science, **344**(2-3), 243 (2005).
[3] M. Dorigo, M. Birattari, T. Stützle, IEEE Computational Intelligence Magazine, **1**(4), 28 (2006).
[4] W. Osten, T. Baumbach, W. Jüptner, Optics Letters **27**(20), 1764 (2002).
[5] U. Schnars, W. Jueptner, Digital Holography. Berlin, Germany: Springer-Verlag, 2005, pp. 116-118.
[6] M. Yousefikhoshbakht, F. Dedehvar, F. Rahmati, Romanian Journal of Information Science and Technology, **16**(1), 65 (2013).
[7] D. L. Applegate, R. M. Bixby, V. Chvátal, W. J. Cook, The Traveling Salesman Problem, ISBN 0-691-12993-2 & Wikipedia TSP description (2006).
[8] R. Hassin, S. Rubinstein, Information Processing Letters **75**(4), 181 (2000), doi:10.1016/S0020-0190(00)00097-1.
[9] M. Held, R. M. Karp, Journal of the Society for Industrial and Applied Mathematics **10**(1), 196 (1962), doi:10.1137/0110015.
[10] H. Kaplan, L. Lewenstein, N. Shafrir, M. Sviridenko, In Proc. 44th IEEE Symp. on Foundations of Comput. Sci, 56 (2004).

*Corresponding author: ahmadzadegan@ee.oulu.fi