ICT for Smart Appliances: Current Technology and Identification of Future ICT Trend

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***Abstract*—**Smart metering and demand response are gaining ground in industrial and residential applications. Smart Appliances have been given concern towards achieving Smart home. The success of Smart grid development relies on the successful implementation of Information and Communication Technology (ICT) in power sector. Smart Appliances have been the technology under development and many new contributions to its realization have been reported in the last few years. The role of ICT here is to capture data in real time, thereby allowing bi-directional flow of information/data between producing and utilization point; that lead a way for the attainment of Smart appliances where home appliances can communicate between themselves and provide a self-control (switch on and off) using the signal (information) obtained from the grid. This paper depicts the background on ICT for smart appliances paying a particular attention to the current technology and identifying the future ICT trends for load monitoring through which smart appliances can be achieved to facilitate an efficient smart home system which promote demand response program. This paper grouped and reviewed the recent contributions, in order to establish the current state of the art and trends of the technology, so that the reader can be provided with a comprehensive and insightful review of where ICT for smart appliances stands and is heading to. The paper also presents a brief overview of communication types, and then narrowed the discussion to the load monitoring (Non-intrusive Appliances Load Monitoring 'NALM'). Finally, some future trends and challenges in the further development of the ICT framework are discussed to motivate future contributions that address open problems and explore new possibilities.

***Keywords*—**Communication technology between appliances, demand response, load monitoring, smart appliances and smart grid.

I. Introduction

RECENTLY a majority of consumers have no idea where their electricity mainly goes to. This may cause a higher energy consumption and insufficient use of electrical energy. Therefore, an active measuring system can be used to reflect users' behavior, and send a feedback to them for improving efficiency of energy usage. ICT for smart appliance aimed at providing control to energy usage by home appliances using information to make more sensible use of energy. Studies have shown that this may reduce energy consumption by 10% to 20% through using dynamic control and feedback technology [5]. The background on ICT for smart appliances will be presented where emphasis will be made to the current technology and identification of future ICT trends for load monitoring.

Information and communication technology (ICT) creates universal connectivity between power producer, grid operator, and customer. This provides consumers with real time updates on their energy consumption. It could account for the distant control of distributed networks that could provide ways for real-time interaction between producer, grid operator, and customer. This could yield enabling environment for demand response, balancing services, dynamic pricing, buying, and selling of power in real-time. ICT also helps to achieve decentralization of the traditional centralized electricity network, and integrate the distributed generation much better. Utility companies allocate 2%-6% of their turnover for Information Technology (IT) spending, thus representing 8 billion Euros annually, and estimated 188 billion Euros by 2030 (2% of utility's turnover) [1]. ICT tends to increase the efficiency of the energy in all sectors of the economy if directed to sustainable uses. This continues to account for 40% of the Europe's productivity growth [1]. The smart 2020 study has estimated that the smart technology can minimize global emissions by 15%, thus integrating ICT in to power sector could make electricity generation more efficient by 40% and its transmission and distribution by 10% [1]. ICT could also encourage the integration of renewable energy sources which is very important for environmental sustainability. ICT provides the consumers with update on real time basis on energy they consume. New applications will soon evolve and can be easily added in to homes and building automatics to make economic use of energy since heating, cooling and lighting of buildings contributes to 40% or more, of the energy consumption in Europe [1].

Costumer's active participations in demand response programs contribute to the smartness of distribution electricity grid i.e. response in real-time to the conditions of grid through shedding loads (light, machines, air conditions, washing machine etc.). The contribution of consumers to system operation can be viewed under Demand response. Two types of Demand Response (DR) can be considered, these are Price-based demand response and incentive-based demand response. Price-based demand response consists of Real time pricing (RTP), critical-peak pricing (CPP) and time of use Tariffs (ToU). Whereas incentive-based DR aims to pay customers who participate to reduce loads [1]. It becomes obvious that demand response program can only be realistic with the help of ICT.

Integrating ICT to the power grid has been a milestone in the process of transition from the traditional grid to the smart grid. The advance in the ICT can be employed to enhance

