Front-End Development for Home Automation Systems using JavaScript Frameworks
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Abstract—Automation technologies are widely acclaimed to have the potential to significantly reduce energy consumption and energy-related costs in buildings. However, despite the abundance of commercially available technologies, automation in domestic environments keeps on meeting commercial failures. The main reason for this is the development process that is used to build the automation applications, which tend to focus more on technical aspects rather than on the needs and limitations of the users. An instance of this problem is the complex and poorly designed home automation front-ends that defer customers from investing in a home automation product. In this context, the current research work investigates the different design problems associated with developing a home automation interface as well as the existing design solutions that are applied to these problems. The Qualitative Data Analysis approach was used for collecting data from research papers and the open coding process was used to cluster the findings. From the analysis of the data collected, requirements for designing the interface were derived. A home energy management functionality for a Web-based home automation front-end was developed as a proof-of-concept and a user evaluation was used to assess the usability of the interface. The results of the evaluation showed that this holistic approach of designing interfaces improved its usability, which increases the chances of its commercial success.

Keywords: Home Automation, User Interface Design, Human-Computer Interaction, Web Application development, Qualitative Data Analysis, JavaScript Framework

I. INTRODUCTION

The primary purpose of building automation systems (BAS) is to optimize cost and energy efficiency in operating building spaces through the automatic and remote control of indoor environmental conditions. This can be done by regulating the heating, air-condition, ventilation and lighting systems of buildings through the deployment of interconnected sensors and actuating devices. Home automation system (HAS) is a specialization of BAS where, besides optimizing energy consumption, the comfort and peace of mind of the home inhabitants are of similar priority.

In recent years, reducing energy consumption in buildings has gained increased interest amongst researchers, due to the growing global awareness about the need to achieve long-term environmental sustainability. Beyond this the numerous national legislations being approved to reduce CO₂ emissions demand immediate actions on this topic. According to the European Commission, buildings account for 40% of energy consumption and 36% of CO₂ emissions in the EU. The European Commission estimates that by using proven and commercially available automation products in buildings, it is possible to reduce the total EU energy consumption by 5-6% and the CO₂ emissions by about 3% [1].

However, despite the wide availability of home automation technologies, a significant number of repeated commercial failures has been noted and the reluctance of customers to invest into these technologies still remains relatively high. Many reasons have been proposed to explain this phenomenon and these include: lack of flexibility and scalability to adapt to new technologies, the diverse availability of products that are not compatible with one another and last but not least, the low usability of HAS technologies. The front-end of the automation system is often reported to be the most unusable product due to its poor design and complex features, which result in home automation technologies being inaccessible to a wide range of non-technical users.

A. Background

Modern home automation system (HAS) architectures are usually distributed across a three-level hierarchy namely: a field level, an automation level and a management level. Figure 1 below shows the main functions that are associated with each level.

Currently there is no single standard technology that covers all the three levels of the architecture and as a result heterogeneous technologies and design solutions have proliferated with no standard principles for interoperability. This greatly affects the development of a management-level application such as a visualization and control user interface as each technology comes with its own data representation that is tightly coupled to its internal requirements. Since it is difficult to integrate all these sources of data into a single information model it becomes complicated for engineers to build a good and universal user interface for the HAS.

With the convergence of automation technologies and Software-as-a-Service business models, home automation has evolved from being an industrial application retrofitted for domestic environments to a
highly consumer-focused Internet of Things application. As home automation is now targeting a wider range of customers, especially non-technology enthusiasts, it is important to include the user needs, wishes and expectations into the design considerations of this technology. Since it is commonly accepted that a home environment holds an emotional attachment for its inhabitants, it means that for HAS application developers, the user experience should be a key design consideration.

With the proliferation of different mobile computing devices through which users interact in order to access information and carry out tasks, application development is now focusing on web-based approaches. This is because nearly all mobile computing devices feature an Internet browser, which uses open Web technologies such as HTML, CSS and JavaScript to render and run front-end applications. In addition, the JavaScript language has evolved greatly over the past decade to incorporate rich and interactive features into the browsers. As a result, the popularity of JavaScript-based application development is rising and it is considered as the next-generation Web standard for developing cross-platform applications since it greatly improves the usability of interfaces and therefore the user experience.

