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A Median Strange Point algorithm for Delineation of Agricultural Management Zones

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Abstract— Use of Precision Agriculture (PA) is the need of an hour to enhance the crop productivity to meet the increasing demand of food supply. Clustering algorithms have been proven to be the best suitable ones to delineate the management zones (as per soil fertility) in PA. Management zones can be treated as sub-fields, which are homogeneous in soil physical/chemical properties. In this paper we have proposed a median strange point (MSP) clustering algorithm for the delineation of agricultural management zones. The median strange point algorithm has been compared with the popular clustering algorithms like K-means, Fuzzy C Mean, Possiblistic Fuzzy C Means and Linde Buzo Gray algorithms. The results obtained demonstrated that for the given number of management zones the median strange point algorithm outputs are at par; in some cases superior than the standard algorithms. The proposed experimentation is carried out on the Sugarcane (Saccharum Officinarum) datastet of a small farm of size 2.83ha (7 acres) in Kanhegaon village, Ahmednagar (Maharashtra), India.

Keywords—K-means, Fuzzy C Mean, Possiblistic Fuzzy C Means, LBG, Management zones.

I. INTRODUCTION

Precision Agriculture (PA) can be viewed as an adaptive cycle in which collection of the farm related data is the first step which is follwed by the analysis of the collected data, relevent management decisions are taken on the analysis results of the collected data in the next step and application of the decisions on the actual farm is the last step. The evaluation of applied management decisions can be verified with the help of farm output/s. This cycle can be continued until the desired results are obtained in the farm. Adoption of PA gives farmer, the ability to decide, manage and apply the soil physical/chemical treatment to be used in different parts of the farm in tillage. The farm management decisions are based on Management zone delineation (MZD) which is one of the major pillars of Precision Agriculture (PA). Management Zones (MZ) are the homogeneous (in terms of soil physical and chemical properties) spatial regions where the application of uniform dosage of specific input is possible [1]. MZs can also be treated as subfields. MZs are usually formed using the yield information along with soil information [2]. Usage of MZ concept can be the blue print of the action strategy in precision agriculture without using very sophisticated machinery. Thus, it can be adopted by both small and large producers. The major benefits of adopting PA and MZD are maximizing the profit by reducing the input and increasing the yield, reducing the stress economically and also in terms of man power and the most important, environment preservation.

With the goal of easy generation of management zones, this paper proposes the unsupervised data mining approach, Median Strange Points algorithm (MSP). The experiments were performed on sugar cane (Saccharum Officinarum) dataset. The results of the proposed algorithm are compared with the standard algorithms like k-means, Fuzzy C Mean (FCM), Possiblistic fuzzy c mean (PFCM) and Linde Buzo Gray (LBG).

The paper is organized as follows. Section II surveys the clustering techniques used in management zone delineation process, Section III details the proposed cluster-based approach, Section IV summarizes the experimental results on the case study (sugar cane) undertaken and Section V concludes the paper and proposes the future work.

II. CLUSTERING IN ZONE DELINEATION

The concept of PA is not new, infact it is being widely used in the USA, some of the European countries and Austrelia. Some of the asian countries have also started to implement the PA concept to get benefited from it. Variable rate technology is one the most popular application technology of PA. For the same the delineation of management zones of the field is a major step in PA. For finding the homogeneous parts of the field, clustering technique of data mining is widely used. Clustering is an unsupervised method in machine learning which does not require training of the data, but it does require the labels for the groups after the application of clustering (depending upon the characteristics of the cluster). The intra-cluster similarity in terms of parameters should be low whereas inter-cluster similarity should be more. Multivariate classification by cluster analysis enables the identification of sub-region in the fields that internally have similar characteristics.