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automation, secure the grid, integrate renewable distributed sources, and allow efficient demand-side energy management [2]. In the demand response, load-shed verification (LSV) plays an important role to improve reliability and eliminate freeloaders who accept incentives without direct controls [4]. Though using LSVs accounts for many challenges, therefore many appliances need to be replaced, because they cannot receive and send LSI. To simplify the problem, LSVs could be received and sent by using residential power meter to monitor the use of electricity and to analyses the load changes. In order for the load to be monitored, the Nonintrusive appliance load monitoring (NALM) algorithm should be implemented. George Hart introduced a real power approach [3]. Now, this technology has been improved by using complex power, state stables, frequency analyses, and more sophisticated learning techniques [4]. One distributed NALM algorithm has been addressed in Nonintrusive load-shed verification. This algorithm includes four aspects: edge detection, building the dynamic table, building the static table, and training. Edge detection is to monitor the change of power corresponding to a large appliance turning on or off. The dynamic table is to identify the current state of the appliance according to the real-time edge event and to correct the errors of static-table. Static table is to establish clusters of on and off events to identify the appliances, while Training is to enable the meter to learn the appliance including in the system. [4]. The evolution of Demand Side management necessitate the needs for Demand response which is further translated in to smart homes, thus; gave birth to 'ICT for smart appliances' where home appliances can communicate between themselves and provide a self-control (switch on and off) using the signal (information) obtained from the grid. ICT for smart appliance aimed to provide control to energy usage by home appliances using information to make more sensible use of energy so that an automated platform for demand response can be provided.

II. Communication Technologies between Appliances

Wireless communications exhibit greater strength in obvious reduction and simplification of home wiring [9]. The recent development in wireless technologies is quite significant and brings the design and implementation of smart appliances in the modern intelligent home network into the public attention. Smart home networking for those old houses and electronic devices required cable connections will be a challenge [6]. Many wireless communication technologies such as Bluetooth, Wi-Fi and WiMAX etc. have been researched and discussed in [6], [7]. Here the discussion will concentrate on analyzing the design and implementation of ZigBee-based smart home system.

A. *Power-Line Technologies*

Power line technologies are used as a response to the accusation of cabling. Power line system is using one type of wiring in every residence in intelligent home technologies. Power line signaling, as a networking medium, has two advantages. One is that they are in place and run to nearly every location where endpoint devices exist. Another merit is that endpoint devices do not require external power source like a battery [7]. Both of these successfully meet the requirements of the smart home communication technologies with low cost and ease-to-use. According to [7], Konnex (KNX) and Local Operating Networks (LON) are two major power line technologies. KNX is one of the best technologies for home and building control, yet there are only few products on the market. The LON technology is basis of the ENEL AMR project, and high efforts required for installing and system integration. Whereas, though these two technologies have solved the issues of data recovery and noise reduction, there are still some challenges involved in the power line technologies including the system integration and operation in future application.

B. *Wireless Communication Technologies*

Compared to the power line technologies, the most significant benefit of the wireless communication technologies is that cabling is not required anymore. Therefore, the problems arising from the noise on power lines will be decoupled by the medium and the placement within the building is almost independent [7]. However, the wireless communication system is not flawless since its channel is always available for the outside world. Besides, with the competition around the wireless applications for access to the medium, the communication security will always be a challenge for the designers to minimize the interferences to the least.

Since the development of the wireless technologies, its implementation in the smart home system starts to emerge in the spotlight. Several wireless technologies of varying bandwidth, operating range and power consumption are available and widely used. They include Bluetooth, ZigBee, Ultra-wideband (UWB), Wireless Fidelity (Wi-Fi) and Worldwide Interoperability for Microwave Access (WiMAX) etc., and each of them distinct from others with its own features [8].

1. Bluetooth

Being the first wireless interface for personal mobile devices Bluetooth has advanced itself ahead of time. However, for home networking specifically, bandwidth has speeded up and increased dramatically in the past few years. As a consequence, Bluetooth is not as convenient as it first unveiled in some cases. For instance, the data operate faster in modern printer than Bluetooth enabled devices [6].

2. Ultra-Wideband (UWB)

UWB is specifically devised for the wireless area networks with low power, short range, but high speed. UWB has an operational range of 10 meters maximum and an original specification based on IEEE 802.15.3 standard using a carrier based 2.4GHz radio [6].

3. Wireless Fidelity (Wi-Fi)

The operational range for Wi-Fi is usually for the entire house, with the data rate reducing to 1 Mbit/s and below at far distances. While when high bandwidth and greater coverage is needed, additional Wi-Fi access points can be added. As for home networking, Wi-Fi is used for interconnecting different devices and for internet access provisioning [6].

4. Worldwide Interoperability for Microwave Access (WiMAX)

WiMAX aims at wireless broadband access provisioning as an alternative to the cable connection. A simple table is shown as the comparison of wireless technologies in parameters:

TABLE I
COMPARISON OF WIRELESS TECHNOLOGIES [6]

	Bluetooth	ZigBee	UWB	Wi-Fi	Wi-Max
Protocol Standard	802.15.1	802.15.4	802.15.3	802.11b,802.11g	802.16
Frequency Band (Hz)	2.4G	868/915,2.4G	3.1-10.6G	2.4G/5G	2-11G
Rates (bps)	1M	20-250K	53-480M	11-54M	70M
Power consumption (W)	>10m	<10m	>10m	>10m	>10m
Security	High	High	High	Low	Medium
Transmission Distance (m)	10	100	40	200	30,000

