Standardization of Light Emitting Diode Feedback on Metered Solar Home Systems

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Abstract

Light Emitting Diodes (LEDs) are used in a variety of devices ranging from watches to solar home systems, as status indicators or communicative tools. They are typically designed to produce light in different colors and intensities. However, the communicative output varies across devices of similar or different functions. This variation and the sense that there is a wide array of expressions that can be employed, makes it hard for users of the devices to deduce the feedback easily. To address this gap, this paper discusses the effectiveness of a standardized light-based interface for metered solar home systems, which has been redesigned using a structured Human Computer Interaction (HCI) design process. The study makes use of the UFuRT (User, Function, Representation and Task analyses) framework to evaluate the use of these devices ethnographically and contextually among solar home-system owners in the Rift Valley region of Kenya. To understand how solar home systems users utilize multi-communicative LEDs, 111 solar home system owners participated in in-person interviews. The results indicate that, on average, 51% of solar-home system owners cannot correctly interpret or do not know the LED feedback of the device they own. The quantitative and qualitative data collected from the in-person sessions was used to design a simulated standardized interface of a metered solar home system. The effectiveness of this newly designed interface was measured by interviewing another set of 43 solar home system users. The results indicate that, on average, up to 63% of solar system owners correctly interpret the LED feedback mechanisms of a standardized design**.** Further, up to 86% of solar system owners correctly interpret specific feedback mechanisms of a standardized design**.** With these findings, the study concludes that using a HCI framework to standardize the interface design of LED-touting devices increases the expressivity and user understanding of feedback relayed by these devices. Thus, manufacturers and industry governing bodies need to consider a universal vocabulary of light-based design that can be widely adopted to solve device usage challenges.

Keywords: *Human-Computer Interaction, Light Emitting Diodes (LEDs), Metered Solar # Home Systems, Communication, Interface*

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1.0 Background

Many electronic devices employ small communication lights, called Light Emitting Diodes (LEDs) to relay feedback or state to users, for their action or awareness (Figure 1). These devices that incorporate feedback interfaces have rapidly increased over the years in various iconic forms (Morgan et al., 2018, Harisson et al., 2012). It has become commonplace to see LEDs in a variety of devices ranging from watches to solar home systems, as status indicators or communicative tools. Additionally, the proliferation of the Internet of Things (PEW Research Center, n.d.) continues to heighten product diversification. Even so, the diversification of these devices into different molds and shapes has resulted in a variety of lighting behaviors across different devices and designs (Morgan et al., 2018, Bauman & Thomas, 2001). This variation and the sense that there is a wide array of expressions that can be employed makes it hard for users of the devices to easily deduce the feedback. Further, interfaces that require memorization or repetition to grasp, make for a cumbersome user experience, especially considering the number of LED-touting devices now available.

This research focuses on small to medium-sized technically enforced solar home systems that have emerged as a sustainable lifeline for rural African communities who still lack access to grid power (World Energy Outlook, 2014). Indeed, 80% of those not served with grid electricity are those that occupy Sub-Saharan Africa and Rural Asia (Rolffs et al., 2014). To fast-track development and the achievement of Millennium Development Goals (MDGs), governments have had to approve and start proactively promoting solar home systems as the most feasible and cost-effective alternative for rural electrification (Nieuwenhout, 2001). Over the years, such devices have adopted the use of LED point lights riding on the wave that made LEDs the dominant lighting technology such that by 2012, the lighting technology accounted for 97% market share (Lighting Africa, 2012).

The biggest hurdle to the adoption of these solar home systems has been established as their high initial cost (Urmee, 2009), which seems to have been countered by the advent of Pay-As-You-Go (PAYG) technology. This technology enables customers to pay over a period of time, at much lower costs than traditional microfinance (Harrison et al., 2016).

Figure 1

Small single-color lights in some electronic and computing devices

Note. Adapted from *Unlocking the expressivity of point lights (2012).* (https://doi.org/10.1145/2207676.2208296). Copyright 2012 by Harrison et., al 2012.