In the PA literature, there are various methods used for zone delineation. A majority of the methods used are based on clustering techniques. K-means is termed as the classical method for clustering in data mining [3]. This method requires the number of clusters (k) to be formed apriory. It randomly selects the *k* number of means from the given dataset and calculates the Euclidean distance of each data point from these selected means. It distributes the *n* data points to its nearest means. This is a partition method of clustering. With k-means each data point belongs to exactly one cluster i.e., non-overlapping, categorizing k-means as a *hard clustering* technique. K-means is simple to implement, it is fast and also robust. It gives good results if the data points in the dataset are distinct and are well separated [4].

The clustering technique like ISODATA (Iterative Self Organizing Data Analysis) has also been used in the MZD process of PA. Unlike K-means, this technique does not require the predefined number of clusters beforehand. Similar Variance and Gaussian variables in the dataset are the requirements to apply the ISODATA technique [5].

The authors in [6] have used the hierarchical agglomerative clustering (HAC) algorithm to form MZs in PA. The method creates a dendrogram. It usually starts with the single record as cluster and then iteratively merges sample data together based on the similarity measure, thereby creating a dendrogram. The similarity measure can be any of the *Single Linkage, Average Linkage and Complete Linkage.*

The authors in [5, 7] have used non parametric density algorithm for the MZD in PA to determine the number of clusters to be formed, when no previous information about the existence of the groups was known. To estimate the density this algorithm uses hyperspherical uniform kernels of fixed radius. The CLUSTER and MODECLUS procedure in SAS/STAT software does the cluster analysis by nonparametric density estimation. As the clusters are formed without proximal information, the authors in [5] have used the interpolated dataset instead of actual sample data set to reduce the effect of interspersed clusters, whereas the authors in [7] have used the fine grid estimates of the studied variables and also included the scaled coordinates in the attribute space.

From the literature it is evident that the soft clustering technique, Fuzzy c Mean (FCM) is the most popular choice of the researchers worldwide to achieve the MZD in PA. Bezdek[8] introduced the widely used FCM as an extension of *hard c means* clustering method. It is an unsupervised clustering algorithm which can be used for various image analysis, medical analysis and agricultural engineering problems. As k-means calculate Euclidean distance of the sample data points to the means of all clusters, FCM calculates the relevance degree of each sample data point with respect to each cluster center, known as membership degree [9]. As FCM assigns membership degree to each data point w.r.t. each clusters, overlapping clusters can be obtained. In [10] authors have found that, to generate management zones, data from soil Electrical Conductivity (EC) and elevation can be used for obtaining clusters, and they also found from the maps of historical yield data that the accuracy is also comparable.

A reference process model is developed by [11] have used the Business Process Model Notation (BPMN) for general description of the steps, flow of the steps and decisions to be made. The model composed of five sub processes like, data collection followed by data filtering followed by data selection followed by clustering which is further followed by the final sub process of Map evaluation. The model provides the author with the option of algorithms selection such as k-means, FCM, ISODATA, Segmentation Algorithm, Watershed Algorithm and hierarchical clustering. This model can be very useful serving as a reference document for standardization in management zone delineation. It can also be used as a guide for the selection of the right tools, right data and the algorithm, which in turn allows the optimization of MZD and can also help in improving the quality of the maps to be obtained.

Authors in [13,14,15] have noted that the results of combination of Principal component analysis and fuzzy clustering algorithm created accurate management zones.

Not just for zone delineation in precision agriculture using clustering approaches but the researchers are using recent techniques and trends in Precision Agriculture. The author of [16,17 and 18] have suggested the use of machine learning, artificial intelligence, deep learning ,wireless sensor network, cloud computing respectively to either protect the crop or to increase the yield of the crop.

The author in [16] has discussed various solutions and challenges to increase the yield and usage of precision agriculture in medium and large farms. In [17] a smart alert system for detection and protection from trespassing has been developed with the help of IoT for the crop protection. Author of [18] has proposed the use of wireless sensor network and cloud computing together in the field of agriculture to increase the yield production and reduce the waste of resources. The author has considered the soil parameters like soil pH, soil temperature, soil Moisture and humidity as important parameters for the experimentation. He has developed a model which can sense the soil moisture and send the notification using sensor.