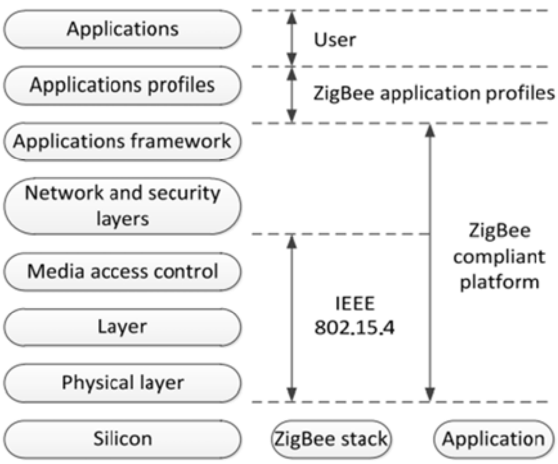


Fig. 1 Structure of ZigBee [6]

III. ZIGBEE TECHNOLOGY

ZigBee technology is relatively new wireless protocols with a strong highlight on energy efficiency or even battery-less operation. The most important benefit with ZigBee technology compared to other wireless communication techniques is the low power consumption. Therefore, the radiation effect can be decreased and the cost of energy will be saved a lot via ZigBee. Additionally, its transmission range will cover about 100m and thus makes it more suitable for home environment. It also characterizes itself to be self-organizing, self-healing and interference that makes it a perfect choice for smart home system in particular [6].

Noticeably, the only weakness of ZigBee compared to other techniques is the low transmission rate (low data rate). Even though, the low speed applications are easier to control in the home networking environment with few communication nodes within 60-500 m2 area and each node will only communicate every 5-15 minutes [6]. Therefore, ZigBee is more reasonable and suitable as part of the integration in smart home control system than other technologies.

The structure of ZigBee is demonstrated in Fig. 1. ZigBee network is comprised of up to 65,536 nodes and is compatible with IEEE 802.15.4. ZigBee nodes include three types of devices, which are coordinator, router, and end device. The coordinator is the first device on the network which starts, configures, and manages the network, which every ZigBee network must have one. When the coordinator is prepared, the other devices can join the network. Routers are employed for routing traffic between different nodes, as well as receiving and storing messages for the children nodes and allowing new nodes to join the network. End devices cannot route traffic and may be mobile devices. It is responsible for requesting any pending messages from its parent node.

A. ZigBee-Based Home Network

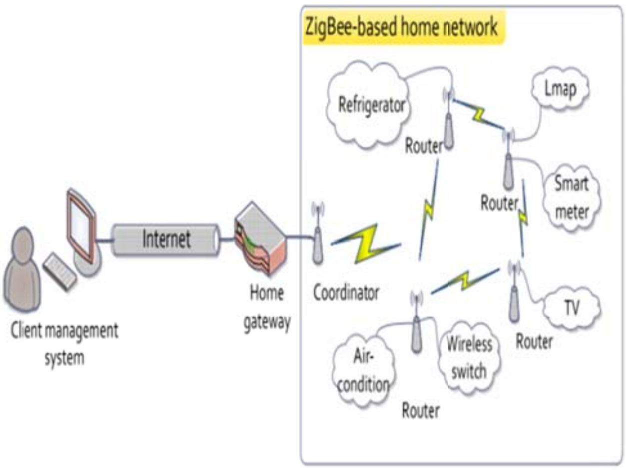


Fig. 2 ZigBee-Based Home Network [6]

The implementation of ZigBee technology in the smart home system is shown in Fig. 2. From this figure, it can be seen that the smart home system is comprised of client management system (CMS), including home gateway (EHG) and ZigBee-based home wireless network. CMS consists of User-Interface (UI) and Common gateway interface (CGI) program, through which users can monitor and control the home appliances at any place where Internet is accessible [6]. EHG is an entrance of home network, which successfully connects the External Internet network and internal home network. On one hand, EHG provides Web service and allows users to remote access home network. On the other hand, it serves as routing, protocol conversion etc. As a core of smart home system, the whole home network plays the role of a wireless local area network composed of ZigBee nodes. The coordinator in home network receives remote messages replying by EHG and sends to the corresponding router nodes for monitoring and controlling home appliances. With the ZigBee receiving module, the controllers of home appliances can be used as end devices of ZigBee wireless sensor network (WSN).

IV. Non-Intrusive Appliance Load Monitoring (NALM)

A. Definition of NALM

Demand response (DR) happened to be one of the fundamental aspects of smart grid. Demand response is achievable through load monitoring. The appropriate approach is to install a sensor in the appliance. This method can achieve an accurate result but it is not cost effective; therefore, a much more economic approach needs to be developed. As a result, a Non-intrusive load monitoring is developed. Nonintrusive appliance load monitoring (NALM) can be used to monitor the operating load and the operating appliances in the main power entry. Comparing with the Intrusive load monitor, the sensor usage could be reduced in NALM and the cost could be reduced as well. The character of non-intrusive could lead to the convenience of installation and the usage for a customer. This type of approach is based on digital signal processing (DSP). The amount of computation is very high, so the high standard DSP should be implemented or the better algorithm needs to be developed to reduce the computation numbers. Thus, a better algorithm is needed to enhance the performance of the monitoring as well.

