

Low Cost Framework for Non-Intrusive Load Monitoring (NILM) to Monitor Human Behavioral Pattern

by

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Human Behavioral Pattern**

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Abstract

Non-Intrusive Load Monitoring (NILM) is a technique that measures and samples voltage and current from an electrical power source in order to infer what devices or appliances are being used at a given time. A NILM system can monitor a single phase or 3-phase electrical system. This system basically captures those waveforms and then calculates the power waveforms for each phase. Thus, a NILM system may monitor the electrical system from a single reference point, such as a circuit breaker box. The associated software is the biggest challenge in this area, as it has to detect on/off events for each device using only the power waveforms.

This thesis presents a low cost framework design and hardware implementation of NILM designed to monitor residential activities inside the home. The motivation for this work is specifically to monitor seniors in their homes, such as is currently done in residential living communities such as TigerPlace in Columbia, Missouri. The goal of this work is to be able to monitor the usage of appliances and electrical devices inside the home, thereby allowing analysis of the daily, monthly, or yearly pattern of usage that might reveal changes in an everyday routine. A key criterion for developing a monitoring system for the home is to protect the privacy of residents; NILM is a natural choice because it does not require any intrusive sensors.

The development, testing, and results from deploying a prototype NILM system are described, along with ideas for extending the work of this thesis.

1 Introduction

1.1 NILM Overview

Non-intrusive load monitoring (NILM), or non-intrusive appliance load monitoring (NIALM), is a technique for analyzing changes in the voltage and current from a power source into a building (or other electrical subsystem) and deducing what appliances are used as well as their individual energy consumption. Put another way, the Non-Intrusive Load Monitor (NILM) is a device that utilizes electrical voltage and current waveform to determine the operating schedule of major loads. NILM is considered a low cost alternative to attaching individual monitors on each appliance. It was initially developed in 1982 at MIT by George W. Hart. While looking at load data for a photovoltaic study, the research team noticed that on/off events for major appliances in the home could be read visually [1].

The non-intrusive aspect of the device is its minimal impact on an existing system. For instance, it could easily install on a meter without shutting the power. Simple wire connections are used to monitor the voltage, and a current transducer is used to measure the aggregate current. These raw measurements are analyzed by the installed software to calculate the real and reactive power which in turn can be used (for example) to perform diagnostics on the electrical system or record the activities of residents in their home.

NILM can detect what types of appliances people have and their behavioral patterns. Patterns of energy use may indicate behavior patterns, such as routine times that nobody is at home, or unusual behavior of residents. It could, for example, reveal when the occupants of a house are using the shower, or when individual lights are turned on and off or even when the occupants of a house are watching TV or cooking and so much more. Figure 1 represents a possible configuration of a NILM system.

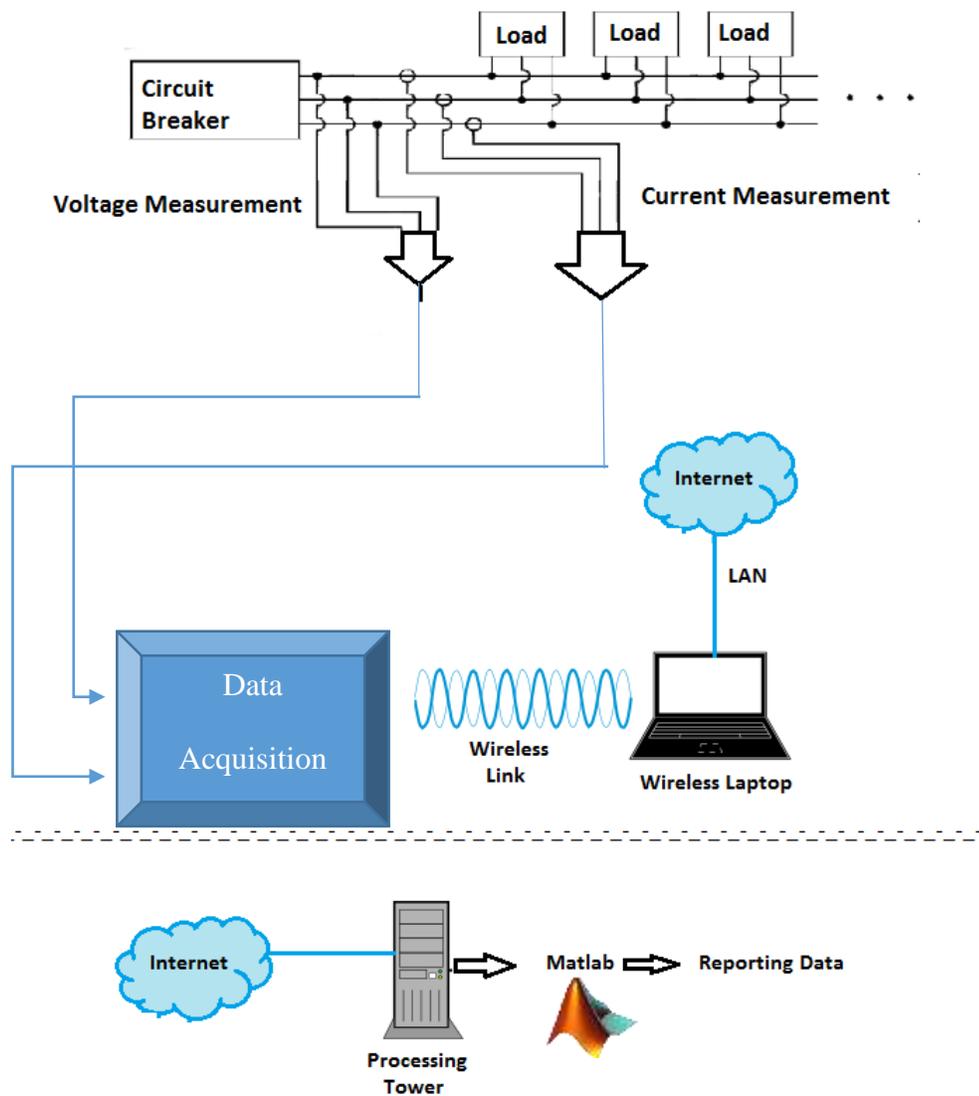


Figure 1. Block diagram representation of a NILM system.

1.2 Motivation for Research

Chronic disease management is the biggest health care problem facing the United States today [2]. In 2005, almost 1 in 2 Americans (133 million) had at least one chronic condition or cognitive problems, and 21% of the population had multiple chronic conditions. These numbers are predicting to continually increase over the next 30 years. Chronic diseases especially affect older adults in whom exacerbations result in dramatic changes and decline in health status, hospitalization, complex treatment interventions, and high cost. Early illness recognition and early treatment is not only a key to improve health status with rapid recovery after an exacerbation of a chronic illness or acute illness, but also a key to reducing morbidity and mortality in older adults and controlling costs of health care [2].

NILM research has proved that power signature can provide useful and cost-efficient tool in recognizing the events in the system and also to diagnostic the system to find the unusual and abnormal activities. NILM can contribute in the of monitoring elders and develop alerts based on the data to notify health care providers of early signs of illness or functional decline so they could further evaluate and intervene with early treatment. A combination of NILM and some other behavioral controlling systems can show the clinical effectiveness and cost-effectiveness of using that in elder housing. The data that is collected with NILM can feed into automated algorithms for illness detection to find earlier signs of illness or functional decline in older adults compared to usual health assessment. Helping older adults remain healthier, active, and control their chronic illnesses with early detection of

changes in health status and early intervention by health care providers, millions can remain independent as they age, avoiding or reducing debilitating and costly hospital stays, and for many, avoiding or delaying the move to a nursing home [2].

The proposed technologies will be tested and evaluated at TigerPlace, a unique independent-living, apartment-style eldercare facility designed by the Sinclair School of Nursing at University of Missouri-Columbia (MU). Access to this cutting edge facility affiliated with MU provides an exceptional opportunity to accomplish our research aims. The potential risks of the elderly people living alone and the dreadful consequences of late response to abnormal situations call for the proposed technology. The remarkable growth of the elderly population and the shortage of eldercare professionals underscore the significance of the proposed research.

1.3 Objective

The findings of the most recent NILM research has shown that the electrical system behavior was evident in the system's power signature and in many cases these data can be used to detect and analyze the system [3] [4] [5] [6]. Section 1.4 provides abstracts of some of the past research that are related to this thesis. As is already mentioned, we hope NILM can contribute to automated illness detection methods to find early signs of illness or functional decline in older adults. The objective of this research is to implement, improve and validate a low cost framework that can be used to allow detection and classification of

on/off events for each appliance in the residential home. Furthermore, this data can be used for illness detection and further analysis.

In this thesis and project, the main goal is finding a low cost way to detect behavioral pattern of using appliances in a residential household. Since elders have regular routines for everyday activities and use almost the same devices and appliances every day, it would be valuable to implement a system to detect the usage of these electric devices and subsequently determine a pattern of behavior for each resident. Figure 2 demonstrate one possible framework for accomplishing this task.

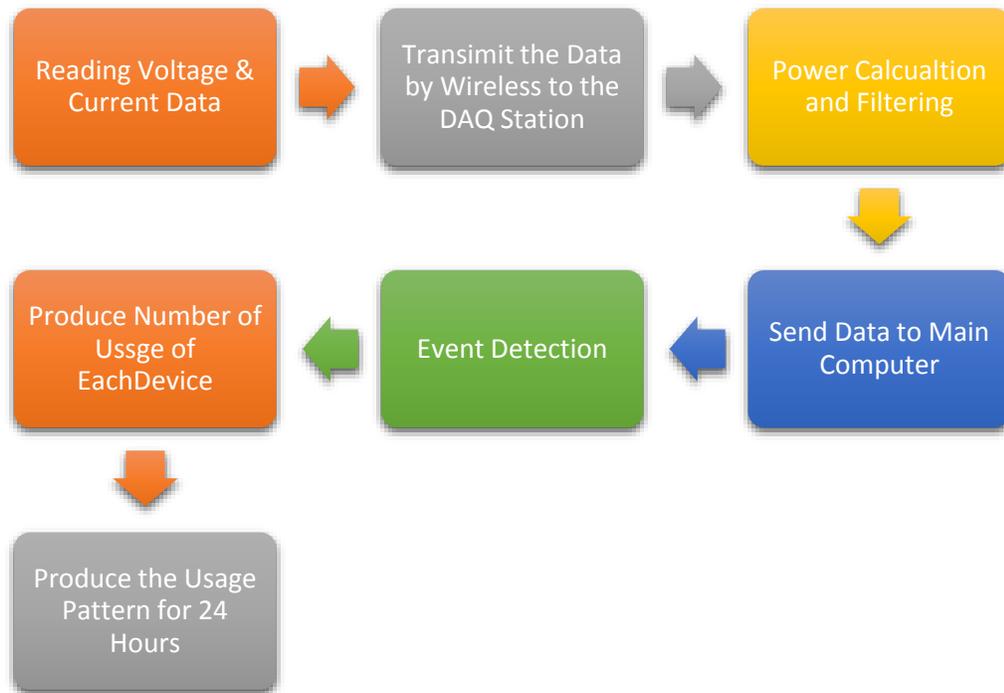


Figure 2. Block diagram of representative NILM process.

1.4 Background and Related Work

Non-intrusive Load Monitoring was invented by George W. Hart, Ed Kern and Fred Schweppe of MIT in the early 1980s with funding from the Electric Power Research Institute [7]. He discovered the NILM idea while he was looking at load data for a photovoltaic study, his research team found out that on/off events for major appliances can be read visually through the power signals. Hart developed this concept into a system where he focused on the amplitude of the active and reactive power consumption of devices and classification in PQ plane. He also found the various states of different devices by using an extraction algorithm to find when devices turn on and off.

In Figure 3 you can see a designed architecture for NILM [1]. It captures signals of voltage and current at each phase and which should be preprocessed to make them ready for the next stage. Preprocessing might include filtering noise or adjusting the phase of each line. Note that NILM measures the aggregate current flowing for the composite load and then by using signal processing technique can disaggregate the operating status of individual loads.

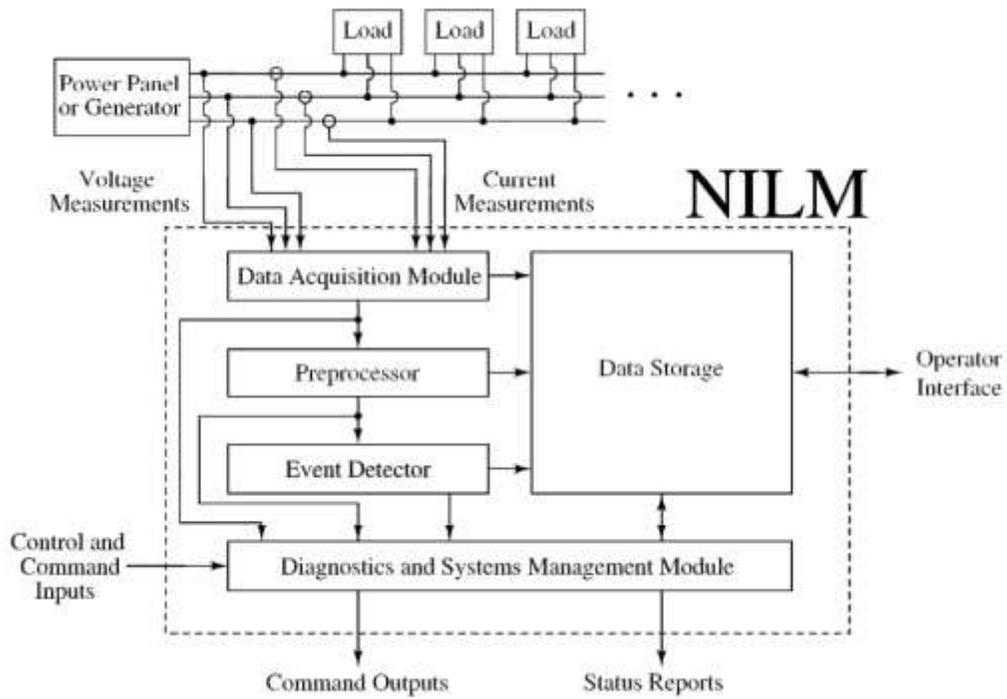


Figure 3: Designed architecture for NILM [8].

After finding the waveforms of voltage and current, the power signal is generated simply by multiplying point-by-point voltage waveforms to the current. In the Figure.4 the voltage and current waveforms are shown.

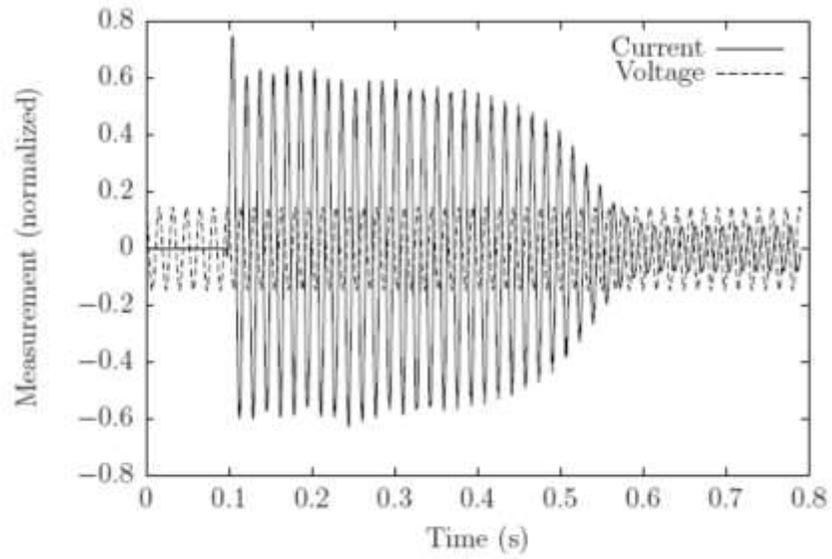


Figure 4: Raw AC voltage and current measurement captured during motor start transient [8]

In the Figure.5 the power signal is generated from the waveforms are shown in the Figure.4 above.

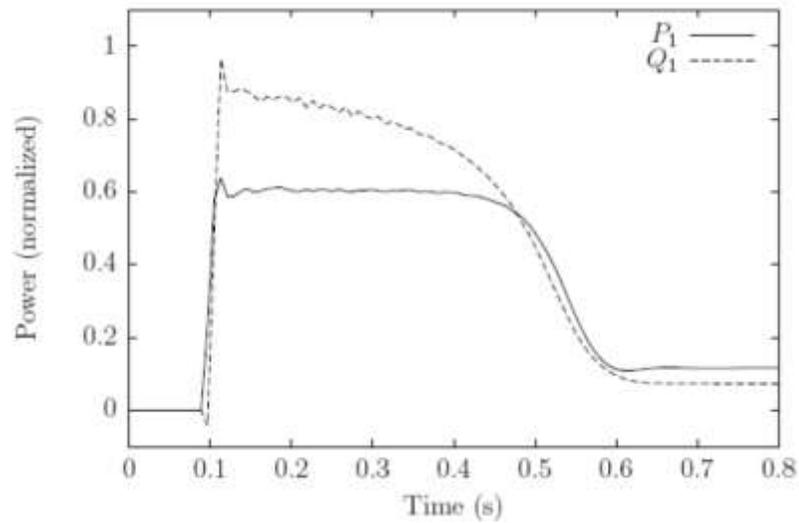


Figure5: Voltage and current signals shown in previous figure are converted into a power waveform. [8]

Figure.6 shown the changes in the power represents turning off or on of the devices in a residential house.

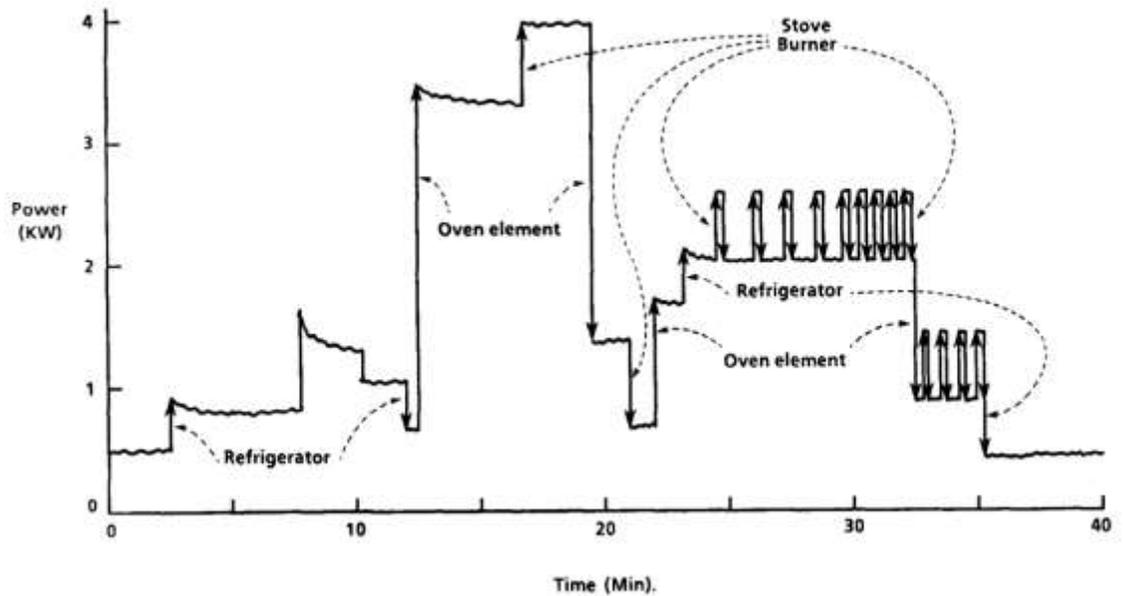


Figure 6 Power vs. time (Total load) [1]

The PQ plane is one method of power representation for appliances, where P stands for Active power and Q stands for Reactive Power. An example of PQ plane for several appliances in a household is shown in the Figure 7. As is obvious, resistive appliances (water heater, Incandescent light bulbs, iron) appear on the real axis and the others (like motors) that have reactive power are spread across the PQ plane.

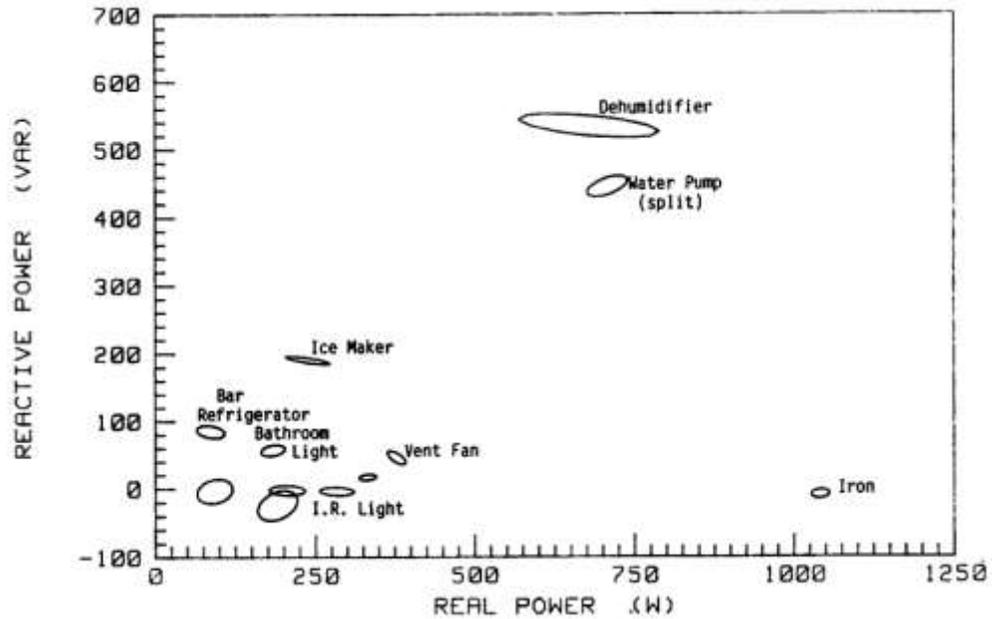


Figure 7 Normalized complex power signature space [1]

Over the past 20 years, several approaches used to analyze the power data in order to find several specifications of systems. For instance, this system can be used in several applications such as finding an engine problem in an aircraft or detect a clog in the vacuum pump in ships [9]. Another example is to diagnose problems in electrical systems for commercial buildings or equipment to detect problems as a precautionary measure before a disaster happens or even to enhance electrical audits.

Some useful applications of NILM include the following:

- Detect Elders Cognitive Problems (by keeping their privacy)
- Perform surveys of both residential and commercial energy consumption.
- Detecting drunk driving [5].
- Demand response system for use on the smart grid.
- Monitor systems on-board ships for safe systems operation with fewer sensors. [10]

One of the important application of using NILM could be in big ships. A study was done utilizing the NILM onboard three different ships to determine its effectiveness in determining the state of mechanical systems through analysis of electrical power data with NILM. Data collected from the Auxiliary Seawater System onboard the USCGC SENECA indicate that the NILM is able to predict several faults (clogged pump inlet strainers, faulty motor/pump coupling, and fouled heat exchangers) as well as provide a backup indication of flow levels to heat loads. Data collected from the Sewage System of the SENECA indicate several metrics which can be applied to cycling systems in general to differentiate between periods of heavy usage and fault conditions. Finally, data collected from the Steering System of the SENECA as well as a yard patrol boat operated by the Office of Naval Research shows the potential of the NILM to be used as a control system without the need for separate mechanical transducers. [11] [12]

Another important application of NILM could be in Smart Homes. The results of analysis for a NILM system can identify various loads with the home and detect the condition of use for loads including of the electric power demands, names or items, time of use and overloaded capacities of loads, etc. The residents of the home can be reminded to save energy by these results. Besides, some related policies of saving energy, reducing CO₂, health and safety care for hidden elderly and the efficiency of electric appliances can be established and planned by these results of smart home. This method requires high resolution data with high sampling rate. [4]

One approach that is not using power signals is using the voltage and current signal directly and by analyzing V-I trajectory and also harmonics of both signals. In this way, there is more information to detect and identify loads.

Choice of load signature or feature space is one of the most essential and fundamental design choices for non-intrusive load monitoring or energy disaggregation systems. Electrical power quantities, harmonic load characteristics, canonical transient and steady-state waveforms are some of the typical choices of load signature or load signature basis for current research addressing appliance classification and prediction. The paper and research was done to expand and evaluate appliance load signatures based on V-I trajectory—the mutual locus of instantaneous voltage and current waveforms—for precision and robustness of prediction in classification algorithms used to disaggregate residential overall energy use and predict constituent appliance profiles. Therefore, wave-shape features are found to be an effective new basis of classification and prediction for semi-automated energy disaggregation and monitoring systems (see Figure 8) [13] [13].

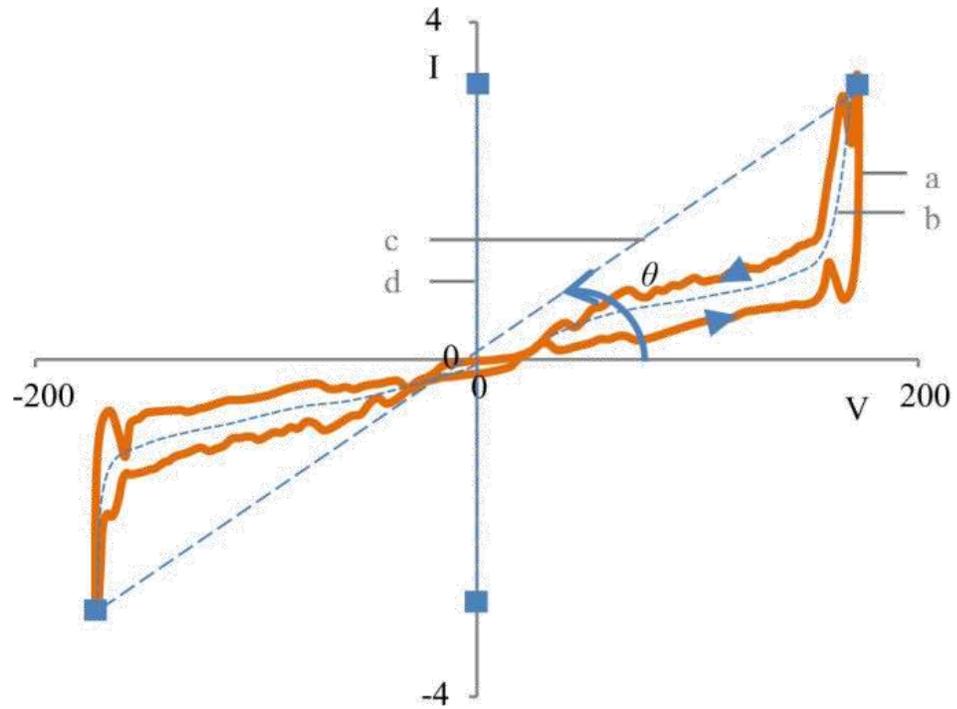


Figure 8 A graphical illustration of wave-shape metrics: (a) V-I trajectory. (b) Mean curve. (c) Reference line joining points of highest and lowest I-coordinate in the V-I plane. From [13].

