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AOCM-OAC: Architecture of Optimal Computational Model for Occupant Action Classification using Machine Learning

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***Abstract**: Occupancy sensing is one of predominant technology used in various control and context aware systems. The efficiency of such systems is highly corelated with the level of accuracy of the classification model of activity or stage detection of the subject or an occupant. The classification approaches based on computer need to evolve optimally for balancing the computational and time complexity with the classication accuracy using occupancy data acquired from Doppler radar. The proposed study presents a simplified framework that emphasizes on feature extraction technique as a medium to obtain more precision in the process of monitoring occupancy. The proposed logic has been implemented using analytical methodology convention and the extracted feature has been subjected to different forms of frequently used machine learning process with respect to processing time inclusive of training and testing period, efficiency, and accuracy of the proposed system.*

***Keywords** : Occupancy Sensing, Doppler Radar, Optimization, Machine Learning, Surveillance, Motion Sensing.*

I. INTRODUCTION

In the last decade it is witnessed that there exists a tremendous advancement into the sensor technology that provides facilitation to the many unique application [1]. Many of the unique application includes structural health monitoring (SHM)[2-3], underwater applications [4], proactive and reactive healthcare systems [5], robotics[6], context based ubiquitous smart applications, Industry 4.0 vision of manufacturing, etc[7]. There is one important sensor namely occupancy sensor plays a very import role to develop various applications such as finding vacant location in a parking facility [8], control system for smart building [9], noise control [10], vehicle occupancy [11], trajectory tracking [12] and various other control systems whose detailed survey is in the work of Mane et.al. [13].The accurate and optimal classification of occupancy sensor data leads to have an efficient application for both context evaluation in terms of occupant activities and building a robust control mechanism [14-16].

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Usage of occupancy sensor has been increasing in commercial as well as in non-commercial application as they are the cost effective mechanism to identify the object-based intrusion in the surveilled area [17]. The potential problem in such sensor is that it offers maximized occurances of outliers just to identify a static object. Hence, the biggest problem in proper execution of the occupancy sensor is that it is quite a challenging task to ensure the reliable operation of the occupancy sensor. There are studies that explored an effective usage of Doppler radar in order to identify various bio-signals in human related motion [18].

A wiser usage of such bio-signals assists in precise identification of an explicit motion of a human body. Apart from this, the evolution of the cost effective transmitting and receiving hardware design also promotes the usage of digital signal processing in framing up an effective occupancy sensing system [19]. It should be known that adoption of the occupancy sensor was constructed on the basis of the cardiopulmonary movement [20].

On the other hand, the significant problem of the traditional occupancy sensor is to actually use the emerging high non-invasive technique that is usually adopted for sensing non-line-of-sights objects. It is also reported to be used in clinical diagnosis too. The system performs identification of the connected shift in the Doppler signal in the respective process of reflection from the human body in the receiver. After the subject has been illuminated by the microwave signal, the modulation is carried out on the reflected signal by the movement of the chest because of the activity of the cardiopulmonary. The system then performs demodulation technique over the integrated signal that has been received will generate the base-band signal. This signal is processed in order to generate the rate of the respiration and the heart associated with the human.

The usage of the Doppler radar for the detection of the heart rate as well as respiratory system is known from many years; however, they utilization has been increased in current times owing to the minimized cost of various computational as well as transceiver devices that is mainly used for monitoring human activity. Therefore, it is felt that if an efficient feature extraction process is implemented than it will offer more cost effective precision in the application of the occupancy sensing using Doppler radar. Further, the proposed system make use of machine learning approach in order to investigate that which machine learning approach offers more suitability in enhancing the accuracy performance of the occupancy sensing.

