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An Unsupervised Pattern Clustering Approach for Identifying Abnormal User Behaviors in Smart Homes

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Abstract

Smart Home is a kind of Home Automation System that provides an intelligent and integrated environment which can recognize the user activity and automate itself accordingly. The automated home environment must have the capacity to monitor, detect and record the daily activity patterns of the user. Thus this intelligent home environment must able to assist and hence increase the comfortability of living for its user. The intelligent home environment can be get automated by modeling it with the daily activity patterns of the users. This modeling of the user activities can be done by implementing the machine learning algorithms. A large amount of data are collected from many sensors from the smart home in order to train the machine learning algorithm so that it can work accurately. But in-case of supervised machine learning the usage of large amount of data for its training results in computational in- efficiency. Therefore using the unsupervised machine learning algorithms are highly recommended. Clustering is a type of unsupervised learning which is used to group the similar user activity patterns into clusters. Since the users will perform the activity in a sequence of events data clustering is not suitable for modeling the activity behavior of the user. Therefore to cluster the activities a new pattern clustering algorithm called K-Pattern clustering has to be proposed. The proposed algorithm must even able to detect the discontinuous and interleaved activity patterns of the user. Thus it overcomes the draw backs of the existing data clustering algo- rithms. After clustering the activity patterns a neural network has to be build as a predictive model to predict the future behavior of the user and thus automating the home system accordingly.

Keywords: *Activity Model, Artificial Intelligence, Neural Network, Pattern Clustering, Smart Homes.*

1. Introduction

The improvement of quality of life for the elderly and disabled people who are lonely in the home and to assist them in case of emergency is the important challenging and essential task of today's world[14].

A home environment [19][20] can be made more comfortable to live by turning it into a smart environment thus improving the quality of life. for the user.

Smart Home is one of the advanced research domain and its general motive is to increase the comfortability of its user with mini- mal cost. A Smart Home is a automated home environment which is equipped with sensors and communication technologies to monitor the user activities and to ensure their safety and security conditions. This automated home contains sensors for monitoring, multimedia for entertainment and alarms for security purposes.

The main aim of the Smart home is to improve the quality of life for the disabled and elderly people who desire to live independently and need a assistant technology for them during emergency health conditions. Thus a home environment can be made as a more comfortable place to live in by incorporating intelligence into it and making it as a smart home to assist the people in their day to day activities.

This smartness can be integrated in homes, public places, clothings, work places etc. It can also be implemented in home devices such as fridge, air cooler etc..

For example, consider a automated home system then,

(1) When the user enters into the home, then the system has to check the temperature outside.
   (a) If the temperature is hot then the system has to automatically switch on the Air Cooler and fan.
   (b) If the temperature is cold then it has to switch the compressor.
(2) During night time if the person is going to sleep, then the bed sensor will get on. Therefore the home system should check whether all the lights,tv,gas stove and other devices are get off. If not then a alert has to given to the user.

By recognizing the normal behavior of the user the system can able to provide automatic response.

There are five different classes of smart homes .The first category is the home that contain smart intellectual objects that has the efficiency to track the events that happens in its environment. The main objective of this class is that the home contains some individual standalone objects that fun--ctions intelligently. The second class of smart homes contain intellectual objects that interact with one other through communication technologies. Its goal is that the connected smart objects can interact and broadcast event information with one other. The third hierarchy of home

are the homes which contains smart objects that have remote control access with the internal and external network. A smart home which is capable of recording, monitoring and tracking the activity of its user are defined as Learning Homes. The last and important form of smart homes are the attentive homes which records the activity patterns of the user from which is used to control the technology.

The main objective for the development of the smart home technologies is that the home environment has to increase the comfortability of its user with reduced minimal costs. Security, monitoring and tracking the activities , health monitoring are the important applications of the smart home technologies. Among them healthcare is the very important application area which is used for the disabled people who wants to live independently. It is proved that the smart homes can upgrade the anatomy of people with disabilities by assisting them. Comfort, Energy Management, Multimedia and Entertainment, Healthcare, Security and safety, Communication are the most important services that are by the smart homes to its user.