B. Statement Of Problem

Considering that building a user-friendly, interactive and multi-target interface for home automation system is a multi-disciplinary task, the development process for developers and designers, especially from the open source community, is a very complicated, time-consuming and very often not successful task. This is due to the fact that there is a lack of definitive design guidelines for front-end development in HAS.

In this context, the current research work is undertaken in order to investigate the design challenges that exist in the three distinct domain areas that are involved in this task, that are: home/building automation, HCI design and user-focused design approaches. The suitability aspects of the UCD approach, to enable developers to include users, usability and system requirements into their development process, is assessed. The outcomes of the research include a set of design challenges and guidelines that should help developers understanding the existing issues and create a more user-friendly, interactive and responsive UI for HAS.

II. LITERATURE REVIEW

The review revealed that the related research work in user interface (UI) development for HAS were conducted in a very fragmented way and each perspective on the matter was specialized towards a specific problem. Therefore, in order to gain a holistic understanding of the different aspects involved in the home automation interface development, the approach proposed by [3] to carry out such a research work was taken. In the context of smart homes, the paper demonstrated that any holistic development work for smart home applications should be based on the relationship between its three main dimensions which consist of home, human and technology.

From the home/technology perspective, one of the main technology-related problems that HAS application developers focus on is the interoperability of the heterogeneous automation technologies. According to [4] these diverse technologies and protocols have caused a problem of integration at the information level due the lack of interoperability of their data representation of devices and building layouts. The lack of interoperability in data description mechanisms makes it difficult to integrate different sources of information at the management level which in turn affects the development of high-level applications to process, visualize and control the entire automation system. Within [5] the problem to manage and aggregate useful information from a large amount of data, being generated by technology indifferent devices, has been described. This design problem was approached by implementing a standardized template system or information model that defines a common language for data representation and storage for both devices and buildings, also called Building Information Model(ing) (BIM). By using standardized templates, it becomes easier to implement applications, as the representation of data is predictable and not dependent on any specific device technology.

From the Human perspective the main challenges involved in the UI development are mostly concerned with concepts that involve usability and acceptability of the interface from the user point of view and the social consequences that may arise from this interaction [3]. The international standard ISO 9241-11 (Guidance on usability, ISO/IEC 1998) defines the usability of a product as “the extent to which it can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” [6].

The usability challenges of HAS interfaces can be clustered into 4 main problems: the first one is the need for users to manage different visualization and control interfaces due to the heterogeneity of technologies in HAS [8, 9]. Different interfaces for each technology means that the interface styles and interaction designs may also differ from product to product making it difficult for the users to learn how to use and manage them [9]. Secondly, the ability of users to understand and configure customized automation solutions that meet their needs is also identified as a major design requirement [10]. This is because end-user configurability enables users to derive benefits from automation technologies by for instance automating energy demanding tasks for low fare times of the day. In order to make end-user configurability user-friendly, using metaphors that are familiar to users were proposed. As an example, using temporal metaphors such as clocks and calendars instead of typing in commands can make user-defined automation more user-friendly [10].

The third usability problem arises due to the different mobile computing devices that are now used to access information and to carry out tasks. These devices have different hardware specifications and therefore require the application interface to be responsive and adapt to different hardware contexts, such as the screen resolution while having to maintain a good user experience. These types of multi-target front-ends are called plastic interfaces [11] and it is considered as the Web.

From the home/technology perspective, one of the main technology-related problems that HAS application developers focus on is the interoperability of the
energy management feature on the interface. Implementing an energy management system through the interface is a powerful mean to help users to achieve energy and economic savings as it can assist users become aware of their energy consumption habits, identify sources of energy wastes in the home and configure automation scenarios that reduce consumption accordingly [13].

Several research works adopted a user-focused research approach to understand the needs and limitations of the users to optimize the design of the UI [2, 7, 10]. According to [12] a good product design for HAS should satisfy users in three main ways: first the product should be designed so that it is useful for the users. Secondly it should allow users to easily and effectively perform tasks and finally a good product design helps users to derive meaning and positive emotional significance from its use. On the other hand, an interface, that is complex to use or can only be used by technology specialists, can be a source of frustration for the other users, which can lead to humiliating situations and increase in anxiety due to the inability to make the system work according to their wishes. The consequences of such frustrations can affect the overall perception of the users about the entire HAS.

