User Profiling in the Intelligent Office

SAIFULLIZAM PUTEH

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Abstract

The research aim is to investigate different methods of profiling user activities in an office environment. This will allow optimal use of resources in future Intelligent Office Environments while still taking account of user preferences and comfort. To achieve the goal of this research, a data collection system is designed and built. This required a wireless Sensor Network to monitor a wide range of ambient conditions and user activities, and a software agent to monitor user's Personal Computer activities. Collected data from different users are gathered into a central database and converted into a meaningful format for description of the worker's Activity of Daily Working (ADW) and office environment conditions.

Different techniques including Approximate Entropy (ApEn), consistency measures, linear similarity measures and Dynamic Time Warping (DTW) are employed to quantify a user's behaviour and extract a user profile. The individual user profile is representative of a user's preferences, consisting of user routine activities, consistency of office usage and their thermal comfort. Using the statistical techniques, consistency and ApEn, it is possible to characterise different users with only a few parameters. Using similarity techniques one can assess the interrelationship of different aspects of a user's behaviour.

This helps to assess the importance of those aspects within the profile. The novel contribution is the use of these techniques within the context of ADW.

This research investigates soft computing techniques to enhance user profiling. A novel fuzzy characteristic matrix is proposed to summarised the ADW. The activity recognition models using an event-driven and a fuzzy inference system are proposed to recognise a worker's activities during times when the office is occupied and unoccupied during a workday. The experimental results demonstrate the models recognise a worker's activities and can classify into six categories (home, lunch, short break, out of office duties, not use computer/lighting and use computer/lighting) with accuracy of more than 90%.

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Nomenclature

Roman Symbols

ADL Activities of Daily Living

ADW Activities of Daily Working

ANN Artificial Neural Network

BMS Building Management System

CI Computational Intelligence

DTW Dynamic Time Warping

FIS Fuzzy Inference System

FSM Finite-State Machines

GL Gower and Legendre Similarity Measure

HD Hamming Distance

JCD Jaccard Similarity Measure

PC Personal Computers

Nomenclature

PCA	Principal Component Analysis
PIR	Passive Infra-red
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
RFID	Radio Frequency Identification
WSN	Wireless Sensor Network

Chapter 1

Introduction

Buildings are becoming the fastest growing energy consuming sector. Applying energy efficiency measures could contribute to the reduction of current energy consumption. To be able to apply energy efficiency measures, it is required to interact with the environment. The availability of modestly priced sensors and low cost computers allow us to consider individualised monitoring and control of the environment.

In this research we are specifically investigating ways to improve the energy efficiency in an office environment. Apart from the energy optimisation issue, there are other factors such as office worker's performance which could be investigated. As reported in [1], one of the major causes of stress for clerical workers is the lack of control of their environmental conditions. If the energy consumption units including lighting, heating and Personal Computer (PC) are made more responsive to the user's habits, routines and preferences, there would be more acceptance of their use.

An office environment equipped with appropriate sensory devices and actuators is required to be able to control the environmental conditions. Such an environment will be referred to as "Intelligent Office" environment. Apart from the monitoring and control of the environment, there should be an intelligent decision-making process taking into account the office user's work activities and personal preferences. This will be referred to as a Building Management System (BMS). Studies in [2–5] have highlighted the importance of different sensors and a wide range of added capabilities in BMS including building security, activity recognition and automation control system.

The rest of this chapter is structured as follows: in the next section an overview of this research is presented. In Section 1.2, the aim of this thesis and the proposed objectives are presented. Section 1.3 introduces the major contribution of the thesis. Finally, the remaining chapters of this thesis are outlined in Section 1.4.

1.1 Overview of the Research

In modern office environments, lighting systems, heating/cooling system and PC are the main energy consumers. Many companies would like to reduce their energy usage for two reasons. The first is that they worry about the environment and want to reduce the impact they have on it. The second reason, and most likely the one that companies care about most, is cost. For example, PCs waste a lot of energy due to being left on for long periods of time when not in use. Even though they have power management modes to reduce their energy consumptions when they are not in use, these are not always being used.

Some workplaces incorporate reactive systems such as Passive Infra-red (PIR) activated lighting, but these can be activated/deactivated inappropriately. Heating systems often work on the assumption of a 9:00 AM to 5:00 PM presence, five days a week, whereas an individual office worker may have a different schedule, including long periods out of the office. Similarly, automated office computer shut down may be set based on assumptions of behaviour that are inappropriate, leading users to try to find ways of subverting the mechanisms so that their computer remains on and avoids the inconvenience of a slow restart.