1.5 Outline

The remainder of this thesis will describe the development of a prototype NILM system for residential activity analysis. Chapter 2 is about designing and developing the hardware for the prototype system, which includes data acquisition hardware as well as a means to wireless transmit the data to a data processing/analysis computer. It also includes some basic signal preparation to prepare the data for further analysis. Chapter 3 discusses the software aspect of the project, including details related to developing and finding the best method to analyze the data recorded by the hardware. Chapter 4 presents results and discusses limitation of this project. Finally, Chapter 5 presents some ideas for future research.

2 System Development and Implementation

2.1 Cost and Limitations

Since it is already mentioned, this system is designed to install and monitor elders' activities. Because of that, there are some limitations that should be considered in designing the system. It is important to maintain privacy of those persons being monitored, but it is also very important to ensure their safety as well. Since most circuit breaker boxes are inside houses or apartments, the system should be small enough to be installed inside the circuit breakers boxes. In this manner, no wires will protrude from the circuit breaker boxes, which is necessary due to the electrical code regulations. Due to this limitation, the system should be all installed inside and be wireless enabled.

The other limitation is the total cost. This project had budget constraints, but this same constraint will exist for any widespread deployment of a production system. Clearly, if the cost of a developed system is too high then it will not cost-effective or practical to have such a system deployed in many homes.

Another limitation is about monitoring multiple residences with one computer. In order to do that, all NILM systems in one complex should be connected to one wireless router. Then, by having only one computer connected to that router, we can gather the data and process it there.

2.2 NILM- Method & Strategy

This section outlines the development and implementation of the NILM hardware that is modified for the eldercare project, along with an associated Matlab software to detect the device status and collect the useful data for further analysis. Figure 9 & 10 are depicting an overview of the idea that is developed in this thesis.

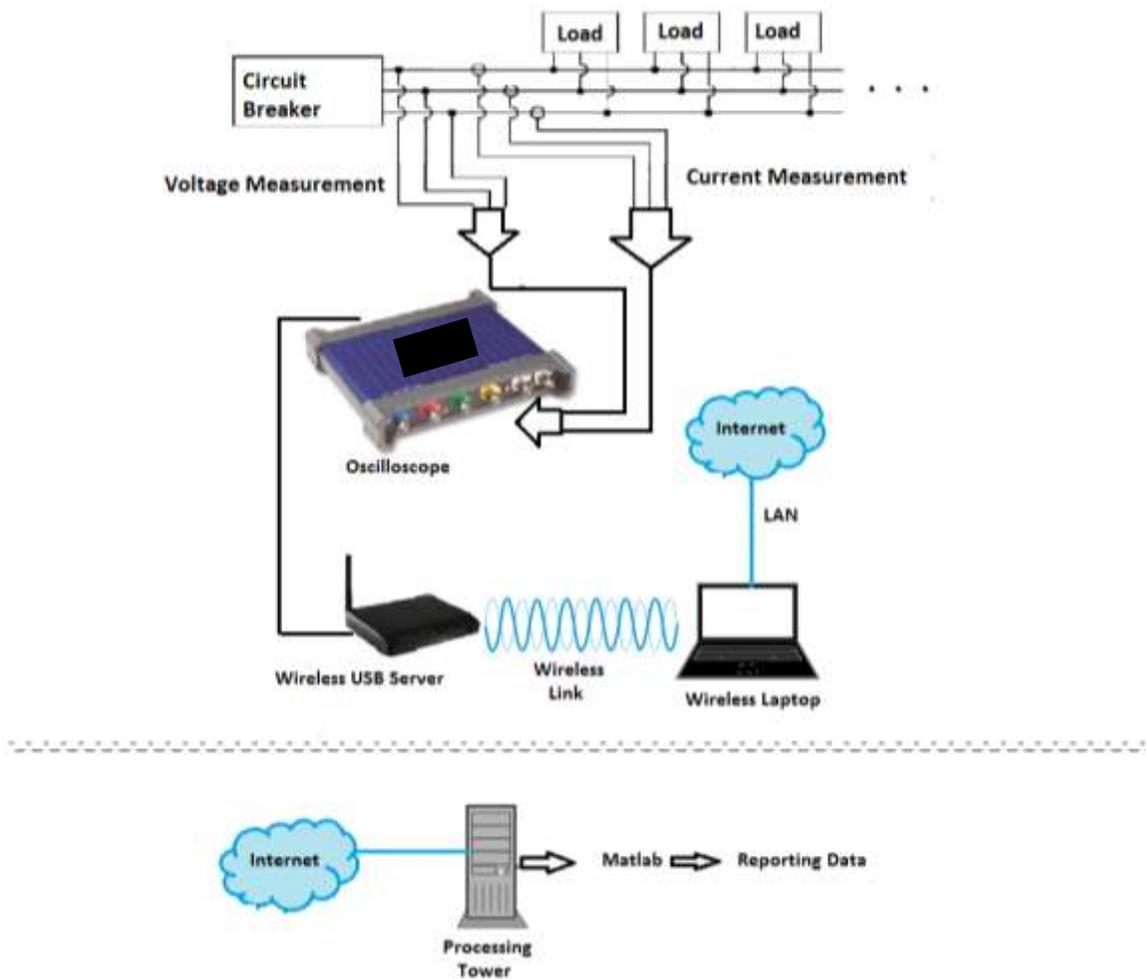


Figure 9 ElderCare House Modified NILM Architecture

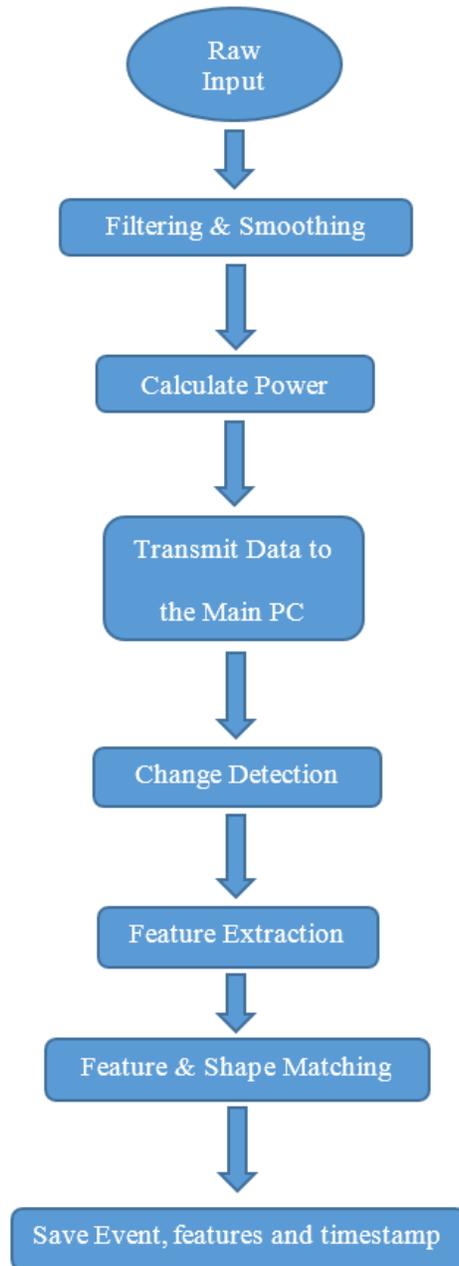


Figure 10 Overview Diagram of NILM

One challenge in the implementation process is to find a way to make a wireless connection between the Laptop and the Oscilloscope. The main issue in this matter is about NEC (National Electrical Codes) regulations, which prohibits wires protruding from the circuit breaker box. At the same time, as a practical matter, we would prefer to avoid any wires or other accessible devices that an elder could potentially disturb or touch. This is especially true when you consider that elders may exhibit mobility or cognitive problems that might put them at a higher risk for dangerous interactions. Due to this, the NILM hardware should be separated into two parts. One part includes the current clamps or probes, an oscilloscope, voltage dividers, a USB wireless server, and a power supply for the oscilloscope and wireless server. The other part consists of a laptop with LabView software installed, which should be connected to the Internet to report the data to the data processing computer for further analysis.

2.3 Developing Hardware Framework

In this section, the selected hardware and the procedure to implement the whole system is discussed. As previously mentioned, we need to construct the hardware in three parts. The first part is comprised of the measuring devices and tools, which includes the current transformers, voltage divider, oscilloscope, wireless USB server, and some other peripherals to connect these devices properly together. The second part is the data logging and signal preprocessing laptop. LabView is installed on this system to set up the oscilloscope and then process the signal, calculating the active and reactive power (P, Q)

and also to find the harmonics for each phase. The third part includes a powerful and fast computer to run algorithms to detect the pattern of appliance usage from the data logged by the oscilloscope and preprocessed by LabView. Figure 11 illustrates the first two part in a diagram.



Figure 11 Data Acquisition & Signal Preprocessing Part of NILM

2.3.1 NILM Hardware Framework- First Part

It is very important to have accurate data in this project. Because of that, we used an oscilloscope to capture accurate and reliable data. Additionally, we would like to perform frequency analysis, but the Nyquist criterion is insufficient and we need to capture the voltage and current signal with more than 2 times of the main signal frequency in order to overcome noise and aliasing problems. We selected the Pico Oscilloscope 3404A. This oscilloscope is a general purpose 8-bit mixed-signal oscilloscope (MSO) that combines fast sampling rates with class-leading deep buffer memories [14].

Initially, we tested an ELITE*pro* XC™ Energy Logger (Figure 12) which also has a built-in wireless option. The problem encountered with this unit was that we were not able to export the data to another software. We also found that the precision of the sampling with this device was inadequate. Since there is a need to transfer the data to Matlab or LabView and this tool only works with its own software (no drivers for Matlab or LabView are available), it could not be used for this research. Furthermore, it only could get 2 samples (maximum) per second, and this is only sufficient for energy auditing and some basic analysis. Since this project is trying to detect the on/off event signatures, two samples per second is woefully inadequate.



Figure 12 ELITEpro XC™ Energy Logger [15].

Since we need to measure the currents of each phase without having to make physical contact with wires (or to disconnect it for insertion through the probe), we used normal current clamp transducers for this purpose. The wires are simply surrounded by the clamps without electrical conduction between them.



Figure 13 Left: Pico current clamp 1mV/A, Right :Mastech current clamp 10 mV/A

We tried several different models of current clamps and selected the Mastech MS3302 current transducer (see Figure 13, right). The output of this clamp is 10mV/A and it supports up to 400A. This makes it a really good candidate for this project because we need to measure small changes in current, and comparing with other choices in the same price range its output is 10 times greater. The only problem that we faced is high non-linearity of the clamp at the higher current range. Regarding that issue we used Pico TA138 – 200A (see Figure 13, left) , the sensitivity of the clamps is 1 mv/A which is not high as the last one but the sensor keeps its linearity even at the higher current range. The only limitation we had is the budget and cost of the tools. Due to that we were not able to purchase very high quality current clamps. The price for some higher quality current clamps start at least 5 times the price of the current clamps chosen for this project. In Figure 14, the clamps are installed on 3 phase system circuit breaker box.



Figure 14 Current Clamps Installed inside the Circuit Breaker

Another important element in this part is the wireless USB server. As already discussed, there is no way to transfer the data from the oscilloscope to the laptop with wires due to NEC (National Electrical Codes) regulations (and, as also mentioned, we must consider safety concerns particular to elders). It is also important to have all of the data from multiple rooms available to one computer, making it more efficient to record and store the data. Because of this, wireless capability is necessary and should preferably connect directly to routers. Given that wireless Internet connectivity is nearly ubiquitous, it would be a good idea to use wireless routers as main node of connections. On the other hand, keeping the private data and sending securely to the server is also important. Because privacy and security of data are important, using wireless router and USB server make it possible to encrypt the data by WPA or WEP encryption.

Several brands of USB servers were tried to find the right one. The one that we selected is “Hawking Technology Wireless-N Multifunction USB Printer and Device Server (HMPS2U)” that shown in the Figure 15.



Figure 15 Wireless USB Server [16]

2.3.1.1 The NILM Preprocessor

The NILM collects and processes two input data streams – line voltage and aggregate current. Using these two quantities, software on the NILM can perform a number of important tasks, including:

- real-power computation
- reactive-power computation
- current-harmonic computation
- power-quality analysis, and
- load identification.

The first four tasks listed above are performed by the NILM's preprocessor. This software is implemented in LabView and performs several calculations such as calculating RMS of signals, active power and reactive power, harmonic analysis, and power quality analysis. In Figure 16, it shown a summary of the LabView and Power Suite Toolbox inputs and outputs. This section provides a qualitative description of the tasks performed by preprocessing, and it also describes how the user should interpret various preprocessed outputs in typical monitoring situations.

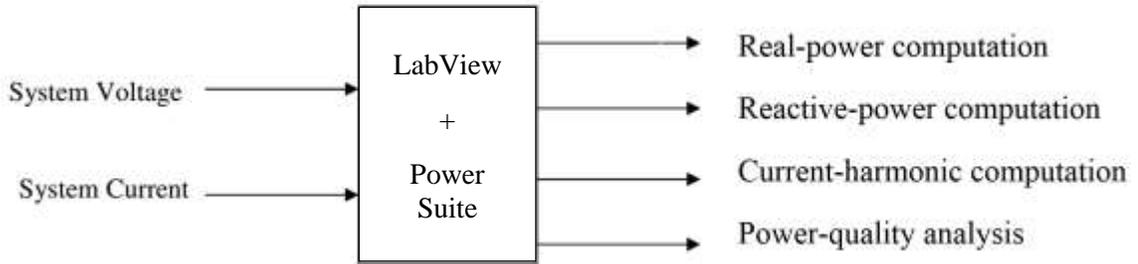


Figure 16 Preprocessor block

Assuming minimal distortion, the line voltage can be approximated as either a pure cosine or as a pure sine. In this example, it will be assumed that the line voltage is a cosine and it can be shown as below.

$$V(t) = V * \cos(\omega t) \tag{2-1}$$

In general, the current drawn from such a source will contain a number of harmonics, i.e.

$$i(t) = I_1 * \cos(\omega t + \varphi_1) + I_2 * \cos(2 * \omega t + \varphi_2) + I_3 * \cos(3 * \omega t + \varphi_3) + \dots = \sum_k I_k * \cos(k * \omega t + \varphi_k) \tag{2-2}$$

Equation 2-2 above highlights a key fact that the current drawn at any one harmonic frequency is characterized using two quantities, namely an amplitude I_k and a phase shift φ_k . The phase shift represents any offset from the line voltage, and the amount of phase shift is strongly dependent on the type of load. Purely resistive devices such as heating elements draw currents that are completely in phase with the voltage, i.e. $\varphi_1 = 0$. By

comparison, a purely inductive or capacitive load will draw a current that is 90 degrees out-of-phase with the line voltage, i.e. $\phi_1 = \pm \frac{\pi}{2}$. These loads are often referred to as purely reactive. Many common devices such as motors consist of both resistive and reactive elements. In those cases, the magnitude of the phase shift will lie between 0 degrees and 90 degrees. The sign of the phase-shift depends on whether the load is either inductive or capacitive in nature (negative shift for inductive load, positive for capacitive load).

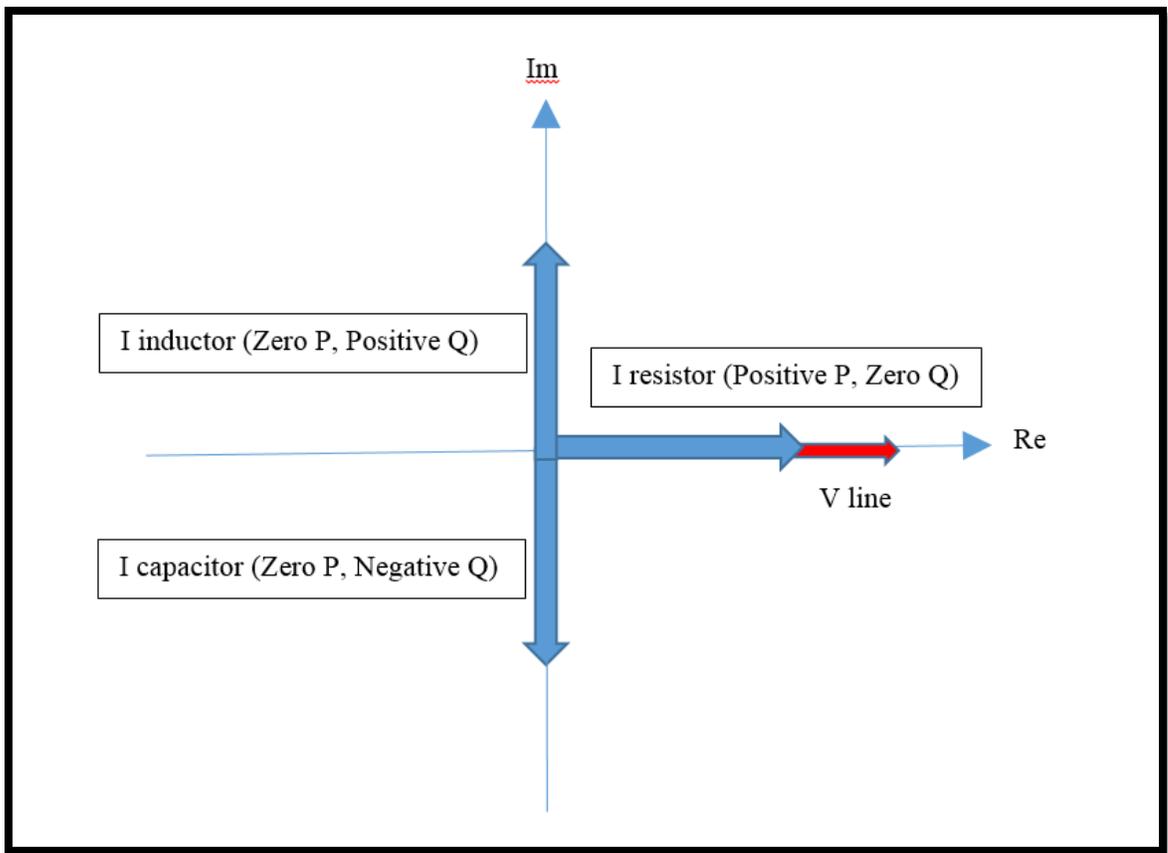


Figure 17. Voltage and current phase relationships for 3 components in PQ plane.

The primary function of the preprocessor is to estimate the real and reactive power drawn from the ideal single-phase source presented in Eq. 2-1.

By definition, the real power is

$$P_1 = \frac{1}{T} \int_T V * \cos(\omega t) * i(t) dt$$

(2-3)

and the reactive power is

$$Q_1 = \frac{1}{T} \int_T V * \sin(\omega t) * i(t) dt$$

(2-4).

These calculations for active and reactive power and along with the harmonics are done in the Power Suite Toolbox in LabView.

2.3.1.2 Power Calculation

The NILM uses measurements of voltages and currents to produce estimates of real and reactive power consumption (henceforth referred to as P and Q, respectively). For a single phase system, the NILM is supplied with the voltage from line to neutral and the current flowing to any loads downstream of the monitoring point. Real power (P) is produced by current which is in phase with voltage and reactive power (Q) is produced by current which is 90 degrees out of phase with voltage. It also estimates the higher harmonic content of current to produce the first three odd harmonics of real and reactive power (referred to as P_k and Q_k for the K_{th} harmonic of P and Q, respectively). If the same sinusoidal voltage is applied to a resistor, capacitor, and inductor, the NILM would produce positive P with zero Q for the resistor, positive Q with zero P for the inductor, and negative Q with zero P for the capacitor (see Figure 17). The convention of using a power angle measured in the counter-clockwise direction from the real axis is employed, so that the power angle for an inductor is +90 degrees while the power angle for a capacitor is -90 degrees [17]. For a more in-depth description of the NILM calculations used to determine P and Q, see [20].

Prior to completing a hardware prototype for capturing voltage and current waveforms, the NILM preprocessing software was given one signal pair from a waveform generator. All tests used 60 Hz as the principle frequency. Channel 2 was chosen to lead channel 1 simply because current generally leads voltage in predominantly inductive circuits. These tests were run and preprocessed data were recorded for each.

2.3.2 NILM Hardware Framework- Second Part

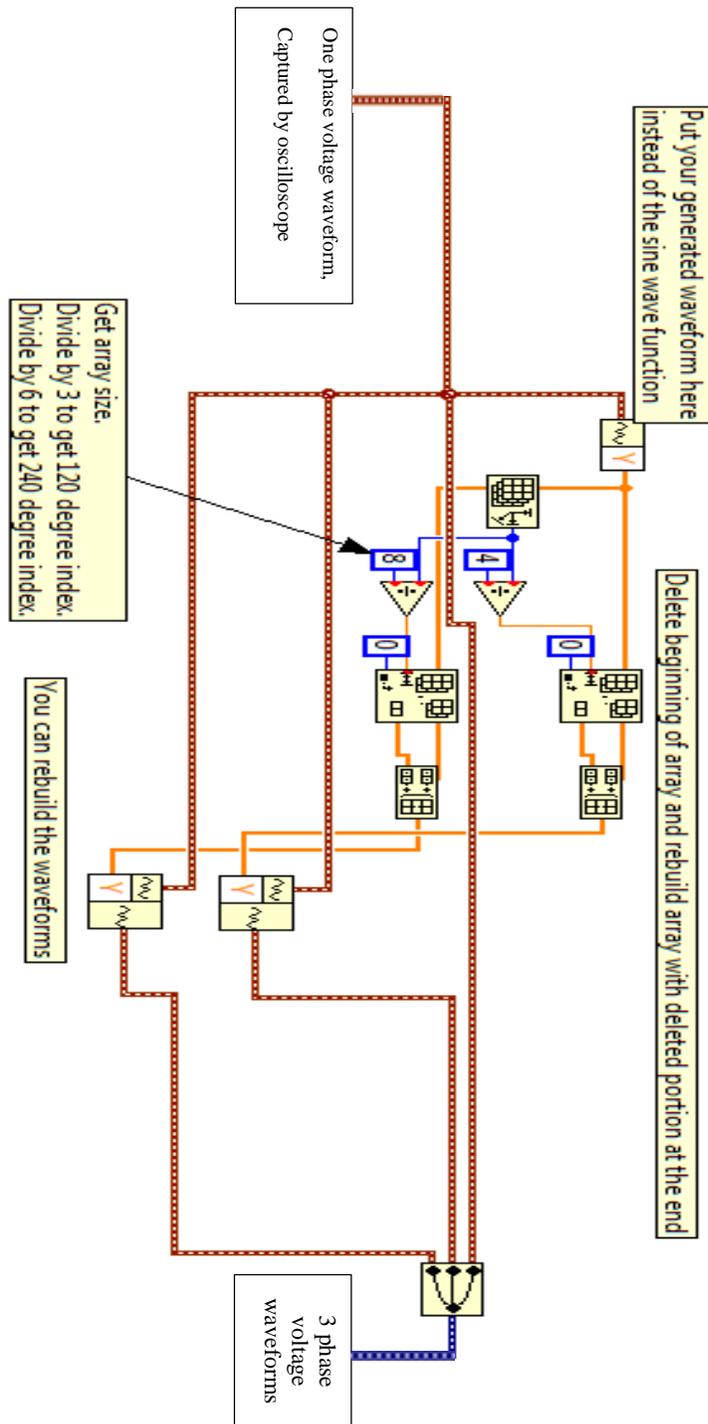


Figure 18 Simulating voltage signals for 3 phase system based on one phase data

In Figure 18, the NILM hardware can measure and capture only one phase of the voltage because it only uses one oscilloscope having four channels, and three of the channels are used to capture and measure currents. If the NILM device is installed on a two phase system, then the second phase is 180 degrees out-of-phase from the first, as is typical in residential 220V service in the United States. (Note that 220V service in the United States is typically referred to as “220V single phase”, but it is really two hot wires from a center-tapped transformer that are naturally 180 degrees out-of-phase – thus our usage here.) Given the limitation of our hardware to capture only one phase of voltage, in order to deploy it on a typical residential installation, the second phase is simulated by taking the data of the first phase, cutting one-half of a cycle at the beginning of the data, and then pasting it at the end of the same array to produce a signal with a 180 degree shift. Simulating the second phase in this manner can be useful to save hardware implementation costs. Alternatively, if we wanted to measure all phases of voltage and current we would need to have two oscilloscope or an oscilloscope with 6 different channels. If the NILM device is installed on a three phase system, then the difference between each phase is 120 degrees. In order to deploy the system in this situation with the data of only one phase, the easiest way is to divide one cycle of the array data into 3 equal pieces and then (cut and) paste either 1/3 or 2/3 of the cycle to the end of the data to achieve phase shifts of 120 or 240 degrees, respectively. This method may cause a little effect on the signals, but it is not important since most of the electrical device on/off events are changing the current signal and not voltages.