Among them healthcare[21][22][23] solutions is vital service offered by the smart environment. Active alarm systems, passive alert alarm systems, Remote support for the users using care staff and family carers, servicing using audio and video telephony system and tele-medicine are different classes of healthcare monitoring systems. Alarms[18] plays a major role in smart homes. But set- ting off and on of the active alarm is the major key issue in these systems. For example, consider the situation that, if the user meets an unexpected event or when the fire break out else if the user goes to a unconscious state then there will not have any time to make a call,to touch and the button worn on the wrist or in the neck. There- fore the usage of passive alarms are mostly recommended.

To overcome the demerits of active alarms, passive alarms are used. For example, In the emergency wards of the hospitals, alerts are to given spontaneously, if the blood pressure or pulse rate of the patients are varied. In these cases, to avoid false alerts the receiver of the alarm (i.e.,) the care takers has to send back a signal to the patient. The user has to acknowledge for the signal by pressing the button worn on the wrist or neck. If the feedback signal is not received within the response time, then the state of the patient is considered to be serious.

Healthcare is the very important application area that is receiving more concentration in the smart home service. Healthcare monitoring at home is done by placing sensors at different objects or places at the home environment. Door, tv, bed are the objects where the sensors can be placed in order to monitor the events. The usage of Wearable sensors can also be recommended. The usage of cam- eras to record the events in the smart homes can affect the privacy of the users. Therefore its usage is strictly restricted.

These data collected from the sensor devices can be used to detect high blood pressure, Chronic diseases, diabetes and can also be used in predicting the anomaly behavior of the user. The activities of the user inside the smart home has to be monitored and recorded form the remote location by the caregiver. Activity Recognition gives the location and time of a activity. By the normal behavior of the user can be modeled. By building the normal behavioral pattern abnormalities in the user behavior can be found. Abnormal behavior is defined as the finding the actions of the user that do not match the expected action. The following figure1 shows how the health care systems are working:

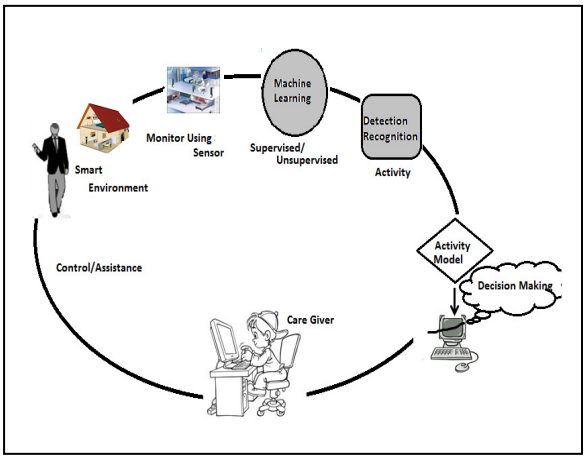

Fig. 1. Activity Recognition in Smart Homes

Here in this figure the user inside the smart home is monitored using the object sensors and the information collected from these sensors are given to the machine learning algorithm as input and processed by the system to detect the abnormalities in the behavior of the user. If any of the unexpected behavior is found then a alert message has to be given to the care giver for assisting the user.

The main benefit of using these health care systems is that it saves time for both patients and the medical institutions. The merits for the patients are that it can save their time and money ,because if the patient is staying in the hospital there must be enormous costs for the patients and the uncomfortability of the patient is also reduced. The doctors can also get benefit by saving their time and thus they can attend only the patients during emergency .

2. Literature Survey

There are various research have been employed in smart home environment to increase the security, safety and comfort of the elderly. Therefore the usage of sensors are recommended inside the smart environment to gather the data about the user activities to track them. The data are used to monitor ADL of the users and to model the general activity pattern of the user based on the temporal and spatial location of the user. Using this any abnormal or unexpected behavior of the activity pattern can be detected and the alerts or given either to the care giver or to the user.

In [23] provides an overview of the sensor devices that can be used in the smart environment such as door sensors, bed alerts, motion detectors, temperature sensors, pressure mats etc. Detection of the user activities usually involves the collection of sequence of observations for recognizing new activities.

The statistical methodology includes decision trees, nave Bayes and k-nearest neighbor etc.. for detecting the activities.HMM(Hidden Markov Model),dynamic bayesian network and conditional random field are the temporal methods available.