The proposed research framework is illustrated in Figure 1.1. There are three distinct phases to develop the research; in the first stage, a data collection system is developed. Different monitoring and data collection system are investigated. The data collection system collects environmental conditions, user activities and office conditions. In the second phase, data mining techniques are applied to identify different user characteristics. Similarity measures are used to compare users' behaviour, detect similar behaviour between different users and also compare the user's behaviour across different days/weeks. In the third stage, activities recognised from a user are represented as user profile. User profile is used to summarise the activities of a user in an office environment. User profile is also used to optimisation environmental control system, so that the office condition are adjusted in line with the individual user.

1.2 Aims and Objectives

The research question in this project is how to understand and characterise the behaviour of an office user in terms that can be used for optimising comfort? To answer the research question, the following aim is identified.

The aim of the research is to record and analyse the detailed behaviour of users

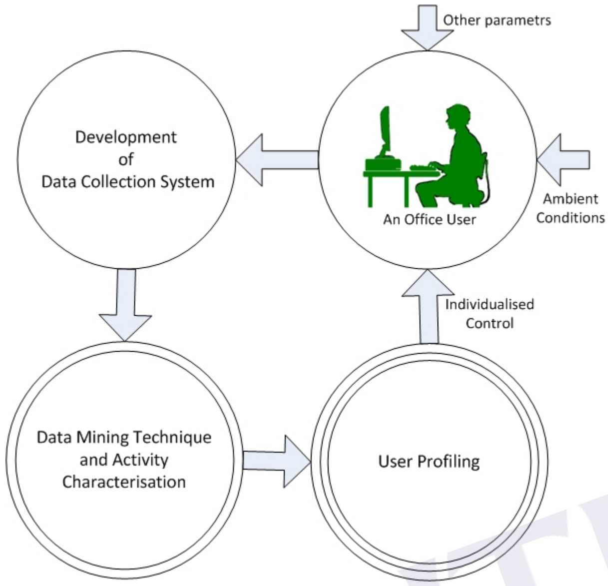


Figure 1.1: Research Framework

in office environments. Activities are monitored using low level sensory devices to detect when office workers enter/leave the room, sit down at the desk, and use the PC. We also monitor when they switch the light on/off, adjust the heating or leave the room to get a drink. Using this low level information gathered from the office environment, a user profile will be created such that the environment could be controlled based on the learned profile.

In order to accomplish the aim of this research, the following objectives are identified:

1. To investigate the requirements for the development of an appropriate monitoring system for intelligent office environment.

2. To investigate the suitability of a Wireless Sensor Network (WSN) to measure all relevant parameters with minimum interference with the users' daily activities.

3. To integrate collected data from different sources and present them in a uniform format. Collected data from different offices must be in a central database and it is essential to store the information in a suitable format for further processing.

4. To investigate efficient and meaningful formats of representation and visualisation of raw data. Raw data in either binary or analog format may not representing the activities in a meaningful format and it is important to convert the raw data into another format to make it more understandable.

5. To extract a user profile based on the collected data from an office worker. The profile represents the user activities in a simple and more meaningful format. User routine activities, consistency of office usage and also user ambient condition preferences should be represented within the user profile.

6. To investigate soft computing techniques to enhance user profiling and create more specific user characteristics which will be use to identify different activities. The user characteristics will form the basis of controlling the lighting, heating and the PC.

1.3 Major Contributions of the Thesis

The main contributions of this thesis are:

- Development of software and hardware required to collect ambient conditions, user activities and office conditions in intelligent office environments. Both wired and wireless systems are investigated for their suitability in an office environment.

- Collect data that represent Activities of Daily Working (ADW) for different office users. The ADW are related to university academic offices representing academic staff working activities, which involve more varied patterns of behaviour.

- Investigate and determine similarities between different users' ADW and also compare the users behaviour across different days/weeks. Both linear and non-linear similarity measures are applied. Different techniques including Dynamic Time Warping (DTW) are investigated. The novel contribution is the use of these techniques within the context of ADW.

- Using statistical techniques to quantify users' behaviour and their preferences and produce a novel signature representing the individual's ADW.

- Proposed a novel fuzzy characteristic matrix to summarised the activities of an office user. The characteristic matrix is presented as fuzzy values which indicate the likelihood of the sequence of activities.

