Outlier Detection in Wireless Sensor Networks
Data by Entropy Based K-NN Predictor

Mannmohan Singh Yadav, Shish Ahamad

Abstract: Anomaly (outlier) detection plays very significant role in ESN based monitoring application using on large data used for biomedical and defence. Wireless Sensor network monitor environmental parameters (temperature, humidity, pressure, vibration etc). Group of sensor nodes forms a (WSN) and observations collected from these sensor produces low data quality and reliability due to the limited energy, memory, computation capability and bandwidth. The dynamic environment of network and roughness of the working condition are also responsible to generate inaccuracy in measurements. In this paper, an approach for outliers detection based entropy value of received sensor voltages is applied using KNN prediction model. The algorithm development and analysis involves a real time database generated on 14 sets of MICA2 wireless sensor kit with anomaly inserted by real time motion based intrusion in the lab by volunteers from Intel Berkeley lab. On each sensor data pair segmentation is applied by fixed window size in order get large outliers’ measurements training dataset. The analysis demonstrates the measurement accuracy in detection of number of outliers that its 86%. Moreover, the algorithm also provides an analysis in terms of impact of variation in distance types and number of nearest neighbours in the KNN prediction model. This work is helpful in the application in the situations where high amount of noise or distortions are present. The outlier part from distorted data can be figured out and recollected to enhance application accuracy.

Keywords: Anomaly Detection, Entropy, K-nearest neighbour, Outliers Detection, Wireless Sensor Networks.

I. INTRODUCTION

WSNs are network developed by collection of sensor nodes. Sensors nodes are small devices with limited energy resources. Low quality data measurement limits reliable real-time monitoring due to presence of anomaly. [1], [2] and fetching out of features from such data is tough. Outlier detection covers multiple fields and analysed for number of application. Several research articles on outlier detection techniques with different criteria including detection methodology based on distribution, density and clustering approach. Some articles investigated outlier’s detection methods depending upon data feature high-dimensionality, uncertainty and frequency domain values. Such classification is used for outliers detection models are described in [3], [4]. Generally outlier detection models follow either statistical approach or non-parametric approach. Non-parametric mode is based on rule base, clustering or support vector [5]. This paper covers a non-parametric statistical approach that adds the nearest neighbour and entropy features related classification models.

It is also observed to include the SVM in some literatures [6]. This paper focused on three detection accuracy along with speed of detection. An article [7] proposed ellipsoidal SVM that uses attributes of data in WSNs. Author proposes Bayesian approach in adaptive contexts [8] for identifying outliers with improved classification accuracy with reduced time and communication complexity. In article [9] worked on taxonomy related scheme for analysis in noisy environments. Principal component analysis [10] using the Mahalobis distance outlier detection is also observed to be used to calculate mapping of feature space to separate outliers. Ina paper [11], the data records from the streets using centre servers are applied on outlier detection to analyse.

II. RELEVANCE OF KNN, ENTROPY AND PROBABILITY DENSITY FUNCTION

A. K-Nearest Neighbour

KNN (k-Nearest Neighbours) [12] is very simple but highly efficient classification approach. When a new data sample is introduced without label or class. The new sample as query is matched to every sample. Then the most similar samples (nearest neighbours) are taken and respective labels are analysed. After this top k similar samples from known dataset are considered [13], [14].

Numerical Example of K-NN Algorithm approach: Here is step by step on how to compute K-nearest neighbours KNN algorithm:

1. Determine parameter K= number of nearest neighbours.
2. Calculate the distance between the query-instance and all the training samples.
3. Sort the distance and determine nearest neighbours based on the K-th minimum distance.
4. Gather the category of the nearest neighbours.
5. Use simple majority of the category of nearest neighbours as the prediction value of the query instance.