Over the past decade, the popularity of JavaScript programming language for web application development has incessantly increased because it tackles the problem of cross-platform compatibility. In addition, JavaScript has enabled the development of rich and interactive applications which focus on providing a user-enhanced experience. This has been made possible mostly by the use of AJAX technology to dynamically update DOM elements without having to reload the entire web page [14]. Other important features that JavaScript frameworks offer for a front-end development are UI-elements like animations and different CSS templates for different screen resolutions when using responsive designs. All these interactive features give the means to developers to enhance the usability and user experience of an interface [15].

III. RESEARCH METHOD

The method that was utilized in this research work was the analytical-based Qualitative Data Analysis approach. By analyzing existing research works and existing interfaces to produce meaningful design requirements and design guidelines this leads to usable, acceptable and satisfying designs. The aim of undertaking a QDA research approach for the context of this project was to gain useful insights and draw out patterns about the existing recurring design problems that UI developers face as well as the existing solutions and best practices that they apply to build good and usable interface for home automation applications.

In the design and development of the home automation interface, the five main stages of the design process included:

1. Data Collection.
2. Qualitative Analysis of Data.

An overview of the different design tools and techniques employed at each stage of the UI design is shown in the Figure 2 below.

A. Data Collection

The data collection process was carried by using the investigative methods of literature study, document review and analysis of existing interfaces so as to examine what had already been found out in previous works.

According to ISO 9241-11 [6] in order to produce a usable interface, the design solutions should demonstrate an explicit understanding of its context of use. The ISO 9241-11 standard [6] defines the context of use as the “users, tasks, equipment and the physical and social environmental factors in which a product is used". Therefore the data collection process sought to answer questions about these three main dimensions and a set of questions to address these concerns were used as guidelines in order to systematically collect data from the existing research papers and to avoid subjective interpretation.

The data collection process was broken down into six main parts:

1. The first part was to define the users of the application which consisted in finding out the characteristics of the typical or stereotype user group for which the application is intended to.
2. The second part was to define the user tasks which should cover requirements concerning mainly the tasks the users need and wish to achieve, the user goals behind the task carried out, the frequency of the tasks, the results users expect from executing the task and the importance of the task to the users.
3. The definition of the physical and social environmental factors was the third part, which tried to define the additional resources such as hardware and software resources in which the interface is expected to work in the real world.
4. In addition to the above set of requirements it was also important to cover usability and other quality design aspects in the data collection.
5. Additional literature study was carried out to capture the functional requirements specific to the domain of home and building automation.

An overview of the different design tools and techniques employed at each stage of the UI design is shown in the Figure 2 below.

1. Data Collection: Document Review, Literature study and Analysis of existing interfaces
2. Qualitative Analysis: Open Coding with QDAMiner
4. Prototyping: Low Fidelity Prototype + Heuristics Evaluation
5. Final Interface: Front-end JavaScript Framework BootStrap + User Evaluation for Usability

Figure 2: design stages for the user interface using the QDA approach.
systems for the development of high-level applications.

6. For the analysis of the existing products, successful designs of other products were analysed so as to draw out best practices that can be reapplied for the context of this work.

B. Qualitative Analysis of Data

The qualitative analysis was done using an inductive approach and an open coding technique whereby recurring topics in the research papers and documents were identified and used to cluster data of similar nature under a common theme. In the context of this current research, the documented design problems and existing design solutions were grouped under common themes which related to a specific design aspect of the home automation user interface.

Grouping problems of similar nature made it easier to find patterns and recurring design challenges for which a common design requirement could be formulated in order to provide a solution to the latter. Also, clustering design solutions and best practices proposed by the literature and existing designs of interfaces under a common theme made it possible to extrapolate the same solution to other design problems of similar nature and to thereby formulate a design guideline that can be reused for future HAS UI development work.

The analysis of the data collected was done using the free version of QDAMiner. In QDAMiner, a code group category clustered data related to a particular design aspect of the interface. The group category is referred to as a theme. A group category could consist of several more detailed colored codes that related to a more specific design aspect of the interface. An individual colored code is referred to as a subtheme. Therefore, a group category or a theme had a set of codes or subthemes. A subtheme in turn grouped together a set of design problems. A subtheme was also associated with a set of design solutions. Furthermore, for each subtheme a set of requirements were derived.