1.4 Thesis Outline

This thesis consists of seven chapters that are summarised as follows:

Chapter 2: Literature Review

This chapter gives a review of the relevant literature related to different aspects of intelligent offices. Initially, an introduction to energy and comfort performance of building is presented followed by outline of building monitoring technologies, building occupant behaviour, human activities recognition and survey of intelligent building environments.

Chapter 3: Experimental Architectures

This chapter reports the experimental architecture development to monitor the ADW in an office environment. The system's development and structure are explained in detail including the WSN for measurement of ambient conditions, the PC monitoring application, the database where all activities are logged and the control server application. A simulator is also developed to generate equivalent pattern to a office worker. The simulator will allow more repeatable testing and assessment of algorithms developed in other chapters.

Chapter 4: Data Analysis Techniques

Both statistical and similarity measure techniques used to generate simple user profile are presented in this chapter. A brief review of linear similarity measures and the DTW algorithm (non-linear similarity measure) used to measure the differences between user patterns are presented in this chapter. Application of the techniques presented in this chapter are presented in Chapter 5.

Chapter 5: User Profiling

This chapter explains the analysis of the office worker's behaviour in an office environment. Statistical techniques namely consistency measures and approximate entropy measures are used to construct an individual user profile for energy and comfort optimisation. In this chapter, similarity measure techniques are also used to identify similarities between user activities. Some experimental results are presented demonstrating the similarities and dissimilarities in user activities with respect to the energy usage. Different techniques including hierarchical clustering and Principal Component Analysis (PCA) are used to identify energy usage behaviour.

Chapter 6: Enhance User Profiling

In this chapter user characteristics are used to summarise user activities. A fuzzy characteristic matrix is proposed to represent the user activities based on start-time and duration of an activity. Sensor data gathered from users are used to create these models. Then, the chapter introduces an event-driven model and a fuzzy inference system for recognising user activities. In an event-driven model, IF-THEN rules are used to determine the transition events. The fuzzy rules and the membership functions of activity recognition are defined based on sensory signals and temporal variables. The experimental results are presented, the proposed activity recognition methods have demonstrated able to identify ADW of a user, either she/he in office and out of office.

Chapter 7: Conclusions and Future Works

This chapter provides the pertinent conclusions arise from this thesis and formulates some future research in monitoring the daily activations of the worker in office environments for office energy and comfort optimisation.

Chapter 2

Literature Review

2.1 Introduction

Nowadays, the energy performance of building and occupant comfort are both priorities. The aim of building technology is to achieve energy efficiency and at the same time increase occupants' satisfaction. Rapid progress in software and hardware have made it possible to improve the intelligence of BMS. This is necessary in an era of increasing energy costs. In order to help reduce all these problems, the "intelligent building" industry need to be further explored. Intelligent building system should allow integration and automation of all technologies and computational intelligence techniques to optimise energy consumption [6], occupants' well-being [7], safety [8] and work productivity [9].

Figure 2.1 shows that energy consumption in the United Kingdom has continued to increase since 1970. Although, buildings in domestic and services sectors have had less attention regarding production of Carbon Dioxide (CO_2) emission than vehicles and industrial machines, improvement in building performance to

