A Novel Approach for Serial Crime Detection with the Consideration of Class Imbalance Problem

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Abstract

Objective: The main objective of this research is to reduce the burden of crime investigators by identifying the series of crimes happening at different places. And also, this work aims to reduce the investigation time by grouping similar crimes happened in different places based on its behavior with the consideration of the class imbalance problem. **Methods:** In this research, Majority Weighted Class Oversamplingand Modified Cut Clustering (MWMO-MCC) method is introduced to identify hot spots of serial crime location. MWMO technique is used to handle the class imbalance problem which occurs due to varying size of different crime data's. MCC algorithm is introduced to handle the insertion and deletion operations where the existing methodology called graph cut clustering algorithm cannot handle these problems in case of dynamic growth of data's. The proposed methodologies deal with the class imbalance problems effectively and also the modification processes over the partitioned graphs are supported well than the existing researches. Results: The proposed methodology of this research work namely MWMO-MCC is used to detect the hot spots of serial crimes by identifying the similarity relationship exists among the crimes happened in different places. The experimental tests conducted were proves that the proposed methodology can leads to well detection of serial residential crimes than the existing methodologies. The performance evaluation of this research work proves that the proposed methodology is improved in terms of performance metrics called jaccard index, mantel index and the journey distance time. Conclusion: The findings of this research work demonstrate that hot spots of serial residential crimes are identified by clustering them effectively using the proposed research methodology called MWMO-MCC and it has high possibility of detection of crimes than the existing methodology.

Keywords: Cut Clustering, Incremental Clustering, Majority Weighted Class Oversampling, Serial Crimes

1. Introduction

A serial crime can be defined as multiple offences committed by a serial offender. A serial offender can be defined as someone who has committed two or more crimes of the same type. The detection of linked crimes is helpful to law enforcement for several reasons. Law enforcement needs to handle a large amount of reported crimes, and the detection of series of crimes are often carried out manually. A decision support system that enables law enforcement to decrease the amount of cases when reviewing crimes would increase resource efficiency[1]. Group the similar type of crimes into one group by using MCC appraoch and overcomes the

problem of class imbalance by using MWMO approach. This proposed methodology is used to cluster the serial crimes in the efficient manner and finally the resultant cluster can be used by the CID department to identify the hot spots of serial crimes.

Craig Bennell[2] et al., have done research about the ability of students and police professional in terms of serial crime detection accuracy. To do this, he has given the training set of data which consists of variety of serial crimes conducted by different persons. The training data consists of informations like location of offences, entry locations, distance between those locations and the target characteristics. Finally he has concluded that the students outperformed than the police department in their

capability of finding serial crimes. The students have taken the approach of logical finding of connection among the crimes happened whereas the police departments taken the policy of finding the physical connections among the crimes happened. Finally students outperformed than the police department in their classification accuracy.

Duan M.Y.[3] et al attempts to generate the directional relationship between the different spatial points in which crime occurring more. Geo-info Graph Spectrum factor is used for predicting the distance relationship among the various locations. Distances between the two spatial objects are measured by using the metric called hausdroff distance metric. This metric will retrieve the distance among the various locations which can be further analysed in order to retrieve the spatial contents. By using this distance measure, directional relationship can be established in the efficient manner.

Jorge Ferreira[4] et al attempts to find the serial crime that are happening in different locations by findng the similarity relation between different crimes. This is based on the idea of person who are commiting similar crimes in different location must have unique features. Geographic Information System decision support tool is used for better analysing the details of various crimes happened. This work design a framework using GIS and spatial models which can identify the exact location where the most of crimes of same nature is happening frequently. This work also combined Intelligence-Led Policing (ILP) methods for the better decision making process.

Lucy Markson[5] et al performed linkage analysis between the different crimes to differentiate the linked crimes with the unlinked crimes, thus the serial crime detection would be easy. Behavioural similarity, geographical proximity, and temporal proximity is used to improve the accuracy of prediction of serial crimes by differentiating linked crimes from unlinked crimes in the efficient manner. Data mining approaches plays an concerned role in the prediction of crime behaviours which is exlained detailed by Colleen McCue[6] in the detailed manner. He analysed the importance of data mining and predictive analysis approaches in the crime analysis process.

Newman[7] introduced the modularity based clustering approach which attempts to group the networks data's that are similar to each other. This is used to form a community structure by grouping the most similar network sized data's together and achieves maximum divisions. This is done by using new computer algorithm which can find the better community with improved accuracy and precision value.