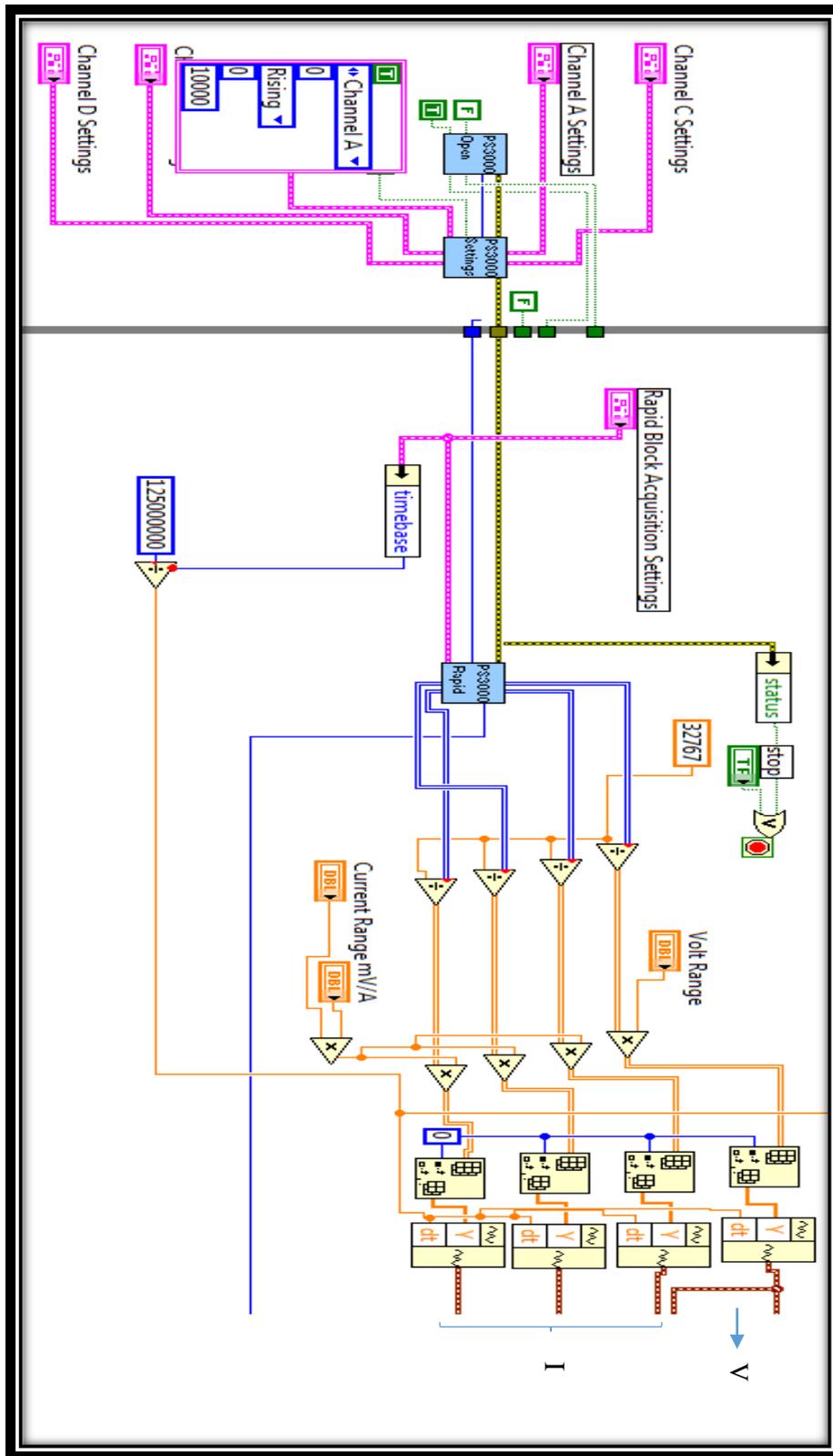


Figure 19 Oscilloscope Setup in LabView+ Main Signal calculation

In Figure 19, the oscilloscope setup and value calculation section is shown. Configuration of some parameters is required to start and run the oscilloscope. Some setup values include setup information for each channel such as channel number, time division, volt division, AC/DC setting and offset correction. Triggering setting must also be configured such as the time base, sampling time, synchronizing trigger channel, USB power setting and number of samples in each time base.

Since the values returned from the oscilloscope are in binary format and the scale is the ratio of the full scale (which is 16 bits), we can convert them to volts (or millivolts) easily as in Eq. 2-5.

$$\text{Channel value} = \frac{(16 \text{ bit out value from Oscilloscope})}{32767} * \text{Volt division} \quad (2-5)$$

The formula to determine the time interval requires time base and number of samples in that time base. We can then calculate the time interval between the samples and convert it to seconds (or milliseconds) with Eq. 2-6.

$$\text{Sample}_{\text{interval}} = \frac{(\text{timebase} - 2)}{6250000} \quad (2-6)$$

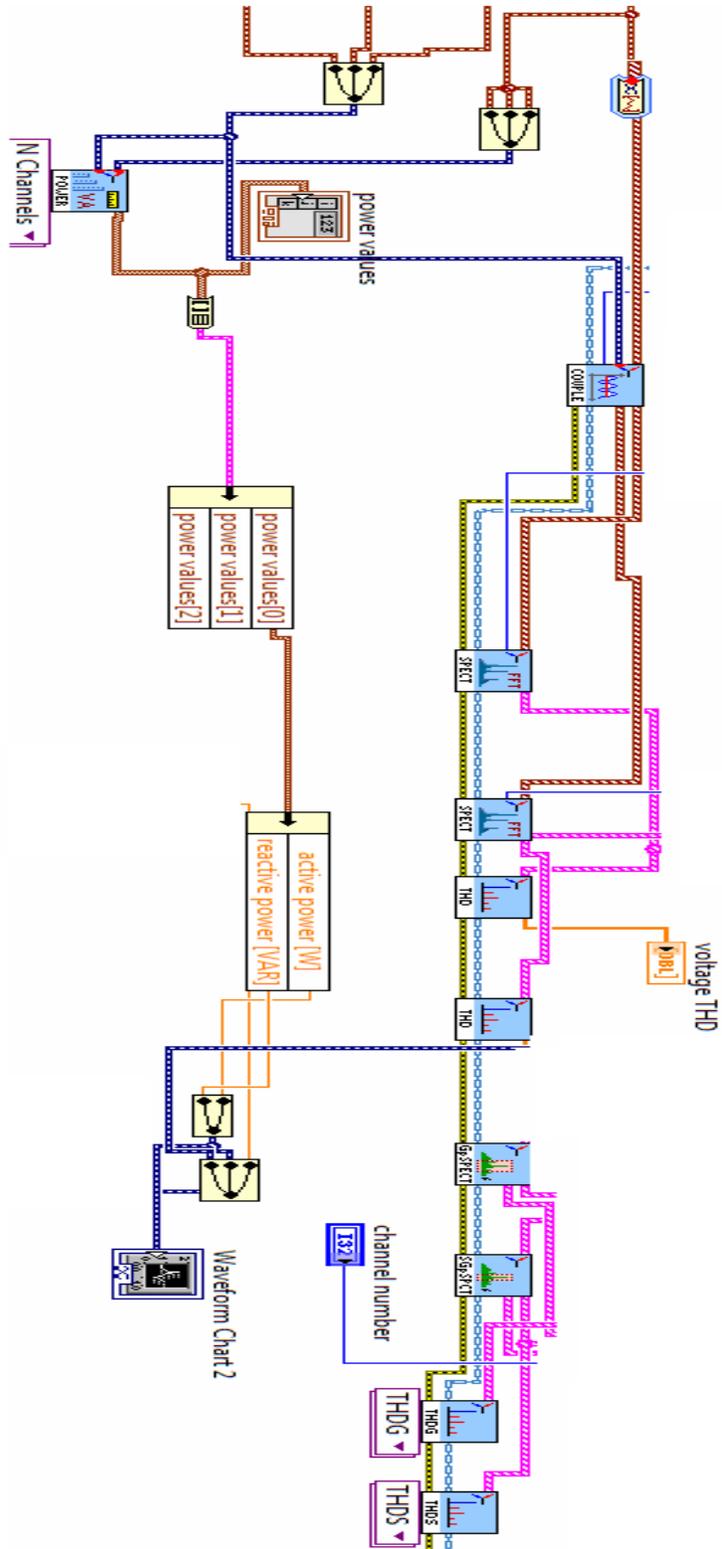


Figure 20 Power Suit module in LabView

Figure 20 illustrates power calculation for both active and reactive part in LabView.

We also need to save data from each day in separate files, so Figure 21 illustrates a process for labelling of each text file with the date of the recorded data. This process also incorporates the timestamp (time of day) of the data into the filename. Since these data are analyzed with Matlab, the format of the time should be in a way that Matlab can detect it easily, so the easiest way is to represent the time in number of second since midnight. Each day starts at 1 and ends at 86400 seconds. For instance the file names and path that is produced by this module is like “2013-8-21.txt” which represents the day that signal is being sampled.

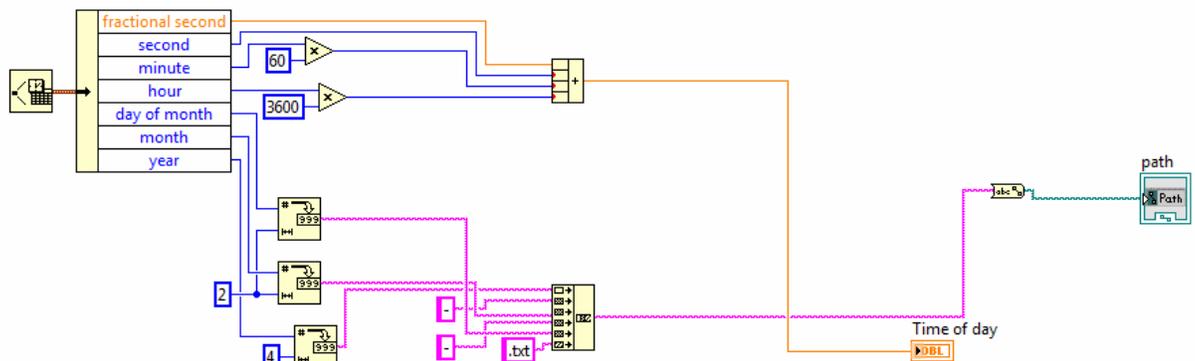


Figure 21 Automatic File path maker- LabView Module

2.3.3 NILM- Third part

The data processing/analysis portion of the hardware includes a powerful computer with Matlab in order to process the data and find the device status. Ultimately, in our application, this computer could also use automated algorithms to detect cognitive problems arising in the residents being monitored via NILM.

At first, the system was tested to see if we could process the data with LabView in real-time and get results. Among the techniques used to detect the signals, one of the important ones was detecting the power signature of appliances in the LabView software. Some codes were developed to run within LabView, but many limitations were encountered, including:

- low voltage resolution of the power signal capture
- low sampling rate of the system
- lack of sufficient computational power on the LabView laptop, and
- LabView does not readily allow development of non-real-time algorithms to achieve the detection we need.

A screenshot of some developed LabView code is shown in Figure 22. This module detects the on/off events from the main signal by using an average and sliding window on the power signals.

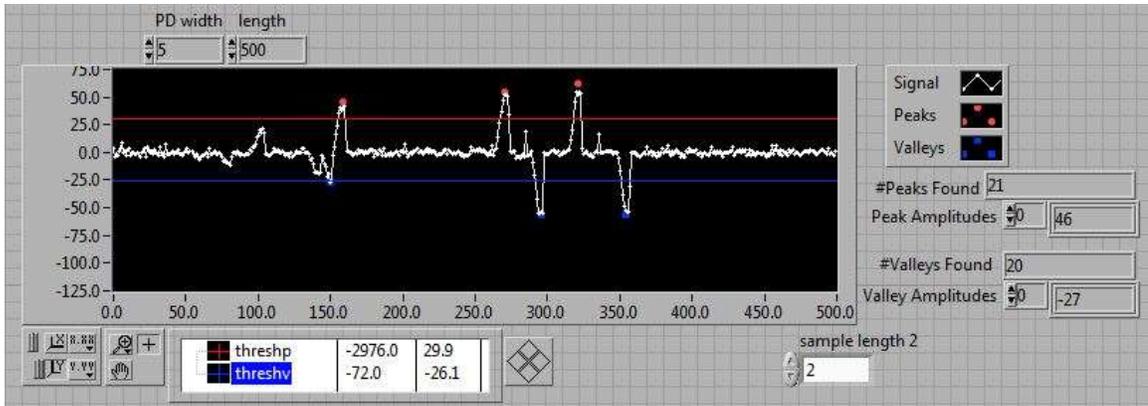


Figure 22 Sliding average window on power signal detecting events in the real-time

As mentioned, we faced a problems regarding computing power since it is necessary to deploy a small laptop in the resident's home (to minimize intrusion). This laptop is used to record the data, do some filtering and smoothing on the signal and calculate the power signals. It is not able to handle a lot of calculations. The other issue is about having Matlab on site on the laptop. Since are target for deployment (TigerPlace) is off-campus, there was no access to the network-license of Matlab there. Last and not least is about LabView; LabView sends commands to the oscilloscope to capture the signal and then return the value back to LabView. If a calculation starts and stops in the laptop, it will affect the sampling rate drastically, and in some cases the data acquisition can be stopped for several milliseconds. Due to the all mentioned reasons above, it was decided to let the laptop just sampling and preprocessing the data, and then transferring the all preprocessed data to the powerful computer in the lab to take care of the rest of the analysis. Consequently in the final project the third part of the NILM system is considered as a powerful and fast computer with Matlab installed in it to run the algorithm for event identification.

2.4 System Installation

Typical NILM installations in the past involved the acquisition of voltage and current data through the insertion of transducers in a distribution panel or controller which required shutting off the power and installing the system. Since our NILM system requires power for the oscilloscope and also the wireless power supply, an extra breaker is installed in the circuit breaker box in order to provide maximum safety. Obviously, the amount of room available inside the circuit breaker is limited, so we need to minimize the required space for elements in the system; accordingly, one power supply can be used for both the oscilloscope and wireless adaptor. In our particular case, the power supply of the wireless adaptor can provide power for the adaptor, and the oscilloscope can be configured through the software (LabView) to run from USB power (provided from wireless adaptor). Our system will be connected to ground via the ground port of the oscilloscope. This connection is made direction to the ground bus inside the circuit breaker box. Figure 23 and 24 shows one installation of this prototype.



Figure 23 Oscilloscope and wireless USB adaptor

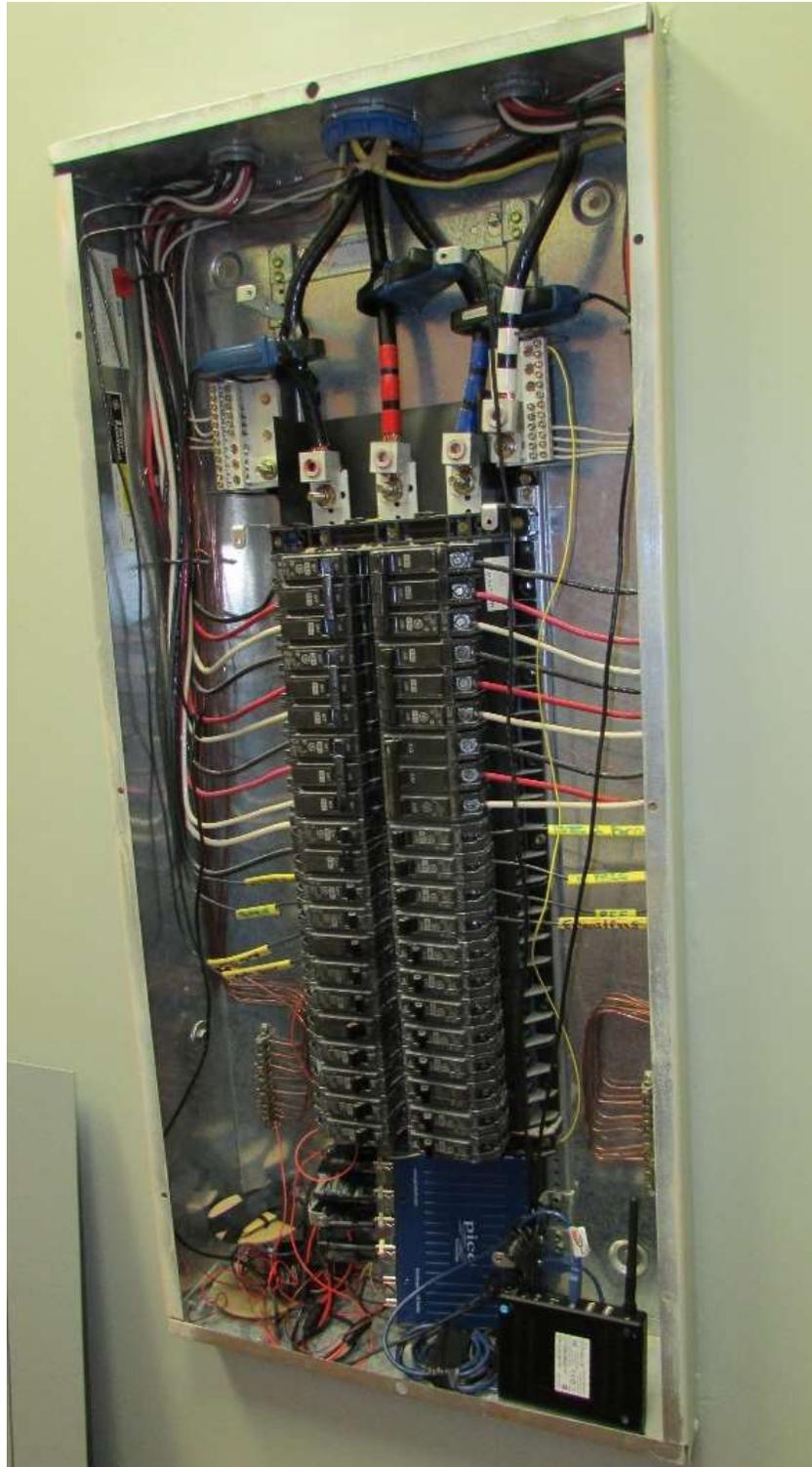


Figure 24 NILM wireless data Acquisition installed inside the circuit breaker

3 Detection Algorithm Development

3.1 Real-time detection

In this section, the method that deployed to detect the device status in LabView is discussed. The first thing that is necessary is to detect the right signal and detect the right changes in the whole power signals. In order to do that, a real time averaging module is developed with 4 knobs to change the threshold values. It finds the average for every 5 samples and then when new sample value arrives, it is compared with the average. If it is not in the defined range it would be detected as an event and then the code measures the amplitude of the peak, the time, the duration of the event, and some other features. Figure 25 depicts both the block diagram and main frame of the module in LabView.

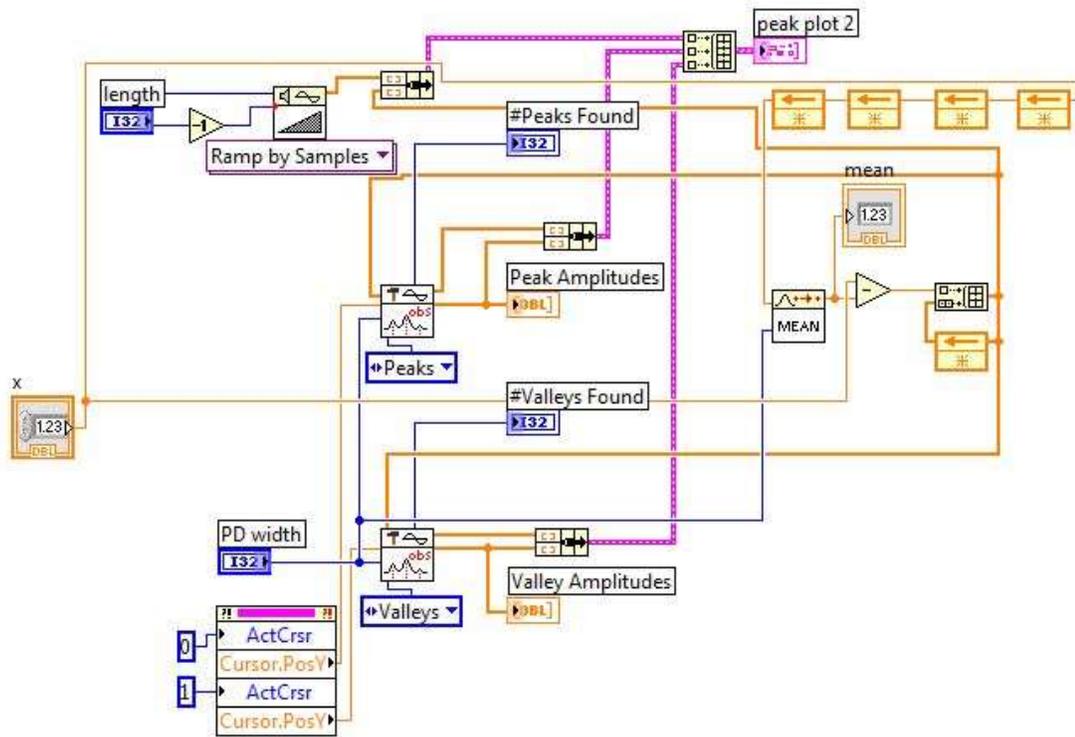
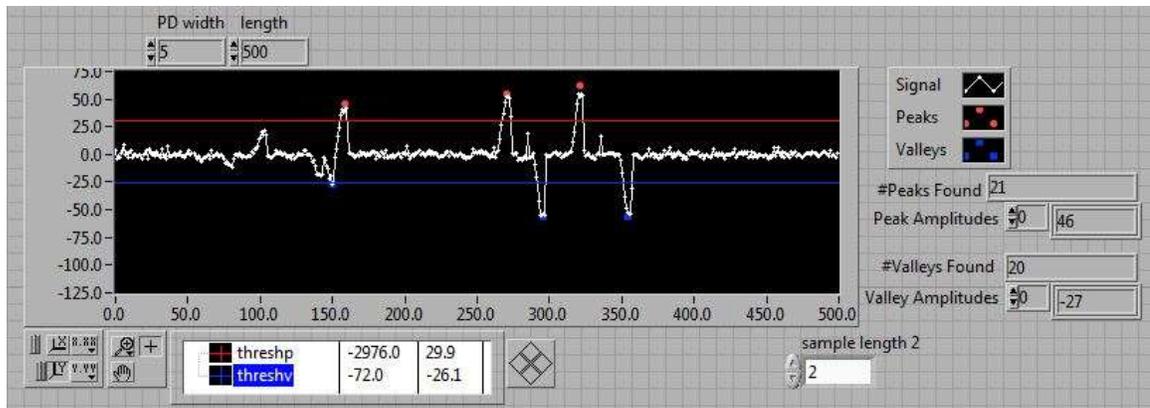


Figure 25 Developed Module to detect the peaks and valleys with their values

Figure 26 is an example of event detection with this module. In the bottom of the figure are the active and reactive power signals. The lower portion of the figure depicts some devices being turned on and off; the upper portion of the figure is the output of the LabView module explained above.

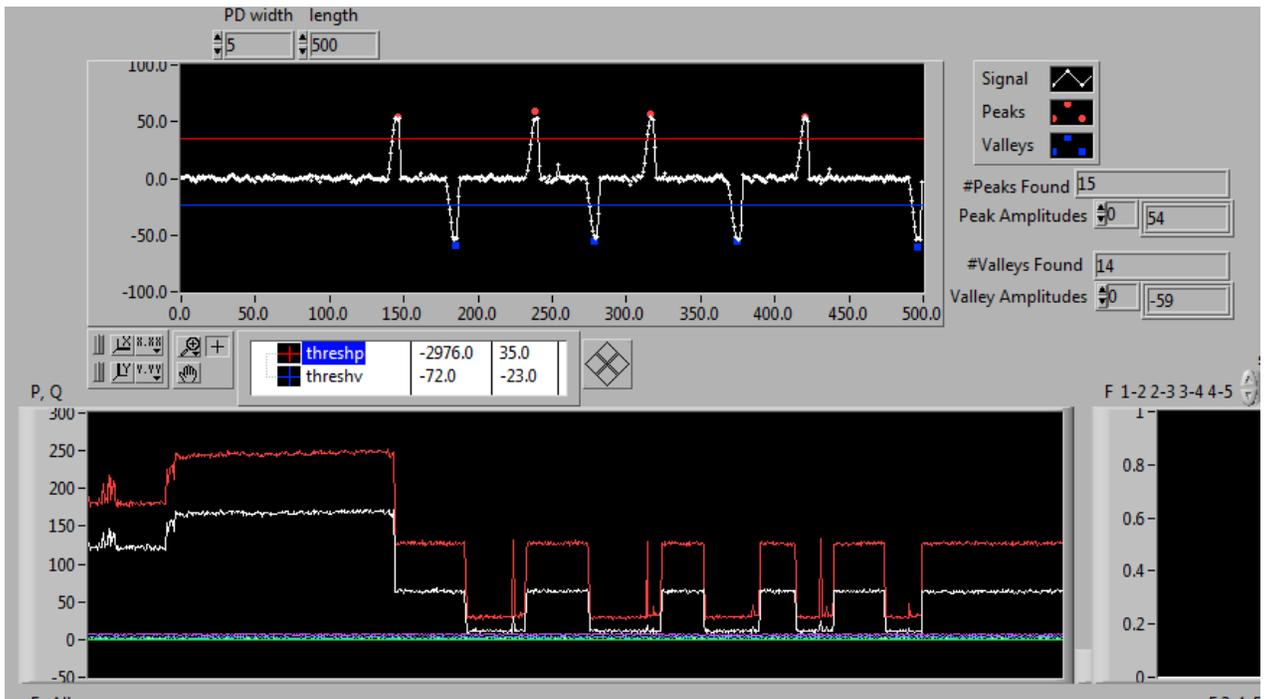


Figure 26 An Example of Real-time detection with developed module in LabView

This method demonstrated some results, but ultimate was not successful due to some problems. As previously mentioned, a major problem that we faced was the lack of computing power; the LabView laptop is not able to handle a lot of calculations. We also encountered problems maintaining a sufficient sampling rate on the laptop when LabView was performing calculations. Because of the problems encountered, it was decided to do the all analysis and calculations with Matlab on a separate workstation, and not in the laptop

that is used for data acquisition. All of the data are transferred via Internet to the processing computer. The method by which we implemented this was to set and synchronize the output folder of the DAQ system in LabView to a DropBox.com account. In that way, when the data is completed and produced in the DAQ laptop, it automatically will be synced between the two computers without needing (manual) remote access to the DAQ laptop.

3.2 Event Detection in Matlab

In the default operating mode, the system samples the power signal at about 12 Hz, so the two second data windows are represented by two 24 index arrays – one containing real power and one containing reactive power. The 24 index power array is passed to a detection algorithm that determines where rapid power changes are located in time. This is accomplished by passing the array through a change-of-mean filter that calculates the difference between the original power signal and the output of a low pass filter. The result is a processed signal that only contains rapid power changes. The process is illustrated in Figure 27 and three example of deploying this method on the power signal is depicted in Figure 28.

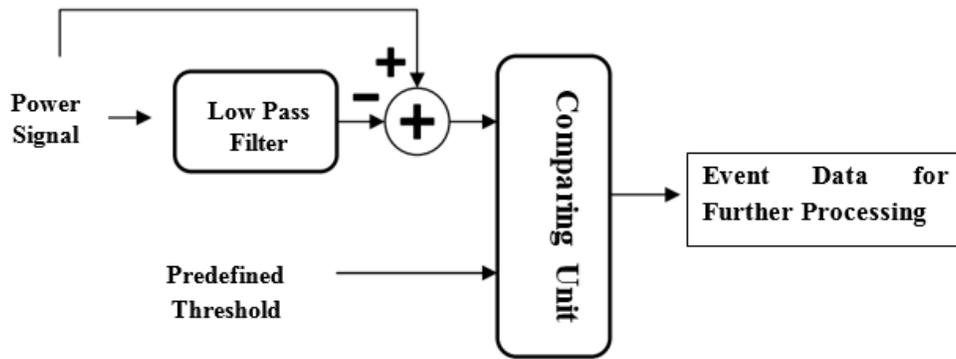


Figure 27 Event Finder Diagram

The filtered signal is then passed to a comparator that identifies any array index where the signal exceeds a preset detection threshold. Three 24 index arrays are initialized to further process the signal: Time, Active Power and Reactive Power. The threshold is set depending upon the environment. For instance, if this system is installed for an industry, then the threshold would be higher than if the system installed for residential use (due to high power consumption loads and nature of industrial electrical demands).