The organization of the presented paper is as follows: Section **"A"** discusses about the existing literatures where different techniques are discussed for detection schemes used in power transmission lines followed by discussion of research problems in Section **"B"** and proposed solution in **"C".** Section **II** discusses about system implementation that is discussed with respect to implementation strategy as well as discussing various form of dependencies and assumption being carried out in planning the proposed algorithm implementation followed by discussion of result analysis in Section **III.** Finally, the conclusive remarks are provided in Section **IV.**

A. The Background

Existing approaches towards the occupancy sensing has been discussed in our prior literature [21]. Albesa and Gasulla [22] have used investigated the usage of inductive links for detecting occupancy factor where the study considers magnetic coupling concept for enabling experimental analysis. Cooley et al. [23] have developed a capacitive model for carrying out occupancy sensing while Hossain [24] have maximum a posteriori principle for detection occupancy. Adoptiion of inductive principle for similar purpose was also seen in work of George et al. [25]. Most recently, the work of Amayri et al. [26] have presented a model that uses Bayesian Network for estimating occupancy. The performance of the occupancy sensing is further investigated with respect to pattern-based approach along with the compressive sensing over under-used spectrum as seen in the work of Eltabie et al. [27]. Usage of spectrum over the occupancy sening along with the usage of the deep learning has been presented by Hlope et al. [28] where the authors have also used stochastic method. However, the idea is more inclined toward the spectrum sening with emphasis over recovery of magnetic state space. Yang et al. [29] have carried out occupancy sensing with respect to the internet-of-things considering channel state information. Wu et al. [30] have used a motion sensing approach for occupancy sensing where machine learning has been used. Study towards similar approaches of smart sensing is also carried out by Cao et al. [31] with focus on intelligence building process with primary concern about energy management. Santra et al. [32] have carried out occupancy sensing using continuous waves of frequency modulation for effective sensing capability. The approach is based on detection as well as counting of the human on the basis of the biosignals. The work carried out by Luppe and Shabani [33] have carried out implementation of the model that focuses on detection of an object on the basis of the sensory data. Nesa and Banerjee [34] have carried out the modeling of occupancy sensing where evidence theory has been used over the data aggregated by sensors. Jin et al. [35] have worked on occupancy detection system using smart meters with the emphasis over the power management too. Similar trend of work is also carried out by Shen and Newsham [36] where occupancy detection is carried out by signals generated by Bluetooth signals of cellular devices. The work carried out by Liu et al. [37] has used specific form of the sensor in order to perform occupancy sensing. The authors have used hidden markov model in order to perform statistical computation of the space. The work presented by Jin et al. [38] have used sharing concept of the environmental factors in order to perform detection of the occupancy. Khan et al. [39] have presented a hybrid approach in order to enhance the accuracy of the detection process. Adoption of deep sensing approach has been witnessed in the work of Li et al. [40] where stochastic approach as well as state-based approach has been used for performing spectrum sensing. Similar trend of work towards using spectrum sensing has been also carried out by Mariani et al. [41] where cognitive radio was a part of the study implementation. The next section discusses about the issues associated with existing system.

B. Research Problem

From the survey work, it is quite clear that there are very less amount of standard model towards occupancy sensing. The most recently implemented proposed system is capable of using Doppler Radar for i) performing occupancy sensing using intermittent wave signal and ii) incorporating granularity for detecting the physiological features. However, the work done till this level is not enough for performing classification of different forms of event or set of actions that the subject might be undertaking. Normally, such operation will have dependencies of multiple number of sensors to make the objective of multiple detection of single or multiple event, which is an expensive affair. Hence, at present, there is no present technique that performs classification of different forms of uncertain user activity under the monitoring area. Therefore, the primary problem to be addressed in this part of the study will be to develop a cost effective optimized model that is capable of discretizing the various forms of dynamically identified user activity. The secondary problem to be solved in this part of the study is to develop such a optimized mechanism by further investigating for usage of novel attributes to be used

C. Proposed Solution

The current work is an extension of our prior work [21][42]. This is the last phase of implementation and hence will focus on further enriching the mathematical model for incorporating optimization. The core emphasis will be also to introduce a new variant of Doppler radar inspite of conventional one that can significantly assists in performing better classification of subject mobility event. The tentative architecture is as shown in Fig.1.