Mostafa Ahmadi[8] et al introduced a novel approch for finding commercial burgalaries that are happening in different location. The main goal of this work is to handle the crime department investigations in the efficient manner. This work attempts to find the patterns of crime that are happening in different location based on their crime nature using hierarchical model. Geographical Analysis Machine is used for pattern recognition that finds the nature of serial crimes efficiently. The overall research work is tested on the urban area crime data set from which it is proved that the proposed research work provides better result in terms of accurate detection of serial crimes.

Noah Fritz[9] et al tries to find out the various features that can be useful for the crime analyst, decision makers to operate on GIS tool efficiently to analyse the crime nature. This is done by gathering data from various crime locations and finding the similarity level. Unique features of similar crime data is identified which represents the common characteristics of serial crime. The relationship among the similar kind of crime data that are gathered in different time peirod are identified to map the crimes to exact locations. This time based relationship extraction of various similar crime features can provide an convenient way for decision makers to predict the crime locations using GIS.

Rachel Boba[10] et al analysis a various tools that performs crime investigation using real world crime data set. The real world crime traces are gathered in this work for better identification of crime analysis tool. These crime traces are used to analyse the various tool boxes which are handled effectively in this methodology in order to filter out the best device tool that can perform the crime investigation process effectively. These crime analysis tools can convert the document information into a readable report that is understandable by the public audience. Finally, the authors have concluded that the graphical information system tool is the better one than others which can identify the spatial relationship between the different crimes, thus the crime detection can be done accurately.

Ramin Zabih[11] et al, introduced a novel segmentation approach which can function separately on image space and the feature space. This segmentation process is beginning by presenting an energy minimization formulation, where the energy function enforces both

clustering quality in feature space and spatial coherence in image space. The energy function can be minimized in an Expectation- Maximization style using graph cuts, as long as the clustering quality measure obeys a linearity criterion. The parametric clustering method obeys the linearity criterion, while the non-parametric method obeys it under certain assumptions, which we have empirically validated. The overall research of this work concludes that the proposed research work can better cluster the images and feature space efficiently.

Rizwan Iqbal[12] et al discussed different types of classification algorithms that can be used for classifying the crimes exist in the different locations. Various types of data sets related to the crimes which are happened in different locations are gathered and classified. This classification is done with the consideration of parameters called the crime type; type of weapons used and so on. Finally he has proved that the decision tree algorithm provides a better result than the naive bias algorithm.

Silvia Ferrari et al[13] attempts to design a network model which focus on displaying the criminal behaviours that are residing the various locations. This network model is designed with the consideration of the physiological behaviour of the criminals. This research work provides a better behaviour model by using which nature of crimes can be analysed effectively. Walter Didimo et al[14] implemented a new software system which can be used to analyse the financial crime activities in the visualized manner. This newly developed software system deals with different types and sizes of the networked data sets for prediction of financial crime activities.

2. Detection of Residential Crimes

In India, there are several kinds of crimes are exists. The crime rate can be well calculated by accumulating and recording the information about each and every crime happened in different locations separately[9,10]. The crime investigation is the main process which is done by the crime investigation department to study and find the people who are responsible for criminal offences. Among that serial crime is the important element which demands to be find effectively to reduce the crimes. But the crimes occurred in different location will have a different characteristics based on the culture and behaviours. The data's gathers from the different positioning of the

country will be more in volume and it will be really difficult to process. It is necessary to deliver an automated mechanism for processing the large amount of data to find the serial crimes accurately. By introducing the automated mechanism for analysing the behaviours of crimes, time and wastage of man power can be reduced. And besides, the crimes can be mitigated which are taking place in different location in a timely fashion. This is performed to identify the hot spot locations where the crimes are occurring.

One of the most important device tools which is used for analysing the geographical data's are Geographic Information System (GIS). GIS is a type of computer system which is meant for collecting, breaking down and presenting the spatial or geographical data's. By applying this tool, the Crime Analysis Mapping (CAM) can be managed effectively. CAM is the process of treating the spatial context of criminal offences and other law enforcement procedures with the aid of geographic information and the crime analysis techniques. By utilizing this approach called CAM, the geographical location of offences and their publications can be identified easily. Crime can be found in the effective way by understanding why and where the crime took place. Patrolling can be ameliorated by providing the maps displaying the crime location or the country where the concentration of crime is high. A map consisting of movements of criminal activity, high density areas, and temporal information can be very much useful for the decision makers of the police departments.