In paper[2], DTFRA(Discovering of Temporal Features and Relations of Activities) the usual start times of the activities was discovered using k-means clustering technique. It then uses the temporal association rule to find the order of the events. The use of k-means cluster algorithm is that it has the problem of dealing with the outliers. In paper[6], EM-algorithm was used to form group of similar objects. The algorithm is simple and fast but the efficiency of the algorithm depends on the number of input features, number of objects and number of iterations. In paper[10] k-means clustering approach was used for partitioning with a centroid. Using any of the distance measure the points are assigned to a cluster with the minimum value. But the efficiency of the algorithm depends upon the number of clusters, selecting the cluster center, number of iterations.

In paper [7], uses probabilistic models such as Hidden Markov Models(HMM) to find the unobservable activities from observable sensor data. The problem of using HMM is that many activities are interleaved. In paper[5], FPAM(Frequent and Periodic Activity Miner) algorithm was used to mine the data to find the frequent and periodic patterns of activities. It is also modelled using Hierarchical Activity Model. The dynamic adapter modifies the model if there is a change in the resident behavior. It uses Apriori algorithm to find the frequent patterns.

Paper [9], uses Emerging pattern mining algorithm for modelling the activity. It uses EP score, which is a probabilistic measure of likelihood for the occurrence of patterns and the sliding window algorithm for the time series data. The demerit is the computation of EP score. Because the method of computation of EP score has not having statistical foundation. Further the use of sliding window leads to segmentation inaccuracy and poor performance.

In [12][24] emerging patterns are used to recognize the activities. The essence of all these methods is to handle the activity detection as the pattern-based problem.

3. Motivation and Problem Definition

There are various number of approaches that are available for tracking the users location and to recognize their activities. Since the activities of the users are so complex, modeling of activities is a essential, challenging and tough task. Therefore an efficient algorithm that uses relevant sensor information, to detect the activities of the user has to developed. The activity recognition task has the following challenges:

- Concurrent activity recognition: The users in the smart homes can do multiple activities concurrently. For example, the users can make a call their friends using mobile while eating. The new novel approach must have the capacity to detect these concurrent activities.

- Interleaved activity recognition: The users can do interleaved activity. For instance, while preparing meals in the kitchen, if the mobile phone rings in the living room, then the user will stop cooking, goes to the living room, attend the call and continue the task in the kitchen.

- Interpreting Ambiguity: Each event will attain a different meaning at different instance of time. For example, The event of Opening the fridge will be included both in cooking and House keeping activity.

- More than one user: The user may have their pet animals or they can have some visitors at regular basis.

Therefore the main goal of this paper is to detect and recognize the activity of the users using a novel unsupervised learning method. The users will do the actions in the series of sequence of event events and each individual user will do the activity in different orders ,data clustering is not suitable to cluster and detect the activities, since it will cluster only the events and not the activities. For example, Let us consider the activity of going to office by the user. Then the sequence of events

are getting up from bed, preparing meals, taking bath, eating ,putting things in bag, taking bag and locking door and going to office. This activity can also be done in the order like getting from bed, putting things in bag, taking bag, preparing meals, eating, taking bag ,locking door, going to office.

Since each user is having their unique way of performing each activity, the new proposed algorithm must able to detect the activities even though it is done in different order.(ie) It must be able to detect both continuous and discontinuous events. It must also be able to detect the discontinuous actions too.

Therefore we propose the pattern clustering to cluster and detect the activities of the user rather than data clustering.

4. Proposed System

The main goal of this proposed methodology is to track the activities of the user inside the smart homes using pattern clustering algorithm. In the proposed system the raw sensor data is first converted into sequence of events. It is then given as input to the frequent pat- tern mining algorithm to mine the most frequent patterns from the sequence of events. Then the pattern clustering algorithm is applied to find the similar patterns.