Figure 3 shows the different relationships between the themes, subthemes, design problems, design solutions and citations of sources. The direction of reading is from the flat to the pointed end of the arrow.

![Figure 3: Overview of the coding and clustering process used in the analysis stage](image)

The analysis of the data collected led to the creation of eight main categories or themes. For each main theme a number of subthemes were defined, as the data collected referred to a more detailed design aspect of that theme. A break down and description of three of the themes and subthemes used for the coding process of the data collected is shown below:

- **Information**
  - **Analytics**: Computation of information, making queries on data, viewing time-based data
  - **data_aggregation**: Data from different sources are used to compute more complex information
  - **information_view**: The visualisation and presentation of data and information

- **Interface**
  - **interface_reusability**: Using the same interface for different home automation systems
  - **interface_interoperability**: Compatibility with different technologies, data sets or data sources.
  - **web_services**: Provide data from external web services to the user from the interface.
  - **basic_features**: What are the basic tasks that the interface should offer.
  - **interface_view**: The visualisation and presentation aspects of the interface
  - **data_representation**: how data from different technologies is represented on screen.
  - **interface_adaptibility**: The ability of the interface to adapt to different contexts of use.
  - **interface_learnability**: The intuitiveness of the interface.
  - **desired_features**: Tasks that users wished to be able to perform on the interface.
  - **advanced_features**: More complex tasks that can be performed on the interface.

- **Interaction**
  - **interaction_acceptability**: Techniques used to make the interaction more acceptable for the user
  - **interaction_ease_of_use**: Techniques used to make the interaction easy for the user to use the application
  - **interaction_generic**: Using same interaction techniques and abstractions to interact with different technologies.
  - **multi_tasking**: Techniques to allow users to switch from one task to another.

IV. IMPLEMENTATION

The following section details the steps taken in the implementation of the proof-of-concept for home automation interface, which was built to meet the functional, usability and user requirements.

A. User groups of home automation

The qualitative analysis of data allowed the identification of two distinct groups of home automation users. The first group consisted of early technology adopters who had extensive knowledge and experience in using automation applications. The second group consisted of users who did not have a technical background and had to interact with the HAS mainly because of living together with the early adopters. A summary of the main user characteristics are shown below:

• Description of Persona 1:
  o Young to middle aged.
  o Leader of the family.
  o Considered to be a technology guru or specialist who is responsible for HAS management, configuration and troubleshooting.
  o Has deep technical expertise in engineering-related or IT-related profession and thus is able to tinker with home automation.
  o Primary user of the HAS.
  o Wants peace of mind by connecting to HAS to check on the status of the home.
  o Gets tired of using the HAS after many years of tinkering and fixing the HAS and thus wants an easier way to manage system.

• Description of Persona 2:
  o Young to middle aged.
  o No or little technical or programming background.
  o Passive user of technology who does not actively engage in using or configuring or managing the HAS.
  o Being able to use web-based interfaces and modern applications on mobile devices.
  o Wants convenience by automating boring and complex tasks.
  o Wants peace of mind by connecting to HAS to check on the status of the home.
  o Wants to achieve cost and energy savings.
  o Does not like to feel humiliated by not being able to understand how to carry out a task.

B. Home Energy Management scenario

Due to the wide scope of the user needs and tasks, system and usability functionalities collected from the data collection process, it was necessary to define a specific scenario for the implementation of the proof-of-concept.

The scenario selected was the incorporation of a home energy management feature in the HAS front-end so as to help users become aware of their energy consumption habits and motivate them to decrease their power consumption by making use of the automation features. The user requirement consideration was decided if it matched either of the following criteria:

• Criteria 1 was a HAS specific requirement that focused on user experience, usability, interactivity and/or responsiveness.
• Criteria 2 was a requirement that focused on user experience, usability.
• Criteria 3 was a requirement that focused on the needs, expectations or limitations of the users.
• Criteria 4 was a requirement that was related to managing the energy consumption in the home using the HAS.