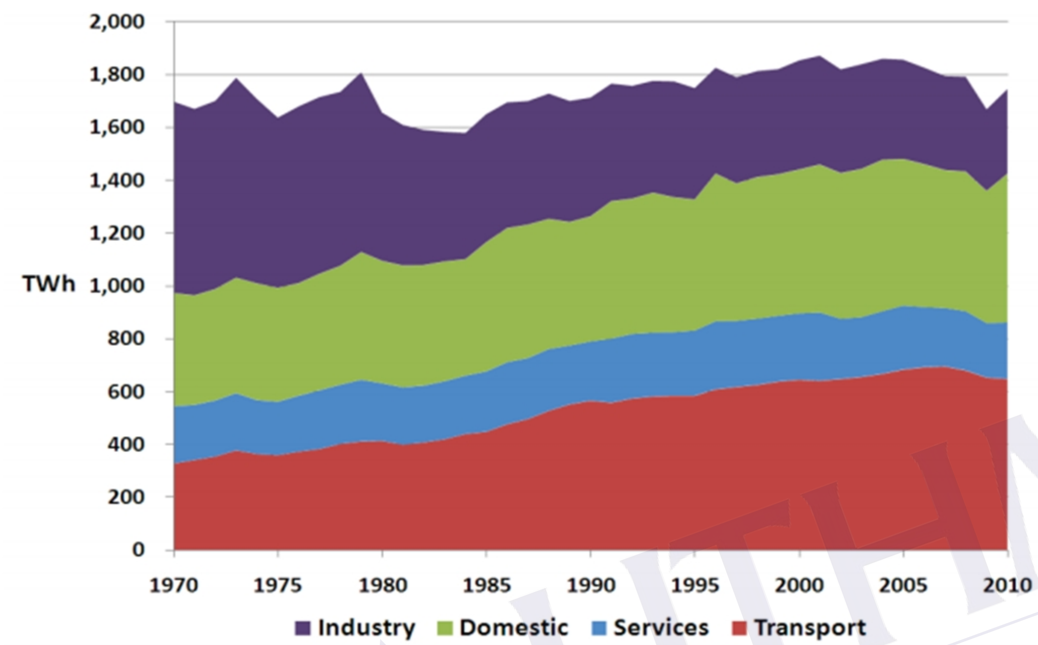


Figure 2.1: Energy consumption in the UK by sectors [10].

achieve energy efficiency and maintain thermal comfort [11], would also help to reduce CO_2 emissions.

Energy consumption by energy source and sector in the UK is shown in Figure 2.2. Electricity is the main energy source followed by gas for the buildings sector. Thus electricity management is a big part of BMS. Improving the effectiveness of BMS will not only benefit the building occupants, but help long term energy sustainability [12].

2.2 Energy Efficiency in Buildings

The energy cost of a building is directly proportional to its capacity and hours of energy usage. For example, the study in [13] used private office buildings

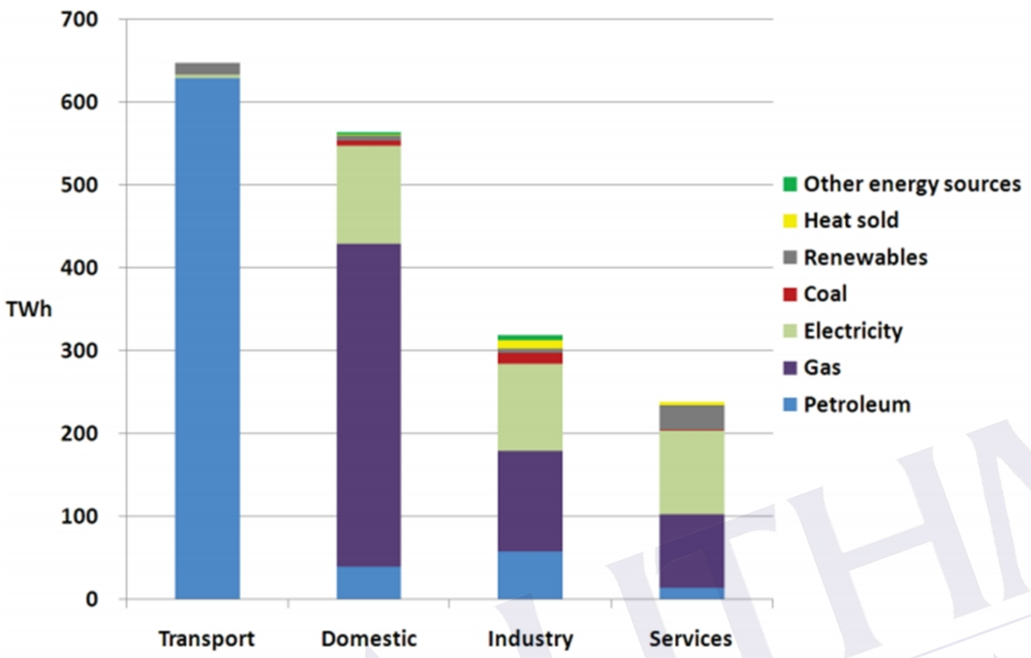


Figure 2.2: Energy consumption by energy source and sector in the UK (2010) [10].

to find the relationship between energy usage and operating hours. In another study [14],it is found to be difficult to optimise the thermal comfort preferences of individuals in the office at all times. The important factors to be considered is that each individual has different thermal comfort satisfaction, and at different times and places an individual has different preferences of comfort in an office environment. In [15] they improved office efficiency based on heating, cooling and lighting to propose a future office environment. The study in [16] showed that social and personal factors can influence one's perceived health and comfort. In order to investigate individual comfort, it is necessary to investigate the relationship between personal, social and building factors.