B. Entropy

Entropy represents the average information present in a specific dataset. If the value of the signal data is not varying in terms of the receiving end on other side user then it is treated as null information in the specific segment of the. But if the data is defected by some kind of anomalies then data segment values differ and there is possibility of adding of some undesired information. As a result this causes some significant increase in entropy in this segment. This work such kind of abrupt increase in entropy value with every measurements is used as a feature to detect the anomalies in sensor pair data. It may be described in another ways as the amount of entropy value represents the dataset feature as events of occurrence of anomalies. A classifier may be added that is developed to decide using a trained manner to interpret if there is a way to measure or keep track of

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*Correspondence Author

Mannmohan Singh Yadav*, Department of Computer Science & Engineering, Integral University, Lucknow, U.P., India.
E-mail: man_mohan_100@rediffmail.com

Shish Ahamad, Department of Computer Science & Engineering, Integral University, Lucknow, U.P., India. E-mail: shish@iul.ac.in
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changes in entropy with each dataset obtained within limits of some error, when an anomalous data point is returned [15]. The entropy calculation is multiple types in this paper Shannon Entropy is used to detect the anomaly. Shannon Entropy is defined as:

\[ G(f(x)) = \int_{-\infty}^{+\infty} -f(x) \log(f(x)) \]

Where: \( f(x) \) represents the probability density function of the dataset \( x \).

For applying equation (1) to the entropy of the data \( x \) we should have the \( \{x\} \). Thus first of all we need to evaluate it or at least approximate it in a reasonably accurate manner. This issue of finding PDF i.e. \( f(x) \) also have a number of ways but in this work, the \( k \)-nearest neighbour approach is used.

K-Nearest Neighbour method for PDF Estimation is explained here with small introduction about KNN. Basically KNN method uses the distance between a data point and its \( k^{th} \) nearest neighbour to calculate the volume of the region. The value of this volume containing \( K \) nearest neighbours is used to approximate the pdf of the dataset at that point using the equation:

\[ f(x) = \frac{(k-1)}{NVol} \]

Where: \( Vol \) is the volume of the \( k \)-nearest neighbour region for each data point, \( k \) is the number of nearest neighbours considered, and as before, \( N \) is the size of the dataset. The distance measured is generally applies the Euclidean distance formual and also keep in track of maintaining equidistant to neighbours in all directions. This it is represented as a circle in two dimensions, sphere in three dimension, etc. Another problem quickly comes as both the Equations (1) and (2) are coupled. This may have some impact on the result. To avoid this, a data-split method is invoked to maintain a balance in between accuracy of entropy measurement within a tolerance level of errors.

C. Probability Density as a Function K-Nearest Neighbour

This entails the database splitting in an arbitrary manner into two smaller datasets. These sub datasets are arbitrarily labelled as \( N \) and \( M \) set. From the use of \( M \) data set points the pdf of the entire set is estimated, the \( N \) data set points are then applied to estimate its entropy. In this way the Equation (2) is then written as:

\[ f(x) = \frac{(k-1)}{MVol} \]

It is also observed that more the points used in estimating the pdf for the \( M \) data points, the better the estimate and higher the accuracy.

III. OUTLIER DETECTION IN WSNs

Outlier is due to errors, noise, missing values in a data. These abnormality causes reduction in the system performance. Outliers are due to errors and attacks and effects monitoring of real life applications in surveillance and tracking tasks [16]. In recent data mining methods used for anomaly detection focus is given to the identification of events or observations which do not ensure any kind of an expected pattern in a dataset under consideration. Anomalies are also known with other names like outliers, noise, exceptions or deviations [17]. Anomaly detection techniques are described in three broad categories. First of all the basic category consists of unsupervised anomaly detection techniques it belongs to anomalies in an unlabeled data. The second is supervised anomaly detection that require a specific type of data labelled with “normal” / “abnormal” or “true”/“false” etc. and involves the process of training a classifier. The third one is semi-supervised anomaly detection based techniques and represents the normal behaviour developed by normal training data as per availability [18].

A. Applications

Anomaly detection is applicable in a variety of domains like intrusion scheme, fraud alarms approach, health monitoring in diagnosis, event and checking of the ecosystem disturbances in terms of pre-processing of minimizing the anomalous records from the available data collection. In learning it often helps in supporting the statistically significant increase in accuracy.