C. Prototyping

The template layout of a dashboard was used for the design of the energy management for the current home automation interface as it was found in the previous stages of the development cycle that it was efficient and user-friendly way of conveying and analyzing a large amount of numerical and statistical information to users of an interface application.

The initial mock-ups were evaluated with a set of three users using a set of heuristics principles introduced by [2] for evaluating the usability of interfaces. The following heuristics were used to evaluate the prototypes:

• Visibility of system status: Providing appropriate visual feedback and timely use of interactive UI features.
• Match between system and the real world: Avoiding the use of technical language and using metaphors that are understood by users.
• User control and freedom: Using simple interaction steps to facilitate navigation throughout the interface.
• Consistency and standards: Ensuring that the layout, UI components, metaphors and look-and-feel of the interface are consistent and standard.
• Recognition rather than recall: Helping the user to build a mental map of the interface by using familiar metaphors to minimise their need to memorise details.
• Flexibility and efficiency of use: Adapting layout of interface and using interaction techniques that help users to efficiently carry out tasks.
• Aesthetic and minimalist design: Minimising superfluous details and excessive text content.

D. Final Home Automation Interface

Due to its popularity for building responsive front-end applications Bootstrap was selected for developing the home automation interface. Besides Bootstrap the Harp.js workflow was used to make the development process even more easy. This makes the usage of template files for the general layouts of several web pages easier, faster, more maintainable and reusable for other applications.

Bootstrap as well as user-defined CSS files were used to customize the appearance of each UI component as well as the general layout of the application page.

Figure 4(a) below shows the implementation of the Charts section using interactive and UX enhanced components in order to convey meaningful information to the user while minimizing the use of text content.

Figure 4: Chart view of the front-end

E. User Evaluation of Final Interface

In order to carry out a user evaluation of the final HAS interface, a set of tasks were selected in order to evaluate the different usability aspects. The four tasks that were assigned for the evaluation are as follows:
• T1 - Find out the current total energy consumption of your home and whether it is within normal values
• T2 - Find out the current energy consumption of all the lightning systems in the home and whether or not you are within your targeted limit.
• T3 - Which is the device in the home that is consuming the most energy at the moment?
• T4 - How much cost savings or additional expenses are you incurring at the moment?

The usability tests involved a user group consisting of 8 participants. The users are aged between 18 and 60 years old and are all familiar with using web browsers and web applications on the PC as well as on mobile devices. Out of the 8 people, 4 people have technical background and programming knowledge for the case of high-skilled users and the remaining 4 users were selected on the criteria of having no technical or programming background but who are familiar with using PCs and mobile phones for the case of low skilled users.

The usability tests involved users filling a questionnaire in order to evaluate their perceived experience out of interacting with the interface in order to carry out the tasks assigned. The satisfaction level experienced by the users was then evaluated against a 5-points Likert scale ranging from ‘highly satisfied’ to ‘Very Unsatisfied’.

To help users answer the questionnaire, an explanation of the Likert scale was given to them:

• Very Satisfied - The feature met your expectations and made you derive positive feelings.
• Satisfied - The feature could be further improved to meet your expectations but it was satisfactory enough.
• Not so satisfied - The feature has to be improved in order to make it easier and more acceptable to use.
• Not Satisfied - The feature did not meet your expectations, it was not easy to use.
• Very Unsatisfied - Besides not meeting your expectations and its lack of usability, the UI feature made you derive strong negative feelings.

V. RESULTS

The success rate of the four tasks (T1 - T4) assigned to the users for the home automation interface developed in this design process was 100%, which showed that the interface proved to be usable for users to successfully perform their required tasks and access information about the energy consumption of devices or of the home.

For the tasks T1-T4 the results showed that the majority of the users responded positively (Very Satisfied and Satisfied) for the use of the different interactive UI features: use of charts to display statistical data or the use of widgets to display key analytical data. The results obtained also showed that the majority of them felt the use of these UI elements improved the ease of use and learnability of the interface while making the access to the information very fast. However, a number of 3 users, all of them belonging to the high skilled user group, felt that the appearance and functionality of the gauge chart UI element to display the total home energy consumption could be improved in order to make users understand the functionality of this feature better.

