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Visualization of Electricity Consumption: Software Prototype through Literature Survey

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Abstract:-Visualization of energy consumption is widely considered as an important means to assist the end-users and the energy managers in reducing energy consumption and bringing about sustainable behavior. However, there are no clear design requirements to develop the energy monitoring visualization. This paper makes a leap forward in identifying the functional and non-functional requirements through a systematic literature review (SLR) of 28 papers. Also, the recommendations to tackle the requirements are also presented, which would help the visualization designers or researchers in designing the visualization. Through the information from the SLR, a software prototype for 'visualization of electricity consumption' is proposed, which is created using open source software.

Keywords:Energy consumption, visualization, energymonitoring, software prototype.

I. INTRODUCTION

Visualization of energy consumption has huge potential to support energy conservation in households. Globally, there are numerous key factors such as depleting conventional energy resources [11], global warming [2, 17, 23], etc. which emphasize the need for energy conservation. Although the design of visualization of electricity consumption is prevalent, no explicit set of design criteria for visualization have been specified. The main objective of the visualization is to bring a sustainable behavior among the end-users. Several research efforts identified the criteria, but they were not targeted towards all classes of end-users and developers. The paper conducted a rigorous literature survey, which analyzed the functional and non-functional requirements to achieve sustainable behavior among the end-users in energy conservation.

The paper is organized as follows: Section II details the related work in this research. Section III illustrates the systematic literature review (SLR), followed by the results of the SLR in section IV. The section V explains the proposed software prototype, followed by conclusion in section VI.

II. RELATED WORKS

Visualization of energy consumption is in its infancy, which has the history far behind in late 1970s, when a psychologist placed post cards with daily energy consumption. This research effort exhibited the hope for energy reduction among the households. The energy consumption was visualized in various forms, but it became digital, when the real time energy information was visualized in a personal computer in the late 1990s.

Although the visualization existed, the research efforts were very less compared to all other fields. In the mid 2000s, the energy monitoring utilized the mobile platforms which became handy and easily accessible for the end-users. Lot of research efforts helped in making visualization highly exhibitive and technologically sound. Currently, the energy monitoring started moving towards bringing the sustainable behavior through the human computer interaction (HCI).

III. SYSTEMATIC LITERATURE REVIEW

Systematic literature review (SLR) is conducted and an initial set of 232 papers is found from the resources such as Scopus, ScienceDirect, IEEEXplore, ACM Digital Library, SpringerLink, and INSPEC using key search terms such as {(*visualization* OR *informationvisualization*) AND (*energy consumption* OR *energy utilization* OR *electricity consumption*)}. After removingduplicates and applying quality and relevance filters, a total of 28 papers were identified to undergo data synthesis (i.e., the process of summarizing the extracted data in the understandable format). The quality filters and the relevance filters used are explained in Table I. The Grounded Theory's open coding and constant comparison method [27] were used for data synthesis. It is the bottom up approach for identifying the patterns within the raw datasets [27].

TABLE I. QUALITY AND RELEVANCE FILTERS

Quality Filters	(a) Is the article peer-reviewed? (b) Does the article report unambiguous findings based on evidence and argument? (c) Is the article written in English?
Relevance Filters	(a) Do the articles discuss both on visualization and energy consumption in households, workplace, public buildings, etc.?

A. Research Question

The goal of this review is to understand the current evidences and challenges in the visualization of electricity consumption, and to provide comprehensive solution to the following research question. *What are the functionaland non-functional requirements/goals for visualizing the electricity consumption?*

IV. VISUALIZATION OF ELECTRICITY CONSUMPTION

The central theme of the software application is '*Visualization of Energy Consumption*'. The application visualizes the household appliances' electricity consumption. The application targets the devices such as mobile devices, iPad, desktop, etc. (cross platform). The main contribution in this research is to bring a sustainable behavior among the end users.

A. Functional Requirements for Visualization of Electricity Consumption

Table II explains the functional and non-functional requirements and its recommendations from the literature. The first functional requirement is *User InterfaceEngagement*, i.e., engaging the user for a long time toattain sustainable behavior through user interface [8]. This could be achieved by portraying the real time data (i.e., energy consumption data displayed every millisecond) and by the effective choice of visualization techniques. The visualization techniques are any 2D [1, 2, 4, 6, 7, 9, 11-14, 16-21, 24-26, 29] or 3D diagrams [6, 10, 16] such as charts, graphs that portrait the energy consumption in a household.