Looking into the future of residential and office buildings, Mitsubishi Electric Research Labs (MERL) has collected motion sensor data from a network of over

200 sensors for two years in a 2-floor office environment [17]. This data is the residual trace from the people working in MERL. The dataset has been made publicly available as a benchmark to identify social and individual behaviour in office environment. Similar datasets have been collected in a home environment as part of CASAS smart home project [18].

Many issues apply to BMS, such as how to design and operate to comply with standards [19], sustainability [20], and maintaining comfort for everyone [21]. Research work needs to focus on designing, inventing and manufacturing intelligent building technology. At the education and society level, energy-awareness campaigns need to encourage people to save energy, whilst human resource programmes need to produce competence people to retrofit, operate and maintain in a manner that reduces the use of energy.

2.2.1 Building Characteristics

The largest portions of energy consumption by consumers are space heating, cooling and office equipment [22]. In addition, [23] reported that residential homes, commercial sector, offices, warehouses and premise are the main contributors to energy consumption and carbon emissions. According to these reports, we can state that office buildings are an important sectors to focus on, in order to achieve energy efficiency and at the same time improve indoor thermal comfort.

Kazanasmaz et al. [24] developed an office building prediction model to determine daylight luminance using Artificial Neural Networks (ANNs) . A study in [25] has carried out research on the daylight pattern depending on movement of sun, latitude of the building, climate condition, ambient temperature and sunshine availability. Although their work is aimed at designs to help predict luminance within buildings, the predictions could also be used once the building is in use to ensure that the artificial lighting is switched on/off before the occupants realised that they needed it [26].

2.2.2 Energy and Comfort Monitoring

Different occupant satisfaction levels and weather influence thermal comfort and the perception of thermal conditions. The study in [2] has developed a Multi-agent Control System to improve the efficiency of control systems for indoor environments including user preferences. This study took into consideration users' preferences on thermal, luminance comfort, indoor air quality and energy conservation.

Due to the differences in internal heat load, the characteristic differences between zones over the building and individual physiological/psychological differences, it is impossible to satisfy everyone with the same indoor condition provided to all occupants [14]. Investigation into the comfort levels of pupils by [19,27,28] showed that the wrong temperature in the classroom led to poorer learning performance. Similarly, performance studies of call centre workers in Sacramento [29] showed that light levels, ventilation status and temperature all had significant effects on performance, though the effects are intertwined and complex. Seppanen et al. [30] have collated studies on temperature and performance, and provide convincing evidence of the importance of maintaining the office temperature between 21-25°C to optimise performance. Aries et al [31], for example, use multiple survey items to assess worker discomfort, sleep quality and hindrance, in order to relate building aspects to any physical and/or psychological effects. However, Haynes [9] points out that while there is sufficient evidence to support claims that office comfort affects productivity, there is no agreement as to how office comfort should be measured.

The workplace research by Knoll [32] stated that enhancing environmental control can improve users' performance and productivity. Rashidi [33] highlights the fact that it is important to monitor and recognize all activities that the worker regularly performs in their working environment.

Thermal comfort can be affected by heat transfer such as conduction, convection, radiation, and evaporation heat loss. There have been a number of studies relating thermal comfort to human psychology factors [34]. Behavioural adaptation such as the occupant's clothing, taking hot/cold drinks, etc. are psychological adaptations and affect the capability to adapt to the thermal environment [35]. Fanger's formulas [36] is based on average criteria for population comfort and it is widely used in themal standards such as Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) [37, 38].

Canadian Centre for Occupational health and Safety (CCOHS) [39] have suggested the thermal comfort setting, as shown in Table 2.1. This table is an adaptation from American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standard [40]. This table is based on numerous comfort evaluations under controlled steady state conditions using thousands of randomly selected respondents [41].

2.3 Intelligent Buildings

The rapid development of intelligent technology such as sensors, computer technology, simulation technology and system networking have provided opportunities to generate a high degree of intelligence in environment control systems. For example, a study in [42] designed an intelligent residential lighting control system based on a ZigBee wireless sensor network and fuzzy controller. Experimental results showed that the system contributed to economy and energy efficiency. In [43–45] it is shown that simulation tools for thermal comfort are capable of quantifying the relationship of surface materials, indoor and outdoor environments. Focusing on the intelligent building, a study in [46] developed eight key intelligent building indicators in order to construct models for appraising intelligent building systems.