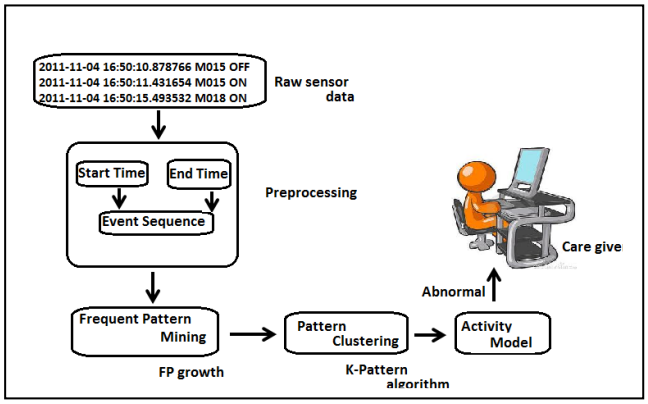

Fig. 2. Architecture of the proposed methodology

4.1 Raw Sensor Data Format

The raw sensor data collected from the sensor devices are represented with the following parameters. Each sensor data consists of the date and time at which the data is collected, sensor id and state of the sensor. The following table TABLE-I illustrates the sensor data representation. It is described as follows. In the sensor field 'M' represents motion sensor when its state is 'ON' then the person is with in its range, 'D' represents Door sensor ,its having two states 'OPEN' and 'CLOSE' and T represents Temperature sensor.All of the dataset are taken from WSU CASAS smart home project[17] by D. Cook. Learning setting-generalized activity models for smart spaces, IEEE Intelligent Systems, 2011.

Table-1 Sensor Data Representation

DATE	TIME	SENSOR ID	STATE
2011-11-04	00:03:50.209589	M001	ON
2011-11-04	00:03:57.399391	D001	OPEN
2011-11-04	03:49:52.412755	T001	12

4.2 Preprocessing

Before giving the data as input to the frequent pattern mining algorithm it is to be preprocessed . The preprocessing of the raw sensor data is done by taking the sensor id and its state . For Example, If sensor id=M001 and its state is On then during preprocessing its value becomes 11 else 10 where in "11" the first "1" represents the sensor id and second in represents sensor state.

4.3 Frequent Pattern Mining

Frequent patterns are subsequence that appear in a data set with frequency greater than or equal to some specified threshold. For example, a set of items, PC and printer that appear frequently together in a transaction data set, is a frequent patterns. Finding frequent pat- terns plays an essential role in Clustering the patterns. FP growth algorithm is used for mining the patterns and it is given as input to the clustering algorithm. Thus the frequent activity patterns of the user behavior is identified.

4.4 Pattern Clustering

The Sensor data has to be given as input to the machine learning algorithm to build the normal behavioral pattern of the user. Since using the supervised learning has the computational inefficiency a unsupervised machine learning algorithm has to used. Clustering is defined as the process of grouping up of elements that are having similar characteristics.

It is a type of unsupervised machine learning algorithm used to cluster the unlabelled data. Since the user inside the smart home will do the actions in the series of events data clustering is not suitable for clustering the events. Therefore new pattern clustering algorithm is used to overcome the drawback. In this paper a pattern clustering algorithm called K- Pattern Clustering algorithm is used. The input to the algorithm is the frequent activity pattern datasets and the output is the cluster of activity.

4.5 K-Pattern Algorithm

In this proposed methodology a pattern clustering algorithm is used in order to cluster the similar patterns. Pattern clustering is used to build the normal behavioral model of the smart home resident.

```
Algorithm 1: K-PATTERN CLUSTERING(NC,CP)
Input: NC- Number of clusters          . Initially it is zero
       C1:n - set of Cluster Centers
       P1:n - set of Input Patterns
Output: Set of Clusters
1  Read the Input dataset
2  begin
3    for each Pattern P in the dataset do
4      if NC = 0 then
5        C1 ←P1          . First Pattern as Cluster Center
6        j ←1            . Index of the Pattern
7        NC ←1
8      else
9        j ←j+1
10       Get next Pattern Pi
11       Assign Pi to Cluster
12       Cluster (NC,C,Pi)
13   return Clusters
```

Whether algorithm to cluster the Smart home dataset. The description of the Algorithm1 is as follows. The input given to the Pattern Clustering algorithm are the frequent pattern activities that are mined using frequent pattern algorithm.Initially Consider the number of clusters(NC) as 0 The line 1 is to read the input dataset. Check whether number of clusters NC=0 done in line 4.If true then taken the first pattern as the cluster center and increment the cluster count done in lines [5 to 7]. Then lines [10-12] reads the next input pattern. If the number of difference between both the patterns are less than the user specified threshold then the two patterns belong to the same cluster and the new cluster center is to be recalculated else the pattern belongs to other cluster and the cluster count is get incremented. To check this condition it calls Cluster algorithm2 at line 12. Line 13 returns the cluster.

```
Algorithm 2: CLUSTER(NC,Ci, Pi)
Input: NC- Number of clusters
       C-set of Cluster Centers
       P-Input Pattern
Output: Patterns are assigned to Clusters
1  l:Cluster label for each pattern
2  foreach Cluster center Ci do
3    if dif f ≤ thresholdthen
4      li ←cluster id
5      recalculate cluster center
6      center(Ci, Pi)
7    else
8      Assign it as a new cluster
9      nc ←nc+1
10     return Clusters    . Patterns are assigned to Clusters
```