In the former work, the crime analysis function is performed by utilizing different methodologies. In all the previous works, the crime mapping is executed as follows: collecting the data's from various sources which will symbolize the position and type of crime happened there, and referencing those data's into an exceptional location. After referencing the data location, the crime behaviours would be mapped to the police and finally the hotspot of crime will be mitigated.

When analysing the crime data's from different positions, there may be a probability of omitting details about some location. These details can be pulled up by putting on the interpolation method which will obtain the information about the unknown information by applying the known information surrounded by it. However, these existing research works consists of some issues which is necessary to be addressed for the better analysis of crime details. Some of the problem found in existing

methodology is, when gathering a spatial data from different location about the crime behaviours, the data's gathered will not be the same size and character. These data sample plays a major role in analysis of criminal behaviour. But different sizes of data samples cannot be combined for processing due to class imbalance. This problem needs to take care of in further works.

In the proposed research work, the class imbalance problem is handled in which the total number of data's present in the one class will be less than the data present in the other class. This class imbalance problem needs to be addressed carefully for better crime detection. Uneven distribution of data samples among different classes is known as Imbalanced learning problems. The class that is having more number of samples is called the majority class and the class with less number of samples is the minority class. Some of the most popular approaches to deal with imbalanced learning problems are established along the synthetic oversampling methods. This oversampling method to deal with the imbalanced learning problems might have some failures due to incompatibility to handle the synthetic minority samples. To overcome this problem in this work, a novel synthetic oversampling method, i.e., Majority Weighted Minority Oversampling (MWMO) technique is proposed which is applied to ameliorate the problems of imbalanced class and make the useful synthetic minority class samples. The advantages of the proposed methodology are

- Selection of suitable subset class from the original minority class samples,
- Assigning weights to the selected samples according to their importance in the data, and
- Using a clustering approach for generating the useful synthetic minority class samples.

Graph cut clustering algorithm involves repeated coarsening of the original graph to smaller size graph, partitioning it and then remapping the partitions back. Yet it does not state, how to modify the clusters under dynamic scenario, when edges and vertices may get added or deleted arbitrarily. This algorithm requires processing of the entire graph, every time the graph structure undergoes some change. To surmount this trouble, in this work, an MCC algorithm is proposed for undirected graphs which can maintain clusters efficiently in presence of insertion and deletion of edges and vertices. The detailed explanation of the proposed research methodologies are given detailed in the following sub sections.

3. Identification of Informative Minority Classes using MWMO

In this section, the informative minority set is constructed using MWMO technique. To do so, the following process is performed:

- First the filtered minority set S_{minf} will be identified from the original minority set, S_{min}. To do this, we compute nearest neighbor, $NN(X_i)$ for each data sample. $x_i \in S_{min}$. Then, each X_i will be removed if its nearest neighbor $NN(X_i)$ contains only the majority class samples. The removed minority class sample is called as noisy data because it is entirely surrounded by the majority class samples. From this we can say that MWMOTE can remove and as well as prevent from the noisy data's i.e., Noisy synthetic sample of the data.
- For each data sample, $X_i \in S_{minf}$, MWMO will constructs nearest majority set $N_{maj}(X_i)$. The samples in $N_{maj}(X_i)$ will be the borderline majorities and expected to be located near the decision boundary when nearest majority k_2 samples is small. We combine all the $N_{maj}(X_i)$ to form the border line majority set, S_{bma}.
- For each $Y_i \in S_{bmaj}$ MWMO constructs $N_{min}(Y_i)$ and combines all such $N_{min}(Y_i)$ to form S_{imin}. The parameter k3 used in $N_{min}(Y_i)$ needs to be large enough for including all the hard-to-learn minority class samples required to generate the synthetic samples. A large k3 ensures the participation of many difficult samples in the sample generation process. The generated samples will likely add sufficient and essential information to learning.

3.1 Assign Weight Value

In the preceding section, we showed how MWMO constructs a set of the hard-to-learn minority class samples, S_{imin} to be applied for generating the synthetic samples. Even so, all the samples of this site may not be as significant. Some samples may provide more useful information to the data than the others. Hence, it is necessary for assigning weights to the samples according to their importance. A large weight implies that the sample requires many synthetic samples to be generated from and nearby it.

This is due to the insufficiency of information in its minority concept. It is now understood that S_w is to be computed by considering the aforementioned observations. The MWMO considers them and employs the majority class set S_{bmaj} in computing S_w which can be described as follows: Each majority class sample $Y_i \in S_{bmaj}$ gives a weight to each minority class sample. $x_i \in S_{imin}$.