B. Common Anomaly Detection Techniques

Anomaly detection techniques that is prevalent and proposed in various literatures. Some of these are described below:

1. Density-based techniques: It consists of k-NN, factor, and variations based on this scheme.
2. Techniques based on the subspace-based and the correlation-based outlier detection methods for high-dimensional database set.
5. Bayesian Theorem Model classifier using the probability theory
6. Hidden Markov models(HMMs) based supervised classifier.
7. Cluster analysis application in outlier detection.
8. Fuzzy logic with human expert knowledge embedding.
9. Feature bagging score normalization and diversity.
10. The performance analysis of methods depends on the type of available data set and model parameters.

WSN has low cost and energy but high quality performance. It can be improved by outlier detection scheme. Outlier detection depends on the accuracy and the resource consumptions with high detection rate. Generally algorithms face multiple problems in outliers’ detection like:

(a) High cost of communication
(b) Modelling objects with the outliers
(c) Application based scheme of detection
(d) Outlier source based identification process
(e) Distributed data related challenges
(f) Communication failures issues
(g) Dynamic topology problems

C. Outlier Detection Method

(a) Statistics based detection approach
(b) Distance techniques
(c) Clustering-based schemes
(d) Classification-based detection approach
IV. PROPOSED ALGORITHM FOR OUTLIER DETECTION USING KNN CLASSIFIER

A. Load & Initialization using the Variables

a) Each sample has time gap \( t = 0.5 \) sec., segment length = 50 samples. For 14 sensors data has 14x13 = 182 sensor pair id and each sensor pair record has 3127 sample after pre-processing of total 3600 sample record 30 minutes [19].

b) Sensor data matrix \( Z_{182 \times 3127} \) and motion data vector \( \_1 \times 3127 \) (which is as outlier [0 or 1] dataset) stored in the excel sheet.

c) Take the different distance type as:

\[
\text{distname} = \{'\text{cityblock}', 'chebychev', 'mahalanobis', 'minkowski', 'euclidean', 'seuclidean', 'spearman', 'cosine', 'hamming', 'jaccard'\}
\]

B. Select Sensor Pair Ids:

Pair id is id any two sensors communicate with each other. It is selected randomly to create a training data set.

C. Data Segmentation:

a) Dataset is divided into segment of length 50 samples thus total segment are 62 and it is stored in another matrix.

b) Motion dataset which is known as outlier data is also segmented into 62 segments of 50 samples.

c) Each pair is broken into segments such that total segment per sensor pair = floor \( \frac{\text{total sample}}{\text{segment length}} \) = 62.

d) Calculate the entropy and number of outlier of each segment of \( Z \). Number of outlier is named as outlier level.

D. Segment Entropy Evaluation:

a) After segmentation the entropy of each segment is evaluated this is input of K-NN predictor algo.

b) Each segment is selected iteratively and entropy is evaluated.

c) Save the entropy of all segments as variable ‘Entrpall’.

d) Outlier data is also taken segment wise and outlier are summed and saved as outlier level.

e) Total pair id = 182 for segment length = 50 we have 62 segment and we take random pair id of 10 pair id thus 620 data recorded are generated and considered as training dataset.

E. KNN Model Development:

a) After finding the entropy and outlier KNN is applied with entropy data variables.

b) Initialize rloss & kloss(prediction inaccuracy of training & testing data). MDL all = cell of 9x10 to save all KNN models at 9 nearest neighbours (2 to 9) and 10 different types of distance : CVMDL is cell for cross validated data.

c) Use the classifier function as in nested loop \( i = i + 1 \) and \( ja = ja + 1 \) using function:

\[
\text{mdl} = \text{ClassificationKNN.fit(Entropy values, Outlier level value, 'NumNeighbors', ia, 'Distance', dist_name{ja}).}
\]

d) Find the percentage of model inaccuracy and save as rloss(ia-1, ja) and developed model as ‘cvmdl’.

e) Find the cross validation model as kloss (ia-1, ja) after applying model testing.