For clustering the patterns we propose a new clustering algorithm called K-Pattern Cluster. The input to the algorithm is the set of frequent activity patterns, number of clusters and the output is the set of clusters. The steps involved are as shown in Algorithm1. Our new pattern clustering algorithm called K-Pattern Clustering algorithm overcomes the drawbacks of using data clustering.

The input to the algorithm is the set of cluster centers and the pattern and it produces new cluster center as the output. Line 3-6 checks If the difference between any two patterns is less than the threshold. If it is true then two patterns belong to the same cluster and have to recalculate the cluster center. For this recalculation of cluster center line 6 calls the center algorithm3. But if the difference is greater than the threshold then it is assigned into a new cluster and the cluster count is get incremented through lines7-9. The input to the cluster algorithm3 is the cluster center and the new pattern. Lines 6-11 recalculate the new cluster center as follows: For the length of the sequence line 7 compares and get the common items in both cluster center and the pattern. Line 8 take the index of the items that differ in the two patterns and check for the priority table to get the sequence with highest priority at line 9. Then at line 11 the new cluster center is formed by concatenating the items formed at line 8 and 9.

The new cluster center is formed as follows:

- (w)get the sequence that are same in both patterns.
- Get the items that differ in both patterns and check for the prior- ity table.
- Take the items that are having highest priority and concatenate with the w.
- Thus the new cluster center is formed and this value is returned to the cluster function.

```
Algorithm 3: CENTER(Ci, Pj)
Input: Ci – ClusterCenter
       Pj – InputPattern
Output: new cluster center
1  w:common sequence in both patterns
2  pr:Priority table of the sequence
3  o:itemsets that differ in both sequence
4  e:length of the pattern
5  begin
6    for e do
7      w ←compare ci and pi      . Common sequence in both
       patterns
8      o ←itemsets differ
9      m ←compare o and pr       . Get sensor items with high
       priority
10     Form the new cluster center
11     c[i] ←w+m
12   return Ci                   . new Cluster Center
```

4.6 Predictive Model

After clustering the patterns, a predictive model is to be build to de- cide what event (i.e.,)action the user is going to do next in the near future.HMM[13] can also be used for modelling the activities.It is widely used method for identifying the temporal and spatial rela- tionships between the sensor data[15][16][25][26].It may also be used in finding the time series forecasting.But the demerit of using the HMM model is that if the data volume is too large then it will take long runs.To overcome this drawbacks we are moving for the artificial neural networks to model and predict the activities.

ANN performs the computations as it is done by the human brain.To perform computations with neural network first it is to be trained using datasets and then tested.Artificial neural networks are formed by the interconnection of artificial neurons which solves problems of real system. The aim of neural networks is to do com- putations human-like and predicting the values. After clustering the frequent patterns the clusters are get labelled and is given as training set to the neural network to build the predictive model. This model is then used to predict the normal and abnormal events in the testing phase.

5. Experimental Result

In this section we have discussed the solution for implementing the activity recognition of the user inside the smart home. Here a set of four activities like sleeping, eating, preparing meals, House Keeping are taken into consideration for the experiment which are to be detected. In this work, a training phase is implemented to build a activity model then a predictive model is to be build to predict the future activity of the user in the home. The experimental set up is quit is very easy.

The data set was collected form CASAS smart home test bed developed by D.Cook in the project of ”Learning setting-generalized activity models for smart spaces”. The activities of the user in- side the smart home are monitored using sensors. The following figure3 describes the infrastructure of the smart home. There are three different types of sensors used inside the smart home. They are Motion sensor, Door sensors and Temperature sensors. The sensor IDs that begin with ’M’ indicates the motion sensors, ’D’ indicates Door disclosure sensors and ’T’ indicates temperature sensors. The home consists of two bedrooms, Living room, Kitchen and a office room. Each consists of multiple sensors and each sensor is having its unique id to identify and locate the events. Therefore there are a total of thirty-one motion sensors, five temperature sensors and four door disclosure sensors.