This weight is called the information weight. $I_w(y_i, x_i)$. For x_i we sum up all the $I_w(x_i, y_i)$ to find its selection weight, $S_w(x_i)$. This can be expressed as,

$$S_w(x_i) = \sum_{y_i \in S_{bmaj}} I_w(y_i, x_i) \tag{1}$$

In MWMO, $I_w(y_i, x_i)$ is computed as the product of the closeness factor, $C_f(y_i, x_i)$ and the density factor, $D_f(y_i, x_i)$.

$$-I_w(y_i, x_i) = C_f(y_i, x_i) \times D_f(y_i, x_i) \tag{2}$$

The minority class samples having more majority class neighbors in S_{bmaj} will get a higher selection weight. Below, we describe how MWMO computes the two factors. Closeness factor: $C_f(y_i, x_i)$: The computation of the closeness factor is very straightforward. If $x_i \notin N_{min}(y_i)$ then $C_f(y_i, x_i)$ is 0, otherwise $C_f(y_i, x_i)$. We compute $C_f(y_i, x_i)$ using the following the two steps:

- We first compute the normalized Euclidean distance, $d_n(y_i, x_i) = \frac{dist(y_i, x_i)}{1}$ Where dist (y_i, x_i) is the Euclidean distance from y_i to x_i and l is the dimension of the feature space.

- We then compute $C_f(y_i, x_i)$ in the following way:

$$C_f(y_i, x_i) = \frac{f\left(\frac{1}{d_n(y_i, x_i)}\right) * CMAX}{C_f(th)} \tag{3}$$

Where $C_f(th)$ and CMAX are the user defined parameters and f is a cut-off function. In this equation, the inverse of the normalized Euclidean distance $\frac{1}{d_n(y_i, x_i)}$ is first applied to f. We do so for ignoring the values that are too high and for slicing them to the highest value $C_f(th)$. The value, therefore, found would lie [0, CMAX]. We define f in the following fashion:

$$f(x) = \begin{cases} x & \text{if } x \leq C_f(th) \\ C_f(th) & \text{otherwise.} \end{cases} \tag{4}$$

Density factor: $D_f(y_i, x_i)$: The density factor facilitates the observation 2. This implies that the sparse cluster should have more synthetic samples than the dense cluster, given that both the clusters are equally removed from the decision boundary. It should be held in mind that the observation 1 cannot be violated in satisfying the precondition of the observation 2. Hence, MWMOTE computes $D_f(y_i, x_i)$ by normalizing $C_f(y_i, x_i)$. That is:

$$D_f(y_i, x_i) = \frac{C_f(y_i, x_i)}{\sum_{q \in S_{imin}} C_f(y_i, x_i)} \tag{5}$$

4. Incremental Learning

The success of finding hot spots of serial crimes is largely dependent on how we partition the set, S_{min}. In the existing research work, Graph Cut Clustering (GCC) is used for partitioning the graph data in the efficient manner. This work lacks from efficient partitioning in case of arrival of more data in run time. The insertion and deletion of data points in the graph in run time would be more difficult process. In short GCC cannot perform well in the case of dynamic growth of serial crime data.

For this purpose, in this research work modified cut clustering is introduced which can process the insertion and deletion of newly arrived data into the graph in the efficient manner. MCC used an increment clustering algorithm which works by putting the two variables over every vertex (clusters). Those variables are, "in cluster weight and out cluster weight". In cluster weight is determined as the total of weights of edges that are joining the vertices present in the same bunch. Out cluster weight is determined as the total of weights of edges that are interlinked the vertices present in different clusters. The incremental clustering can support four types of operations. Those are Edge Insertions, Edge Deletion, Vertex Insertion, and Vertex Deletion. Edge clustering will be easy process when it is added for the connection of vertices present in same cluster. For this type of insertion adjacency matrix update is enough. But if the edge is added which is interconnecting the vertices present in between the clusters, then it is necessary to update the clusters. Besides all the processes will be exercised to generate the clusters.

The cluster obtained after completing all these procedures will determine the hot spots of similar crimes happened in different locations. Each and every cluster group will consist of similar crimes happened in different locations. This cluster group can be used by the police department to detect and reduce the serial crimes occurred in different placements.