The earliest solution of NALM was developed by Fred Schweppe and George Hart in the 1980s [3]. The solution they developed is based on the real power monitor. It could analyse the transients, cluster the similar transients, and compress the cluster. Then use the character in the cluster to identify the appliance that is used.

B. Feature Extraction of NALM

The feature extraction of Power can achieve many methods according to [10], [11], some use time domain transient state (on or off), steady state to form the signature of power. Some use triangle model and rectangular model to describe the power feature. Some more advanced solutions are using frequency analysis to extract the transient state.

1. Turn on and off Transient and Steady-State

Different loads have different transient behaviors that are determined by the physical and electrical characteristics [12]. The transient behaviors could be a part of classifications because of the different behaviors for verities of appliances. However, the transient behavior is a very short period. The precise measurement must be implemented in the meters. In [13], the coreless Hall-effect current transformer (HCT) is adopted. Then the transient and harmonic current could be measured accurately that could be used to classify the load signatures in NALM.

The turn-on and turn-off transient could be determined using:

$$\Delta I = I_k - I_{k-1},\ I_k = \frac{\sum_{j=1}^{N}|i(j) - mean(i)|}{N} [13]$$

where k stands for the number of sample period, N stands for the number of sample points in one period and mean i stands for the average value of N samples current I in one period. Two thresholds could be set for turn-on and turn-off event.

The transient period could be detected using;

$$\Delta I' = I'_k - I'_{k-1}, I'_k = \log(\sum_{j=1}^{N}|i(j) - mean(i)|^2) [12]$$

where k, N and i stand for the same meaning with last equation. Here, set a threshold to detect the transient period. When the $\Delta I'$ is less than the threshold, the transient period is end. Define that the transient period isT_t. The features used during period are the peak current, average current, and RMS current. The equations are [11]:

$$I_p = \max_{0<j<N} i(j) \quad (1)$$

$$I_{avg} = \frac{\int_{t_0}^{t_0+T_t} i(t)dt}{T_t} \quad (2)$$

$$I_{rms} = \sqrt{\frac{\int_{t_0}^{t_0+T_t} i^2(t)dt}{T_t}} \quad (3)$$

During steady state, the differences of the RMS, average and peak current could be used to identify the appliance.

2. Triangle and Rectangular Method

This method is to modulate the power pattern into two classes. One is rectangular model; the other is the triangle model.

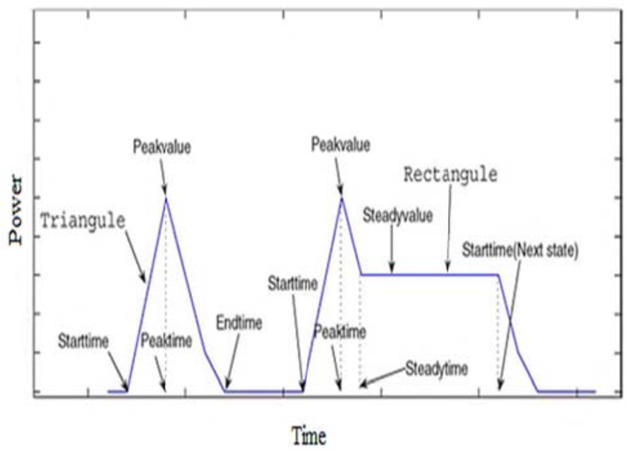


Fig. 3 The Model of Power Signature [10]

Fig. 3 shows two models of power pattern. The triangular model uses four values to describe that are start time, peak time, peak value and end time. The rectangular model uses five values to express that are start time, peak time, steady time, steady value, start time of next state. Using this method, one appliance includes triangles and rectangular model of power pattern. The triangular is used to modulate the short-time operating period such as washing operating of washing machine. The washing machine also includes the triangular model of power pattern such as spinning operation. Then the program can use these patterns to identify the appliance

3. Evaluation and Time-Frequency Analysis Solution

The Extraction of the overlap power becomes a problem, for instance; a 3kW air conditioner and a 100W laptop run at the same time. The laptop may be identified as the fluctuation of the air conditioner. In [14], the author supposes to use the frequency analysis with Fast Fourier Transform. The power signal is also a no-stationary signal. The short-time Fourier transform is a solution for the no stationary. This type of method can extract the frequency changing with the time. Use this method could solve the overlap problem very well. However, this method has a problem. The time resolution and the frequency resolution cannot be very high at the same time. The relationship is defined as

$$\Delta t * \Delta f \geq \frac{1}{4\pi} \text{ [15]}$$

where Δt is the time resolution and Δf is the frequency resolution. It can be deduced that when time resolution increases, the frequency must decrease. While frequency resolution increasing, the time resolution decreases. It is not so good to solve the NALM problem.

