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Reconstruction of curves from point clouds using fuzzy logic and ant colony optimization

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ABSTRACT

A new approach based on fuzzy logic and ant colony optimization is presented for the reconstruction of curves from a set of unorganized points. Fuzzy clustering is used to reduce the number of points to cluster centres. Ant colony optimization is used to construct a travelling salesman path which is a closed curve. Extra edges are deleted and new edges are added using the fuzzy membership function. The algorithm presented in this paper has been used for reconstructing open as well as closed curves. The results obtained for multiple and self-intersecting curves are also good. Various examples for open, closed, multiple and intersecting curves with complicated shapes are shown to illustrate the significance of the presented algorithm.

1. Introduction

Reconstruction of curves from a set of unorganized points is a problem with lot of practical significance and thus is encountered in various applications including reverse engineering, medical imaging, handwriting recognition and computer aided design. In many practical applications of engineering and science we need to fit a curve to an unknown, unordered and noisy data. The problem is not a trivial one and so considerable effort has been put to find solution to this problem in a most general form.

There are various approaches to Curve Reconstruction. The first one is based on Delaunay Triangulations. Various algorithms have been developed using this approach namely Crust [1], NN Crust [2] and Conservative Crust [3]. The major drawback of these approaches is that the efficiency of the algorithms is very low in case of dense point clouds [4] and moreover they are sensitive to noise. Guo [5] has used Delaunay Triangulations for reconstructing curves from point cloud but then the approach used is not able to handle self-intersecting curves. Self-organizing maps have also been frequently used in the domain of Curve Reconstruction. Kumar and Kalra [6] have given a reconstruction algorithm based on growing self-organizing maps. But the drawback of this approach is that it cannot handle curves with self-intersections and multiple components. Clustering has also proven to be a good approach for dealing with the problem of Curve Reconstruction. Clustering reduces the storage and computational time by reducing the data set to a few points that represent the entire data. Yan [7] has used fuzzy c-means clustering for reconstructing curves from unordered point set. Along with that he has used the concepts of graph theory to generate meaningful curves. Travelling salesman path is not a new concept in the field of reconstruction of curves from a set of unorganized points. It was first proposed by Giesen [8] for a uniform sample and later this condition of uniform sampling was removed by Althaus and Mehlhorn [9]. The major drawback associated with this approach is that it can reconstruct only closed curves and also cannot deal with the multiple components. Bandwidth selection approach as given by Ozturk [26] is useful for reconstructing open and closed curves without self-intersections. A Robust Line Fitting (RFL) method given by Hasirci and Ozturk [10] can handle point clouds with self-intersections but its applicability to multiple curves is not established. Another approach given by Ohrhallinger and Mudur [11] is based on treating the problem of determining the shapes from a set of unorganized points as minimization problem. The advantage achieved by this method is that it works well for sparse point set and can efficiently detect sharp corners. But again this approach can be used only for non-intersecting curves and is not applied to dense point clouds with noise. Ellipse based principal component analysis (PCA) was used by Ruiz and Vanegas [25] for reconstructing closed self-intersecting curves. Later Principal component analysis along with Gauss–Newton optimization algorithm was used for reconstructing curves from point cloud by Ruiz [27]. The method is able to deal with open, closed and self-intersecting curves but the issues of multiple curve components and sharp corners have not been discussed.

The method given in this paper is implemented on the dense point clouds with noise as done in [6,11] and uses some of the concepts given in [6,7]. The major difference is that we have used the travelling salesman path to generate an initial closed curve and

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then edges are deleted and added to produce a final curve which is piecewise continuous. The ant colony optimization has been used to find the travelling salesman path which otherwise is a NP Hard problem. The approach used is better than the one using self-organizing maps [6] because it is not possible to deal with self-intersecting curves and multiple curve segments with the clusters formed by the maps. Also the proposed method is better than the one given in [10] because it cannot handle multiple curves for a dense point cloud with noise. A detailed comparative analysis is presented in Section 4. So the advantage achieved is that our method can handle complicated shapes including open curves, closed curves, smooth curves, self-intersecting curves and multiple curve segments.

The remainder of the paper is bifurcated as follows: The theoretical concepts of ant colony optimization and fuzzy c-means clustering are outlined in Section 2. The proposed algorithm for reconstruction is presented in Section 3. Various examples of complicated shapes are shown in Section 4. The conclusion of the entire work is given in Section 5.