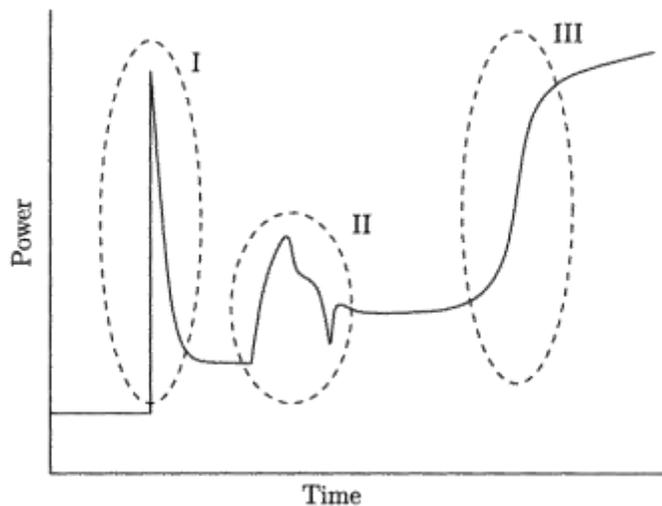


Figure 28 Start-up transient example of three different device

3.3 Features Extraction

In signal processing, feature extraction is a special form of dimensionality reduction. In our case, since the input data to the algorithm is too large to be processed and it is suspected to be notoriously redundant, the input data will be transformed into a reduced representative set of features (or feature vector). Transforming the input data into the set of features is called feature extraction. If the features extracted are carefully chosen, it is expected that the feature set will contain the relevant information from the input data, allowing the detection task to use this reduced representation instead of the full size input. The other important aspect of doing feature extraction is for a later stage of the code; since we are trying to find the best match for each signature, it is necessary to capture features such that similar events have feature vectors that are near each other in vector space. By using feature extraction, we can classify the signatures by their characteristics. Shape matching is not enough to detect the events because some of the events could have the same shape but different values or even different duration. Therefore, there is a need to have a valid procedure to first compare some of the main features of the signals with the prerecorded signals, which can then allow a subsequent step for shape matching.

Feature extraction involves simplifying the amount of resources required to describe a large set of data accurately. In this case, the features are in a matrix along with the data for the shape of the events. After the features are calculated, they are put into a matrix as explained below.

The first row of the matrix is the device type which is determined by the average power consumption at the transient after passing overshoot or oscillations. The second row is the overshoot time; this represents how much time it takes to reach to the maximum or peak – in some cases it can be overshoot, and in the other cases if there is no overshoot it can be the time that it reaches the nominal power. The overshoot time helps us to find and detect appliance status easier. Even so, since every device has its own power signature at turn-on and turn-off, it is still necessary to make use of other features. The third row is the average power consumption of the device at the transient after passing overshoot or oscillations. The fourth row is amount of the peak or overshoot value of the signal at the transient. The last row is the “area under the curve” (AUC). This feature is selected because in some cases there are some oscillations in the signature at the time the device goes on. The AUC represents the amount of energy (e.g. KWh) used within a given time interval and help to separate different devices. All features are illustrated in Figure 29 and Table 1 shown an example of extracting features along with the signal data for the events shown in Figure 30.

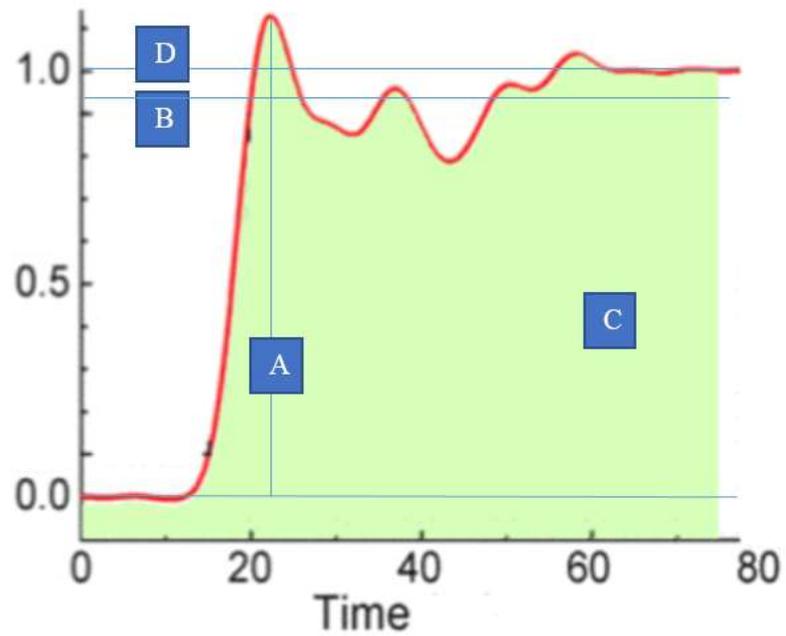


Figure 29 Features used to detect signals a. Overshoot, b. signal average, c. AUC (Area under Curve), d. final value

Table 1 A sample of Feature Matrix with the signature data

	Active Power Features	Reactive Power Features	Active Power Signal	Reactive Power Signal
Class	2	2	1.207159	3.479331
O.S Time	134.008	163.01	0.869018	0.743569
Mean(Ave)	255.08	52.35	415.2768	105.1903
O.S (Max)	415.27	106.37	405.4617	101.0334
Final Value	189.1	21.2	402.9554	106.3728
AUC (Area Under Curve)	167.18	36.61	363.5012	75.36213
			303.722	56.68046
			273.1344	55.58607
			250.4979	38.45884
			194.6295	16.47704
			194.6295	16.47704

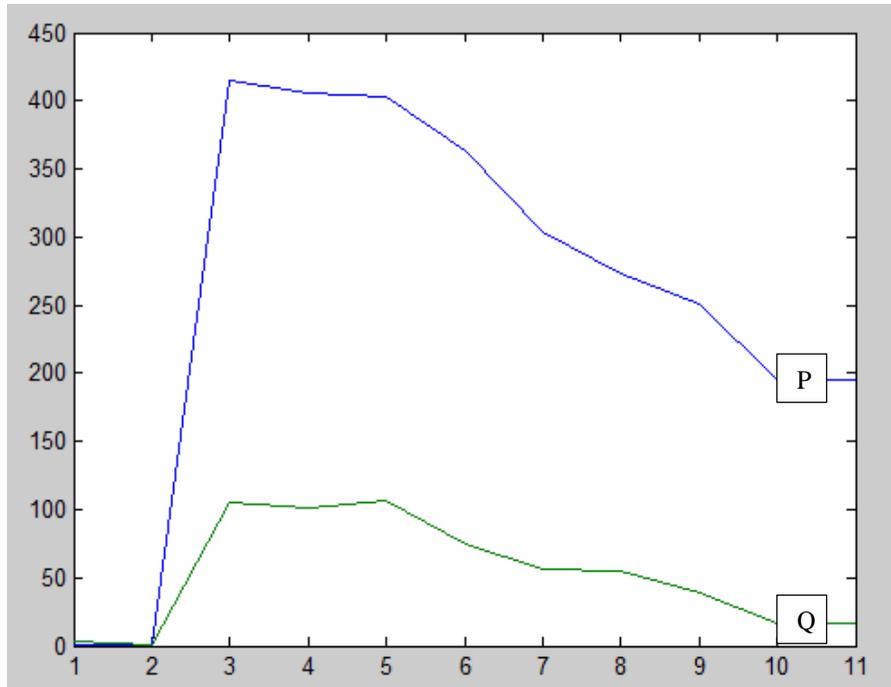


Figure 30 plotted graph of the data from Table 1

When performing analysis of complex data, one of the major problems stems from the number of variables involved. Analysis with a large number of variables generally requires a large amount of memory and computation power. Additionally, a classification algorithm which over-fits the training sample may generalize poorly to new samples. Feature extraction is a general term for methods of constructing combinations of the variables to get around these problems while still describing the data with sufficient accuracy.

3.4 Reselecting the Features

In the previous section we tried to use overshoot time, Max Overshoot of the signal, signal average (mean), the amount of difference between the overshoot the average and the final value, and the AUC. A problem encountered is that since the sampling rate is not very high, the rise time (time of Max Overshoot) is not accurate and then this value can falsely indicate differences between two same signals. In Figure 31, the two events shown are the same (from the same device) but there is a difference in overshoot time in the active power. Since we used milliseconds as the time scale for overshoot time in order to have the maximum accuracy, the observed time lags makes this feature not accurate enough to be used as a discriminating feature to detect between the signals.

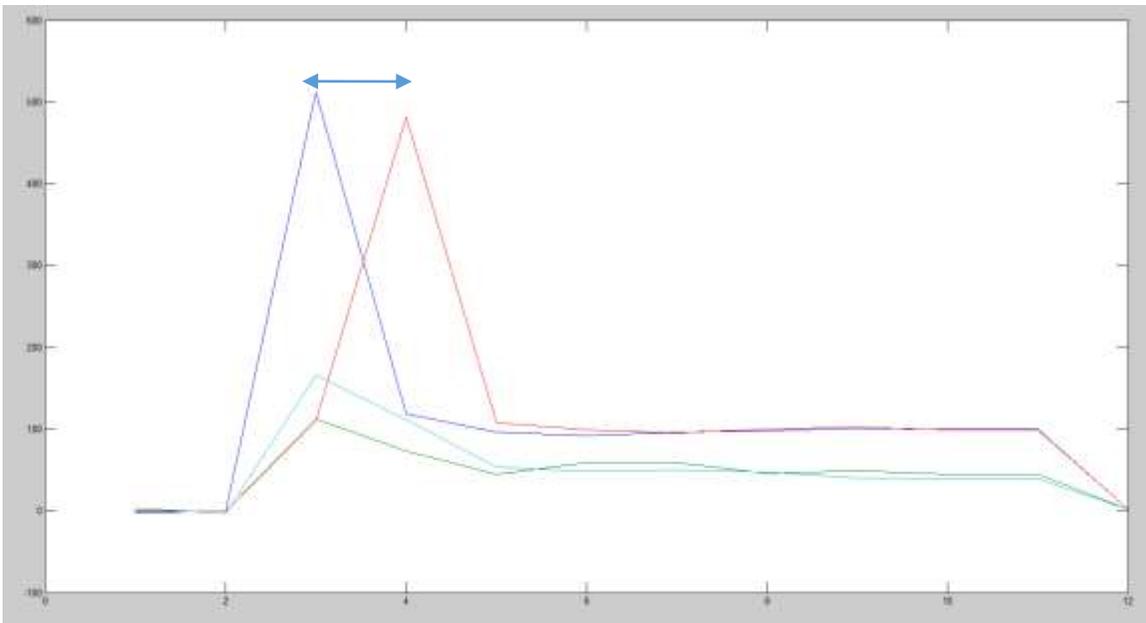


Figure 31 Overshoot time difference between the two same power signatures for the same device

In order to solve this problem the set of features used for classification should be changed. The new features selected include Max Overshoot of the signal, signal average (mean),

Minimum of the signal, the average of two last samples which is kind of the last value of the signal in the windows of looking and the last one is the AUC(area under curve).

With these features there is some improvement, but there are still some problems. Minimum of the signal in the large loads is a great feature, but for the low consumption loads when some of the large loads are already online (making electrical noise) and then the power signal has fluctuations, it makes it hard to find the right minimum for small loads. It gets worse for the reactive power signal when there is a large load online and the device that we are trying to detect does not have reactive power at all (or it is very small). In the Figure 32 the power signatures are depicted for a lamp (40 Watt). The left one is the turning ON signature, and it is clear the active power jumps and goes up to about 40 W; however, the reactive power decreases and fluctuates which is not correct for that device. The orange lines give the power signature representation of the lamp without having any other loads online. In the right, it is the same scenario for the lamp when it goes OFF; the reactive power signature in this situation is not that useful.

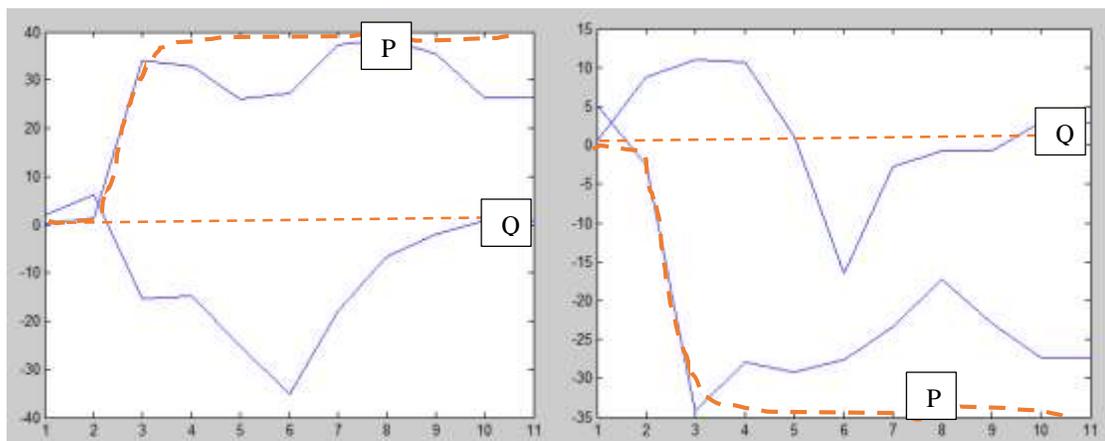


Figure 32 Low Consumption loads issues

In order to overcome this problem a bit, in class zero (which is assigned for devices under 100 W), the minimum feature mentioned above is not being used to find matches. Additionally, the reactive power features are not used for classification of devices in class zero.

Figure 33 illustrates an overview of the Feature matching and also next section regarding the shape matching.

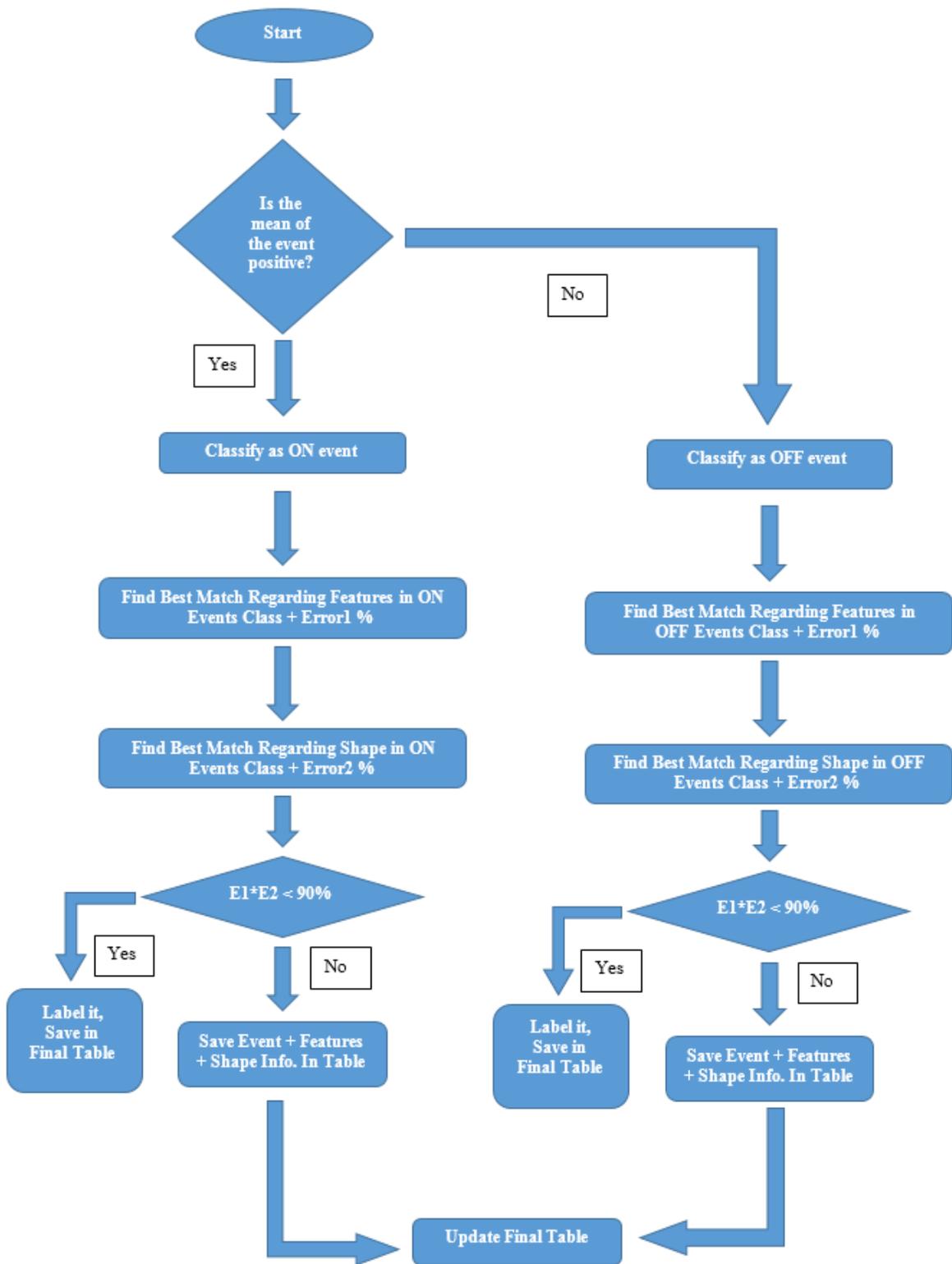


Figure 33 Matlab algorithm for signal classification

3.5 Signature Shape Matching

After the code tries to find the best and nearest matches using the feature matrix, and then if the differences are reasonable, it will go and try to find the best matches using the signal shape and format by using the cross-correlation (`xcorr`) function in Matlab. The reason that the code is not trying to find the status at the beginning by shape comparison is that the cross-correlation function looks only at the shape and not the amplitude (or the other extracted features). Thus, relying solely on cross-correlation would likely give incorrect classifications when we can effectively use other features with more discriminating power. We need a way to filter and classify the signals first by using a feature extraction function. Subsequently, since some of the events could have a similar features, the code then tries to use cross-correlation to find the best match. Additionally, cross-correlation will shift the signals to find the best match positions, so if we use this function directly without any other method to validate the signals, we will get poor classification because some signals look the same when they shifted a bit.

One example of the cross-correlation function is described below. In Figure 34 a specific event from the prerecorded data is depicted. In Figure 35, the same event happened and after feature matching we must perform shape matching. This shape matching (cross-correlation) will find the correlation ratio between this unknown (unclassified) event and events that are already classified. (The process of event classification will be described in Section 3.6.) As shown in Figure 36, the output of the cross-correlation will yield a peak

at the point where the shape of the signal is most similar, and the value of the cross-correlation at this peak (which we will call $xcorr_{max}$) is used to determine the similarity between the compared events. For instance, in this case $xcorr_{max}$ equals 0.9976 (where 1.0 would represent exactly identical signals). The threshold for $xcorr_{max}$ that we used in this project for the accuracy is about 0.85. Therefore, after finding the pre-classified event with the nearest feature vector, if $xcorr_{max} = 0.90$, then the unknown signal will be newly classified as the same event. If the $xcorr_{max} < 0.85$, then it means that we have detected a new device (because no such event currently exists in the table of pre-classified events). Therefore, this new device (event) is recorded in the table so that similar events can be recognized in the future.

$$\max(xcorr(event, table\ events, 'coeff')) * \max(xcorr(event, table\ events), 'coeff') = .9976$$

(3-1)

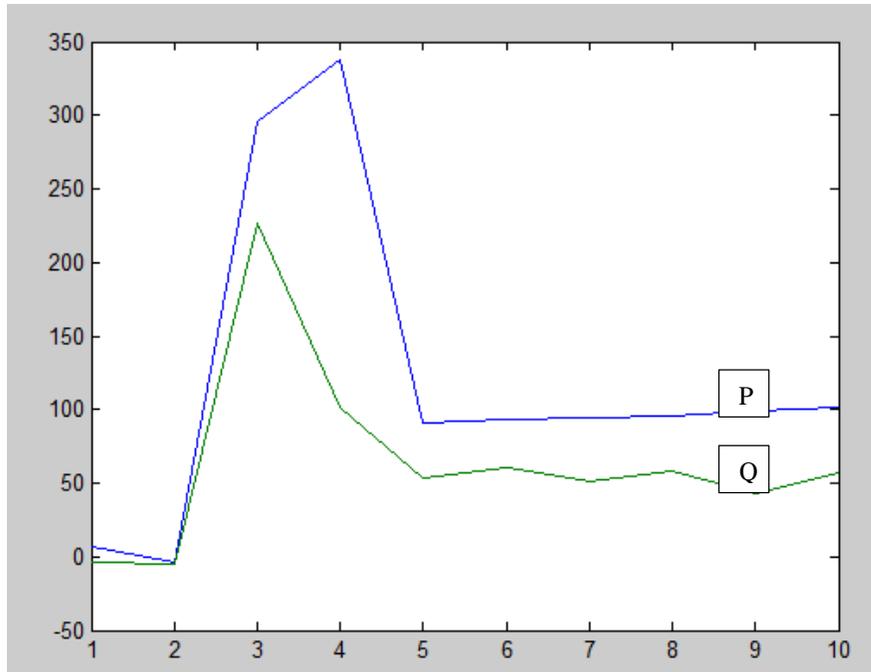


Figure 34 Signal Shape representation of a specific event

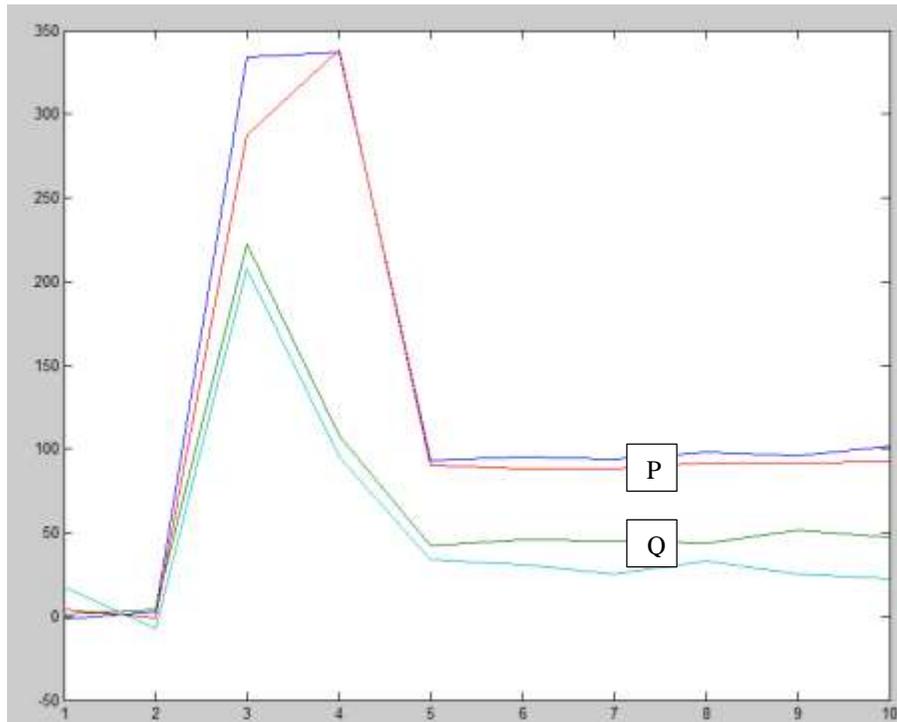


Figure 35 Two events with the same signature

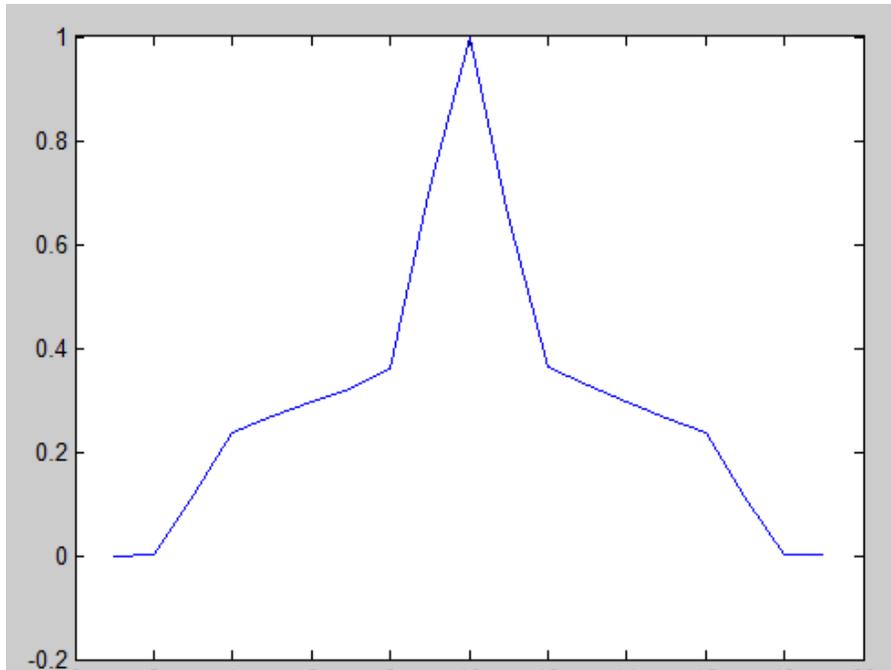


Figure 36 Cross Correlation output for the Figure 35

3.6 Automated Event Detection/Classification

In order to find the best match (if one exists) for each unknown event, the system automatically detects the signatures and compares it with the table of event feature matrices that are already classified from prior observations. If no matches are detected, the system will add the feature matrix of the unknown event into the table as a “newly discovered” device. Additionally, the signal data is saved so that the cross-correlation with future “unknown” events may be calculated for future classification.

Table 2 represents configuration of the mentioned table and the data is for the event shown in Figure 37.