V. RESULT AND DISCUSSION

WSN monitors physical parameters changes in parameters are due to various reasons. Outliers represent unusual readings in sensors due to e.g. sensors fault, a change in some monitored parameter property, obstacle or communication faults in sensors, etc. As a result readouts are different from others in common ambient conditions such that they follow a different distribution. Outlier or anomalies detection specifies abnormal behaviour in data. A basic application of WSN is detection in large areas related to environmental change (temperature, atmospheric pressure or the received signal which are different from which are received in past. Anomaly detection becomes more challenging than conventional detection due to less knowledge of the signal that is to be detected [20],[21]. Various approaches are proposed for outlier detection. This paper follows entropy estimation of data segments. The aim of this analysis is to verify the outlier detection methods by KNN classifier using data entropy as a parameter:

- Estimate PDF of a data by data-split technique
- calculate entropy of the data using PDF
- use entropy as metric to detect outlier by using KNN
- To investigate different distance metrics and numbers of neighbours on KNN classification accuracy.
This method is applied to actual measured data that incorporates literature survey on the use of anomaly detection in sensor networks along with MATLAB simulation on sensor pair data. Validation of k-NN technique on the recorded signals found at: www-personal.umich.edu/~kksreddy/rssdata.html. The data is generated under an experiment conducted at the University of Michigan. The 4th level of the EECS office block has the site of the research. Mica2 platform has been used for this experiment, in this fourteen sensor nodes arbitrarily deployed inside and outside a lab space. Broad casting is used for Wireless sensors network applications and the received signal strength (RSS) in terms of voltages called as received signal strength indicator circuit (RSSI). In this work the data is for pair of transmitting and receiving sensor nodes RSS value for a 30 minute period. Total 14 x 13 = 182 sensor pairs of RSS value measurements at sample time of 0.5 sec is collected to give 3191 samples of data. During the data recording the volunteer student’s walked through the lab at random interval of times. It created anomaly patterns in the values RSS. A web camera employed to record the walk through activity as ground truth resemblance. Experiment produced the 182 RSS sequence data array to support the model development task of detection of any intruders (anomalies). The original raw data is stored in the matrix of size 182 x 3191. Using webcam records manual record is made as value of 1 to indicate the presence of an intruder.

![Fig.2. Block diagram of outlier detection process](image)

![Fig.3. Received signal strength vs time](image)

![Fig.4. Intruder motion (anomaly) vs sample](image)

![Fig.5. RSS data segments of received data at length of 50 samples.](image)

![Fig.6. a) Entropy value vs segment of pair id 167, b) Anomaly level segmentwise vs segment of pair id 167.](image)
Fig. 7 (a) Percent Training Accuracy vs distance type* at different number of neighbours.

Fig. 7 (b) Percent Training Accuracy vs number of neighbours at different distance type.


Fig. 7 (a) the plot is shown for percent training accuracy for each distance type * (1 to 10) at different no of neighbour varying from 2 to 9. It can be observed that at distance type “1” that is “cityblock”. The training accuracy is highest at 2 nearest neighbour that gradually decreases as no of neighbour and finally become constant for large no of neighbour. Similar trend in Fig. 7 (b) is observed in distance type 2 to 6 but at distance 7 to 10 accuracy is obtained similar irrespective to the nearest neighbour. The highest accuracy observed as 86% at distance type secludian and nearest neighbour equals to 2. In all the cases training accuracy is found to be above than 75%.

Fig. 8 (a) Percent Testing Accuracy vs distance type* at different number of neighbours.

Fig. 8 (b) Percent Testing Accuracy vs number of neighbours at different distance type.


Fig. 8 (a) the plot is shown for percent testing accuracy for each distance type * (1 to 10) at different no of neighbour varying from 2 to 9. The training accuracy is highest at 3 nearest neighbour that gradually decreases as no of neighbour and finally becomes constant for large no of neighbour. Similar trend in Fig. 8 (b) is observed in distance type 2 to 6 but at distance 7 to 10 accuracy is obtained similar irrespective to the nearest neighbour. The highest accuracy observed as 78% at distance type secludian and nearest neighbour=3. In all the cases testing accuracy is found to be above than 70%.
Outlier Detection in Wireless Sensor Networks Data by Entropy Based K-NN Predictor

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<th>Minkowski</th>
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Table II. Percent accuracy for testing data set

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Table III. Result analysis of Training/Testing dataset

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<th>No. of Neighbour</th>
<th>Distance type</th>
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A results which are discussed above are generated after running the KNN algorithm for training and testing dataset at several attempts in each algorithm the algorithm autonomously varies the no of neighbour and the distance type. Table I display the accuracy obtained at a specific attempt at which we get highest % accuracy. In this table rows represent the number of neighbours varies from 2 to 10 and columns represent the 10 different distance type. Similarly Table II show the accuracy obtained during outlier detection by KNN applied on testing data. The result of both table are summarised in Table III for different attempt for both training and testing data. After the result analysis in training dataset 86% accuracy with 2 no of nearest neighbour & euclidean distance. In testing analysis 78% accuracy with 3 no. of nearest neighbour & euclidean distance.