The authors of this paper have used the standard clustering algorithms for the MZD process to get the defined MZs. In the experimentation it was noted that, for the dataset undertaken, the results obtained using FCM were not accurate in terms of soil nutrient distribution. Clusters formed were overlapping giving little space to create and label different management zone using FCM; this could be the result of small dataset and the also the even distribution of some soil nutrients across the field. Possiblistic Fuzzy c Means created one empty cluster, whereas K-means gave good results but the initial selection of means was affecting the results in terms of soil nutrient distribution for the labeling of created management zones and also the time complexity. Linde Buzo Grey can work for only even number of clusters. The authors in this paper have proposed an algorithm, Median Strange Point (MSP) Algorithm to address the issues faced in the experimentation using k-means, FCM, PFCM and LBG approach on multidimensional dataset. Following section explains the details of the algorithm.

III. MEDIAN STRANGE POINT ALGORITHM

The Median Strange Point (MSP) algorithm tries to locate the cluster centers from the dataset as per the required number of clusters which are away from each other, by selecting the first two centers of the clusters by calculating centroids for the clusters formed by the median of the most important dimension of the multidimensional dataset. If the numbers of required clusters are more than two, the third point is selected in such a way that it is equidistant from the first two points and is termed as strange point. As the algorithm uses median for formation of initial clusters, the algorithms is named as Median Strange Point. Euclidian distance is used to locate the strange point/s and also to calculate the distances for the distribution of the data points to individual clusters from the dataset. Following are the steps for the MSP algorithm:

1. The dataset is sorted around its first dimension (the most important parameter of the dataset).
2. The median of the dimension is calculated using ($\frac{n}{2}$) for even number of samples and ($\frac{n+1}{2}$) for odd number of samples, where n is the number of samples. The median value is used to divide the dataset into two clusters.
3. The Centroid of the newly formed clusters are calculated as C1 and C2, and the distance of each data point with respect to both the centroids is calculated using the Euclidean distance formula for n-dimensional space

$$d_{p,\,q}=\sqrt{\sum_{i=0}^{n}(pi-qi)2} \quad \ldots\ldots\ldots\ldots.(01)$$

4. Redistribute the data points around C1 and C2 as per the distance calculated in step 2, to cluster-1 and cluster-2.
5. Locate the third point as a strange point *Str*, which is equidistance from both C1 and C2. i.e

   if (d(C1,*Str*)==d(C2,*Str*))

   then, C3=*Str*

   else if (d(C1,*str*)<d(C2,*Str*)|| d(C1,*Str*)>d(C2,*Str*))

   relocate the strange point *Str*.
6. Repeat the steps 2-4 until desired K (number of clusters) value is obtained.

The sorting technique used for the sorting of the first dimension is quick sort. The average case time complexity for quick sort is *O(n log n)*. The next step is to find the median of the sorted dimension and form two clusters of the dataset. This step will require 2 unit times. Calculating the Centroid in the next step will require O(*n*) amount of time. Locating the strange point in the next step will take O(*(k-2)d*) amount of time. Redistribution of data points to their respective cluster centers will take O(*n*) amount of time. Hence the total time complexity for the MSP can be calculated as,

T=O (n log n +n +n+ (k-2)d +n+2)

T= O (n log n+3n+ (k-2)d+2) ………..…………..(02)

If the values of n, k and d are substituted in the equation 2, it is evident that the MSP algorithm works much faster than the classical k-means and FCM algorithms, which have the complexities as O(ntkd) and O(ntk^2d) respectively, where t represents the number of iterations.