5. Experimental Results

The experimental test for this work has been conducted over the crime data set which is collected across the various locations. The crime data set consists of information about the nature and type of the crimes that can be happened in multiple locations at different times. This work tends

to mitigate the hot spots of locations where the number of crimes happened are more in number. And also this hot spot mitigation will give the knowledge about the similar type of crimes that were happened in different locations. This performance evaluation is done to prove the proposed works in this research which is named as Majority Weighted Minority Class Oversampling and Modified Cut Clustering algorithm (MWMO-MCC) with the existing algorithm called Graph Cut Clustering algorithm (GCC). Final results proved that the proposed methodology works produces better results than the existing methodology. This performance evaluation is done based on the performance metrics called the journey distance time, mantel index and the jaccard index. This performance analysis are represented in the graphical represented which is explained in the detailed manner in the proceeding sections.

5.1 Data Set

We use crime data set of various regions in Coimbatore city, India for analysing and predicting the series of burglaries. The crime data considered in this work consists of attributes like different types of crimes for eg., kidnap, robbery, rapes, murder and gambling etc., latitude and longitude of crime which denotes the exact location where the crimes happened. By using these information, the different types of crimes are analysed and finally the similar types of crimes are grouped together to predict the various crimes.

5.2 Journey Distance Time

Journey distance time is the one of the metrics which is considered for the performance evaluation of proposed methodology. This metric is defined as the time taken to travel between the different locations where the similar types of crimes happened. This metric value need to be increased in value than the existing approaches. This metric indicates the efficiency of prediction of similar types of crimes happened in different locations which are located in the different places with no unique characteristics. The actual values that are retrieved for the journey distance time measure is shown in the Table 1.

The values given in Table 1 are illustrated in the graph format as like follows in Figure 1. This graph illustrates the performance improvement in the proposed methodology than the existing approaches.

Table 1. Journey Distance Time

Number of Data Points	Journey Distance Time	
	MWMO-MCC	GCC
2	0.75	0.69
4	0.75	0.745
6	0.91	0.85
8	0.91	0.9
10	1	0.91
12	1	0.92
14	1	0.92
16	1	0.93
18	1	0.96
20	1	0.98

In Figure 1, the performance evaluation is done by comparing the proposed methodology against the existing approach. The numbers of data points are taken in the X axis and the journey distance measure is taken in y axis. From Figure 1, it can be proved that the proposed methodology can detect the crimes that happened in the different locations with different distances than the existing work.
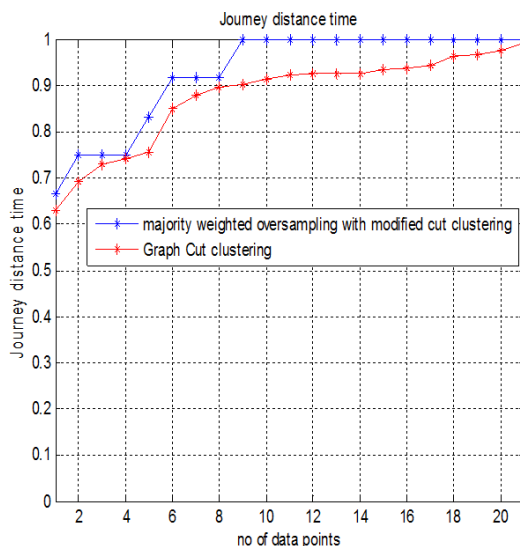

Figure 1. Journey Distance Measure.

The proposed methodology achieves higher advantage than the existing approach where the different types of crimes are handled even in case large dissimilarity presence. For most of the graphs, the speed advantage is more than 20 times. The advantage is the least for crime data which are well dense. They run respectively 8 and

6 times faster than the graph Cut Clustering Algorithm. For same value of number of data points, the clustering quality is nearly identical for both the algorithms and hence, we do not show comparison plot for clustering quality of these two algorithms.

5.3 Mantel Index

The mantel index is used to represent how the data points are correlated with each other. The main motivation of this research is to find out the similar types of crimes occurred in the different location in which the correlation among the data points are necessary to be considered. This is done by calculating the mantel index value across the data points present in the input data set. The mantel index is calculated as follows:

$$r = \frac{1}{(n-1)} \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\left(x_{ij} - \bar{x}\right)}{S_x} \cdot \frac{\left(y_{ij} - \bar{y}\right)}{S_y} \quad (6)$$

Where
x, y = variables measured at locations i, j.
n = number of elements in the distance matrices.
S_x, S_y = standard deviation of variable x and y.

The mantel index needs to be increased than the existing methodology to improve the performance. The actual values obtained for the mantel index is given in the Table 2.