VI. CONCLUSION

In this article the results of evaluation are presented using data sets of actual wireless sensor to validate the acceptability and effectiveness of detection performance using entropy as parameter and KNN as predictor. The development of code is performed on MATLAB 2015a software. Outlier detection is challenging due to the lack of open access real time data. The algorithm discussed in this paper is based on time-series sensor data acquired from a wireless sensor nodes of Mica2 based network of half hour of recording of received signal strength[22]. The datasets has outlier due to intrusion caused by motion of volunteers in lab during recording session. In this way motion injects outliers in the datasets.
We calculated entropy of the data segments then trained the KNN using 62 segments of 182 sensor pair records. Each segment length was of 50 samples of 25 second duration. As a performance metrics training and testing accuracy is calculated. The highest accuracy is 86% is obtained and 78% for testing data. The novelty of this approach is that the number outliers that is level of anomaly is predicted and in other journals related to this field only predicts whether anomaly is present or not. It can be concluded that the KNN approach is faster and simpler than other methods. If proper selection of distance and number of neighbours is performed than using the entropy as a feature the anomaly detection can be performed with low complexity and higher accuracy.

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20. AymenAbid, Awatef Ben FradjGuiloufi, NejahNasri, “Centralized KNN anomaly detection, as well as lab sections. I have total academic teaching experience of more than 12 years with more than 13 publications in reputed, peer reviewed National and International Journals. I have guided 6 Dissertation at postgraduate level in the field of Wireless Sensor Network, DBMS and data mining. My research area includes- Data Mining, Machine Learning, wireless sensor network.

AUTHORS PROFILE

Mannom Singh Yadav pursuing his Doctorate in computer science & engineering from Integral University, Lucknow, Uttar Pradesh, India got enrolled in 2015 session and his research is going on Data Mining & wireless sensor network and done M.Tech. from AKTU University, Lucknow, Uttar Pradesh, India. I have been working as the Assistant Professor of Computer Science & Engineering at Azad Institute of Engineering & Technology Lucknow, UP. I have taught more than 7 subjects of Computer science & engineering in both Under graduate and postgraduate courses, as well as lab sections. I have total academic teaching experience of more than 12 years with more than 13 publications in reputed, peer reviewed National and International Journals. I have developed a diverse teaching and research record. I have taught more than 10 subjects of Computer science in both undergraduate and graduate courses, as well as lab sections.

My favourite part of teaching is helping a struggling student learn challenging material by altering my approach to meet his/her needs. I have guided several projects at undergraduate level in field of Database, Security, WSN and Application development. I have guided 16 Dissertation at postgraduate level in the field of MANET, VANET, Cloud computing and Security also guided one Ph.D. scholar in VANET. Currently I am supervising B.Tech, M.Tech and PhD students in various fields of recent trends and technologies. I have published more than 45 research papers in field of computer science in reputed International Journals and conferences including SCI, Scopus, Springer and IEEE.

As indicated on my curriculum vitae, I received my Graduate and post graduate degree in field of computer science and Engineering and started working on energy efficiency & security issues in sensor networks during my M.Tech. I completed my doctorate from Integral University in 2014 in Computer science & Doctoral research was in the field of Security in Wireless sensor networks.

Shish Ahamed is currently working as Associate Professor in department of computer science & Engineering, Integral University, Lucknow, India. My total Teaching and research experience is more than 18 years. Currently I am teaching graduate and postgraduate courses in Computer Science .I have developed a diverse teaching and research record. I have taught more than 10 subjects of Computer science in both undergraduate and graduate courses, as well as lab sections.

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