Even so, it necessitates that the systems have some form of technical enforcement and hence the need to include LEDs as a cost-effective feedback mechanism on the units (Tippenhauer et al., 2012). The problem with this approach is that most users of these systems have had limited exposure to many of these iconographic devices for them to build an understanding of the different feedback mechanisms. Multiple distributors of solar products have also bemoaned the difficulty they face with addressing customer complaints mostly because of communication difficulties and limited technical expertise (Stimulus, 2018). Low literacy levels, combined with the technicalities of the devices tend to necessitate agents to be sent to the field to address customer issues, and this can be expensive and time-consuming which is unsustainable.

Evidently, LEDs are highly efficient in the design of low-cost consumer electronics. However, product diversification has not allowed for standardization of the feedback design. This gap has led to different lighting feedback mechanisms on similar products such as solar home systems, leading to most consumers not being able to expressively comprehend the various communications. The inability of consumers to understand feedback from these high utility home systems leads to user frustration, product returns, default in payment and sometimes customers reverting to non-renewable and pollutant sources of energy.

Research suggests that for computer systems to continue to meet users' continuously diversifying views, their general understanding needs to be reviewed and new ways of designing and making prototypes have to be explored (Harper et al., 2008). For example, design researchers advocate for small single-color light emitting elements with variable intensity over time as being the best definition of simple (Catalano & Harrison, 2014).

Therefore, solving the technical understanding of such systems could potentially help current users and owners of these devices, and also push for greater adoption of the solar systems in general. For that reason, the main hypothesis of this paper is that a *standardized light-based interface for a metered solar home system increases the effectiveness and usability* of the device. To validate this hypothesis, the following are the objectives of this paper.

1. To show how different solar home systems relay feedback.
2. Highlight challenges arising from interacting with non-standardized LEDs.
3. To apply HCI principles in determining the design considerations that define standardized LED feedback mechanism.
4. To compare the effectiveness of standardized and non-standardized LED point lights.

Related Work

There are a number of researches that have highlighted the need for standardization. In a 2016 study by Thirtyacre, it was noted that in small unmanned aircraft systems, the lack of standardized human computer interfaces among devices from different manufacturers, for setting geo-fencing parameters, led to various input and interpretation errors (Thirtyacre et al, 2016). Thirtyacre and team noted that these errors were both of omission (such as failure to enable the geofence) or commission (such as setting incorrect parameters) and could lead to serious safety-of-flight problems.

They also pointed out that standardization has already helped a lot in areas such as cockpit displays of today's manned aircrafts which mostly have similar layouts from decades of refinement. A similar recommendation was made in a Human-Computer interface study, which documented that the role of standardization is big in that it drives many aspects of product development ranging from measurement to testing but most importantly, seamless data exchange at interfaces (Blind & Gauch, 2009).

In the context of light communication, there have been some recommended standardizations for applications that use Visible Light Experimentation (VLC). The Visible Light Communication Consortium (VLCC) and Institute of Electrical and Electronics Engineers (IEEE) already stipulate a number of principles to govern design of LED products to complement extra services or existing visible light infrastructure (Alam et al., 2016). These standards have provided a minimum benchmark for development of many of the existing VLC interfaces in vehicles, infrastructure, and even mobile devices (Khan et al, 2017).

For purposes of comparing usability between two user applications, Nahm and Zhang operationalized the UFuRT (User, Function, Representation and Task analyses) framework and successfully identified usability differences in a bid to identify the right tool for Clinical Research Data Management (Nahm & Zhang, 2009). The framework was also successfully applied by other researchers in the optimization of an Electronic Healthcare Record application to meet specific healthcare providers' needs (Amith et al., 2012).