In [47, 48], surveys are conducted to assess the weighting given to intelligent criteria of buildings. The results showed that work efficiency is the most important selection criterion for various intelligent building systems, while user comfort, safety and cost effectiveness are also considered to be significant. This finding indicated that any intelligent building system must perform efficiently to contribute to practicality and building occupants' satisfaction. Research by [49],

Table 2.1: Ranges of temperature and relative humidity for offices (adapted from ASHRAE standard).

Temperature and Humidity Ranges for Comfort		
Condition	Relative Humidity	Acceptable Temp. $(^{\circ}C)$
Summer(light clothing)	If 30%, then	24.5 - 28
Summer(light clothing)	If 60%, then	23 - 25.5
Winter (warm clothing)	If 30%, then	20.5 - 25.5
Winter (warm clothing)	If 60%, then	20 - 24

took into account the BMS to monitor daily energy operations in order to support the decision making process of selecting energy saving measures.

A BMS is needed to integrate all intelligent building aspects to contribute comprehensive strategic management, in order to analyse and report the building performance, and then provide data analysis to any decision making system. It aims to provide intelligent functionality to respond to the energy demand and comfort of building environments for normal daily operation [49].

2.4 Human Behaviour Recognition

Human activities recognition in buildings is the subject of interest for many researchers. Activities recognition in home environments [33, 50–56], hospital environment [57, 58] and the office environment [59–61] are being investigated.

Liming et al. in [5] have conducted research based on sensor-based human activity recognition. They suggested a complex process of activity recognition that can be approximately classified by four basic steps. They are:

1. to choose and deploy appropriate sensors in order to monitor and capture user's behaviour in building.
2. to collect, store, and process perceived information for data representation at appropriate level.
3. information gathered from monitoring place based on user's activity daily living are used to create computational activity models.
4. to select and develop intelligent algorithms to infer activities from sensory data.

Human activity recognition and pattern discovery is explained in [62]. Tabak and deVries [63] examined the intermittent activities that interrupt the planned "normal" activities of office workers. They found that probabilistic and S-curve methods could be used to predict activities (such as "smoking", "go to toilet") and these could be used in fine grained simulations of building performance. However, they cautioned that the results applied to typical Dutch office based organisations, and other office environments might need further experiments to generate data.

More survey results based on the human activities monitoring system and activities recognition techniques are presented in the following sections.

2.4.1 Activities Monitoring

People's activity in a building is based on their schedule of work, lifestyle and social activity. Xin et al. [64] mentioned that one of the key features of an intelligent environment is to provide monitoring Activity of Daily Living (ADL) . In many studies [50,55,58,64–67], ADL are monitored to assess elderly people's activity in the home environment, and attempts are made to process activity sequences to make them more understandable. For example, daily home activity involves basic functions like preparing breakfast or food, showering, walking, sleeping, watching television, reading books etc.

Recently, advanced intelligent sensor technology has resulted in various types of sensors that have been used by researchers to get features from activity monitoring. A study in [54] has used physiological sensors (cardiac frequency, activity or agitation, posture and fall detection sensor), microphones, PIR sensors, door sensors and state-change sensors. This monitoring system has been combined with a fuzzy logic system for recognizing activities in readiness for the next generation of smart houses. David Naranjo et al. [68] have proposed hardware and software design and implementation of low-cost, wearable, and unobtrusive intelligent sensors for monitoring human physical activities. Many researchers have successfully conducted research with similar ideas in activity monitoring systems, such as Interactive Continuous Autonomic Logging and Monitoring (iCALM) [69], human activity recognition in pervasive health-care systems [58] and occupancy monitoring system [70].

2.4.2 Activities Recognition Techniques

To recognise human activities, different computational techniques have been applied. Data mining techniques including Discontinuous Varied-Order Sequential Miner (DVSM) [33], classification tree methods [71–74] and Hidden Markov Models(HMMs) [75–77] have been used. More intelligent computational techniques including Fuzzy Inference Systems(FIS) in activity detection [78, 79] and some hybrid soft computing approaches namely neuro-fuzzy techniques [80, 81] are investigated. Some statistical methods and Bayesian classifier are discussed in [74, 82, 83].