IV. EXPERIMENTATION & RESULTS

Saccharum Officinarum (sugarcane) dataset is taken for the experimentation. 31 samples were collected from the 2.83 hectares of land from Kanhegaon, Kopergaon, Ahmednagar, Maharashtra, India. The dataset is consisting of 7 major and 7 micro important nutrients (total 14 nutrients as parameters). The major nutrients like pH, Electrical Conductivity (EC), organic Carbon (C), available nitrogen (N), Phosphorus (P), Potassium (K) and CaCO3 and the micro nutrients like manganese(Mn), Iron(Fe), Zinc(Zn), Magnesium (Mg), available Sulphur (S), available Calcium (Ca) and available copper (Cu) were measured for each sample. The analysis was done in the “Krishi Vigyan Kendra” (PIRENS) laboratory, Babhleshwar, Ahmednagar, Maharashtra, India. Along with the major and micro nutrients Latitude and Longitude were also noted against each collected sample, for the final formation of management zones.

Statistical analysis of the data was conducted with respect to min, max, mean, median, standard deviation, kurtosis and skewness. To understand the data and the relationship between the soil nutrients, correlation analysis of the data was conducted; the correlation matrix is shown (Table 1). Table 2 shows the standard range considered for all the soil nutrients for labeling the zones.

As all the nutrients were equally important there was no application of dimensionality reduction technique on the dataset before the application of clustering algorithm. The MSP algorithm was applied on the original dataset generated from the above mentioned site and also on the interpolated dataset. R (version 3.3.0) was used for the experimentation. Using the Elbow method and NbClust package of R, the optimal number of cluster were calculated as 3 (as per the farmer’s requirement also the number of clusters were 3). The cluster analysis was conducted with respect to the accuracy of the cluster formation as per soil nutrient distribution in the MZs. Analysis of variance (ANOVA) was also performed to check if the use of the MSP algorithm for delineating management zones could identify the spatial variability for the site undertaken for experimentation. To evaluate the effectiveness of MSP algorithm for identifying the spatial variability of soil nutrient properties in delineating MZs, t-test was performed. The analysis of t-test indicated that the three MZs created were different from each other as also observed by other researchers [16, 17]. Accuracy of the result was calculated using cluster performance accuracy (CPA) equation. The equation is as follows:

$$CPA=\left(\frac{Between\_SS}{Total\_SS}\right) * 100 \quad \text{......................... (03)}$$

where Between_SS is sum of square between the clusters and Total_SS is the Total sum of square for all clusters.

The result of created MZs using MSP algorithm is shown in Figure 1. It was evident from the analysis (Table 3) of each zone that there was heterogeneity of soil chemical properties across the MZs formed. For the nutrients like pH, N, P, Ca, Mg, Fe and Zn, significant difference was seen.

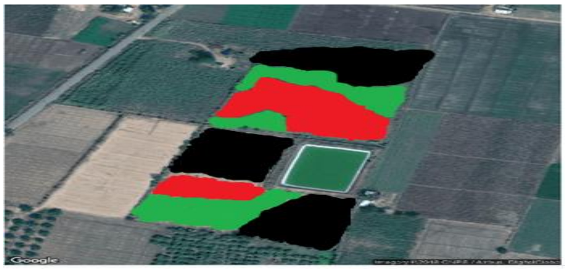

Figure 1. *Management Zones using MSP algorithm for study area (Black: high fertile, Red and Green: Low fertile)*

Using these differences and considering the standard soil nutrient distribution for each created zone, Zone 1 was labeled as High fertile zone, as the nutrient distribution in that zone was as per the standard nutrients values. Though nutrients like K, Ca and Mg were far from the standard values mentioned, overall fertility of the zone was still high, whereas zone-2 and zone-3 were labeled as low fertile zones, as per the soil nutrient distribution (ref:Table 2). It was also noted that, the nutrient distribution in the zone 2 and zone 3 were more or less similar. This had happened as some of the soil nutrients were evenly distributed across the field (2.83 Ha) undertaken for experimentation.