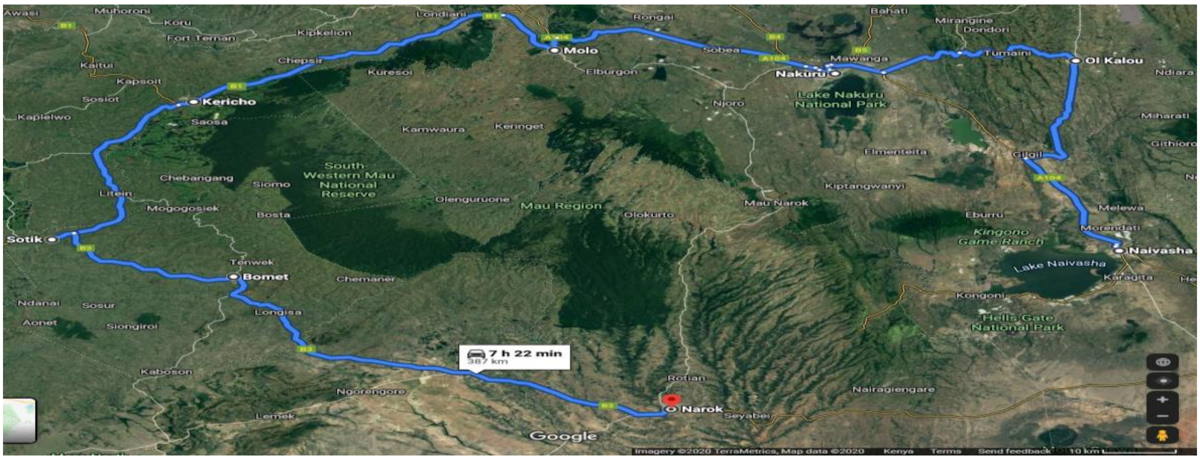
The past research justify the work in this study by highlighting how lack of standardization can be detrimental to usability. They also show some of the ways standardization problems have been solved to good measure, through HCI frameworks like UFuRT.

2.0 Materials and Methods

Study Area

The research was conducted in areas that are relatively rural but well exposed to solar distribution and related products. These areas included Ol Kalou, Molo, Sotik, Kericho, Nakuru, Naivasha, Narok and Bomet (Figure 2). At the time of research, some of these areas were fairly well-performing regions on sales for Solar Home Systems in the country and represented some of the earlier regions where solar pilots were carried out in the country (Off-Grid Solar Market Trends Report, 2018). For that reason, the study can be considered comprehensive as it made use of the significant solar penetration and the large population in the counties for sampling.

Figure 2: ***Geographical proximity of the study locations***



Note. Screenshot captured of the map of the area of study. From *Google Maps* .

Target Population

Following the UFuRT HCI framework, the target users of this research were selected on the basis of ownership of the target devices, as a way to establish the required level of knowledge and cognitive understanding to address the study's research questions (Zhang & Butler, 2007). Convenience sampling was used because the study needed to cover users dispersed in various areas of the wider geographical region (Figure 2).

The field work for this research was carried out in two phases. In the first phase, 111 users participated in in-person interviews and practical device-walkthrough. This number of participants was established to be more than sufficient to cover at least 98% of the needs of the target demographic of the study (Faulkner, 2003 and Guest et al., 2006).The in-person interview approach was taken to capture subjective understanding or perceived usability and general user attitude (Assila, 2016). The first phase of the study addressed the first three objectives of this paper. Results obtained from the first phase provided the basis for design considerations made in creating the standardized feedback system. In the second phase, 43 users were shown the newly designed standardized interface. The purpose of this phase was to compare effectiveness of standardized and non-standardized LED point lights.

Target Devices

For this research, the 4 most available products in the region of study were selected for evaluation. These four devices were the ones that were widely used among the sample population of solar home system owners. Further, information on financial and operational performance of PAYG companies is not shared publicly (Lighting Global, 2017). Therefore, there was no public record that could be used to check the most widely used solar home system devices in the general public. Thus, this research relied on on-the-ground information to determine which devices the target population utilized.