As mentioned previously, when sensor information is collected and activities are detected based on individual activity, the intelligent environment needs a model to track each activity and also to recognise forthcoming activity to help people improve their quality of life [33]. Song et al. mentioned in [84] that behavioural pattern mining is a significant process to recognise the relationship and limits between real user's behaviour and an event log. Therefore, the model of behaviour pattern mining needs a process to determine the form of the mined results. Consequently, the process model influences the design of the mining algorithm and the related approach. They introduced the major stages of behaviour pattern mining as summarised below:

1. **Events recording:** This stage arranges the original data for behaviour pattern mining. The basic types of information include activity, event, participant, and time. The logged data may be extended as appropriate for any particular requirement.

2. **Prepossessing:** This stage provided the log format to fit the mining method, reduces noise and checks for the record. As a characteristic of behaviour pattern mining, common event logs may be passed on to make use of existing work-flow mining methods.

3. **Mining and discovering:** Implement mining algorithm to discover the behaviour patterns.

4. **Verification:** This stage applies the discovered results to system improvement and research, and checks out if the results fit the experience of the real world.

A study in [85] used a semantic-based similarity to update user profiles representing user preferences. They have monitored internet usage of a user to create a profile for each user. Based on the user profile, they have provided relevant information to the internet user. Ghulam et al. [86] proposed an agent-based user profiling to analyse user behaviour on the web for constructing user profile. They categorised the user profile into demography and user interest. Iglesias et al. [87] used a classifier to create a user behaviour profile. The classification method is used to develop user profiles based on computer activity.

Danni Wang et al. [88] used statistical properties of occupancy in single person office. Their work proposed a probabilistic model to predict and simulate occupancy in a single person office. A study in [89] proposed a Thermally Activated Building System (TABS). Their experimental work has shown that TABS model demonstrated that it is able to cope with user behaviour such as time of arrival, departure and temporary absence. Taherian et al. [90] also contribute in this area. However, their work identifies the user behaviour based purely on electricity usage in households and office spaces to produce an energy profile.

2.5 Data Representation

In order to store the collected data from the environment, it is essential to represent them in an appropriate format. Data will be collected from different sources with different time scale and even different format (analog and binary). To investigate the best form of data representation, many researches have been conducted in this area. The following sections will review these.

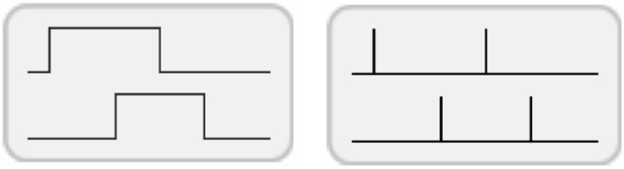
2.5.1 Temporal Data Representation

Lee et al. [91] have been discovering knowledge from temporal interval data in their research. According to Allen's theory about an algebra of temporal relations on interval [92], they proposed a new temporal data mining technique to extract temporal interval relation rules from temporal interval data. Lee et al. claimed that the proposed approach increases the model efficiency to identify activity from temporal interval data. Nazerfard et al. [53] proposed a framework for Discovering of Temporal Features and Relation of Activities (DTFRA). This framework discovers activity from data based on start time and duration using k-means clustering. The proposed approaches by Lee et al. and the DTFRA framework have shown that both approaches are able to predict start time intervals and represent the temporal features of activity patterns [53, 91].

2.5.2 Time Series Representation

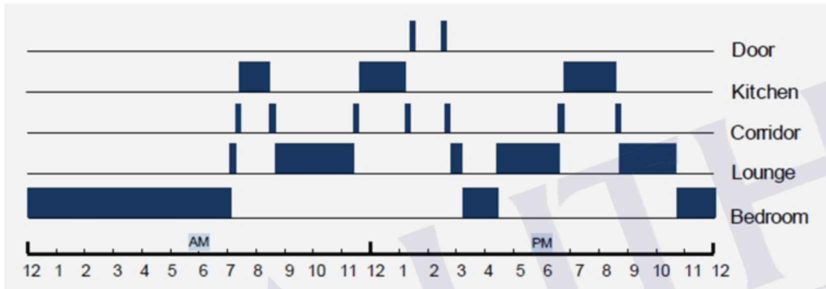
Time series analysis is often used in multi-sensory data representation. Kasteren [93] has discussed the advantages and disadvantages of time series with discrete time intervals for the recognition process. He determined that if an interval is very small, it would incorporate signal noise, while a moderately large interval will smooth out important aspects of the signal. He proposed different feature representations, i.e. change the binary data $X(t)$ to change points Xt as shown in Figure 2.3. Binary data representation uses the sensor data directly and '1' indicates that the sensor is activated and '0' is inactivated. The change point representation indicates when a sensor event takes place, i.e. showing '1' when it changes state.