To address the *One-size-fits-all* requirement [8], the visualization software provides every function in the form of widgets. The end-user or energy manager could choose the appropriate widget to choose their need. *Improve end-user cognition* [5] is another design requirement whichcould be solved by suggesting the end-user with energy conservation tips. E.g. Use cold water for washing instead of warm or hot water. The next functional requirement isto *Avoid Peak Pricing* [8]. This could be achieved by displaying the alert box with the message "Peak pricing has started, postpone the energy usage whenever applicable". The requirement *Accuracy inRecommendations* [12] could be accomplished by makingthe energy tips active, i.e., tips could be provided based on the environmental sensors (light intensity, temperature, humidity, etc.), e.g., avoid using dryer as the temperature is high enough to dry the clothes under the sun. The end-user might look for *Easily Understandable Metrics* [25, 29] such as cost of electricity (in $) rather than other metrics such as kilowatt (kW), kilowatt-hour (kWh), and pounds of CO_2 emission (gCO_2), which could not be understood by the novice user.

TABLE II. DESIGN REQUIREMENTS AND CORRESPONDING RECOMMENDATIONS

	Design Requirements/ Goals	**Recommendations**	**Evidence from Literature**
Functional Requirements	User Interface engagement	Real time energy consumption data, interesting visualization techniques	[8]
	Avoid Peak Pricing	Alerts displayed to inform the end-users about the energy pricing	[8]
	Improve end-user cognition	Suggestions to improve energy conservation	[5]
	Easily understandable metrics	Use the cost (in $) instead of kW, kWh, CO_2 emission etc.	[25, 29]
	Motivational factors	Incentives, Rewards & Claim	[2, 8]
		End-users could be challenged to achieve pre-set goals, e.g. 1% or 2% savings	[4, 15]
		Competition among social peers	[2, 4, 7, 8]
	Accuracy in recommendations	Sensors would be used to provide accurate recommendation for the end-users	[12]
	Suitable for both end-users and energy managers	Drop downs could be used to choose between end-users and energy managers	[1, 2, 4, 6, 7, 9, 12, 14, 16, 19-21, 24, 29]
	Target both vision and hearing sense	Energy consumption suggestions/tips could be provided through recorded voice	[4]
	Disaggregation	Information regarding individual appliance could be provided	[15]
	Energy Prediction	Prediction of energy for a day, week or month (i.e., energy bill)	[7]
	Historical information	Comparison of energy consumption among different days, weeks, months or months of two consecutive years, etc.	[2, 4, 7, 14, 15, 24]
	Affective energy conservation	Environmental impact due to energy consumption	[5, 11, 15]
	Cumulative savings	$100 per year is more effective than $2 per year or $0.30 per day	[28]
	Fault Detection	Alert displayed when any of the sensors is not working	[7, 22]
	One-size-fits-all problem	End-user could select the widgets, which they are interested in	[8]
No	Portability	Cross platform development software such as *PhoneGap* could be used.	[11]

	Extensibility	Open source software could be used to increase extensibility	[6]
	Accessibility	The software application could be made available online for being easily accessible	[11, 25]
	Understandability	Visualization could provide balloon help (similar to tooltips) and help manual	[4, 13]
	Scalability	The ability of the application to scale in order to accommodate future information in the visualization	[2, 4]

There are several *Motivational Factors* for improving the energy conservation. They are (a) *Incentives, Rewardsand claims* [2, 8] (i.e., saving the energy would result inthe increase of reward points, which could be claimed once a threshold is reached. The incentive could be a voucher or discounted energy bill [8]), (b) *competitionamong the social peers*, i.e., the visualization coulddisplay comparison of energy consumption among friends in a social community, if desired [2, 4, 7, 8]. (c) *Pre-setenergy goals*, i.e., the energy consumption goal for a day,week or month could be specified such as 1% less, 2% less, etc. [4, 15]; in addition, the end-users would be notified on the current energy consumption level to motivate them. The visualization software must be*Appropriate for both end-users and energy managers*. Toenable this feature, the application holds a drop down to toggle between end-users [2, 4, 7, 9, 12, 14, 16, 19-21, 24, 29] and energy managers [1, 6, 7]. End-users and energy managers see the appropriate widgets respectively to choose. Almost all the literatures on *visualization ofenergy consumption* target only on vision sense [4]. To goup to the next level, the study targets both vision and the hearing senses by introducing voice enabled visualization software to inform the end-users. The voice delivers three important information. They are (a) ‘What to do?’ i .e., suggestions from the visualization software. E.g. please switch off the light. (b) ‘Why?’ i.e., the reason b ehind the suggestion. E.g., the surrounding light intensity is high.(c) ‘Benefit’ i.e., to specify how the suggestion h elp the end-user. E.g. it helps in bill reduction, almost saves $100 per year.