Table 2 Sample of a Recorded data in table

Active Power Features	Reactive Power Features	Active Power Signal	Reactive Power Signal
10	10	7.246445	-2.86872
201.012	134.008	-3.40095	-1.78428
1067.817	170.9636	754.7667	624.0476
1389.643	624.0476	1389.643	159.9359
321.8259	453.084	1382.42	160.0557
644.0641	109.6266	1376.162	157.3865
0	0	1372.856	157.1883
0	0	1369.14	153.5242
0	0	1366.743	157.8362
0	0	1365.204	157.6391
0	0	1365.204	157.6391

The first column contains the features for the active power signal, second contains the features of the reactive power signal, the third contains the signal data and shape of the active power, and the last column contains the signal data and shape of the reactive power.

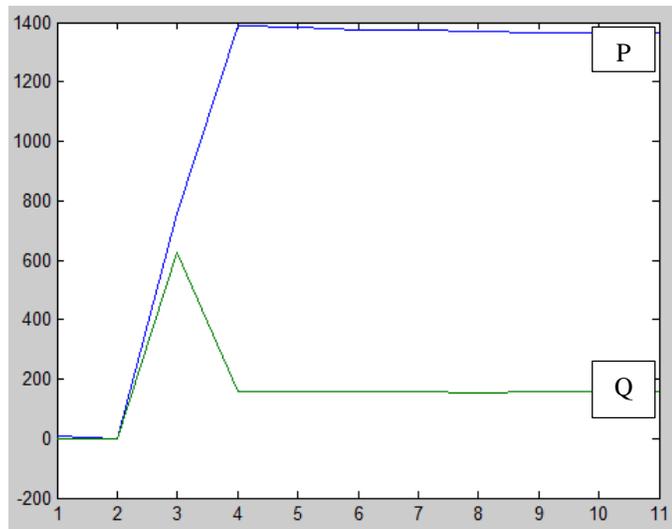


Figure 37 Representation of Active and Reactive Power Signals of Table above.

The software for event detection consists of 5 different sections. The first part is to import the data from the text file to Matlab. By running the code, a window will pop-up and ask

for the data file (which is typically a text file). Since there are different ways to save data in the text file, in the next step the code tries to determine the column numbers for the active and reactive power of each phase as well as the time column to make sure that it will extract all information correctly. After extracting the data from the text file and putting it in a matrix, the system will detect the number of phases. If the system is single phase it will leave the data as-is, but if the system has two or three phases the code will accumulate the phases to construct only one active power and one reactive power signal. Processing one active power and one reactive power signal is much easier than processing 4 or 6 signals. The advantage of this approach is that even though some appliances use two or three phase, by processing the accumulated power signal it is easier to detect the signature of every device by a common method.

The second part of the classification software finds and detects the reasonable changes in the power signal. This calculation requires a defined threshold to detect only valid events and ignore the noise and other fluctuation in signals. After considering the power signal and experimenting with some values, a minimum change of 35 watts was determined to be a good threshold (which means that the code is not able to detect loads below 35 watts. For instance, if there is a load such as a small lamp (10 Watts), if it goes ON or OFF it is not possible for the system to detect that and it will be treated as noise or some irrelevant changes in the power signal. The reason that the threshold should be 35 Watts and not less is because setting this value lower (5 Watts for example) will result in a huge number of events, many of which are likely just noise or changing in the loads.

Detecting the events can be accomplished simply by defining a sliding window on the power signal and calculating the signal average for at least 11 samples in a row (which is

the same size as window that is defined to roll over the signal). The sliding average window is like a low pass filter that smooths the rapid changes which are like higher frequencies in the signal. By comparing the average value point-by-point inside the window against a specified threshold, if a value is found that exceeds the threshold it will detect it as an event (see Figure 38).

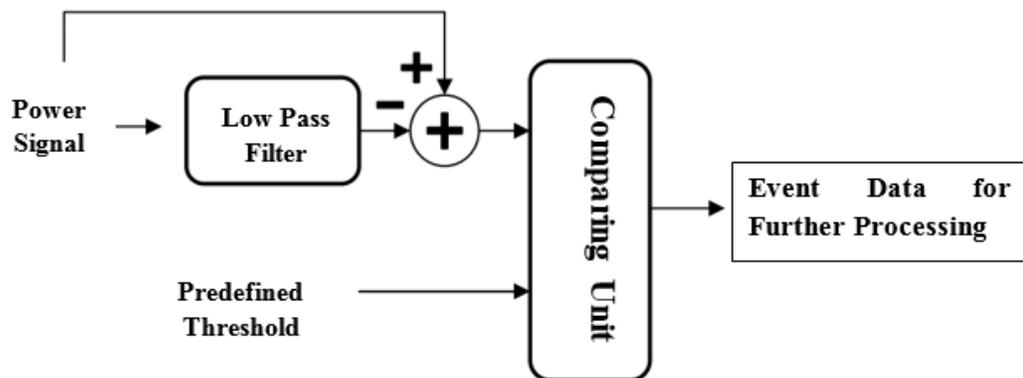


Figure 38 Event Detection diagram

By considering a small "window" of the signal, these algorithms look for evidence of a step occurring within the window. The window slides across the time series, one time step at a time. The criteria for detecting a step were determined experimentally.

The third part of the code is for finding the valid events while cancelling-out the others. Some events that are detected by the event detection section may not be actual events (for instance, it could be large noise, LabView lag issues, laptop RAM issues, or some other

problems mentioned earlier). “Noise events” may occur where there is a very short spike in the power signal lasting less than 100 milliseconds. The process measures the duration of a candidate event from the signal, and if the duration is too short the candidate is considered noise and is deleted. For valid events, it was determined experimentally that capturing 0.5 seconds of the event provided sufficient data for extracting features and subsequent classification. Figure 39 depicts one event for 0.5 seconds. The other part of the code in this section is used to prepare the signal and normalize it such that the beginning of the captured event starts from a “zero” level (see Figure 39, lower portion). Normalizing the event signature in this manner allows for consistent feature extraction and cross-correlation, as described earlier in this chapter. To determine the baseline value (offset) to subtract to accomplish this normalization, the signal immediately before a detected event is averaged over a short window (about 11 samples total). This offset is then subtracted from the signal over the 0.5 seconds of interest to produce the event signature for classification.

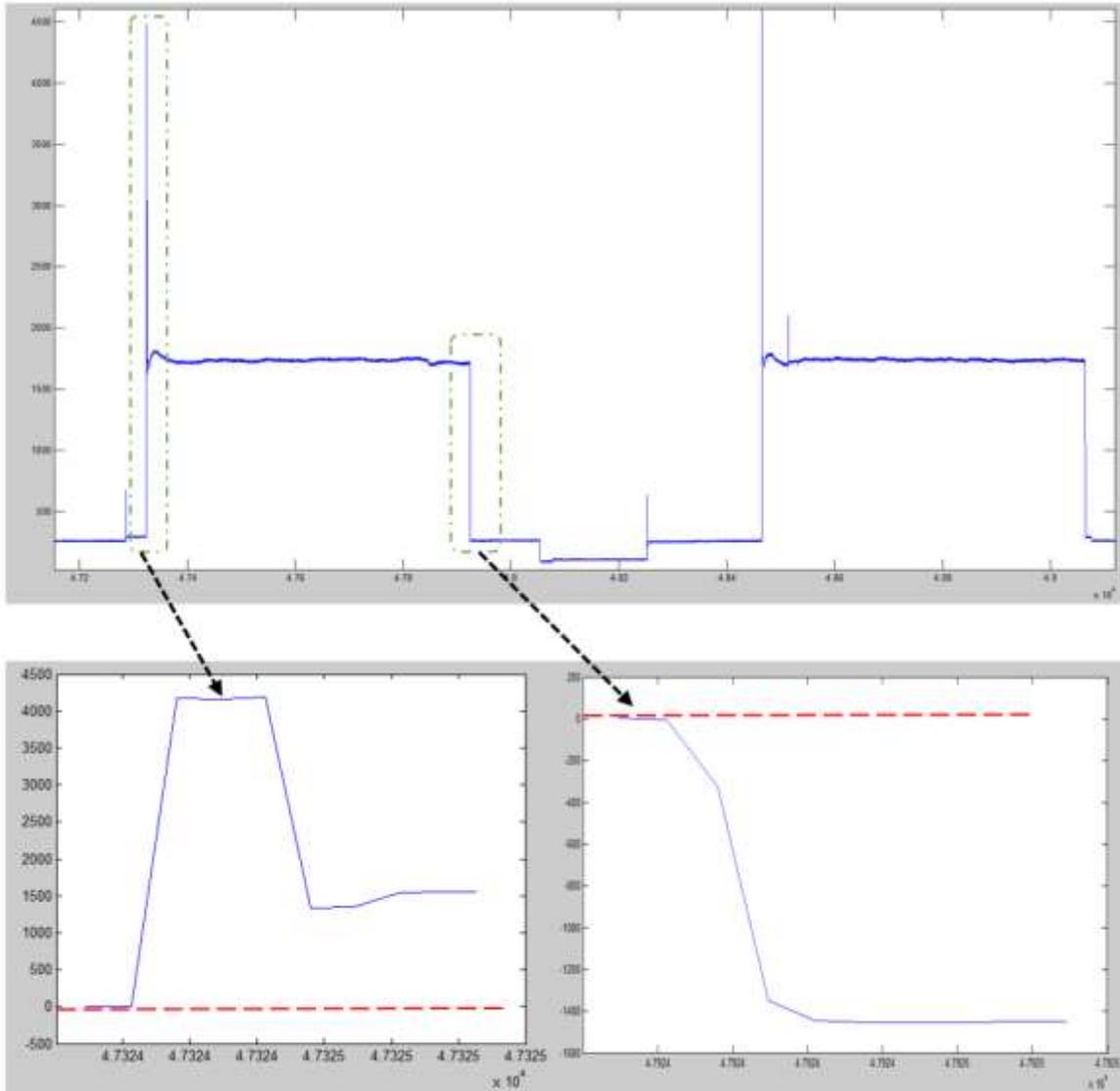


Figure 39 Turning ON-OFF power signal (up), cut and trimmed turning ON power signal signature (down-right) cut and trimmed turning OFF power signal signature (down-left)

Another element at this stage is resampling the data for each event to make all of them have the same sampling rate. Different sampling rates are caused by LabView software and Windows issues (RAM leakage, paging files, etc.) as described in section 2.3.2.

The fourth part of the code is to find best match for each event through the table of data that has already been fed into the code. First, for each event the code tries to find the best match based upon the features that are extracted from the signatures and signals. The method finds the nearest distance between the event feature vector and all the prerecorded feature vectors. In order to do that, we use simple subtraction between the elements of the feature vectors and then add all the distances together to find the total distance. The nearest one is the closest match. Since some events could be new and finding the close match will not help to identify the correct device, another mechanism is needed. If the total distance is less than the average power of the event, then it is acceptable; if not, it will not go through the next level the code, instead saving the feature vector and the shape information (the resampled data of the event) into the table, labeling it as a new device.

As already mentioned, one of the features is the class type. Note that this “class type” does not refer to the classification of similar events, but rather is a function of average power consumption by the device during the ON or OFF event. For instance, class 0 is for the appliances which consume power between 0 and 100 Watts, class 1 is for the appliances which consume power between 100 and 200 Watts, class 2 is for the appliances consume power between 200 and 300 Watts, and so on. The only issue with defining class type in this manner is that some events will have an average power consumption (during the ON or OFF event) near the boundary of the classes. Assume a device consumes 202 Watts in a normal condition during the ON event. Since this value is not precise (exactly constant) for each ON event of this same device (and further may depend on the temperature and a lot of other things), this device can exhibit a bit different power consumption during each ON event. Usually the power consumption during the ON (or OFF) event for each device

will fall within a range. Assuming the range for the device just described is between 195 Watts to 207 Watts, then assigning the right class type for the event would be a problem. In order to overcome this problem, during event detection, each unknown event is compared with preexisting events within the class to which it is assigned, and also to the events within one class above and one class below to make sure a “borderline” device does not miss the opportunity to be classified with other similar events.

Next step is to try all signals and signatures in the classes that match with the class of the events (including one class above and below) and then by using cross-correlation function find the best match through the table. Initially, we tried to use the correlation function to find the best match, but the problem with that is since the sampling rate is not high and also the start point of the signatures can be a bit shifted in time, the correlation function is not a good choice and gives the wrong results. Therefore, the signal may need to be shifted a bit to find if it fits with one of the signals in the table or not, and the cross-correlation naturally provides this result.

In signal processing, cross-correlation is a measure of similarity of two waveforms as a function of a time-lag applied to one of them. This is also known as a sliding dot product or sliding inner-product. It is commonly used for searching a long-signal for a shorter, known feature. It also has applications in pattern recognition, for discrete functions, f and g , the cross-correlation is defined as:

$$(f \star g)[n] \equiv \sum_{m=-\infty}^{\infty} f^*[m]g[n+m]$$

The cross-correlation is similar in nature to the convolution of two functions.

For instance, in the Figure 40 there is one example of this issue. In the active power signals it is very clearly shown that the peak is not always at the same spot, but the whole signal has the same shape and should be classified together.

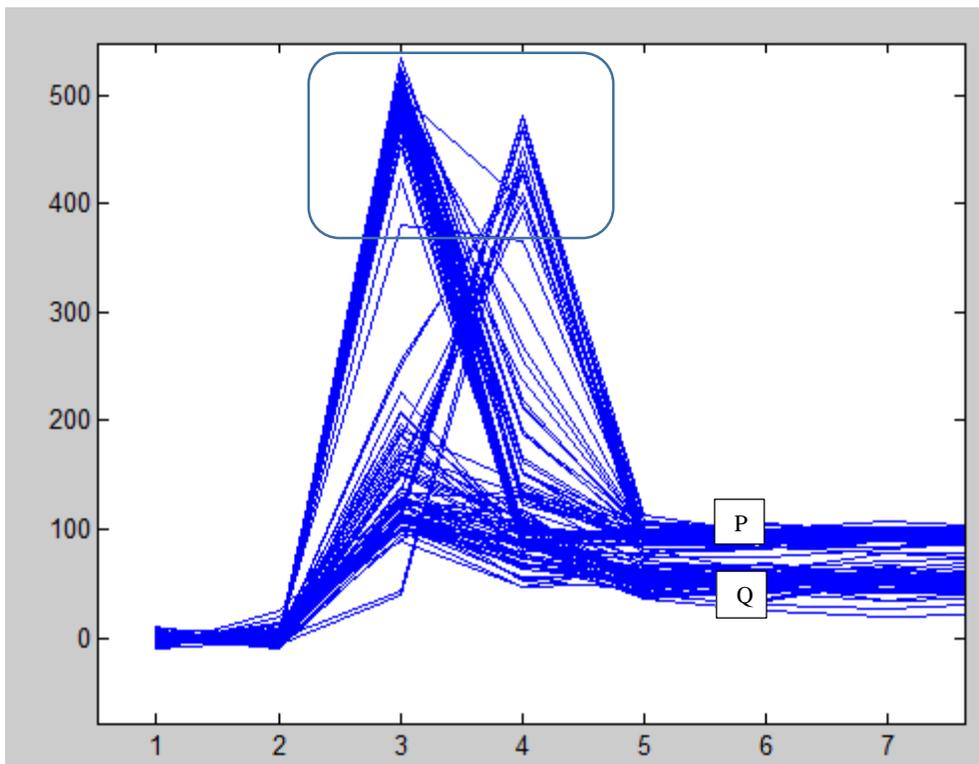


Figure 40 Time shifting issues in the signals

In the following figures there are two examples of the events with similar signatures that went through the feature matching and then shape matching. The features of each signal in Figure 41 & 43 are depicted and compared to each other in the Figure 42 & Figure 44.

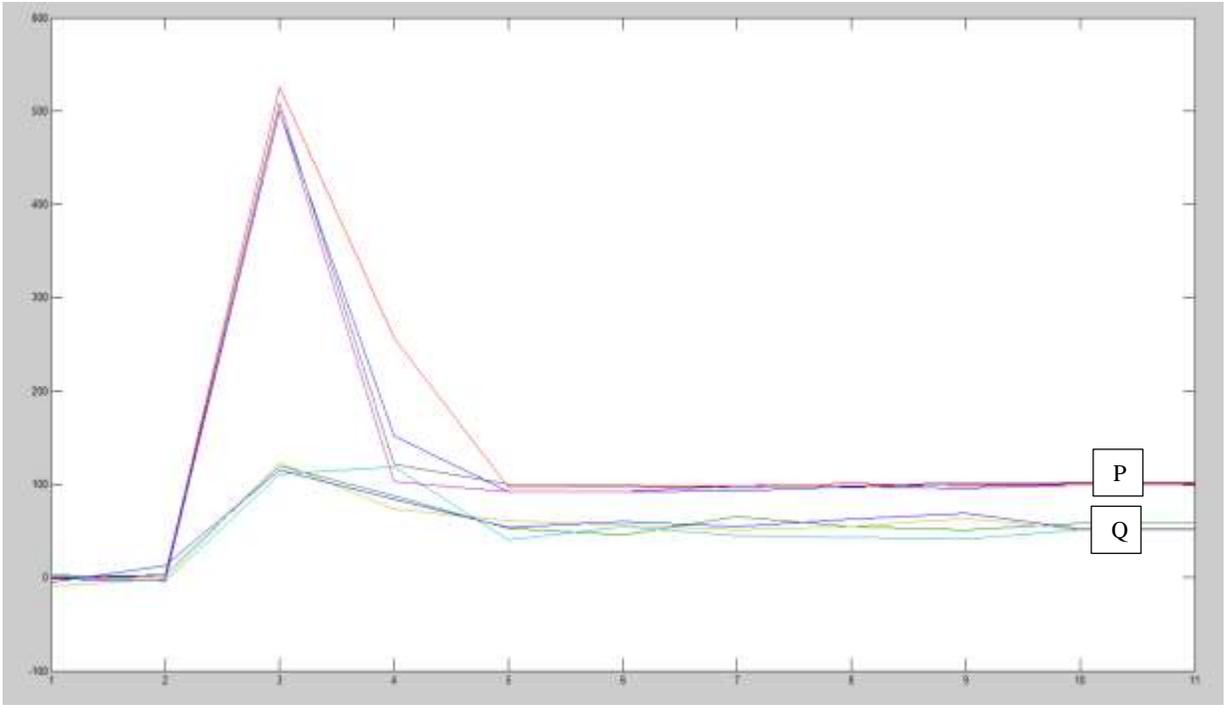


Figure 41 Four turning ON events with the same Signature

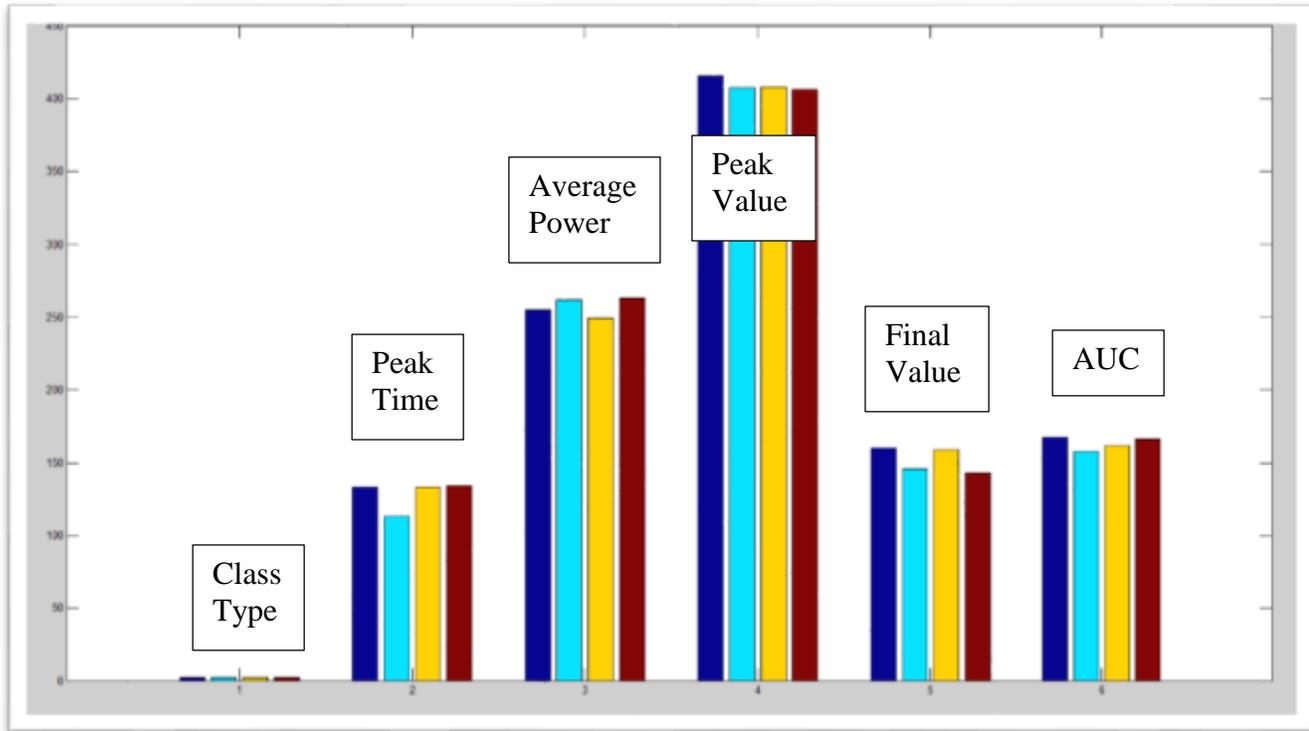


Figure 422 Features of Active Power for four turning ON events shown in Figure 42

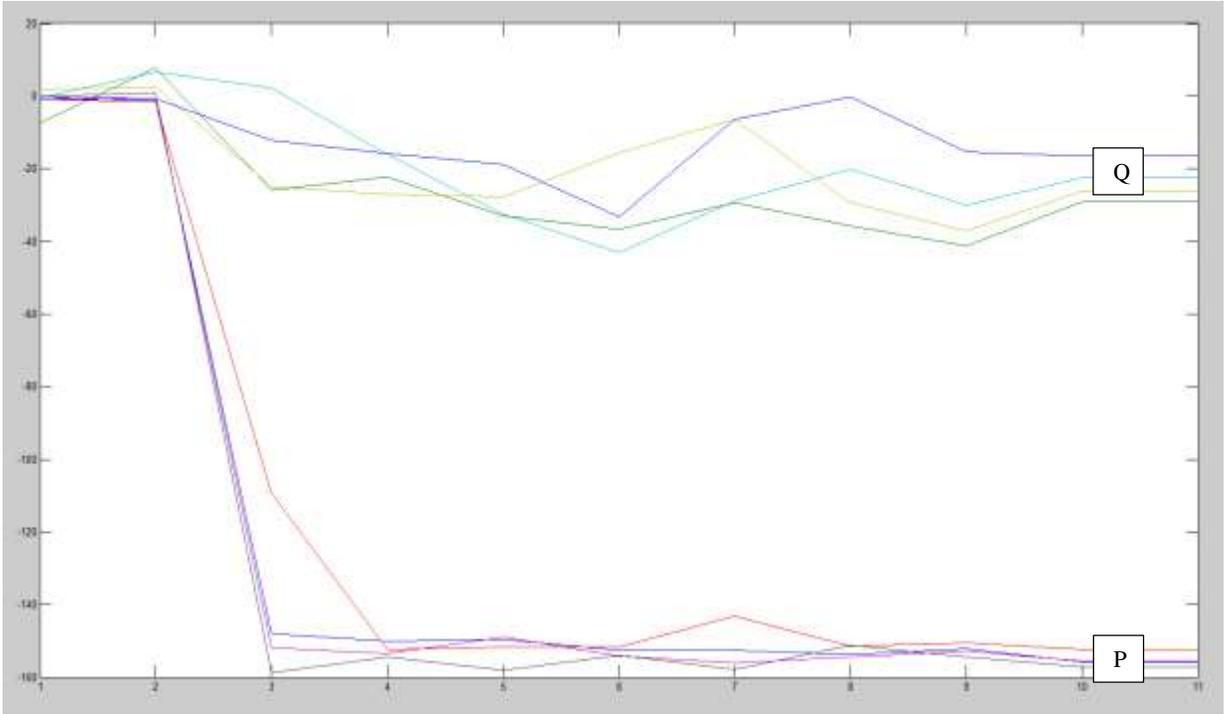


Figure 433 Four turning OFF events with the same Signature

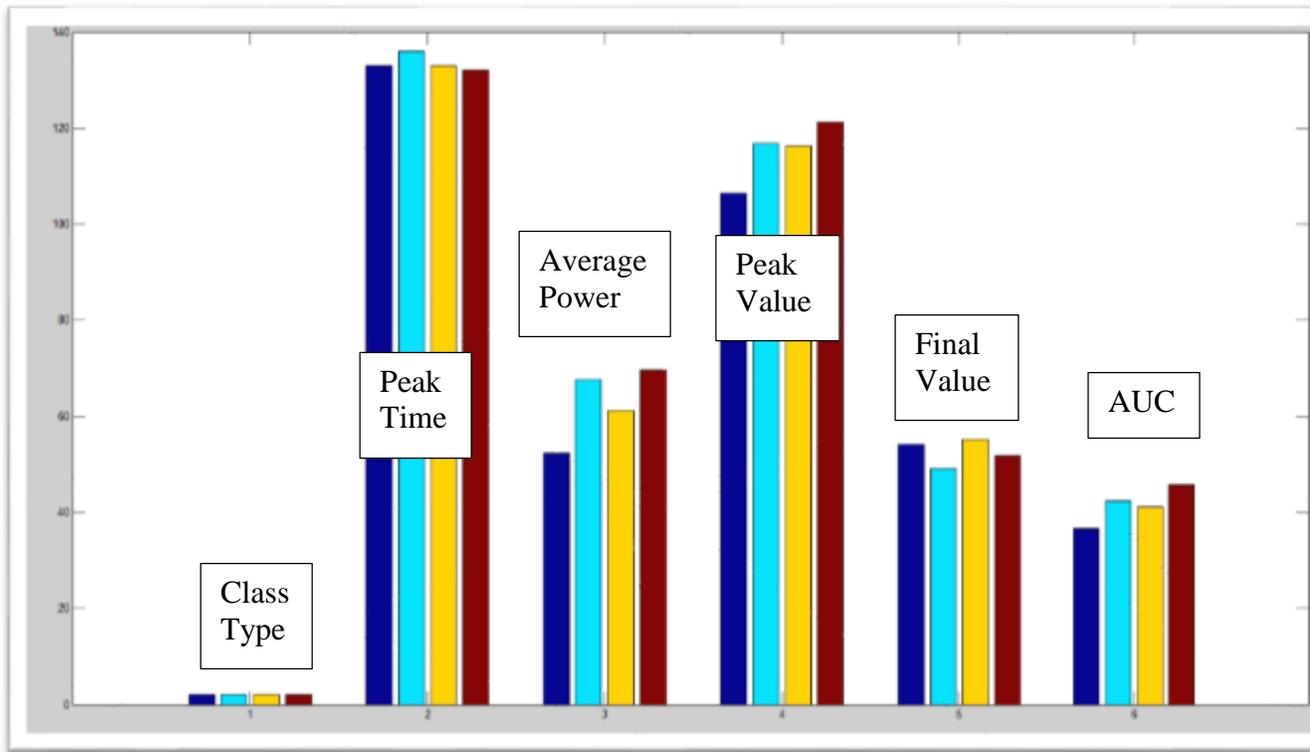


Figure 44 Features of Reactive Power for four turning ON events shown in Figure 42