Because of the short time Fourier transform problem, another time-frequency analysis is developed to solve the drawback of STFT. The Discrete Wavelet transform is used in [13], [17]. The structure of the Wavelet Transform output is showed is showed in Fig. 4.

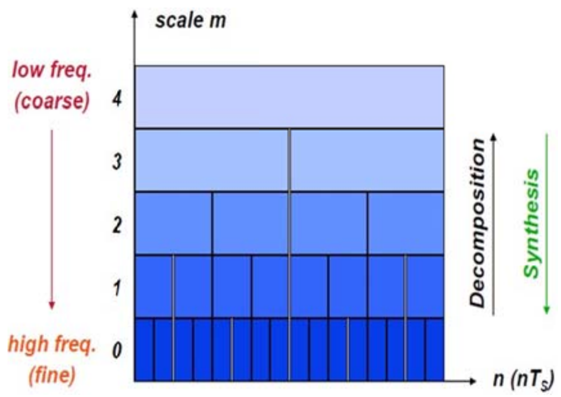


Fig. 4 The structure of the Wavelet Transform output [15]

Fig. 4 shows the approximate waveform on low frequency and detailed frequency and time resolution on high frequency. This is a suitable solution for NALM to extract the transient pattern and position the appliances on or off. The reason is that steady state is on low frequency and the transient process is on high frequency.

The Wavelet process includes several stages that extract the low frequency components and high frequency components. The Wavelets include mother wavelet and the daughter wavelet. The relationship between them is defined as:

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{a}} g\left(\frac{t-b}{a}\right) \tag{4}$$

where 'a' is the scale factor, 'b' is the shift factor, $\Psi_{a,b}(t)$ is daughter wavelet and $g\left(\frac{t-b}{a}\right)$ is the mother wavelet.

The Continues wavelet Transform is an integer of a series of mother wavelets multiplied by the input signal. The equation form is defined as

$$W_{a,b} = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} g\left(\frac{t-b}{a}\right) x(t) dt \quad \text{[13]}$$

where x(t) is the input signal and $W_{a,b}$is the coefficients of the Wavelet output. In Practice, the Wavelet transform is discrete, so the Wavelet output is the sum of finite wavelets multiplied by the input sampled signal. Normally, it would use multilevel-decomposition process to break the original signal into several lower resolution components. The Wavelet process is showed in Fig. 5

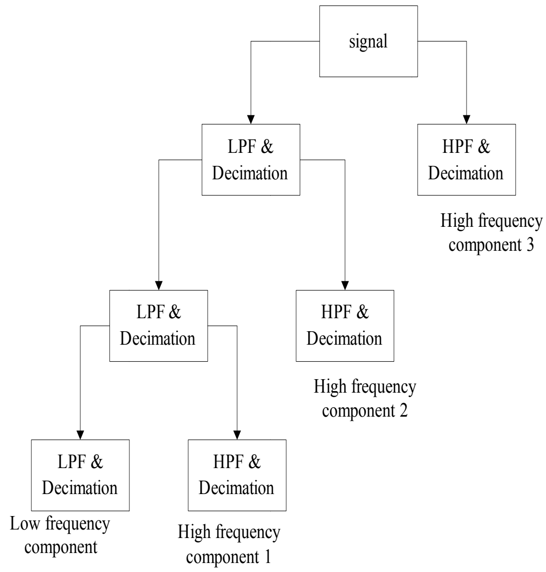


Fig. 5 Decomposition process of DWT [13], [15]

Fig. 5 depicts the decomposition process of DWT, signifying that the low frequency component is the steady-state power. The high frequency components are the turn-on or turn-off transient. The achieved transient state can be used to do the matching combining with Power.

C. Identification and Classifier Method

After the feature extracted, the classifier could be used should be used to classify the information into several classes for training. The identifier is used to match the achieved data with the training data.

1. Support Vector Machines

Support Vector Machines (SVM) could be used as a classifier to identify the appliances feature. Here, use a two-class of data as an example to illustrate the SVM. The work diagram is showed in Fig. 6.

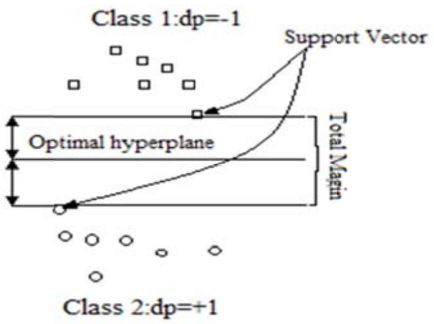


Fig. 6 Work diagram of Support Vector Machines [12]

In Fig. 6, it could be observed that two classes of data are separated by two support vectors +1 for class 2 and -1 for class 1. When identification begins, the candidate data is to be compared with these two classes of data. If the data is similar to the data of class 1, the data belongs to class 1. Finally, count the number of data identified in each class that can determine the candidate data belongs to class 1 or class 2.