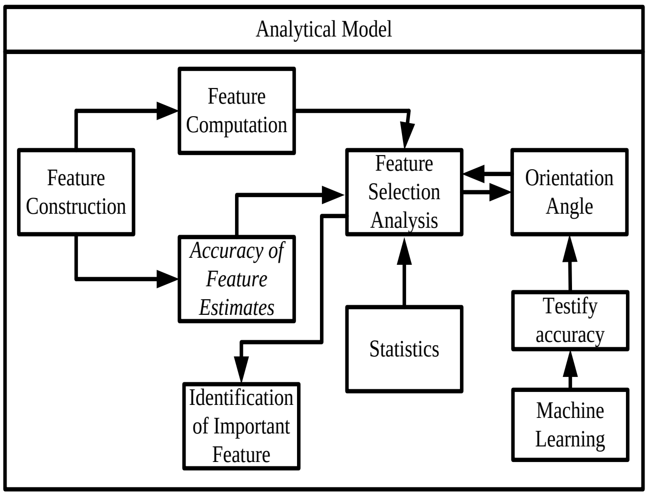

Fig.1 Tentative Architecture

This part of the study will mainly focus on anaytical model for novel attribute construction that could perform efficient classification of various events that can further offer more granularities in occupancy sensing. The proposed idea is basically to develop a highly cost effective feature extraction algorithm that offers significant performance improvement over the signals obtained from the the Doppler radar where motion-based approach is used for framing up the concept of the actions of the movement of the human in order to achieve a track of points. These track points are utilized for performing the identification of the occupancy. The first stage of the investigation will comprise of attribute computation as well as to chalk out certain accuracy-based logical conditions for attribute estimate. Finally, an algorithm will be constructed for selection of better attribute so that the system doesn't need to process too many of the dynamic attribute. A joint attribute mechanism will be also attempted for including different forms of detection attributes based on Doppler radar signal along with angular degree for tracking the orientation considering both known and unknown angle. The next stage of the study briefs about the ideology utilized in the implication of the system design.

II. RESEARCH IMPLEMENTATION

The implementation of the proposed study is carried out using analytical research methodology, where the proposed system emphasizes over the extraction of the feature. The core part of the proposed study is to offer better accuracy in its performance while performing occupancy sensing.. This part of the study is focused on designing and developing a novel framework that perform optimization of the proposed system of occupancy sensing. By the term optimization, it will mean to add new and advanced characteristics in order to enhance the system performance without any incorporation of any external resources. This section discusses about the strategy adopted for implementation, system design, and execution flow for understanding the system implementation principle. The dataset reposit is the record set of Embedded Inertial Sensors (EIS) of 30 subjects for the interpretations of Activities Of Daily Living (ADL). Fig.2 highlights the mechanism adopted in proposed system.

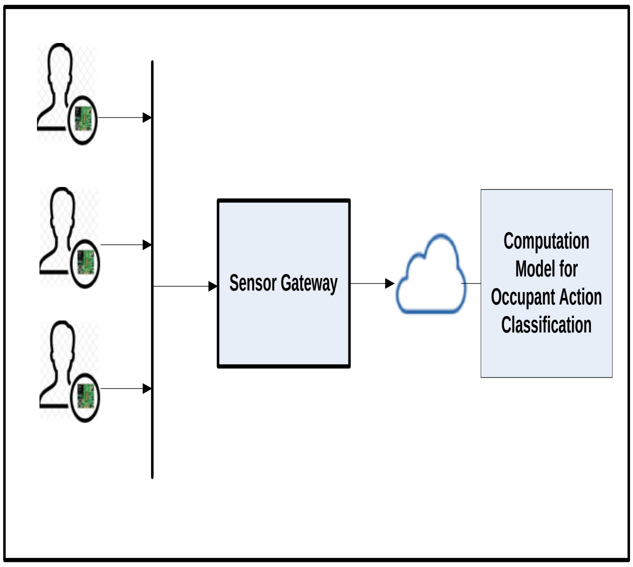

Fig.2 Schematic representation of the RTDA

The implementation of the proposed system is carried out using following stages of operational implementation:

- **Data Acquisition:** The actions of the occupant prediction or the accurate classification models require pure data, whereas the raw data may have noises due to various real-time constraints and system malfunctioning. The approach adopted in the AOCM-OAC is both on the basis of real-time data acquisition (RTDA) from the occupant wearable devices as well as on the standard dataset. Figure 1 illustrates the schematic representation of the RTDA. In order to benchmark the methodology, a standard data set from the work of Kumar et al. [43] a public domain dataset from UCI research lab is used, which is included into the framework to fetch it on the real-time basis.
- **Dataset Description:** The dataset reposit is the record set of EIS of 30 subjects for the interpretations of ADL. The data is meant for both clustering and the classification purpose with 10,299 instances of the record set with 561 attributes as a multivariate and time series data.
- **Data Preparation:** The proposed study constructs a matrix which consists of trained data, test data, and extracted features. All this data are retained in one matrix where the trained and test data will be frequently fetched while performing computation, while the features are extracted.
- **Noise Filtering**: The raw dataset includes 3-axial acceleration and axial angular velocity at the clock cycle rate of 50Hz using gyroscope and accelerometer of EIS. The raw data is partitioned into the ratio of M:N to have consistency of training predictors for the classifier s.t. M>>N, where M is the % of training data and N is % of testing data as well as this proportion provides higher probability of training of all the gestures of the stages of the occupants,

A. Execution Flow

The core implementation strategy of the proposed system is about optimizing the feature extraction process of signal derived from Doppler radar in order to carry out occupancy sensing on the basis of various events. The existing mechanism of extracting features from the signals are not carried out in static manner with presence of more fluctuation over multiple functional conditions e.g. orientation angle, settling time, and signal quality. Hence, the prime logic of the study is that extraction of the proper information associated with the features could assists in overcoming issues of classification connected to investigating the performance effectiveness of the extracted feaure and thereby a unique modeling of framework can be obtained. The proposed system introduces a unique mechanism for extracting the features from the dopplar signal in order to perform identification of the significant feature followed by reduction of the cumulative number of the features. This in terms improves the classification as well as computational performance of the proposed occupancy sensing system. Further the optimized outcomes are obtained by applying machine learning approach in the existing system.

The proposed system constructs an algorithm that is responsible for offering optimal performance of the event sensing. The study takes an input of data which has record of events specific to the actions of the human which after processing yields an outcome of extracted feature that plays a significant contributory role in performing optimization. The significant steps of the proposed algorithm are as follows:

Algorithm for Extracting Feature
Input: *d* (data)
Output: dfeat (extracted feature)
Start
1. init d
2. Extract R_{op}=[d_{test} d_{train} d_{feat}];
3. val_{max}= arg_{max}(R_{op}-arg_{min}(d1))
4. **For** act_{id}=1:max(y)
5. **For** s_{id}=1:max(sub_{id})
6. x_{norm} → x_q/mat(val_{max})
7. d_{feat}=(d_{feat}, x_{norm})
8. **End**
9. **End**
End