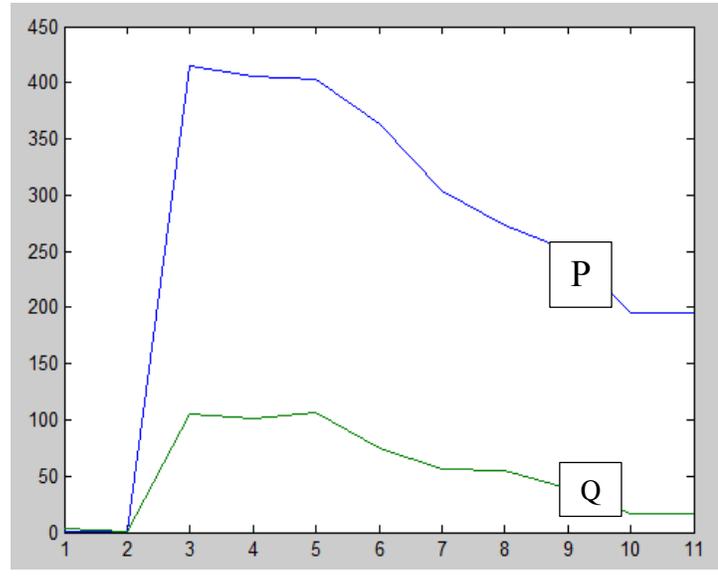
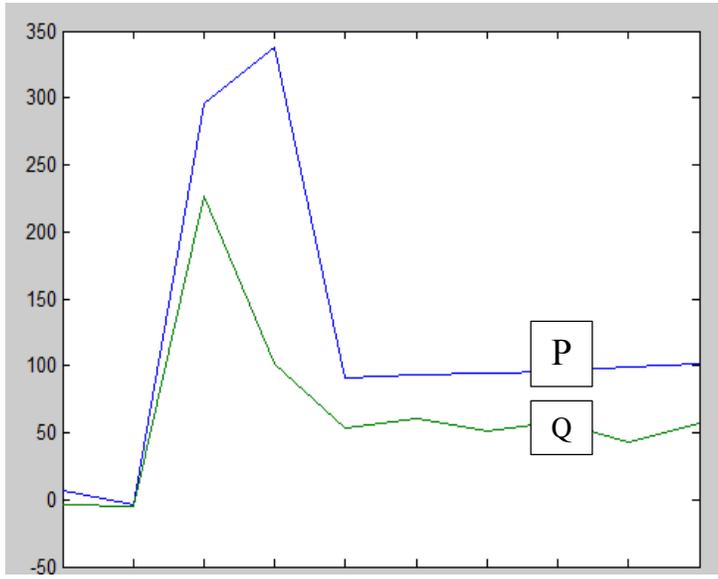


Figure 45 Two different events (active and reactive power)

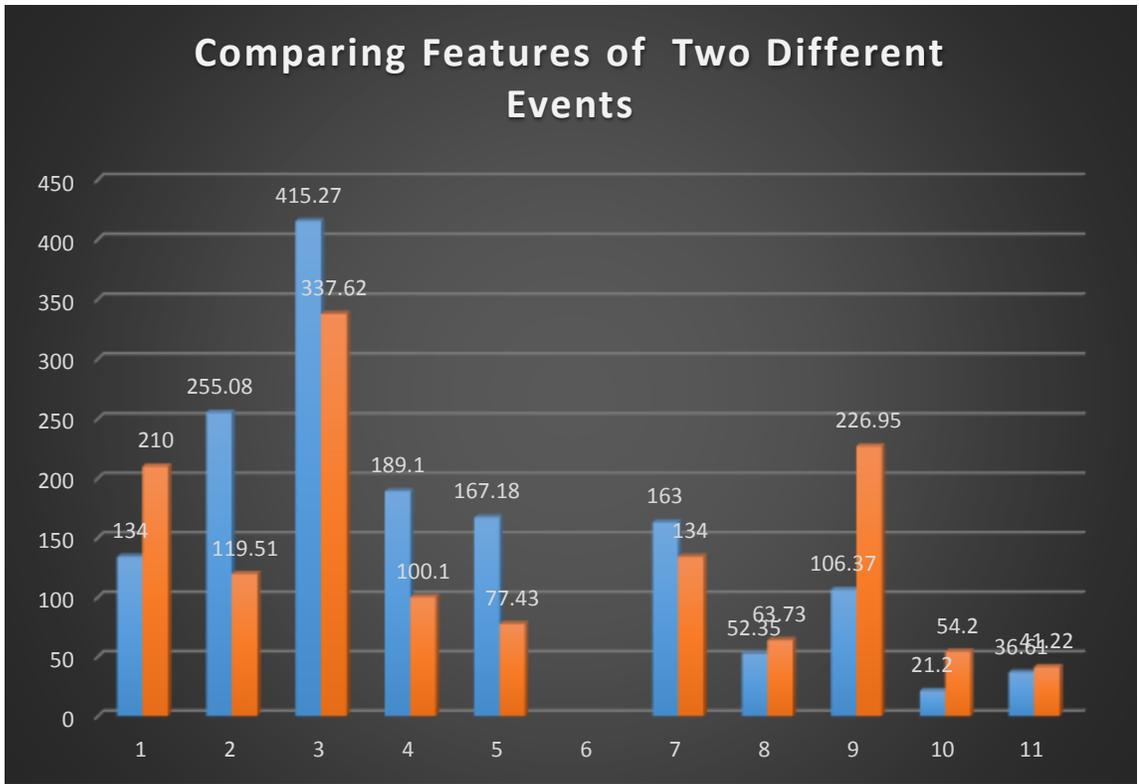


Figure 46 Comparing features of two events shown in Figure 45

Figure 45 showing two different events and Figure 46 illustrates comparing the extracted features from two events shown in Figure 45. This Figure clearly represents that even the events close together regarding the maximum peak and average power, still in the features there are some of them can be used to distinguish between the signals.

If there is no close match detected for a particular event, then the code identifies it as a new device stores all the features to label it as a new device in the table. Since the signal shape is also needed later to compare against other similar events, the signal data (after being prepared and filtered by a low pass filter to cancel the noise) is also stored in the table.

The fifth part of the code is to count and sort all the same events with the time stamp for each event and then give a report for each device. This part also produces several types of representation of the data.

Figures 47 below are chart representations of the data. Each number on the horizontal axes represents a specific event and the events are ON or OFF only. The vertical axes represent the number of counts for each event. Negative values on the vertical axes indicate OFF events and positive values indicate ON events. Pie chart in Figure 48 only represents ON events.

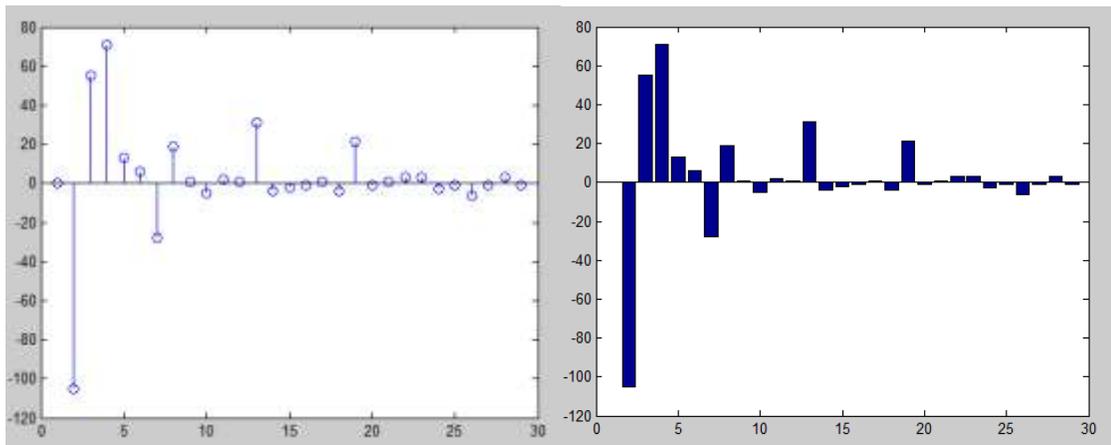


Figure 47 Visual Representation of the number of turning ON and OFF for each appliances

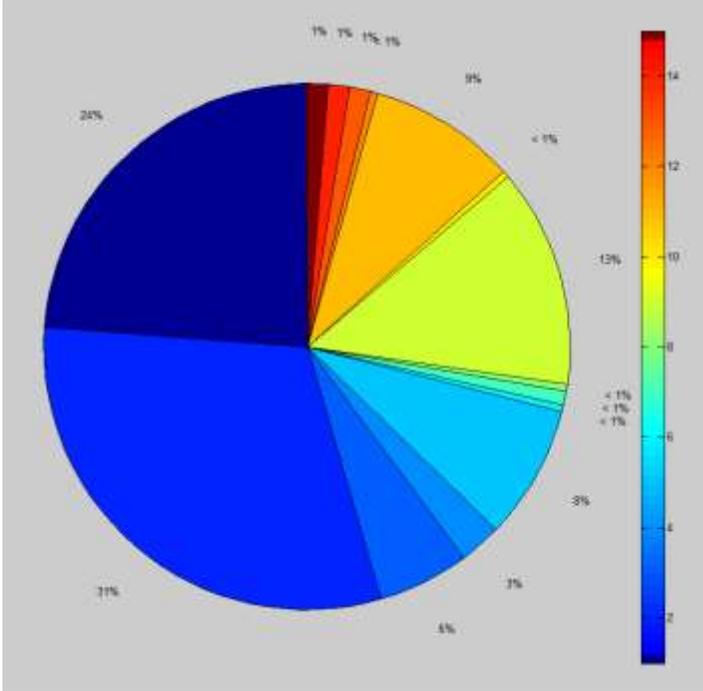


Figure 48 Visual Representation of the percentage of ONLY turning ON for each appliances

4 Results and Conclusion

The low cost Non-Intrusive Load Monitoring installed in TigerPlace shows great promise for future applicability. The single point connections required for a NILM and the capability to monitor the usage pattern of multiple systems in the house are ideal to keep the privacy of residents while making it possible to record the activity that may ultimately detect chronic disease or other issues in the early period of their problem. Early illness recognition and early treatment is not only a key to improving health status with rapid recovery after an exacerbation of a chronic illness or acute illness, but also a key to reducing morbidity and mortality in older adults and controlling costs of health care [2]. In this chapter, some results demonstrating the viability of this task are discussed, along with some observed limitations.

Figure 49 and Figure 50 represent of two days data of a residential home. The largest number of ON and OFF events are for the air conditioner inside the house. The pattern of using the other appliance is a bit different from the other day.

In Figure 51, the line pattern of ON/ OFF events for two days is shown and it is clearly depicted that there is a certain pattern of usage devices and appliances in the home. In day 2 as it is shown the line is longer and it means that there are 3 new events are detected that were not available at the day 1.

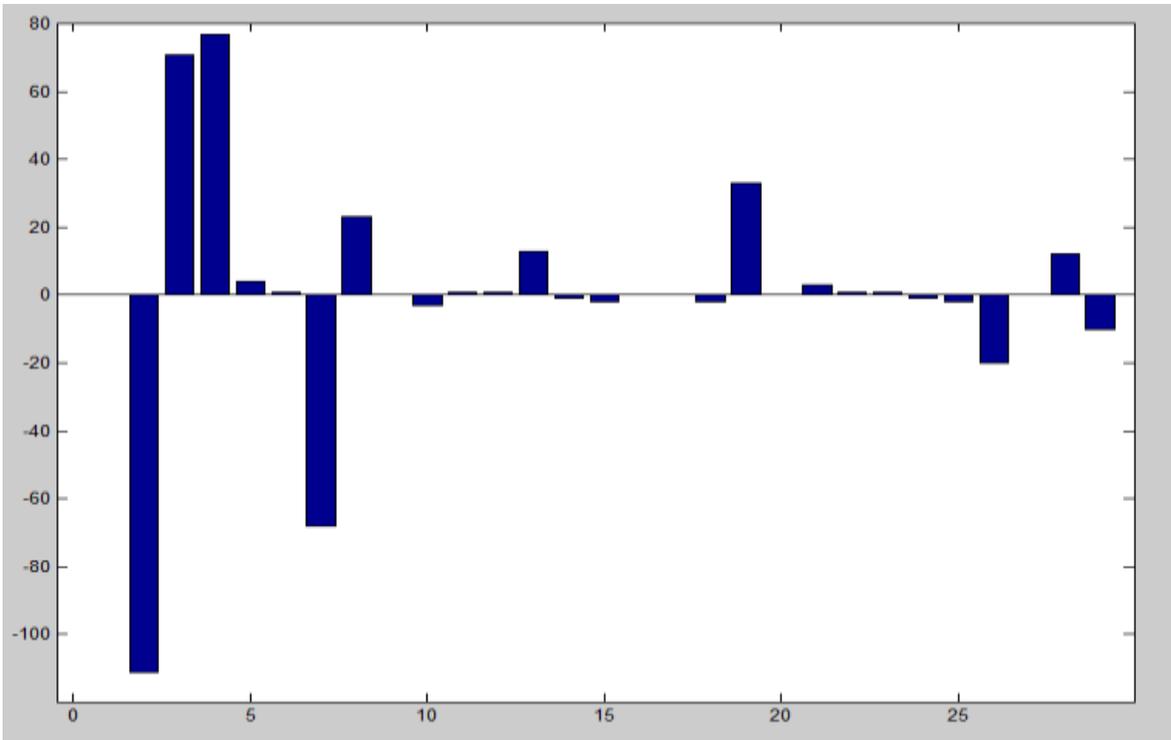


Figure 49 Day 1 Events vs. number of repetition

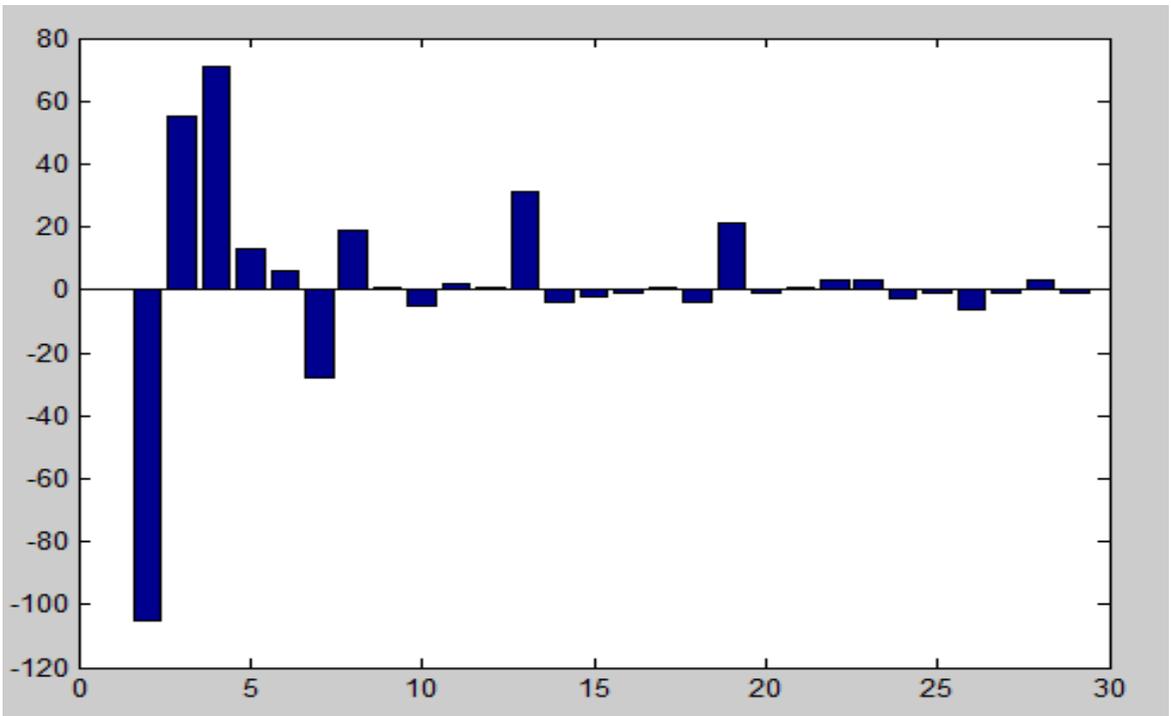


Figure 50 Day2 vs. number of repetition

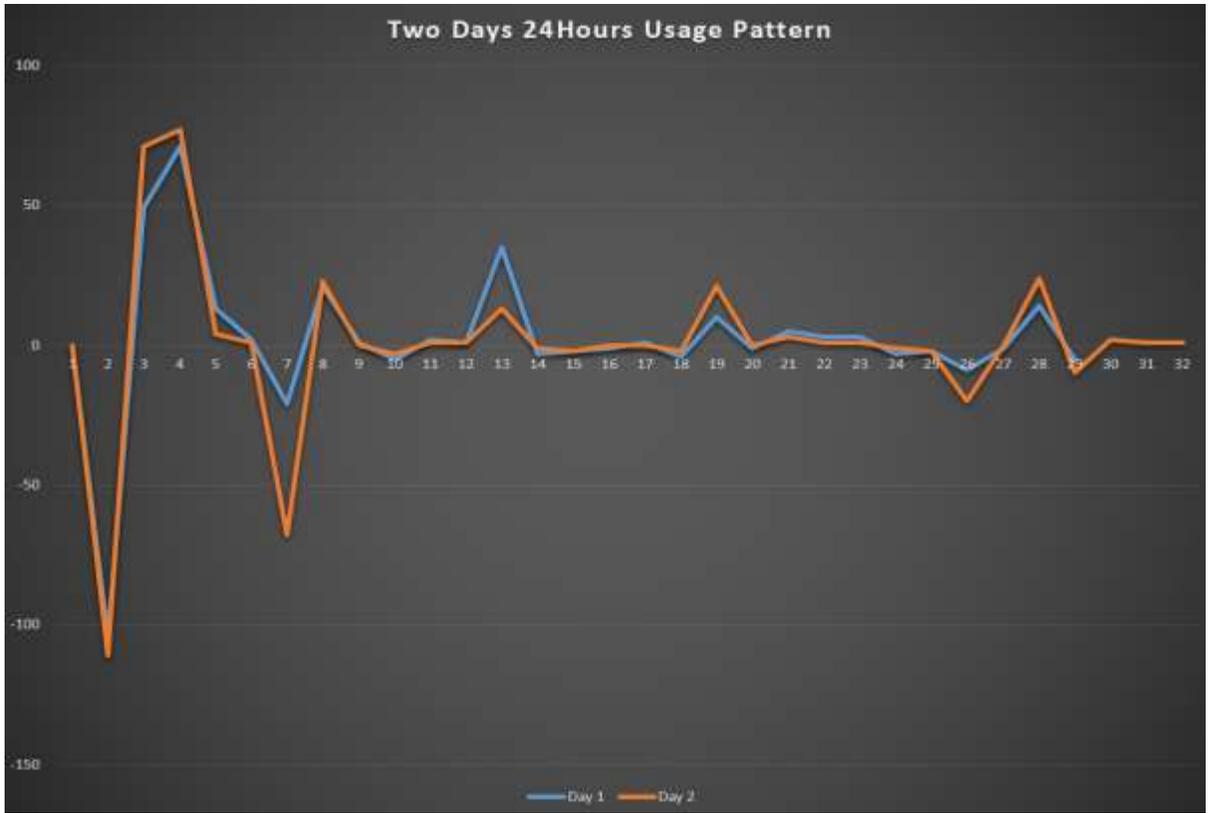


Figure 51 Appliances usage pattern for two days

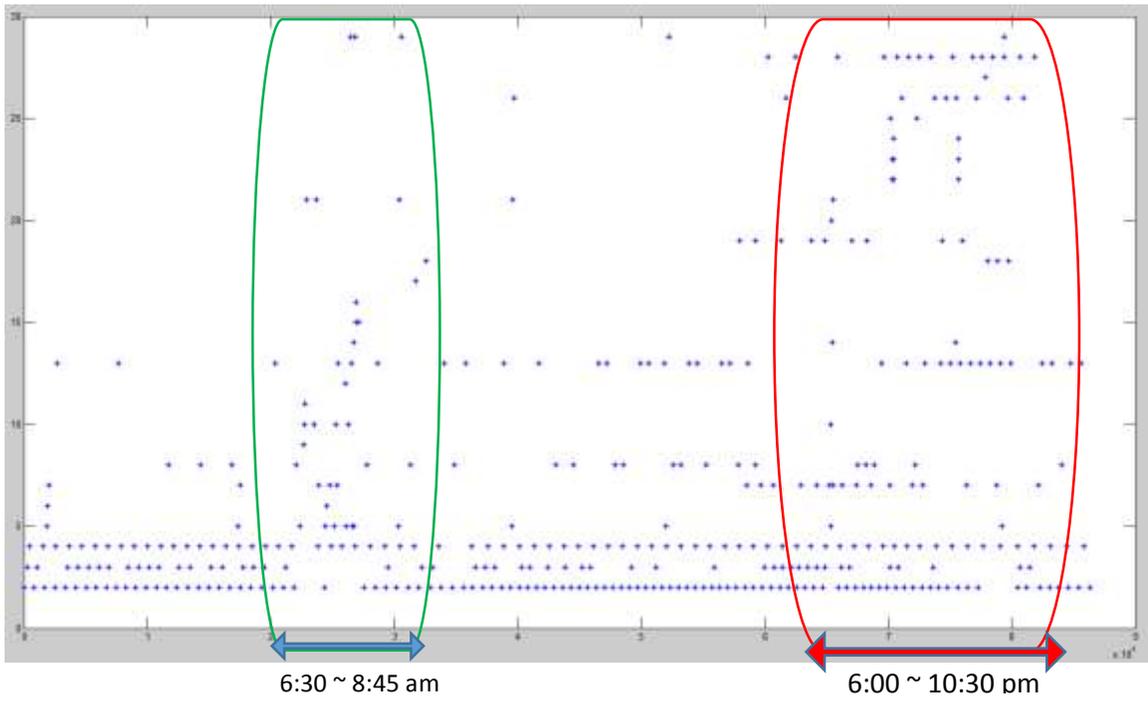


Figure 52 One day pattern for all events (V axis: event number, H axis: time of day in second)

Figure 52 illustrates one day (24 hours) data of a residential home. Inside the green line, which is about 6:00 in the morning to 8:45am, clearly it is shown there are more activities inside the home rather than during the day. The red line indicates the high level of activities occurring between 6:00pm to 10:30pm. This result makes it very clear that for this particular resident, most of the activities are early in the morning and when he/she is coming back from work or school. There is not much activity between 8:45am and 6:00pm. It is obvious that still there are some other activities are seen during the day but most of them or probably all of them are due to the automatic control mechanism of different devices and appliances in home which do not require human interaction (e.g., air conditioner, water heater, automatic lighting system) and so on.

The main limitation of this project is detecting the OFF event of some appliances. Since low resolution signals are being used, and also because the signatures of OFF events for (different) appliances with a given power consumption are very similar, it is difficult or to distinguish between those appliances. This limitation can be overcome, however, because we are primarily concerned with the overall pattern of device usage and detecting the ON events is generally sufficient for this purpose.

Since the power signal used in this thesis has low resolution, we are not able to extract much information from it. Several approaches were tested that did not yield useful results. For instance, some devices have the same active and reactive power signature in the low resolution signals, along with almost the same overshoot, same average, and other similar features, thus preventing device discrimination. The problem of low resolution is even worse when we want to detect the turning OFF events, since most of appliances have a mechanical or electronic switch that will cut the power instantly at the point of turning off,

precluding an obvious transient that can be easily characterized. Although it is still possible to detect some devices with a low resolution signal (as we have demonstrated), these low resolution signals do limit the range of features that we can practically extract for device detection.

Another limitation is detecting appliances that have power consumption near the threshold value. If large loads are being used, then the whole signal has fluctuations and the signal-to-noise ratios of the signatures for the smaller loads are poor. Figure 53 shows two examples of this problem where the signal is not clear enough. The orange line is the power signature representation of the lamp without having any other loads online. In the right, it is the same scenario for the lamp when it goes OFF; the reactive power makes the signature not that accurate. As already mentioned, some modification is done in the code in order to improve this issue, but even so, detection of the loads near the threshold is not very accurate. Sometimes the system may not even detect those events since they may come below the threshold due to fluctuations and noise in the whole signal.

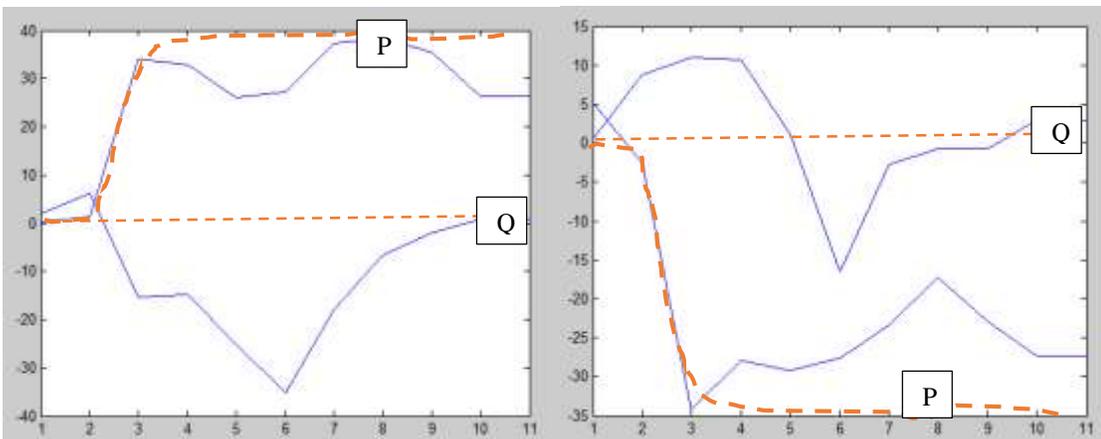


Figure 53 Left, Turn ON signature of a sample small load, Right: Turn OFF signatures of a sample small load

5 Future work

5.1 Current Systems

The NILM Hardware used for our purpose in this thesis was able to collect data for analysis satisfactorily, but there is more room for improvement. Since this projects is intended to minimum the costs and also because of budget limitation there was no opportunity to examine different devices.