According to a survey, most of the end-users misunderstood that the size of the appliance was proportional to the energy consumption [3]. *Disaggregation* [15] is the important requirement for theend-users to understand each household appliance and its energy consumption effectively. *Energy Prediction* [7] is one of the important requirements, which could be solved by predicting the energy consumption of day, month (i.e., energy bill) or year, by modeling the household appliances. Modeling of the appliances could be done by using the *LabVIEW* software. *Historical Information* [2, 4, 7, 14, 15, 24] compares energy consumption among different days, weeks, months, or months of two consecutive years, etc. [15].

Affective Energy Consumption [5, 11, 15] is one of therequirements for motivating the end-users by illustratingthe environmental impact on conserving or wasting energy (e.g. Today, you saved *x*% energy than yesterday, which avoided ‘*x*’ pound of CO_2 emission, which in turn avoided planting ‘*x*’ trees), or specifying benefits to the end-users (e.g. ‘Today, you have saved *x*% energy than yesterday, which would save $*x* per year).

The next requirement *Cumulated Savings* is important in motivating the end-user psychologically. The negligible numbers are neglected by the human mind. It is better to represent the savings or expenses in the cumulated way, i.e., represent $*x* per year instead of $*x* per week. E.g. $2 savings per week or $0.30 savings per day could be neglected by the human mind than $100 per year [28]. The requirement *Fault Detection* could help in identifying the sensors which are not working [7, 22]. An alert box could be displayed to inform the end-users.

B. Non-Functional Requirements for Visualization of Electricity Consumption

The non-functional requirements for the visualization of electricity consumption are as follows. The requirement *Portability* [11] is defined as the ability of the applicationto work on multiple platforms and devices, such as mobile, Internet, in-home display, iPad, etc., which is achieved by using a cross platform supporting software like *PhoneGap*. *PhoneGap* is open source software, which also solves the design challenge *extensibility*. *Extensibility* [6] is defined as the ease for the developers to extend the application.

The term *Accessibility* could be referred as the ease of finding, downloading and using the visualization application online, such as on websites or social networking sites [25]. *Accessibility* could also be defined as the ease of downloading the feedback online for offline processing [11]. This is an important requirement which could be satisfied by developing the visualization software as web-based or mobile-based application.

The requirement *Understandability* [4, 13] could be defined as the ease in recognition of information displayed in the visualization. This could be accomplished by using balloon tips (which is similar to tooltips in Windows) and help manual to help the end-users in getting ease with using the application.

The next non-functional requirement is *Scalability* [2, 4] is defined as the ability of the application to scale in order to accommodate future information in the visualization. The application is expected to be more scalable.

V. PROPOSED SOFTWARE PROTOTYPE

A. Introduction

The development of a software prototype is the initial step in the development of software, which is the third phase (designing) in the software development life cycle. *Software prototyping* could be defined as the sample ormodel (i.e., replica of final product) of the software to evaluate the feasibility in the development of the softwareand the Prototyping involves several iterations after being reviewed by the expert group.

Software prototype for *visualization of EnergyConsumption* is developed using open source software, *Pencil*[1]. There were several design requirements that is toaddressed before developing the prototype. The software requirements were obtained from the systematic literature review, which is summarized in Table II. This prototype underwent several iterations of development after receiving feedbacks from end users and domain experts.

B. Software Prototype - Explanation

The software prototype for visualization of energy consumption is illustrated in Figure 1, which is built using open source software, *Pencil*, to address all the design requirements specified in Table II. The prototype shows application in iPad, but the application is portable across all platforms.

Figure 1. Software Prototype for *Visualization of Electricity Consumption*

On the right hand side of the application, the design requirements are converted into the widgets such as disaggregation, peak pricing, user cognition, historical energy consumption, energy tips, environmental impact, etc., from where the user could choose. The selected widgets are auto arranged on the left hand side of the application.

VI. Conclusion

Design is one of the most important aspects of the software life cycle (SDLC). Our paper identified the functional and non-functional requirements for the visualization of electricity consumption and provided plausible recommendations to address them. A total of 20 design requirements were identified for the application, which were collected from a systematic literature review, followed by the potential recommendations for the requirements for visualization. From the identified requirements, a software prototype has been designed to visualize the electricity consumption with the help of a software tool called *Pencil*. This paper would help the *visualization designers* or *academic researchers* toconsider the requirements and to solve the challenges pertaining to the design of visualization software for electricity consumption.

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