The data collected from the sensors are taken from the volunteer adult. The user inside the smart home was a older woman. The women were having her children and grandchildren as visitors in regular basis. The woman was asked to do the activities inside the

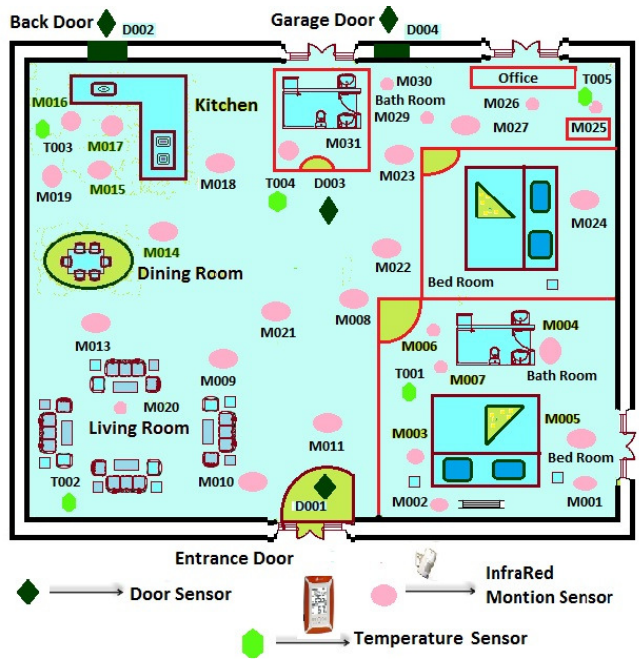

Fig. 3. Smart Home Experimental Layout

home and time limit was given for her to do the work. She can take her own time to do a work. All the necessary items are provided for the user to perform her activities in a normal way. Here we have taken only a set of four activities for the implementation.

Following figures shows the screen shots of the implementation. This figure4 shows the input dataset that was read from the database and are displayed in the text area.

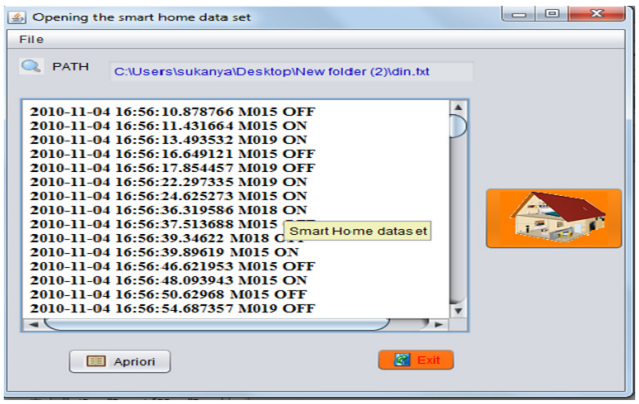

Fig. 4. Reading the input Smart Home dataset

The figure5 shows the screen shot that the input smart

dataset was converted as sequence of events and is stored in the notepad file. Consider the event 31. Here the first '3' represents the sensor id as 'M003' and the next '1' represents it state is 'ON'. This con- version of raw sensor data into event sequence is referred to as pre- processing and is explained in the previous section 4.2

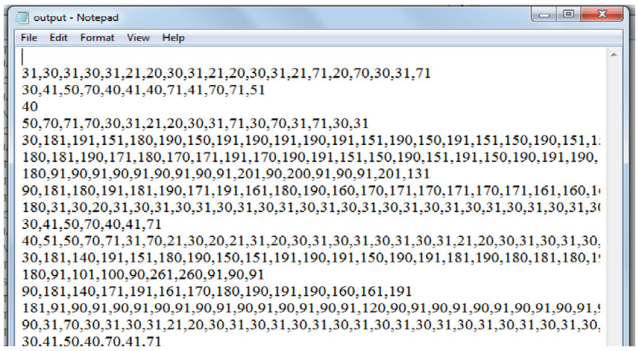

Fig. 5. Generated Event Sequence

This figure6 and figure7 shows that when a new activity pattern occurred inside the smart home then a alert message has to be given. If we consider it as a normal event then it can be added into the cluster else it is a abnormal event.