Although the analog-to-digital conversion by the Oscilloscope performed quit well, it was not very well and it could be changed with other tools to have more resolution data. A more advanced interface between the voltage and current transducers and the PC should also be investigated. High or low pass filters should also be considered at the interface between the transducers and the Oscilloscope.

In the other hand, Selecting and designing the right components and put them together can be a good idea, especially since in this thesis we were looking to find a way to transfer the data wirelessly. One idea can be designing and implementing a system to measure the signals of both voltage and currents and then transferring the signals to one of the analyzing software like Matlab or LabView preferably Matlab, since most of the calculation and analysis is doing in Matlab it would be a great idea to design and fabricate a cheap system

that can connect to Matlab. If it could be possible to detect the devices status at the real-time it is much better to use LabView and if it is not then Matlab is the best choice.

One of the great idea since in this thesis tried not to use very complicated algorithm and low cost tools to detect the behavioral pattern then it could be possible to design a Micro Controller based with GSM enabled framework to do the all task from data acquisition part and also analysis part too. In that way it would be feasible to have this device with a reasonable cost to monitor elders and send alerts to a nurse or the organization that monitor their health.

5.2 NILM Software

The current state of the art in NILM software consists of the preprocessor that converts the voltage and current signals into a power envelope, the automatic data collection discussed in this thesis,

The other topic could be detecting the appliances status by finding the oscillating frequency like natural frequency of the power signal at the turning ON point, as it seems during this research, at the high sampling rate the power signal would be in a high resolution and then it is possible to look at the oscillations and vibration of signatures at the start point or when they are online. In this thesis we are not considering the method that just mentioned but it could be a good research topic.

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TA138 200 A AC Current Clamp



OPERATING INSTRUCTIONS

Introduction

The TA138 200 A AC Current Clamp has a voltage output with standard banana (4 mm) plugs for connection to the PicoLog CM3 Current Data Logger or other compatible measuring instrument.

Using the Current Clamp Safely

Warning: To prevent electric shock or fire and personal injury, carefully read all safety information before attempting to operate the Current Clamp and follow these procedures:

- **DO NOT** use the clamp on circuits rated higher than 600 V in Category II or 300 V in Category III. Use caution when clamping around uninsulated conductors or bus bars.
- **DO NOT** use a clamp that is cracked, damaged, or has a defective cable. Such clamps should be made inoperative by taping the jaws closed.
- **DO** check the magnetic mating surfaces of the clamp jaws. They should be free of dust, dirt, rust and other foreign matter.
- **DO** keep your fingers behind the safety barrier as shown below.

Safety Symbols



This symbol, adjacent to another symbol or terminal, indicates that the user must refer to the manual for further information.



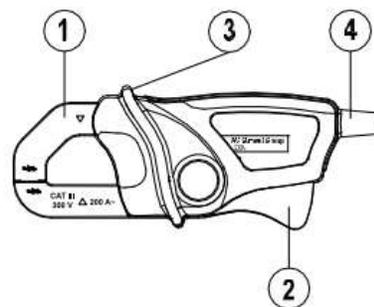
This symbol, adjacent to a terminal, indicates that, under normal use, hazardous voltages may be present.



Double insulation

Adaptor Description

1. Current sense jaw
2. Clamp trigger
3. Safety barrier
4. Voltage output lead



Appendix A

Transducer Specifications

Specifications

• General Specifications

Output impedance	<1 kΩ	
AC bandwidth	40 to 400 Hz	
Jaw opening	16 mm	
Operating conditions	32 °F to 86 °F (0 °C to 30 °C) 90% RH; 86 °F to 104 °F (30 °C to 40 °C) 75% RH; 104 °F to 122 °F (40 °C to 50 °C) 45% RH	
Storage conditions	-22 °F to 140 °F (-30 °C to 60 °C) <90% RH	
Altitude	Operate at less than 3000 metres	
Weight	129 g	
Dimensions	111 x 50 x 33 mm (H x W x D)	
Standards	IEC1010-1 (1995); EN61010-1 (2001) Category II 600 V, Category III 300 V	

• Range Specifications

Function	Range	Output	Sensitivity	Accuracy (of reading)
AC Current (50/60 Hz)	0 to 200 A	1 mV/A	1 A/mV AC	±2.0%±0.5 A

Using the Current Clamp with the PicoLog Software

1. Connect the output lead to the input sockets of the PicoLog CM3 Current Data Logger.
2. Connect the PicoLog CM3 to your computer using the USB cable supplied.
3. Position the Current Clamp perpendicular to and centered around the conductor,
4. Run the PicoLog software on the computer.
5. Select **File > New Settings** and configure PicoLog for a 'PLCM3' device.
6. Select **File > New Data** and click the 'Start recording' button when ready.

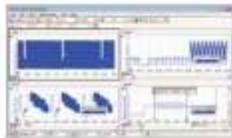


PicoScope® 3000 Series

HIGH-PERFORMANCE 4-CHANNEL OSCILLOSCOPES

Fast, space-saving and USB-powered

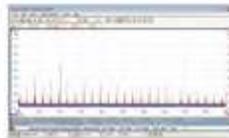
Serial decoding • Mask limit testing • Segmented memory



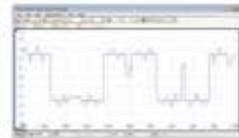
128 MS buffer memory



Serial decoding



200 MHz spectrum analyzer



Arbitrary waveform generator



200 MHz bandwidth

128 MS deep memory

1 GS/s real-time sampling

10 GS/s repetitive sampling

Advanced digital triggering

200 MHz spectrum analyzer

Function generator & AWG

USB 2.0 Hi-Speed

FlexiPower™



Supplied with a full SDK including example programs • Software compatible with Windows XP, Windows Vista and Windows 7 • Free technical support

High-end features as standard

PicoScope 3000 Series 4-Channel Oscilloscopes

PicoScope: power, portability and versatility

Pico Technology continues to push the limits of USB-powered oscilloscopes. The new PicoScope 3000 Series offers the highest performance available from any USB-powered oscilloscope on the market today.



The PicoScope 3000 Series has the power and performance for many applications, such as design, research, test, education, service and repair.

Pico USB-powered oscilloscopes are also small, light and portable. They easily slip into a laptop bag making them ideal for the engineer on the move. The new

PicoScope 3000 series 4-channel oscilloscopes feature FlexiPower™, giving you the option of powering the scope from two USB ports, so you can leave the power supply behind when using the device in the field.

High bandwidth, high sampling rate

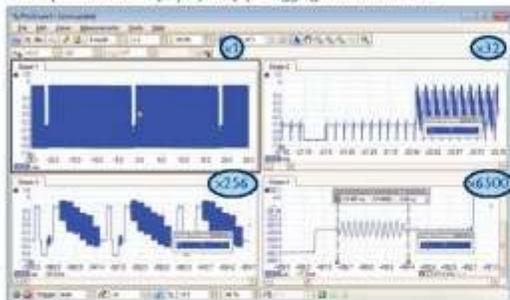
Unlike most USB-powered oscilloscopes, with real-time sampling rates of only 100 or 200 MS/s, the PicoScope 3000 Series delivers a market-leading 1 GS/s. ETS mode boosts the maximum effective sampling rate further to 10 GS/s, enabling even finer time resolution when used with repetitive signals.

Deep memory

The PicoScope 3000 Series offers memory depths up to 128 million samples, more than any other oscilloscopes in this price range.

Other oscilloscopes have high maximum sampling rates, but without deep memory they cannot sustain these rates on long timebases. The PicoScope 3406B can sample at 1 GS/s at timebases all the way down to 10 ns/div.

Managing all this data calls for some powerful tools, so PicoScope has a maximum zoom factor of 100 million combined with a choice of two zoom methods. There's a conventional set of zoom controls, plus an overview window that shows you the whole waveform while you zoom and reposition the display by simply dragging with the mouse.



The deep memory can be segmented to store multiple waveforms, and has navigation tools allowing you to review up to 10,000 previous entries. No longer will you see a glitch on the screen only for it to vanish before you stop the scope. A mask can be applied to filter out waveforms of interest.

Advanced triggers



As well as the standard range of triggers found on all oscilloscopes, the PicoScope 3000 Series offers a class-leading set of advanced triggers including pulse width, windowed, dropout and logic triggers to help you capture the data you need.

Digital triggering

Most digital oscilloscopes sold today still use an analog trigger architecture based on comparators. This can cause time and amplitude errors that cannot always be calibrated out. The use of comparators often limits the trigger sensitivity at high bandwidths and can also create a long trigger "re-arm" delay.

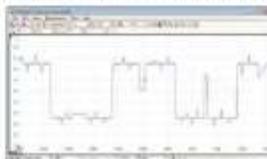
Since 1991 we have been pioneering the use of fully digital triggering using the actual digitized data. This reduces trigger errors and allows our oscilloscopes to trigger on the smallest signals, even at the full bandwidths. Trigger levels and hysteresis can be set with high precision and resolution.

Digital triggering also reduces re-arm delay and this, combined with the segmented memory, allows the triggering and capture of events that happens in rapid sequence. At the fastest timebase you can use rapid triggering to collect 10,000 waveforms in under 20 milliseconds. The mask limit testing function can then scan through these waveforms to highlight any failed waveforms for viewing in the waveform buffer.

Custom probe settings

The custom probes feature allows you to correct for gain, attenuation, offsets and nonlinearities in special probes, or to convert to different units of measurement (such as current, power or temperature). You can save definitions to disk for later use. Definitions for Pico oscilloscope probes and current clamps are built in.

Arbitrary waveform and function generator



All units have a built-in function generator (sine, square, triangle, DC level) with frequency sweeping capability. Combined with the spectrum peak hold option, this makes a powerful tool for testing amplifier and filter responses.

The B models in the PicoScope 3000 Series also include a full arbitrary waveform generator. Waveforms can be created or modified using the built-in AWG editor, imported from oscilloscope traces, or loaded from a spreadsheet.

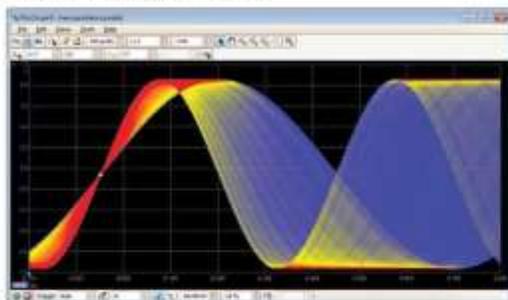


Spectrum analyzer

With the click of a button you can display a spectrum plot of the selected channels. The spectrum analyzer allows signals up to 200 MHz to be viewed in the frequency domain. A full range of settings gives you control over the number of spectrum bands, window type and display mode: instantaneous, average, or peak-hold.

You can display multiple spectrum views with different channel selections and zoom factors, and place these alongside time-domain views of the same data. A comprehensive set of automatic frequency-domain measurements, including THD, THD+N, SNR, SINAD and IMD, can be added to the display.

Advanced display modes



See old and new data superimposed, with new data in a brighter color or shade. This makes it easy to see glitches and dropouts and to estimate their relative frequency. Choose between analog persistence and digital color, or create a custom display mode.

The design of the PicoScope software ensures that maximum display area is available for waveform viewing. Even with a laptop you have a much bigger viewing area and higher resolution than a typical benchtop scope.

Serial decoding



The deep-memory PicoScope 3000 Series is ideal for serial decoding as it can capture thousands of frames of uninterrupted data.

Protocols currently supported are I²C, SPI, RS232/UART, CAN, LIN and FlexRay. Expect this list to grow with free software updates.

PicoScope displays the decoded data in the format of your choice: "in view", "in window", or both at once.

"In view" format shows the decoded data beneath the waveform on a common time axis, with error frames marked in red. You can zoom in on these frames to look for noise or distortion on the waveform. "In window" format shows a list of the decoded frames, including the data and all flags and identifiers. You can set up filtering conditions to display only the frames you are interested in, search for frames with specified properties, or define a start pattern that the program will wait for before listing the data. You can also create a spreadsheet to fully decode the hex data into plain text.

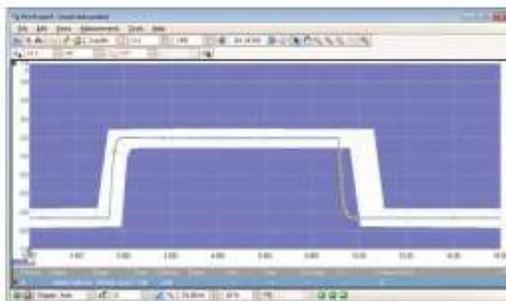
High-speed data acquisition/digitizing

The drivers and software development kit supplied allow you to write your own software or interface to popular third-party software packages such as LabVIEW.

If the 128 MS record length isn't enough, the driver supports streaming mode, which captures gap-free continuous data through the USB port directly to the PC's RAM or hard disk at a rate of over 10 MS/s. Maximum speed depends on the PC's capabilities.

Mask limit testing

This feature is specially designed for production and debugging environments. Capture a signal from a known working system, and PicoScope will draw a mask around it with your specified tolerance. Connect the system under test, and PicoScope will highlight any parts of the waveform that fall outside the mask area. The highlighted details persist on the display, allowing the scope to catch intermittent glitches while you work on something else. The measurements window counts the number of failures and can display other measurements and statistics at the same time.



The numerical and graphical mask editors can be used separately or in combination, allowing you to enter accurate mask specifications and to modify existing masks. You can import and export masks as files.

High-end features as standard

Buying a scope from some companies is a bit like buying a car. By the time you have added all the optional extras you need, the price has gone up considerably. With the PicoScope 3000 Series, high-end features such as mask limit testing, serial decoding, advanced triggering, measurements, math, XY, digital filtering and segmented memory are all included in the price.

To protect your investment, both the PC software and firmware inside the unit can be updated. We have a long history of providing new features for free via software downloads. Other companies make vague promises about future enhancements but we deliver on our promises year after year. Users of our products reward us by becoming lifelong customers, frequently recommending us to their colleagues.

Dependable signal integrity

Most oscilloscopes are built down to a price; ours are built up to a specification.



Careful front-end design and shielding reduces noise, crosstalk and harmonic distortion. Years of oscilloscope experience leads to improved pulse response and bandwidth flatness.

We are proud of the dynamic performance of our products and publish these specifications in detail. The result is simple when you probe a circuit, you can trust in the waveform you see on the screen.

PicoScope 3000 Series 4-Channel Oscilloscopes - The PicoScope Display

Oscilloscope controls: Commonly-used controls such as voltage range selection, timebase, memory depth and channel selection are placed on the toolbar for quick access, leaving the main display area clear for waveforms. More advanced controls and functions are located in the **Tools** menu.

Tools>Math channels: Combine input channels and reference waveforms using simple arithmetic, or create custom equations with trigonometric and other functions.

Tools>Serial decoding: Decode multiple serial data signals and display the data alongside the physical signal or as a detailed table.

Tools>Reference channels: Store waveforms in memory or on disk and display them alongside live inputs. Ideal for diagnostics and production testing.

Auto setup buttons: Configures the timebase and voltage ranges for stable display of signals.

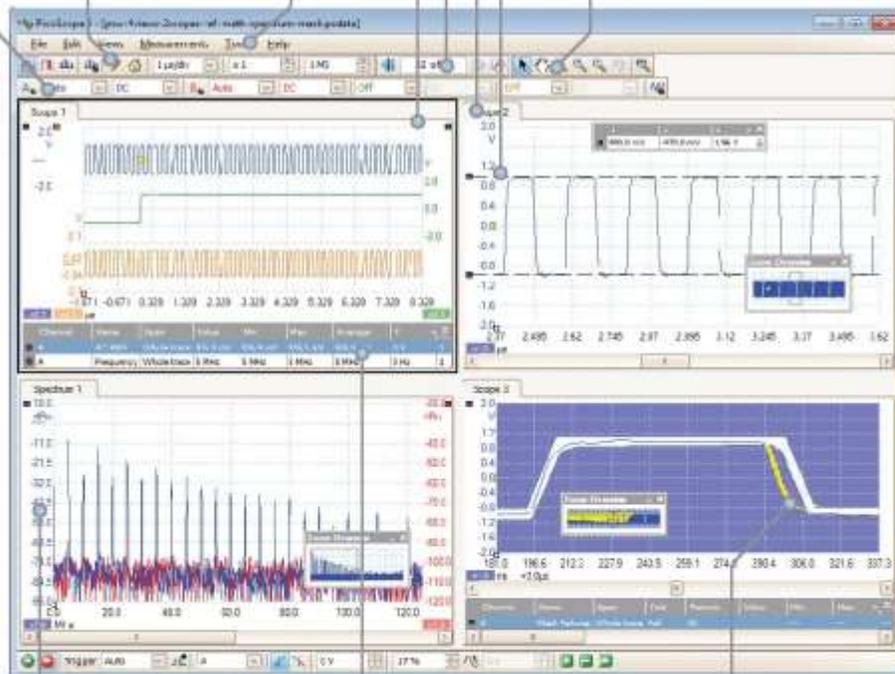
PicoScope's the display can be as simple or as complex as you need. Begin with a single view of one channel, and then expand the display to include any number of live channels, math channels and reference waveforms.

Waveform replay tool: PicoScope automatically records up to 10,000 of the most recent waveforms. You can quickly scan through to look for intermittent events.

Views: PicoScope is carefully designed to make the best use of the display area. You can add new scope and spectrum views with automatic or custom layouts.

Rulers: Each axis has two rulers that can be dragged across the screen to make quick measurements of amplitude, time and frequency.

Zoom and pan tools: PicoScope allows a zoom factor of up to 100 million, which is necessary when working with the deep memory of the 3000 Series scopes. Either use the zoom-in, zoom-out and pan tools, or click and drag in the zoom overview window for fast navigation.



Movable axes: The vertical axes can be dragged up and down. This feature is particularly useful when one waveform is obscuring another. There's also an **Auto Arrange Axes** command.

Automatic measurements: Display calculated measurements for troubleshooting and analysis. You can add as many measurements as you need on each view. Each measurement includes statistical parameters showing its variability.

Mask limit testing: Automatically generate a test mask from a waveform or draw one by hand. PicoScope highlights any parts of the waveform that fall outside the mask and shows error statistics.

PicoScope 3000 Series 4-Channel Oscilloscopes - Specifications

PRODUCT SELECTOR

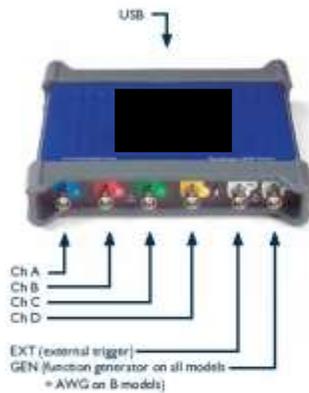
MODEL	BANDWIDTH	SAMPLING	MEMORY	WAVEFORM	PROBES SUPPLIED
PicoScope 3404A	60 MHz	1 GS/s	4 MS	Function generator	4
PicoScope 3404B	60 MHz	1 GS/s	8 MS	Func. gen. + AWG	4
PicoScope 3405A	100 MHz	1 GS/s	16 MS	Function generator	4
PicoScope 3405B	100 MHz	1 GS/s	32 MS	Func. gen + AWG	4
PicoScope 3406A	200 MHz	1 GS/s	64 MS	Function generator	4
PicoScope 3406B	200 MHz	1 GS/s	128 MS	Func. gen. + AWG	4

MODEL	PicoScope 3404A/B	PicoScope 3405A/B	PicoScope 3406A/B
VERTICAL			
Bandwidth (-3 dB)	60 MHz	100 MHz	200 MHz
Bandwidth limiting (-3 dB)	20 MHz, switchable		
Rise time (calculated)	5.8 ns	3.5 ns	1.75 ns
Resolution	8 bits		
Input channels	4		
Input characteristics	1 MΩ ±1%; in parallel with 14 pF ±1 pF		
Input coupling	AC/DC		
Input sensitivity	10 mV/div to 4 V/div (10 vertical divisions)		
Input ranges	±50 mV to ±20 V in 9 ranges		
Analog offset range (vertical position adjustment)	±250 mV (50 mV, 100 mV, 200 mV ranges) ±2.5 V (500 mV, 1 V, 2 V ranges) ±20 V (5 V, 10 V, 20 V ranges)		
DC accuracy	±3% of full scale		
Overload protection	±100 V (DC + AC Peak)		
HORIZONTAL			
Max. sampling rate (real time)	1 GS/s (1 ch), 500 MS/s (2 ch), 250 MS/s (3 or 4 ch)		
Max. effective sampling rate (repetitive signals)	2.5 GS/s	5 GS/s	10 GS/s
Sampling rate (cont. USB streaming)	≥10 MS/s (PC dependent)		
Timebase ranges	2 ns/div to 200 s/div	1 ns/div to 200 s/div	500 ps/div to 200 s/div
Buffer memory* (A models)	4 MS	16 MS	64 MS
Buffer memory* (B models)	8 MS	32 MS	128 MS
Waveform buffer (no. of segments)	1 to 10,000		
Timebase accuracy	±50 ppm		
Sample jitter	< 5 ps RMS		
* Shared between active channels			
DYNAMIC PERFORMANCE (typical)			
Crosstalk	Better than 400:1 up to full bandwidth (equal voltage ranges)		
Harmonic distortion	< -50 dB at 100 kHz full scale input		
SFDR	52 dB typical		
ADC ENOB	7.6 bits		
Noise	180 μV RMS (on most sensitive range)		
Pulse response	< 5% overshoot		
Bandwidth flatness	(+0.3 dB, -3 dB) at scope input, from DC to full bandwidth		
TRIGGER			
Trigger modes	Auto, repeat, single, none, rapid (segmented memory)		
Advanced digital triggers (Ch A to D)	Edge, window, pulse width, window pulse width, dropout, window dropout, interval, logic, runt pulse		
Trigger sensitivity (Ch A to D)	Digital triggering provides 1 LSB accuracy up to full bandwidth of scope		
Max. pre-trigger capture	Up to 100% of capture size		
Max. post-trigger delay	Up to 4 billion samples		
Trigger re-arm time	< 2 μs on fastest timebase		
Max. trigger rate	Up to 10,000 waveforms in a 20 ms burst		
EXTERNAL TRIGGER INPUT			
Trigger types	Edge, pulse width, dropout, interval, logic, delayed		
Input characteristics	Front panel BNC, 1 MΩ ±1% in parallel with 14 pF ±1 pF		
Bandwidth	60 MHz	100 MHz	200 MHz
Voltage range	±5 V, DC coupled		
Overvoltage protection	±100 V (DC + AC peak)		

PicoScope 3000 Series 4-Channel Oscilloscopes - Specifications (continued)

MODEL	PicoScope 3404A/B	PicoScope 3405A/B	PicoScope 3406A/B
FUNCTION GENERATOR (all models)			
Output waveforms	All models: Sine, square, triangle, DC voltage. B models: ramp, sine, Gaussian, half-sine, white noise, PRBS.		
Output frequency range	DC to 1 MHz		
Sweep modes	Up, down, dual with selectable start/stop frequencies and increments		
Bandwidth	> 1 MHz		
Output frequency accuracy	±50 ppm		
Output frequency resolution	< 0.01 Hz		
Output voltage range	±2 V with ±1% DC accuracy		
Output voltage adjustment	Signal amplitude and offset adjustable in approx. 1 mV steps within overall ±2 V range		
Amplitude flatness	< 0.5 dB to 1 MHz, typical		
SFDR	> 60 dB, 10 kHz full scale sine wave		
Connector type	Front panel BNC with 600 Ω output impedance		
Overvoltage protection	±10 V		
AWG (B models only)			
Update rate	20 MS/s		
Buffer size	8 kS	8 kS	16 kS
Resolution	12 bits (output step size approx. 1 mV)		
Bandwidth	> 1 MHz		
Rise time (10 - 90%)	< 100 ns		
PROBE COMPENSATION OUTPUT			
1 kHz square wave, 1.6 V pk-pk (typ.), 600 Ω			
SPECTRUM ANALYZER			
Frequency range	DC to 60 MHz	DC to 100 MHz	DC to 200 MHz
Display modes	Magnitude, average, peak hold		
Windowing functions	Rectangular, Gaussian, triangular, Blackman, Blackman-Harris, Hamming, Hann, flat-top		
Number of FFT points	Selectable from 128 to 1 million in powers of 2		
MATH CHANNELS			
Functions	-x, x*y, x/y, x^y, x/y, x^y, sqrt, exp, ln, log, abs, norm, sign, sin, cos, tan, arcsin, arccos, arctan, sinh, cosh, tanh, freq. derivative, integral, min, max, average, peak		
Operands	A, B, C, D (input channels), T (time), reference waveforms, constants, pi		
AUTOMATIC MEASUREMENTS			
Oscilloscope	AC RMS, true RMS, DC average, cycle time, frequency, duty cycle, falling rate, fall time, rising rate, rise time, high pulse width, low pulse width, maximum, minimum, peak to peak		
Spectrum	Frequency at peak, amplitude at peak, average amplitude at peak, total power, THD %, THD dB, THD+N, SFDR, SINAD, SNR, IMD		
Statistics	Minimum, maximum, average and standard deviation		
SERIAL DECODING			
CAN, LIN, FlexRay, I ² C, SPI, and RS232/UART protocols			
MASK LIMIT TESTING			
Statistics: pass/fail, failure count, total count			
DISPLAY			
Interpolation	Linear or sin(x)/x		
Persistence modes	Digital color, analog intensity, custom, or none		
GENERAL			
PC connection	USB 2.0 Hi-speed		
Power requirements	Powered from 2 USB ports or from AC adaptor supplied (1000 mA at 5 V)		
Dimensions	190 x 170 x 40 mm (including connectors)		
Weight	≤ 0.5 kg		
Temperature range	Operating: 0 °C to 40 °C (20 °C to 30 °C for stated accuracy)		
Safety approvals	Designed to EN 61010-1:2010		
EMC approvals	Tested to EN61326-1:2006 and FCC Part 15 Subpart B		
Environmental approvals	RoHS and WEEE compliant		
Software/PC requirements	PicoScope 6, SDK and example programs. Microsoft Windows XP, Windows Vista or Windows 7.		
Languages (full support):	English, French, German, Italian, Spanish		
Languages (UI only):	Simplified Chinese, Traditional Chinese, Czech, Danish, Dutch, English, Finnish, French, German, Greek, Hungarian, Italian, Japanese, Korean, Norwegian, Polish, Portuguese, Romanian, Spanish, Swedish, Turkish		

Connections



Kit contents



Your PicoScope 3000 Series oscilloscope kit contains the following items:

- PicoScope 3000 Series oscilloscope
- 4 10:1 probes
- Single-headed USB cable
- Double-headed USB cable
- AC power adapter
- Installation Guide
- Software and Reference CD

Software Development Kit

The PicoScope 3000 Series SDK is available for free download. It contains drivers and programming examples in the following languages and development environments:

- C
- C#
- Excel
- LabVIEW

High-quality probes

The probes supplied with these oscilloscopes are chosen to obtain the specified system bandwidth.