In NALM, two classes of training data are not sufficient, because the appliances are normally more than two. The practical application that includes more than two classes of data must be developed. In [12], a multi-level SVM is developed.

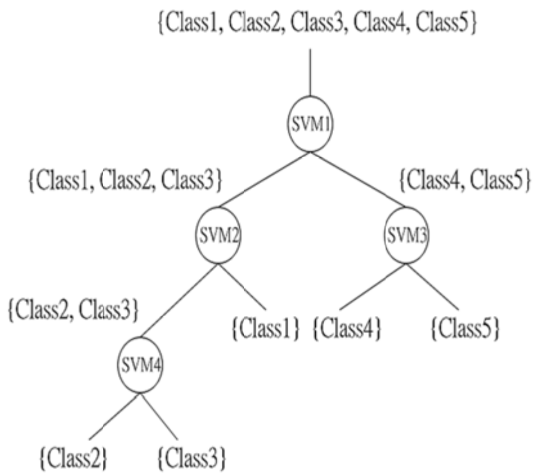


Fig. 7 SVM Tree [12]

Fig. 7 shows the multi-level SVM. When a class of candidate data comes into support vector machines, the machine firstly classify the candidate data into big group-{Class 1, Class 2, Class 3.} or {Class 4, Class 5}. Then do the classification again to put the data into smaller class. In this example, a three level SVM is used that includes five classes used, where the model of the appliances feature could be established by SVM.

2. Dynamic Time Wrapping

Dynamic Time wrapping is also a classifier like SVM. This algorithm is mostly used in Speech recognition, because it can reduce the effect of speech speed. It also can be used in other data recognition such as NALM.

The algorithm is to compare the distance between the training data and the input data. There are two steps to do the classification. First, create the distance matrix. The diagram is showed in Fig. 8.

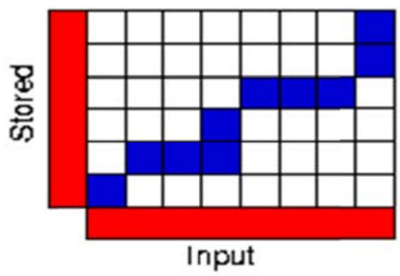


Fig. 8 Example of DTW [17]

As shown in Fig. 8, the start point is on left down corner and the end point is on the right up corner. The blue block is the local minimum distance. The continuous blocks stands for the compressed signal or stretched signal with the time.

The second step is to confirm the minimum distance path using [17]:

$$D\,(A, B) = \min_F \left[\frac{\sum_{k=1}^{K} d(d(k))\,w(k)}{\sum_{k=1}^{K} w(k)}\right] \quad (5)$$

This is a good method to deal with speed changing signal. The precise is very high. However, the comparison efficient of this method is not so high. It still needs to compare one by one. This will cost time when the number of appliances is very high. While the SVM can just reduce the comparison time significantly when the number of appliances is very high

D.A Sample of NALM Test

1. NALM Test

This test is referenced from NALM [17]. In this test, there are 21 days power data (May 29-June 18) to be used and is a non-real time test. There were just five statuses of the appliances that are Fridge (Low), Microwave, Fridge (High), Washing machine, and other appliances. The overlap is not a significant problem. Here, the author has not used any frequency analysis method. The author uses window to extract the power pattern and uses DTW to do the matching. The process diagram is shown in Fig. 9.

During the training period, the program first read all the data from pictures and extract the power pattern. Then use DTW to compress the data into five classes. Lastly, choose one group data for each class and save in the library.