2. Theoretical concepts

2.1. Ant colony optimization

Ant colony optimization (ACO) is a popular algorithm that works the way the real ants work towards finding their food. It was first proposed by Dorigo [12]. The basic principle behind the ant colony is that an ant chooses a path which is most frequently used by its predecessors. This idea is materialized by the fact that the ants deposit pheromones on the path they take from the nest to the food. This pheromone evaporates as the time passes and increases with the increase in the number of ants passing through a particular path. So with the passage of time more pheromone is deposited on the shorter paths which as a final result is selected by all the ants. Ant colony optimization has been successfully applied to Travelling Salesman Problem to generate a solution in polynomial time [13]. We have used an ant system algorithm given by Dorigo [12] to generate a travelling salesman path. The basic working of the algorithm is as given below:

Let there be n cities and the problem is to find a path to traverse all the n cities so that the distance covered is minimum. Let p_{ij} be the probability of the transition from i^{th} node to the j^{th} node by the k^{th} ant such that it is given by:

$$p_{ij}^{k}(t)=\begin{cases}\dfrac{[\lambda_{ij}(t)]^{\alpha}[\mu_{ij}]^{\beta}}{\sum_{k\in A_k}[\lambda_{ik}(t)]^{\alpha}[\mu_{ik}]^{\beta}} & \text{if } j\in A_k\\ 0 & \text{otherwise}\end{cases}$$

where

$\lambda_{ij}(t)$ is the pheromone level on the edge joining i and j at time t;
μ_{ij} known as visibility is the inverse of the distance between nodes i and j;

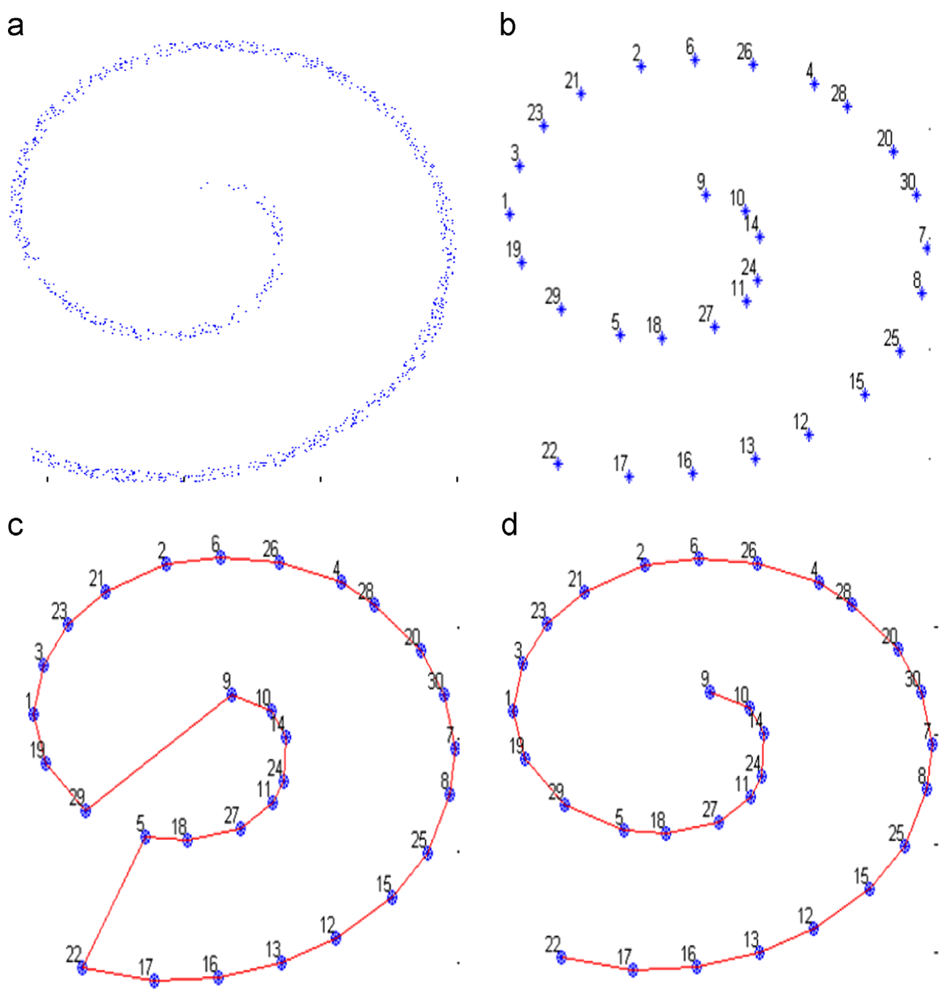

Fig. 1. Curve Reconstruction of a spiral point cloud. (a) Point cloud; (b) cluster centres of the point cloud; (c) travelling salesman path; (d) final curve after the removal/addition of edges.

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