The discussion of the algorithm is as follow: The input to the algorithm is basically an event data *d* (Line-1) from where different scopes of the events with respect to actions are extracted in a matrix R_{op} which has trained data d_{train}, test data d_{test}, and features of data d_{feat} (Line-2). The next part of the algorithm implementation is about extracting maximum value val_{max} from the data matrix which has two different dependable matrices (Line-3). The first dependable parameter is R_{op} and the second parameter is d_1 which is basically a matrix storing d_{train} and d_{test} (Line-3). The maximum value val_{max} is calculated as highest possible matrix of d_1. The next part of the algorithm is to consider all the maximum value of y, which is a matrix consisting of training and test data (Line-4). The algorithm also considers all the value of identities of the subject sub_{id} (Line-5). It that constructs a normalized matrix x_{norm} with two dependable parameters x_q and

mat(val_{max}) (Line-6). The matrix x_q stores a resized version of the matrix that stores all the data d_1 corresponding to all the respective actions and its corresponding identities. The algorithm finally computes all the features using this normalized vector x_{norm} (Line-7). A new matrix d_{feat} is constructed that retains the value of all the actions corresponding features to designate a specific event. The next phase of the implementation is about applying machine learning approach where the primary step of implementation is about choosing the relevant parameters associated with the size of weight of sparcity, weight of decay attribute, and anticipated mean activation of the hidden units. The second step of implementation of the machine learning is about implementing an unsupervised machine learning targeting for dimensional reduction process using the optimization principle that deals with the approximation of the Broyden–Fletcher–Goldfarb–Shanno approach for enhancing the cost function. The study implements the training operation using second level of such unsupervised learning approach using feedforward network. This operation is then followed by implementing the classification system on the basis of the features extracted by the presented unsupervised learning scheme. The model is also associated with the normalization of the classification approach further over the stack of parameters used in presented system. This mechanism corresponds to individual steps of deep learning approach. The proposed system is also continued to be evaluated with respect to frequently used classification approach in machine learning to find the dominant scheme for occupancy system.

III. RESULT ANALYSIS

The analysis of the proposed study is carried out considering standard dataset [44] which consists of various events of activity that are captured for research-based studies. The dataset consists of 10,299 instances with 561 attributes while the complete dataset is characterized by multi-variate as well as time series analysis. For an effective performance analysis, the study outcome of the proposed system is carried out with respect to three frequently used machine learning approaches on the scale of error rate and efficiency.