Table 1.Correlation Matrix

	pH	**EC**	**Org C**	**N**	**P**	**K**	**CaCO3**	**Ca**	**Mg**	**S**	**Fe**	**Zn**	**Mn**	**Cu**
pH	1													
EC	-0.289	1												
Org.C	-0.603	0.124	1											
N	-0.508	0.0596	0.397	1										
P	-0.77	0.451	0.576	0.51	1									
K	0.45	0.169	-0.386	-0.51	-0.354	1								
CaCO3	0.647	-0.1	-0.548	-0.65	-0.682	0.541	1							
Ca	0.496	0.128	-0.306	-0.561	-0.503	0.642	0.691	1						
Mg	0.438	-0.0656	-0.271	-0.343	-0.59	0.518	0.608	0.567	1					
S	-0.266	0.255	0.319	0.0129	0.286	-0.424	-0.17	-0.121	-0.257	1				
Fe	-0.56	0.444	0.407	0.482	0.652	-0.272	-0.58	-0.506	-0.473	0.191	1			
Zn	-0.455	-0.0287	0.348	0.473	0.41	-0.391	-0.593	-0.59	-0.593	0.0861	0.293	1		
Mn	0.115	-0.288	0.153	0.033	-0.0762	0.211	0.0149	0.125	0.191	-0.223	-0.19	-0.162	1	
Cu	0.00473	-0.0683	-0.356	-0.139	0.114	0.253	0.201	0.0327	0.0402	-0.0961	0.000572	-0.273	0.23	1

Table 2. Nutrient Distribution Standard

	pH	**EC**	**Org C**	**N**	**P**	**K**	**CaCO3**	**Ca**	**Mg**	**S**	**Fe**	**Zn**	**Mn**	**Cu**
Less	4.99	0.8	0.36	254	12.54	<500	<10.00	<500	<250	<10.00	<4.50	<.60	<2.00	<.20
Medium	7.97, 8.06, 8.11	0.93	0.42		14.14, 15.68									0.2-0.5
Perfect	6.5-6.8	.94-.99	.63	261-300	16.5-19.00	500-1000	11.00-12.99	500-1000	250-500	10.00-50.00	4.5-10.00	.61-1.00	2.00-5.00	0.51-0.56
Too Much	>10.0	>1.0	>1.0	>450	>23	>1000	>15.10	>1000	>500	>100.00	>11.00		>50.00	
Courtesy: PIRENS Lab, Maharashtra, India														

Table 3. Soil Nutrient distribution in management zones

MZs	pH	EC	Org.C	N	P	K	CaCO3	Ca	Mg	S	Fe	Zn	Mn	Cu
Zone-1	**6.808**	**1.439**	**0.4**	**261.555**	**14.704**	**1021.451**	**13.245**	**947.656**	**524.961**	**12.86**	**4.495**	**0.624**	**4.402**	**0.628**
Zone-2	7.634	1.574	0.344	249.738	12.053	1146.531	16.212	3155.424	1113.42	12.454	2.104	0.197	4.571	0.633
Zone-3	7.716	1.15	0.266	250.836	10.716	1149.936	16.72	2122.896	1116.058	11.316	2.196	0.366	4.737	0.732

(*Zone-1 identified as High fertile, Zone-2, Zone-3 identified as Low fertile)

The MZs created through this experimentation might be of help for the farmers who use their traditional knowledge for managing the sugarcane field. The zones created may serve as an important information for the site specific management of nutrients in the study area. For example, MZ 3 had the lowest P level, where increasing phosphorus fertilizer application rate would improve the productivity of sugarcane, whereas the same zone has the highest K and Mg which will definitely affect the yield of sugarcane. The static soil based MZs might not be adequate for VRT (variable rate technique) for the small scale farms [12]. The results obtained by using MSP algorithm on both the datasets were also compared with the standard algorithms. Figure 2 shows the overall comparison. The MSP works on finding the unchanging cluster centers from the dataset before distributing the data points to the cluster centers. Here time required for repeated distribution of data points to their respective cluster centers is saved. The computational time for FCM and PFCM is more as more number of calculations is required in both the algorithms for finding the membership values of each data point to each cluster center. As each data point had membership with all the cluster centers and some nutrients were spread evenly across the field, the zones formed were very much overlapping giving very little space to label the zones as high or medium or low fertile. Some data points with standard nutrient distribution had the membership value greater towards the zones with low fertility, thus clustered wrongly decreasing the accuracy of the algorithms. Linde Buzo Grey algorithm can work for even number of clusters only and hence could create on 2 clusters instead of 3 (required number of clusters) clusters.