Akhlaghinia et al. in [70, 94], proposed a signal technique to combine time series of sensory signals in different areas for home occupancy monitoring. They used multiple PIR sensors to monitor single occupant activities in a home environment. The conditions for this approach are that there is no parallel activity in the different areas detected, and that all activities are genuinely from a single

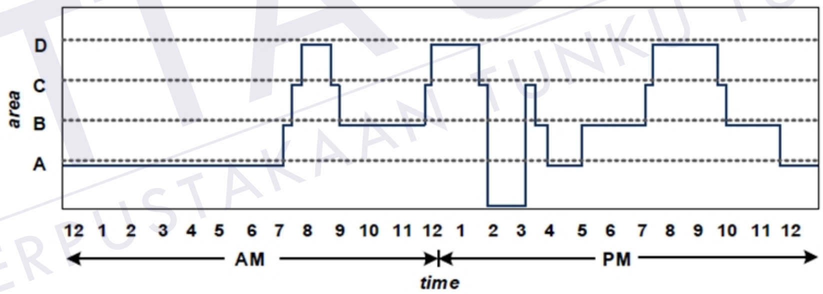


(a) Binary data (b) Discrete-time signal

Figure 2.3: Different time-series feature representation [93]: a) binary data representation b) change point representation.



(a) Individual PIR Signals



(b) Combined Time-Series

Figure 2.4: Time-series representation of PIR sensors [70]: a) activities in different areas b) combined signals.

user. The occupancy signals as shown in Figure 2.4-a can be transformed into a combined occupancy time-series shown in Figure 2.4-b [70]. In Figure 2.4(b), each level represents the occupancy of a certain area.

2.5.3 Gray Coded Binary Representation

Many researchers have applied binary sequence data based on sensory signal in their pattern recognition process [70, 93, 94]. However, there are many issues still present and we need new exploration mechanisms in order to optimise the activity recognition model. For example, Akhlaghinia et al. in [70, 94] have proposed a combination signal technique to combine binary signal for PIR sensors. However, the proposed approach did not allow for overlapping. Therefore, when recording parallel activities from an observation area, binary representation is the best way to record all information. However, it is not as easy to combine all the signals based on bit order or using significant bit position for conversion to decimal or hexadecimal, because it is will increase the distance between one code word and the next [95]. Gray code is associated with many fields such as mechanical position sensors, electronic circuit, and so on [95, 96].

2.6 Office Building Monitoring Technologies

The main factors driving better building operation are the provision of a healthy environment, thermal comfort and energy. Building monitoring technology aim to improve the quality of life for occupants [7, 65, 68, 97] to maintain internal environment conditions [34, 98–102] and safety improvements [8, 103, 104].

BMS need to monitor real time building operation, record data, analyse information, and then address issues as soon as possible. Jang et al. [105] have described a methodology of real time monitoring. They considered that an application for a building monitoring system is divided into three parts: data acquisition, data collection and data retrieval. Authors in [106] described a decentralised system of software agents to monitor and control office buildings. The proposed system is used and resulted in energy saving and increasing customer satisfaction. In addition, LonWorks technology [107] have proposed a typical smart office building system containing an electrical network and a number of electrical monitoring and control devices.

Many companies are active in carrying out research to produce products for hardware and software monitoring of BMSs. A review of current products and companies is presented in Appendix A.

2.6.1 Monitoring Technologies

Development of hardware and software technology have improved monitoring efficiency of environments in and around buildings [105,108]. Hernandez et al. [68] presented the hardware and software design and implementation of a low-cost, wearable, and unobstructive intelligent accelerometer sensor for monitoring of human physical activities. Their proposed model is to improve the healthy lifestyle of people in buildings. The model is used to monitor daily activities and classify them. Tsai et al. [109] recommended that research needs to improve efficiency, accuracy, and power usage of monitoring devices. They have constructed practical designs to reduce the standby power consumption of PIR based power usage for lighting devices. Normal PIR lighting switches are active based on motion detected. The authors in [109] have designed a PIR able to reduce the consumed lighting power from 3 Watt to 0.004 Watt for each detection/activation.

Building activity monitoring is a challenging part of BMS. The tasks include appropriate sensor selection, collection and storage of information, and creation

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