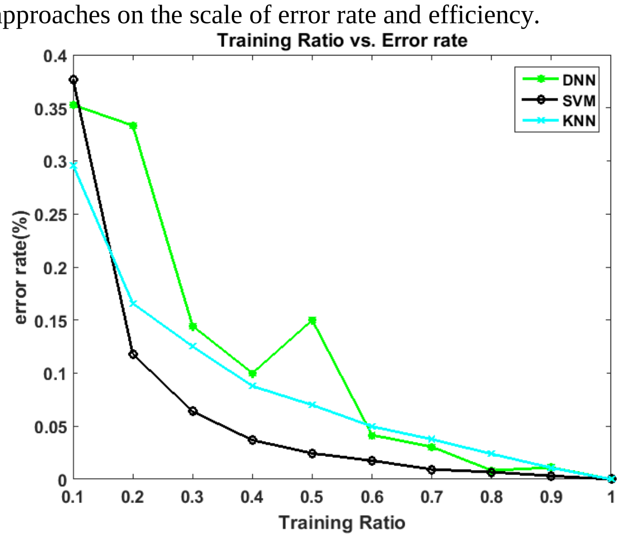

Fig.3 Comparative Analysis of Error Rate

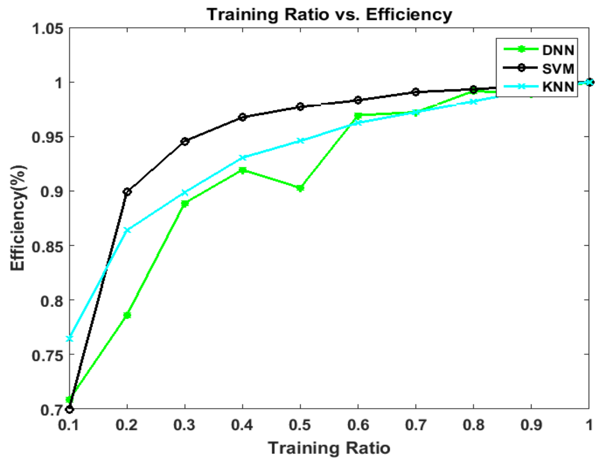

Fig.4 Comparative Analysis of Efficiency

The study outcome shows that proposed system offers better efficiency with SVM and then the next better performance observed is for KNN while DNN is after that. The prime reason behind this outcome is – SVM offers better feature for L2 regularization that successfully resists from various over-fitting problems and hence accuracy factor of SVM is found to be higher than existing KNN as well as DNN (Fig.4).

At the same time, SVM also offers better stability performance even compared to KNN and DNN resulting in better efficiency even in increasing training ratio. The next part of the analysis deals with the processing time and the study considers processing time associated with training as well as in testing in order to investigate the individual performance of approaches under consideration.

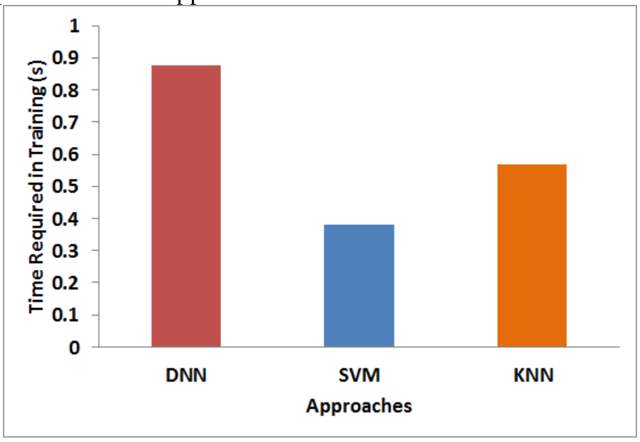

Fig.5 Comparative Analysis of Training Time

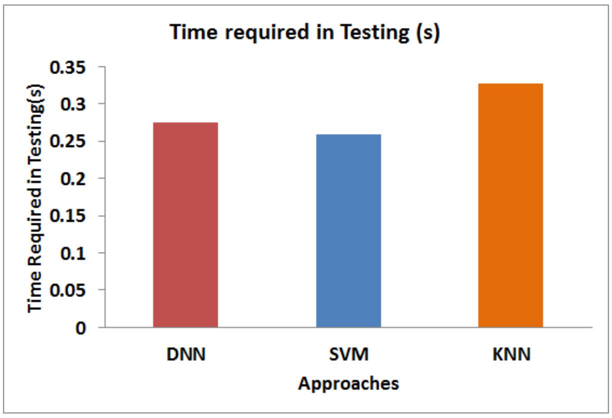

Fig.6 Comparative Analysis of Testing Time

A closer look in both Fig.5 and Fig.6 shows that proposed system offers better performance with SVM in comparison to DNN and KNN approach.The prime reason behind this reduced consumption of processing time is that it reduces the threats of overfitting resulting in faster convergence in its yield and hence reduced processing time. It also shows that testing time is comparative less than training time as training time is inclusive of feature extraction process and hence better performance of cost effectiveness is exhibited.

IV. CONCLUSION

The current paper has presented a discussion about the occupancy sensing mechanism where Doppler radar has been used for capturing the biosignal of the human motion. Therefore, the adoption of the activity sensing dataset has been used and framed in the form of the event and is subjected to the proposed analytical framework where statistical mechanism has been used for extracting the features. These feaures are then being assessed with various machine learning algorithm's that has been frequently reported to be used. The contribution of the work is i) a very simplified, non-recursive, and highly progressive feature extraction has been presented, ii) unlike existing system of occupancy sening using machine learning, where deep neural network has always been claimed to offer better services, the proposed system break this myth showing that SVM and KNN, which are conventonal algorithm, could actually outrun the deep neural network.

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