Table 4 shows the performance parameters used for cluster comparison. It can be noted that the performance of MSP algorithm is at par with standard k-means algorithm and better in comparison with FCM, PFCM and LBG.

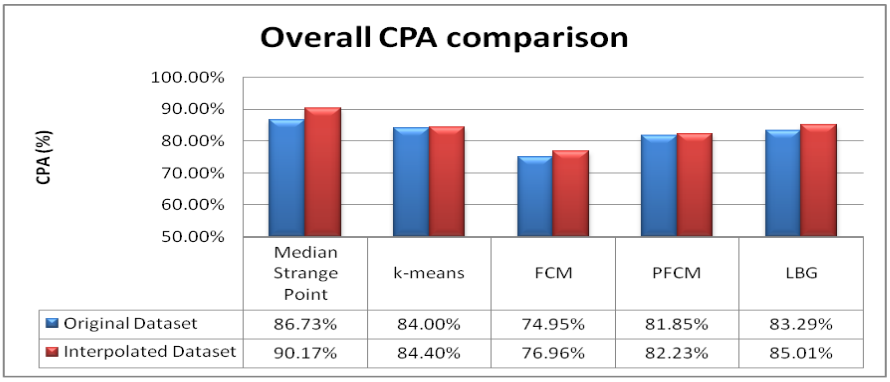

Figure 2. *Cluster accuracy comparison of MSP with standard algorithms*

Table 4. Performance parameters for cluster comparison

Approach	#iterations	Computational time (in seconds)	Accuracy (CPA)	Time Complexity
Median Strange point	**2**	**.28**	**86.73%**	**O(nlogn+3n+(k-2)d+2)**
k-means	2	.35	84.00%	O(ntkd)
Fuzzy C Means	118	.86	74.95%	$O(ntkd^2)$
Possiblistic FCM	139	1.03	81.85%	$O(ntkd^2)$
Linde Buzo Grey	2	.27	83.29%	$nmt\eta_{LBG}+n(m-1)t\ T_{com}$

(*n-number of samples, k- number of clusters, t- number of iterations, d-number of dimensions, in LBG[20]- m-codebook size, n-number of iterations for stopping criteria, t- number of vectors in training sequence, η_{LBG}- computational time for finding distance between two vectors, T_{com-} -unit time for comparing two distortion values)

The performance of MSP algorithm is checked only against the dataset generated for this experimentation. The algorithm needs to be checked exhaustively with other bigger datasets and to be compared with the standard clustering algorithms. Hence the future studies can be based on the bigger dataset, and the various data sources like crop yield and satellite derived data along with (historical) soil properties.

V. CONCLUSIONS

In this experimentation, the spatial variations of selected major and micro soil properties categorizing the soil fertility levels as high and low were quantified and thus creating the three management zones by median strange point (MSP) clustering algorithm. The soil fertility indicators measured in this experimentation were provided by the PIRENS laboratory and showed that low available nitrogen and excess available potassium, CaCO3, calcium (in around 50% of the field) as well as magnesium seems to be the major factors negatively affecting the quantity and quality of the sugarcane yield. Therefore the management of the nutrients like nitrogen, potassium, calcium, calcium carbonate and magnesium in zone 2 and zone 3 is critical for increasing the quantity as well as quality of the sugarcane production. Division of the field into two or three management zones might be helpful for the farmers to adopt site-specific nutrient management, which satisfies the criteria of management zones to be simple, functional and easy to understand. For applying the variable rate fertilization technique the mean values of soil nutrients in each zone can be used as a reference. The proposed MSP algorithm is performing at par with standard algorithm k-means and had outperformed FCM, PFCM with 86.73% accuracy in terms of soil nutrient distribution, creating 3 management zones.

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