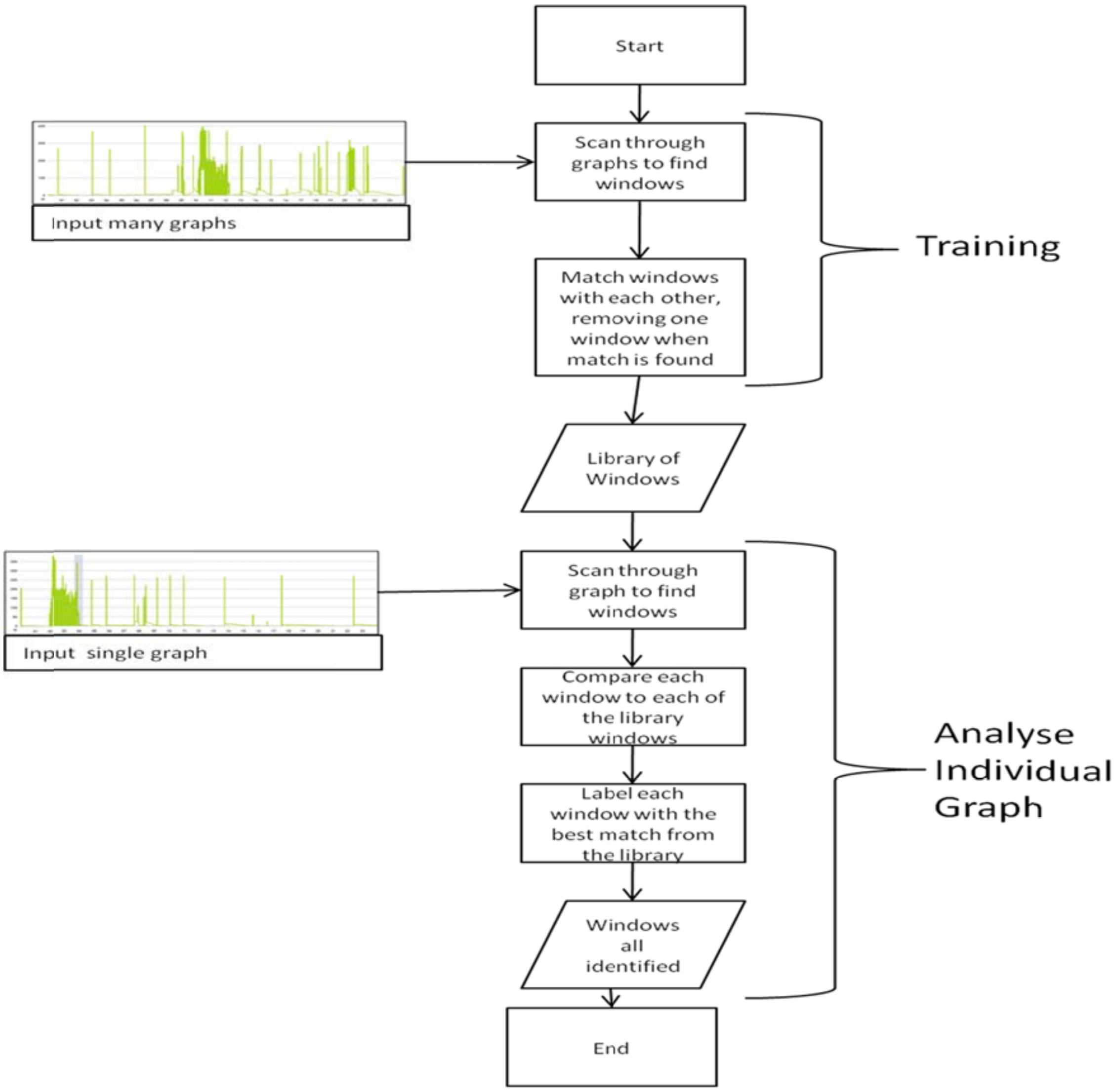


Fig. 9 A NALM Process Diagrams [15]

During Analyses period, the program firstly read the data from one picture for one day and extract power pattern. Then use DTW to do the matching with the library data

2. Test Result

There are 21-days data that could be tested. Here choose several windows results for May 30th. The whole day power usage is showed in Fig. 10. The results are showed in Fig. 11. In Fig. 11, the red line plot is the library data that has been matched with the blue line plot. Most of cases are right in Fig. 11. However, Fig. 11 (c) could be not right. The blue wave could include two types of appliances that are fridge (high) and some other appliances. This results from the feature extraction. There is overlap problem in it. The window method cannot solve this overlap problem, so frequency analysis could be a solution.