- M1007 (supplied with PicoScope 3404A/B)
- TA132 (supplied with PicoScope 3405A/B)
- TA131 (supplied with PicoScope 3406A/B)

Ordering information

ORDER CODE	DESCRIPTION	£	US\$*	€*
PP846	PicoScope 3404A (60 MHz, func. gen., probes)	599	988	725
PP847	PicoScope 3404B (60 MHz, func. gen.+AWG, probes)	749	1236	906
PP848	PicoScope 3405A (100 MHz, func. gen., probes)	899	1483	1088
PP849	PicoScope 3405B (100 MHz, func. gen.+AWG, probes)	1049	1731	1269
PP850	PicoScope 3406A (200 MHz, func. gen., probes)	1199	1978	1451
PP851	PicoScope 3406B (200 MHz, func. gen.+AWG, probes)	1349	2226	1632

Pico Technology, James House, Colmworth Business Park,
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✉ sales@picotech.com

*US\$ and € prices are correct at the time of publication. Please contact Pico Technology for the latest prices before ordering.
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www.picotech.com

PP1037 en-4



ELITEpro XC™

PORTABLE RECORDING POWER METER

THE NEXT GENERATION ENERGY LOGGER
FROM DENT INSTRUMENTS

FEATURES

- For single or 3-phase systems using 80-600V phase-to-phase (AC or DC) services when line powered or 0-600V (AC or DC) when externally powered. Measures up to four channels of energy metrics with currents ranging from 0-6,000 amps.
- Analog inputs record analog data with configurable input ranges for voltage (0-10 VDC) or current loop (0-20 or 4-20 mA) transducers. Analog inputs are used for process or environmental correlation studies with power.
- Line-powered – no need for batteries or external power source.
- User-selectable recording intervals as short as every 1 second.
- 16 MB non-volatile memory standard for months of recording time.
- Better than 1% accuracy (<0.2% typical).
- Fast USB connection and standard Ethernet port.
- ELITEpro XC may be configured with optional Bluetooth® wireless technology.
- Optional Wi-Fi interface allows for remote data collection over wireless networks. Check realtime values using a Wi-Fi-enabled laptop, tablet, or smartphone via a web browser.
- Simple yet powerful Windows-based ELOG™ software package for setup, data retrieval, and analysis. Easy data exporting to almost any analysis program.
- Easy to setup and installs in minutes. Patented PhaseChek™ LED indicators ensure correct CT orientation at installation.
- Rugged and compact—easily fits inside breaker panels and switch gear.

APPLICATIONS

- Measurement and Verification (M&V) Studies
- Electrical Load Profiling
- Energy Audits
- New Technology Assessment Studies

ELITEPRO XC™ DETAILS

FOCUSED ON ENERGY MEASUREMENT

DENT Instruments designs and manufactures data loggers and energy recorders for today's energy professionals. Our products are often the first step in developing strong energy strategies, for maintaining peak operations, and for lowering operating costs. Our company has built a reputation for providing instruments of the highest quality whose robust design, small size and remote data acquisition make them the loggers of choice for companies large and small.

Since the company's emergence in 1988, we have performed energy measurement studies for a wide range of utility, government, and private clients. This unique customer perspective has strongly influenced the design of our products, reflected in their ease of installation and use.

DENT products provide meaningful energy data that is used to accurately allocate energy costs, identify energy cost-savings opportunities and lower utility bills. Our versatile instruments help pinpoint electrical usage and quantify consumption.

A DEPENDABLE AND VERSATILE TOOL TO MEASURE YOUR ENERGY USAGE

The ELITEpro XC is a complete solution for pinpointing electric usage and quantifying energy usage. It is capable of measuring, storing, and analyzing electrical consumption data which is derived from the voltage and current inputs. The ELITEpro XC uses direct connections to each phase of the voltage and various interchangeable CT options such as split-core current transformers or flexible RoCoils™ (for large loads or large cables and bussbars) to monitor current on each phase.

These meters can capture kWh/kW energy and demand data as well as virtually all relevant energy parameters for diagnostics and monitoring on three-phase or single-phase circuit installations. Electrical load diagnostic parameters, such as displacement power factor, are captured in addition to energy and demand values.

The ELITEpro XC's flexibility, size, and ease-of-use make it the ideal tool for gathering detailed consumption information in commercial, industrial, government and retail environments.

FOUR ANALOG INPUT CHANNELS: CORRELATE YOUR CONSUMPTION WITH ENVIRONMENTAL CONDITIONS

New to the ELITEpro XC are 4 analog input channels which can be configured for voltage or current input used in any combination among channels. Analog inputs are especially helpful when used in conjunction with power measurements to correlate the consumption of electricity with environmental, HVAC plant performance, or other process conditions. Typical uses might include logging ambient temperature, building temperatures, solar insolation, tank pressures, duct flows, etc. Obtain this valuable data using just one meter: the ELITEpro XC.

ELITEPRO XC ANATOMY



ELITEPRO XC™ FEATURES

LINE POWERED WITH REDUCED IMPACT ON THE ENVIRONMENT

The ELITEpro XC is powered directly from the phases of the service being measured. It incorporates a broadband power supply which operates on virtually any 80-600V phase-to-phase service. You will not have to worry about constantly changing or recharging batteries, nor finding an external power source at the job site. And you will avoid the negative environmental impact of disposing of batteries containing rare earth materials that are difficult to recycle or reclaim.

MEMORY FOR EXTENDED RECORDING

Measurements are stored in on-board memory at recording intervals selected by the user, which can be as short as one second or as long as once every 24 hours. The ELITEpro XC has 16MB of internal non-volatile memory, which allows for long-term logging sessions. For example, the ELITEpro XC can record a WYE setup with all available system measurements using a 2 minute integration interval for over 160 days!

FAST SAMPLING RATE DISPLAYS POWER QUALITY DATA

Regardless of the user-selectable recording interval, the ELITEpro XC has a waveform sampling frequency of 12 kHz. This is the number of data points the logger samples on each AC waveform (200 points per cycle at 60 Hz; 240 points per cycle at 50 Hz). This fast sampling rate allows for real-time display of voltage, current waveforms, and harmonics. The channel sampling rate is 8 Hz or every 125 mSec.

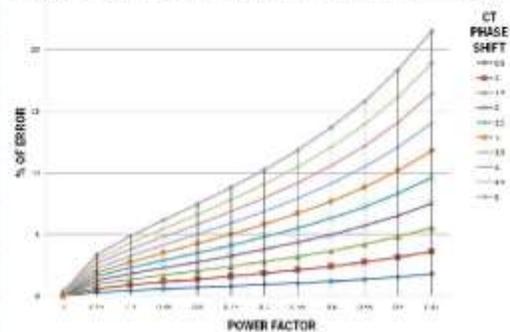


A drop-in, NEMA 4X rated enclosure is available for harsh environments.

EXCLUSIVE CT PHASE ERROR CORRECTION

All CTs exhibit both a ratio error and phase shift error. The CT phase error results from the phase relationship of the input versus output signal difference. This inherent phase angle error affects power readings if left uncorrected. When using CTs with a known phase angle error, the ELITEpro XC can correct for this error—making your calculations more accurate, particularly on loads with low power factor.

EFFECT OF CT PHASE ANGLE ERROR ON POWER MEASUREMENTS



For example, with an uncorrected 3° phase angle error and reported power factor of 0.5, there is a corresponding kW error of >10%.

BI-DIRECTIONAL METERING FOR RENEWABLES STUDIES

The ELITEpro XC design delivers bidirectional metering, which is capable of monitoring power generated by a renewable energy source versus power imported from the grid—ideal for solar power measurements.

FIELD-PROVEN: RUGGED & COMPACT

Measuring in at only 21.6 x 6.3 x 4.7 cm (8.5" x 2.5" x 1.9") and weighing 340 grams (12 ounces), the ELITEpro XC was designed to fit inside panels for safety and convenience. Its rugged plastic housing is even supplied with magnets on the housing to facilitate mounting.

Our optional NEMA 4 rated weather-tight drop-in enclosure delivers stronger environmental integrity, separate voltage plugs, water-tight connectors for both the current leads and the power and communication cables. This option for the ELITEpro XC will meet the stringent requirements of remote data logging.

ELITEPRO XC™ START TO FINISH

EASY SETUP, INSTALLATION, AND DATA RETRIEVAL

Using the ELITEpro XC on your next project is as easy as 1, 2, 3.

1 INSTALL ELOG AND SEND A SETUP TABLE TO THE ELITEPRO XC

The ELITEpro XC is configured using ELOG software. A Setup Table is the file that programs the logger for an upcoming project. Set parameters such as sampling rate and type of service then send the file to the logger. The ELITEpro XC is now ready for deployment.



A simple one-page Setup Table guides you through the ELITEpro XC's flexible metering options.

2 CONNECT THE ELITEPRO XC TO THE PANEL YOU NEED TO MEASURE

Installation and connection of the ELITEpro XC is both simple and straightforward. Magnets on the housing facilitate mounting inside electrical cabinets. A variety of internally-shunted, snap-on CTs and clip-on voltage leads connect to almost any panel load without turning the power off.

3 DOWNLOAD THE DATA FROM THE ELITEPRO XC

At the end of the project, simply connect the ELITEpro XC to a computer with ELOG and download the data file. Analyze the data and create graphs in ELOG or export the data as a .csv file to popular spreadsheet programs, such as Microsoft Excel®.

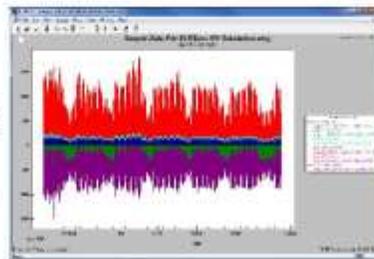


In-Depth Data Analysis: Display your data graphically.

ELOG™ SIMPLE DATA ANALYSIS

POWERFUL SOFTWARE

The Windows-based ELOG software package is used to program the meter, display metered values, and retrieve and analyze the collected data. ELOG graphically displays recorded data, performs analysis, and facilitates automatic remote data collection. Data is also easily exported to popular spreadsheet and database programs for additional analysis. You are provided with an unlimited site license to the software with purchase.

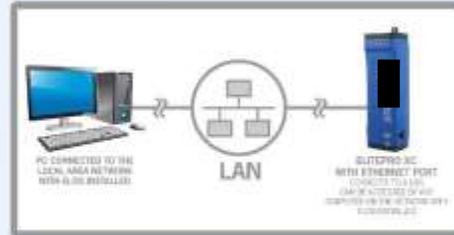


COMMUNICATION OPTIONS

CONNECT TO THE ELITEPRO XC FOUR WAYS

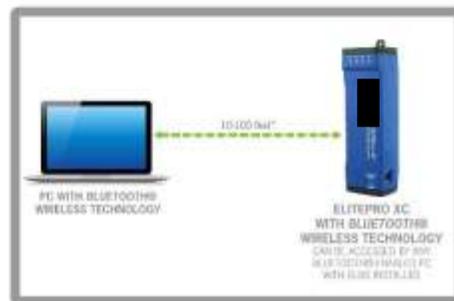
STANDARD USB AND ETHERNET CONNECTIONS

Every ELITEpro XC includes a USB and Ethernet (RJ-45) port. Connect directly to the ELITEpro XC via the included A-to-B USB cable. Or, have the ELITEpro XC on your local area network for convenient remote data download. Supports 10/100 MB Ethernet over Cat 5 or better and can be configured for DHCP or static IP. Schedule automatic data downloads from the logger using AutoPoll software (included with ELOG). Reconfigure the ELITEpro XC for a new project without leaving your workstation.



OPTIONAL BLUETOOTH® WIRELESS TECHNOLOGY

Save time and meet safety requirements by communicating with the ELITEpro XC without removing the electrical panel door. In addition to the standard USB and Ethernet ports, ELITEpro XC instruments may be equipped with an optional Bluetooth® interface, which will allow a PC with a Bluetooth® adapter running ELOG to connect to the ELITEpro XC over short distances (10-100 feet typical) to send setup tables or download data. PC must support Serial Port Profile (SPP).



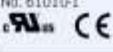
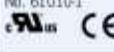
OPTIONAL WI-FI INTERFACE

Need a meter on your local area network but do not have a network connection near by? The ELITEpro XC's optional Wi-Fi interface allows the meter to be connected to a Wi-Fi network and accessed from any PC on the network using ELOG software. Or, configure the ELITEpro XC as its own Wi-Fi hotspot and view real-time data using a Wi-Fi enabled PC, tablet, or smart phone via a web browser from up to 300 ft. away. Two antenna options available: internal antenna (75-300 ft.) or external 3 dbi antenna (150-300 ft.). Use ELOG to switch between Wi-Fi and Access Point mode.



Access Point mode sets the ELITEpro XC as an access point. View real-time data on a Wi-Fi enabled laptop running ELOG software.

ELITEPRO XC™ TRANSFORMERS

	MINI HINGED HBC-020, -050 	MIDI HINGED HMC-100, -200 	HIGH ACCURACY HHS-0005, -0015 	SMALL SPLIT CORE SCS-0050, -0100 	MED SPLIT CORE SCM-0100, -0200, -0400, -0600 
KEY SPECIFICATIONS					
WINDOW SIZE	1 cm (0.4")	2.5 cm (1.0")	1.0 cm (0.4")	1.9 cm (0.75")	3.2 cm (1.25")
OUTPUT SIGNAL	333 mV at rated current	333 mV at rated current	333 mV at rated current	333 mV at rated current	333 mV at rated current
USEFUL CURRENT RANGE	0.25-40 Amps 0.25-80 Amps	1-200 Amps 1-300 Amps	0.05-7 Amps 0.15-20 Amps	1-65, 2-130 Amps	5-130, 4-260, 8-520, 12-780 Amps
ELECTRICAL SPECIFICATIONS					
NOMINAL RATING	20, 50 Amps	100, 200 Amps	5, 15 Amps	50, 100 Amps	100, 200, 400, 600 Amps
ACCURACY	<0.5% at rated current	<1.0% at rated current	+/- 0.5% at rated current	+/- 1% at 10% to 130% of rated current	+/- 1% at 10% to 130% of rated current
PHASE SHIFT	<1.5° at rated current	<0.5° at rated current	<0.5° at rated current	<2° at rated current	<2° at rated current
FREQUENCY RANGE	50 Hz to 400 Hz	50 Hz to 400 Hz	10 Hz to 10 KHz	50 Hz to 400 Hz	50 Hz to 400 Hz
DIELECTRIC STRENGTH	3520 VAC for 1 minute	5200 VAC for 1 minute	5000V around the case 600V rated leads	5000V around the case 600V rated leads	5000V around the case 600V rated leads
MECHANICAL SPECIFICATIONS					
DIMENSIONS	2.6 x 2.9 x 4.2 cm (1.04 x 1.16" x 1.64")	4.7 x 4.7 x 7.0 cm (1.85 x 1.85 x 2.76")	6.4 x 2.5 x 5.1 cm (2.5 x 1.0 x 2.0")	5.08 x 5.34 x 1.95 cm (2.0 x 2.1 x 0.6")	8.26 x 8.6 x 2.54 cm (3.3 x 3.4 x 1.0")
WEIGHT	91 g (3.2 oz)	221 g (7.8 oz)	136 g (4.8 oz)	136 g (4.8 oz)	340 g (12 oz)
POLARITY	White lead is positive	White lead is positive	White lead is positive	White lead is positive	White lead is positive
OUTPUT LEAD	Leads 2.7 m (8 ft) twisted pair, 20 AWG	Leads 2.7 m (8 ft) twisted pair, 22 AWG	Leads 2.7 m (8 ft) twisted pair, 22 AWG	Leads 2.7 m (8 ft) twisted pair, 20 AWG	Leads 2.7 m (8 ft) twisted pair, 20 AWG
OPERATING TEMPERATURE	-15° to 60 °C (5° to 140 °F)	-15° to 60 °C (5° to 140 °F)	-20° to 55 °C (-4° to 131 °F)	-20° to 55 °C (-4° to 131 °F)	-20° to 55 °C (-4° to 131 °F)
STORAGE TEMPERATURE	Maximum 105 °C (220 °F)	Maximum 105 °C (220 °F)	Maximum 80 °C (176 °F)	Maximum 80 °C (176 °F)	Maximum 80 °C (176 °F)
CASE PROTECTION	White nylon, UL 94 V-0	White nylon, UL 94 V-0	Epoxy encapsulated housing ABS/PVS UL 94 V-0	Epoxy encapsulated housing ABS/PVS UL 94 V-0	Epoxy encapsulated housing ABS/PVS UL 94 V-0
SAFETY SPECIFICATIONS					
SAFETY REQUIREMENTS	UL Recognized: UL STD 61010-1 Certified to: CAN/CSA STD C22.2 No. 61010-1 	UL Recognized: UL STD 61010-1 Certified to: CAN/CSA STD C22.2 No. 61010-1 	Compliant with IEEE C57.13-1993 CE Mark 	Compliant with IEEE C57.13-1993 CE Mark 	Compliant with IEEE C57.13-1993 CE Mark 
WORKING VOLTAGE	600 VAC Category II	600 VAC Category II	Maximum 600 Vrms UL 506	Maximum 600 Vrms Category II	Maximum 600 Vrms Category II

The ELITEpro XC can be equipped with a wide selection of current transformers, which can be interchanged depending on your project needs. Choose from compact and economical Split-Core CTs, convenient Clamp-On style CTs, or the versatile Rogowski Flex CTs. All CTs are shunted and each type offers its own particular advantages depending on your application.

LARGE SPLIT CORE SCL0600, 3000	150A CLAMP-ON CON0150EZ	1000A CLAMP-ON CON1000	ROCOIL R16, R24, R36, R72
			
5.1 cm (2.0")	5.2 cm (2.0")	5.2 cm (2.0")	16": 13 cm (5") 24": 19 cm (7") 36": 26 cm (10") 72": 56 cm (22")
333 mV at rated current	333 mV @ 150 Amps AC	333 mV/A @ 1000 Amps AC	131 mV/1000A @ 60 Hz 110 mV/1000A @ 50 Hz
30-780, 20-1300 Amps	.5 to 300 Amps	20 to 1200 Amps	EXC/ESP/PS3/PS24: 5-5000 Amps* PS18: 50-3500 Amps
600, 1000 Amps	150 Amps	1000 Amps	3000 Amps
+/- 1% at 10% to 130% of rated current	<1% at rated current	+/- < 1%	+/- 1% reading
<2° at rated current	< 1° from 5 to 25A 1° from 25 to 150A < 1.5° from 150 to 300A	+/- < 1°	< 1° at 50/60 Hz
50 Hz to 400 Hz	50 Hz to 400 Hz	30 Hz to 5 kHz	40 Hz to 5000 Hz
5000V around the case 600V rated leads	5200 VAC, CAT III	5200 VAC, 50/60 Hz between primary, secondary and the outer case of the handle	7400 VAC around coil 1000 VAC rated leads
12.07 x 12.70 x 3.05 cm (4.8 x 5.0 x 1.2")	8.7 x 5.0 x 1.9 cm (3.4 x 1.9 x 0.8")	21.6 x 11.1 x 4.5 cm (8.5 x 4.4 x 1.8")	Length 16" (40 cm) Length 24" (60 cm) Length 36" (90 cm) Length 72" (180 cm)
748 g (26 oz)	136 g (4.8 oz)	500 g (19 oz)	16": 184 g (6 oz) 24": 216 g (7 oz) 36": 312 g (11 oz) 72": 495 g (17 oz)
White lead is positive	Red lead is positive	Red lead is positive	White lead is positive
Leads 2.7 m (8 ft) twisted pair, 20 AWG	2.4 m (8") 22 gage, 600V	3 m (118") Double insulated	2 m (79") shielded cable
-20° to 55 °C (-4° to 131 °F)	-20° to 70 °C (-4° to 158 °F)	-10° to 50 °C (14° to 120 °F)	-10° to +80 °C (+14° to +176 °F)
Maximum 80 °C (176 °F)	-25° to 70 °C (-13° to 158 °F)	-20° to 70 °C (-4° to 160 °F)	Maximum 80 °C (176 °F)
Epoxy encapsulated housing ABS/PVS UL 94 V-0	White ABS, UL 94 V-0	IP 40 (IEC 529) UL 94 V-0	Thermoplastic Rubber UL 94 V-0
Compliant with IEEE C57.13-1993 CE Mark	UL Recognized: UL STD 61010-1 Certified to: CAN/CSA STD C22.2 No. 61010-1	CAN/CSA STD C22.2 No. 61010-1	CE Mark, Double Insulation, EN-61010 CAN/CSA STD C22.2 No. 61010-1
			
Maximum 600 Vrms Category II	Maximum 600 Vrms Category III	Maximum 600 Vrms Category III	Maximum 1000 Vrms Category II

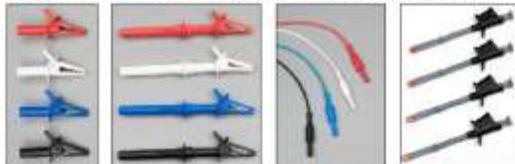
*Depending on meter compatibility, ELITEpro-SP (x212 or newer firmware) and PowerScout 3 (x316 or newer firmware) rated for 5-5000A.

ELITEPRO XC™ SPECIFICATIONS

TECHNICAL		POWER	
SERVICE TYPE	Single Phase (two wire or three wire), Three Phase-Four Wire (WYE), Three Phase-Three Wire (Delta), DC Systems (Solar/Battery)	LINE-POWER	From L1 Phase to L2 Phase, 80-600V (AC or DC) CAT II DC/50/60 Hz, 125 mA, 5 W, or 10 VA max. Non-user replaceable. 5 Amp internal fuse protection.
VOLTAGE CHANNELS	3 channels, CAT II, 0-600 VAC (line-to-line) or 600 VDC	POWER IN	6-10 VDC, 500 mA
CURRENT CHANNELS	4 channels, .67 VAC max, +/- 1 VDC. Ideal for 333 mV full scale CTs	POWER OUT	6 VDC, 200 mA max
MAXIMUM CURRENT INPUT	External transducer dependent. 200% of current transducer rating (mV CTs). Measure up to 6000A with RoCoil CTs.	COMMUNICATIONS	
MEASUREMENT TYPE	True RMS using high-speed digital signal processing (DSP)	USB (STANDARD)	USB standard (Type B), 1.8 M (6 to A-to-B USB Cable included)
LINE FREQUENCY	DC/50/60 Hz*	ETHERNET (STANDARD)	Standard RJ-45 Connector supports 10/100 MB Ethernet over Cat 5 or better. Configure for DHCP or Static IP.
WAVEFORM SAMPLING	12 bits	BLUETOOTH® WIRELESS TECHNOLOGY (OPTIONAL)	Internal antenna with 10-100 ft range (typical). Requires Bluetooth® wireless technology adapter on Windows PC. Adapter must support the Serial Port Profile (SPP).
CHANNEL SAMPLING RATE	125 seconds	WI-FI ADAPTER† (OPTIONAL)	Wi-Fi option available as two separate configurations: • Internal antenna, typical range 75-300 ft. • External 3 dbi antenna, typical range 150-300 ft.
INTEGRATION PERIOD	1, 3, 15, 30 seconds; 1, 2, 5, 10, 15, 20, and 30 minutes; 1 and 12 hours; 1 day	MECHANICAL	
ENERGY MEASUREMENTS	Volts, Amps, Amp-Hrs (Ah), kW, MWh, MVAR, MVARh, kVA, MVAh, Displacement Power Factor (DPF). All parameters for each phase and for system total.	OPERATING TEMPERATURE	-7 to +60 °C (20 to 140 °F)
ANALOG MEASUREMENTS	0-10 Volts, 0-30 or 4-20 mA current loop. Non-isolated, external power for current loop. User scaling for sensor reporting in physical units.	OPERATING HUMIDITY	5% to 95% non-condensing
ACCURACY	Better than 1% (<0.2% typical) for V, A, kW, MVAR, kVA, PF, Analog	ENCLOSURE TYPE	ABS plastic, 94V0 flammability rating
RESOLUTION	0.01 Amp, 0.1 Volt, 1 Watt, 1 VAR, 1 VA, 0.01 PF, 0.01 AWh	WEIGHT	340 g (12 ounces)
LED INDICATORS	Tricolor (red, green, blue); 1 LED indicates communication (blue for wireless, Bluetooth® or Ethernet); 4 LEDs for correct phasing (PhaseCheck™).	DIMENSIONS	21.6 x 6.3 x 4.7 cm (8.5" x 2.5" x 1.9")

A VARIETY OF VOLTAGE CLIPS

Several voltage clips options are available to meet your project needs: Croc Clips, Fused Crocs, Colored Leads, or Shark Clips.



Croc Clips

Fused Croc Clips

Colored Leads

Shark Clips

* ELITEpro XC loggers that are equipped with a Wi-Fi package contain an internal antenna. An external antenna is optional. You may toggle between using the internal and external antenna if it is available on your logger by checking or unchecking the *Use External Antenna* checkbox in ELITE.

† US/NORTH AMERICAN ELITEpro XC configuration includes 4 color (black, blue, red, white) voltage leads and croc clips. INTERNATIONAL ELITEpro XC configuration includes 3 black voltage lead connectors, 1 white connector (internal) and 5 color (black, blue, red, white, yellow) voltage leads and croc clips.

ORDERING INFORMATION

EXC ORDER STRING

VOLTAGE LEAD COLORS (CHOOSE ONE)

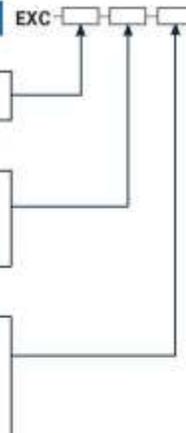
- U = US/NORTH AMERICAN†
- I = INTERNATIONAL†

ADDITIONAL COMMUNICATION OPTIONS (CHOOSE ONE)

- N = NONE (ETHERNET & USB ONLY)
- B = BLUETOOTH® WIRELESS TECHNOLOGY
- W = WI-FI WITH INTERNAL ANTENNA
- WE = WI-FI WITH EXTERNAL 3 DBI ANTENNA

VOLTAGE CLIPS (CHOOSE ONE)

- C = CROC CLIPS
- F = FUSED CROC CLIPS
- S = SHARK CLIPS
- L = UNTERMINATED LEADSET
- N = NONE



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