For example the database consists of only four events like sleeping, eating, meal preparation and relaxing and each activity is having its own activity pattern. Other than this if new activity bathing occurs in the home then a alert message will be given. The caregiver has to check whether it is normal new event or an abnormal event. If it is a normal new event then it is added into the database else the user has to be assisted.

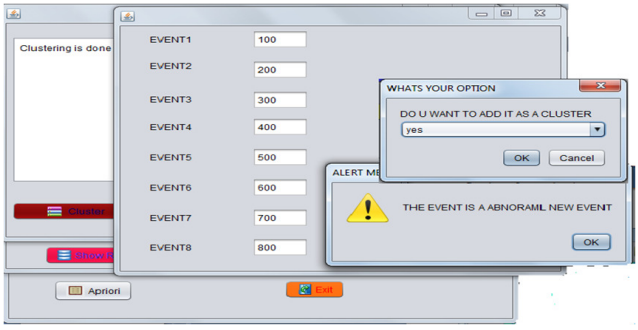

Fig. 6. Checking for a new Event

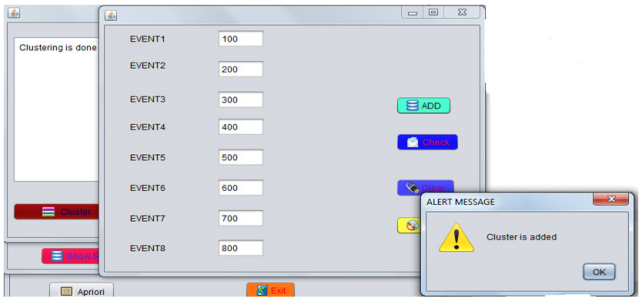

Fig. 7. New Event is added to the cluster

The following figure8 shows the predictive model build for the activity. The predictive model has to be build in order to predict the nearest future activity of the user. The predictive model was build using the neural network. Here echo recurrent neural network is used to build the model.

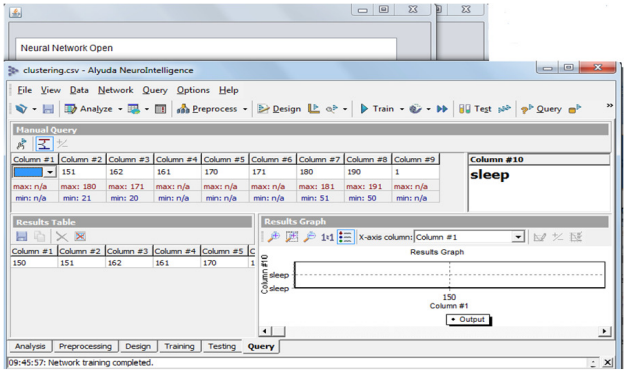

Fig. 8. Predicting the next user Activity using Neural Network

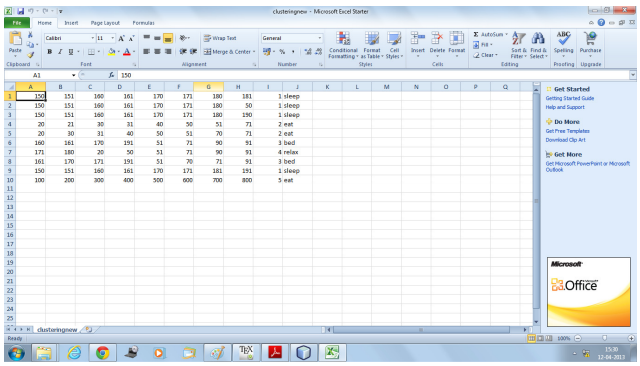

Fig. 9. clustering output

The figure9 shows the similar activities that are grouped into clusters.

6. Complexity Analysis

The new proposed K-Pattern Clustering algorithm has the time complexity of O(nXm) where n represents the number of patterns and m represents the number of clusters.

7. Conclusion and Future Work

The algorithm presented in this paper proves that pattern clustering is the most efficient method for identifying the activity model of the user. It is very useful in finding the anomaly behavior of the user. It also reduces the misprediction rate of the activities than the data clustering algorithms. Further the predictive model used here works effectively to predict the values. The datasets used for this project are based on a single user smart environment which is embedded with motion, door and temperature sensors. The data collected from these sensors are used by the caregivers to predict the user activity. The future work of this project aim at predicting the abnormal behavior in multiple occupancy and also uses semantic reasoning for modelling the behavior of the user.

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