The results of the evaluation of the satisfaction derived by the users when using the dashboard themed interface for the home energy management functionality show that the majority of the participants felt that the current interface designed was usable enough and provided meaningful and useful features to them. Some design aspects concerning the experience of using the interface on different devices, the readability of the interface content on mobile devices and the organization of the information and UI components could be improved to further enhance the user experience.

VI. DISCUSSION

From the outcome of the research undertaken it was confirmed that the UI development for a home automation application was a multi-disciplinary task and required a holistic understanding of the main design issues that were associated with each of the field involved.

The QDA approach proved to be suitable to derive requirements for the design of the interface. This claim was supported by the results of the evaluation of the final interface developed, which showed that applying a holistic approach to this design task produced a good, usable, responsive and interactive interface from the users’ perspectives.

Taking into consideration the positive results of the evaluation of the home automation interface designed and developed from the requirements derived from the data collected and analyzed using the QDA approach, a set of design guidelines were shortlisted and proposed to help developers build home automation applications that meet user, usability and functional requirements of automation systems.

The design guidelines proposed are as follows:

1. Having a universal, reusable and technology independent interface.

Due to the heterogeneity of technologies in HAS, different interfaces and interactive systems are used to access and control the devices. To develop a universal interface that can be reused independent of the technologies used by the devices, a generic and technology-independent way of representing the home, the devices and their different functionalities is required.

2. The different interfaces of the HAS have different layouts and interaction styles for each different manufacturer’s brand of device.

The consistency and look-and-feel of the layouts should be standard and predictable for the users. The general practice is to organize the HAS devices into their location or functional areas.

3. Making sense of the large amount of sensor data to display meaningful information.

The emphasis should be on the representation of data that is useful to users instead of individual sensor data. Thus the different sources of sensor data should be aggregated to allow the analysis, integration and
computation of complex information that is useful to the user.

4. Technical metaphors and descriptions are very often used in the interface.

The interface should be usable by not only technology enthusiasts but also by the majority of the other non-technical users. Thus using user-friendly metaphors to describe the behavior and state of the home so that all users can understand the system is an important design principle.

5. Allowing users to personalize the HAS to adjust the scheduling and customization of automation tasks and specifying level of autonomy to be delegated to the system.

6. Users are frustrated by the complexity of the interaction with the device.

7. Different device interfaces and control systems add to the cost of ownership.

By using open standards to develop the interface can help reduce the cost of buying a HAS.

8. Increasing the ease of use of the interface.

The information architecture should be clear and intuitive. The UI design should be well understood by the users so that to motivate them to explore advanced functionalities. The usability of the interface can be improved for first time users by providing a step-by-step tutorial guide.

9. Satisfaction from acceptability of the interface from the users’ point of view.

It is good practice to inform users about the current state and future tasks of the HAS, including the automated tasks that are about to start and give them the opportunity to cancel them so as to avoid unpleasant situations where unaware users are caught by surprise.

10. Having an interface that is able to adapt to different end-target devices such as PC, tablet or mobile phone.

It is recommended to apply responsive design rules in order to make the interface adapt to different screen resolutions.

VII. CONCLUSION

This paper presented the Qualitative Data Analysis design approach to design a user-friendly, interactive and responsive user interface for a home automation system. The outcomes of the document review and literature study done at the data collection stage of the QDA confirmed the idea that developing a UI for a HAS was a multi-disciplinary task that involved the automation field, the HCI field and on the user-centered study field. Therefore, applying a design methodology that incorporated the design challenges and requirements from all these research areas was important to build a good interface.

Developing prototypes that were evaluated through heuristic analysis tests ensured that usability problems could be caught during the early stages of the development process and that the design of the final interface was already improved and validated at an early stage by the users directly. Finally, the experience that users can derive from using the interface can be evaluated by measuring the success rate and satisfaction level when conducting a set of tasks on the final interface. The higher the success rates and satisfaction level, the more usable the interface was perceived to be usable which certainly would play a significant role in the prospective commercial success of the HAS.

The choice of the home energy scenario exemplified the contribution that home automation technologies could bring to increase awareness amongst people about their energy consumption habits. It was argued that the more usable the home automation interface was, the more users were going to be motivated to use it into their everyday lives to achieve cost and energy savings.

REFERENCES