Table 2.   Mantel Index

Number of Data Points	Mantel Index	
	MWMO-MCC	GCC
2	0.75	0.59
4	0.75	0.73
6	0.91	0.79
8	0.91	0.85
10	1	0.88
12	1	0.895
14	1	0.9
16	1	0.94
18	1	0.96
20	1	0.98

The graphical representation of these values is represented in the Figure 2 in which proposed approach is compared with the existing methodology.
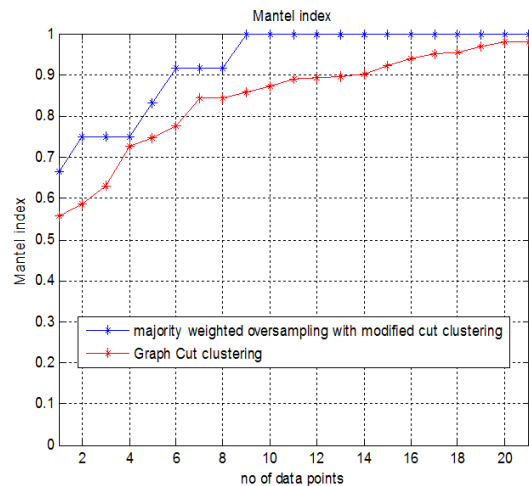

Figure 2.   Mantel Index.

In Figure 2, numbers of data points are taken in the x axis and the mantel index values are spotted in the y axis. From the graph, it can be proved that the mantel index values are improved in the proposed methodology than the existing approach.

For crime data set, when the number of clusters are present with the same sizes then the processing can be done in the efficient manner by using existing approach. The proposed methodology improved in terms of mantel index in terms of both varying sizes of clusters with the large variation of over sampling.

5.4 Jaccard Index

The jaccard index is used to represent the similarity between the data points. The jaccard index value is used to measure how much the crimes happened in different locations are matched with each other. The Jaccard coefficient measures similarity between finite sample sets, and is defined as the size of the intersection divided by the size of the union of the sample sets:

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|}$$

Where
A, B = Data points

This jaccard index value needs to increase in the proposed work, which indicates that our proposed methodology can detect the most similar crimes than existing method. The actual values of jaccard index

obtained for both existing and proposed approach is indicated in Table 3.

Table 3. Jaccard Index

Number of Data Points	Jaccard Index	
	MWMO-MCC	GCC
2	0.75	0.01
4	0.75	0.09
6	0.91	0.18
8	0.91	0.22
10	1	0.46
12	1	0.57
14	1	0.58
16	1	0.64
18	1	0.72
20	1	0.92

These values are represented in the graphical form to show the accurate difference between the proposed methodology and the existing methodology in Figure 3.
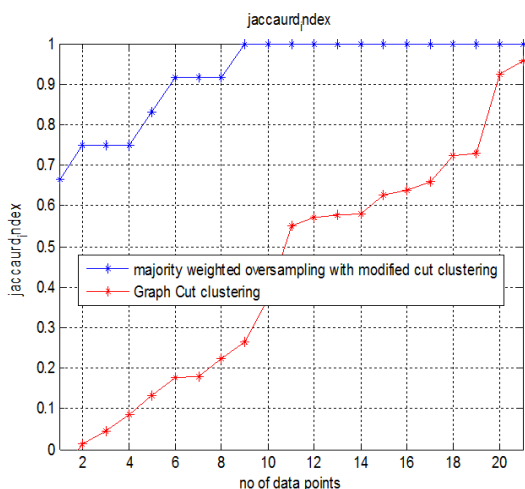

Figure 3. Jaccard Index.

In this graph, numbers of data points are plotted in the x axis and the jaccard index values are plotted in the y axis. It is proves that the jaccard values of proposed methodology is higher than the existing approaches.

Therefore, the experimental results of this approach confirms that the proposed methodology is improved in terms of all of the performance metrics where the different relationship present among the various data samples are handled in the efficient manner. And also the different sizes of data sizes are handled in more effective way which consists of different computational complexities.

6. Conclusion

In this work, the automated analysis of crime investigation is done to reduce the burden of crime investigators. It is done by introducing a novel approach called the Majority Weighted Minority Over sampling and Modified Cut Clustering (MWMO-MCC) algorithm. The experimental tests were conducted and compared with the existing methodology called graph cut clustering method. The performance analysis is made by comparing it with the existing methodology and it is proved that the proposed method improves in its performance over metrics called clustering accuracy.

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