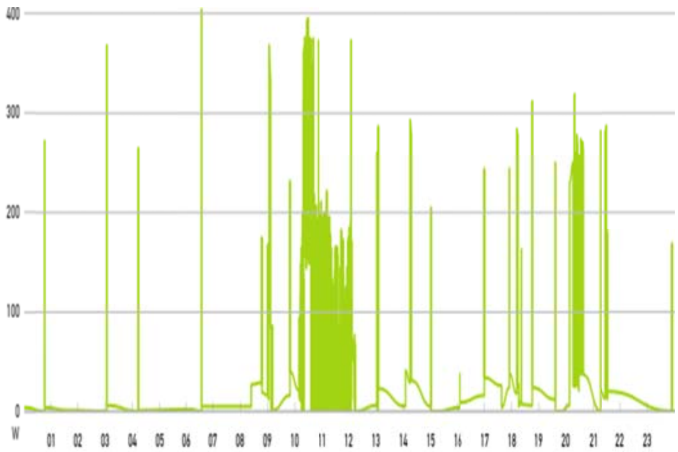
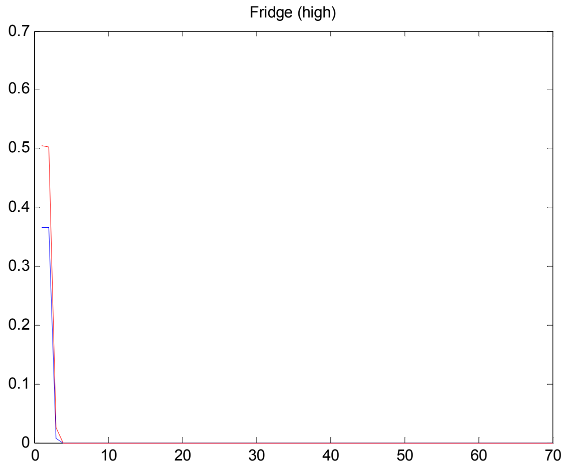
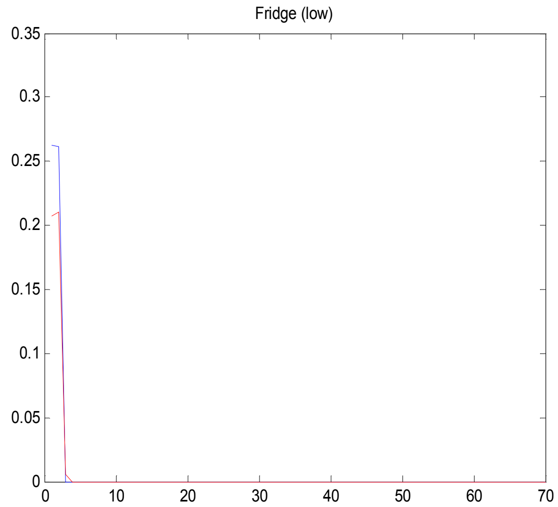


Fig. 10 Power sage for May 30th



(a)



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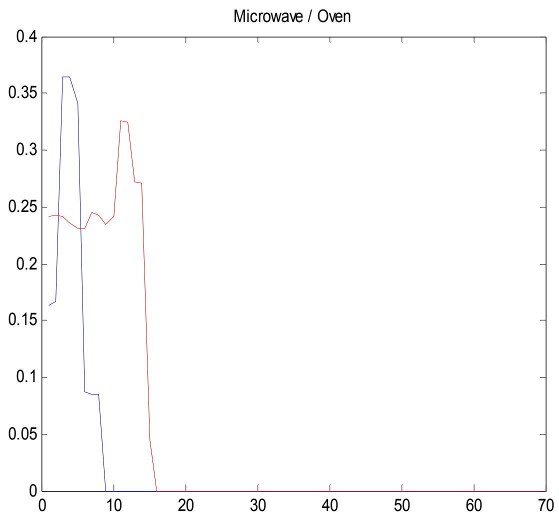

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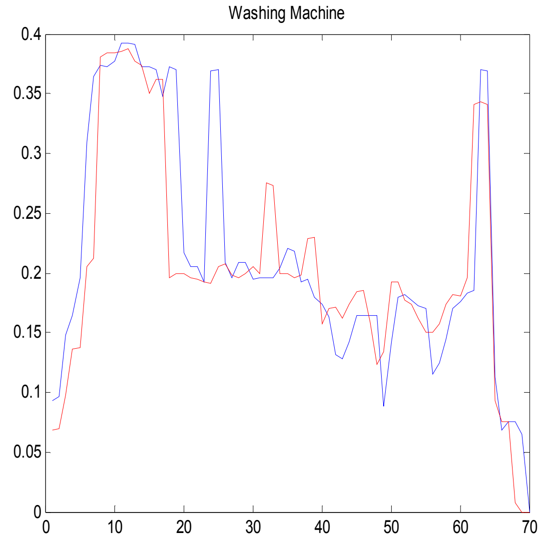

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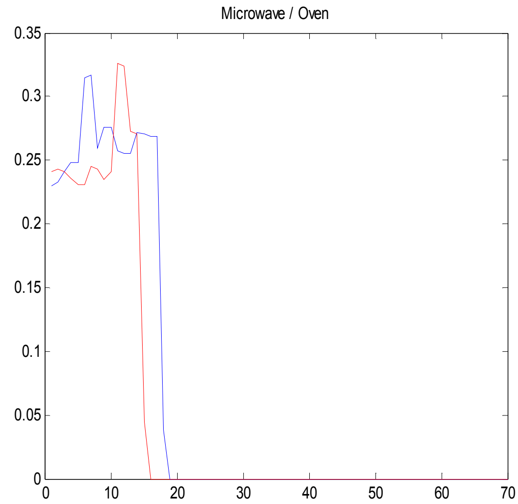

(e)

Fig. 11 Several Matching Results for May 30th

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