These four devices are: Fosera home system (Figure 3), Sunking 60/120 home system (Figure 4-left), Sunking Pro/Boom (Figure 4-right), and JUA home system (Figure 5)

Figure 3

Solar Home Systems by Fosera which is activated via Keycode (through infrared remote)

Note. Image showing sample Fosera Home System and it's accessories. From *Angaza* https://www.angaza.com/. Copyright 2018 by Angaza.

Figure 4

Sun King Home (left) and Sun King Pro (right) Home Systems by Green Light Planet

Note. Image showing sample Sunking Home Systems and some accessories. From *Angaza* https://www.angaza.com/. Copyright 2018 by Angaza.

Figure 5

Solar Home System by JUA Energy which uses credit keycodes for activation

Note. Image showing sample JUA Home System and it's accessories. From *Angaza* https://www.angaza.com/. Copyright 2018 by Angaza.

Evaluation Metrics

The study's focus was on the most important functions and representative tasks for PAYG operations of solar home systems. After installation of a solar home system, a user can check the status of the device and activate it with credit via a payment keycode. Checking the device status can only yield two outcomes: either device is enabled or disabled. Activation can only yield three results, keycode accepted, rejected or repeated. In the case of a device being enabled or disabled, the observations were taken immediately the power button was pressed. In the case of keycode acceptance the observations were taken after the last digit of the keycode was pressed. These represent the 5 intrinsic tasks being evaluated in this research: Device Enabled, Device Disabled, Keycode Accepted, Keycode Rejected and Keycode Repeated.

These five specific modes were selected because they are the only PAYG modes available on a metered device that uses a keycode activation protocol. All these modes utilize LED lights to relay the feedback to the user. For example, if the user entered a wrong keycode they would see a red fast blinking LED light on the Sunking home system.

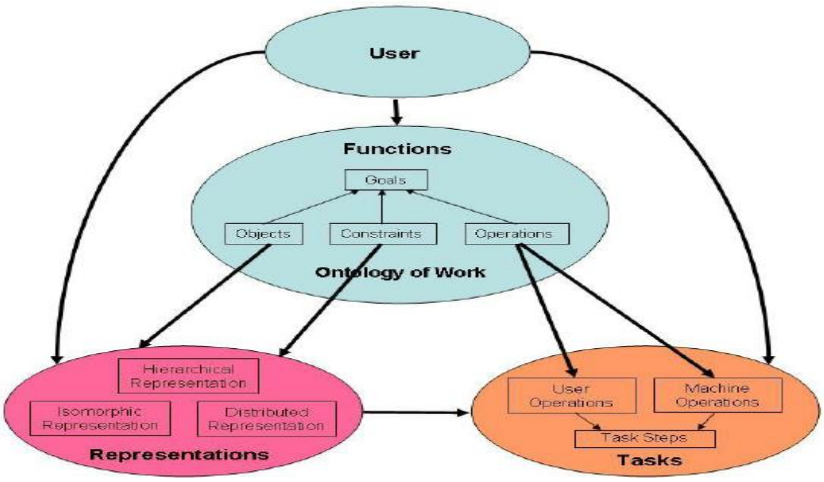
Framework

The usability challenge of non-standardized LEDs is supported by the UFuRT (User, Function, Representation and Task analyses) Human-Computer-Interface (HCI) conceptual framework (Zhang & Butler 2007). This framework emphasizes that a large number of information systems failures are not due to technical flaws but a result of failed systematic consideration for human and other non-technical issues during the design and implementation process. Figure 6 shows the UFuRT framework. Figure 7 shows the adoption of the framework to define this research. The components in User-Centered Design, as stipulated in the adopted framework in Figure 6 are User, Function, Representation and Task analyses.

In this study, the users are the owners of the solar home systems that employ LED feedback iconography. The functions are represented by the primary operations and measurable units for metered devices such as checking the status of the devices and activating them as necessary. The representation is the relationship between LED behavior exhibited by the devices and the feedback that it is supposed to relay. Finally, the tasks or steps needed to result in the LED-light feedback that completes the operation are either pressing the power button (for device status) or applying a keycode (for activation)

Figure 6

The conceptual framework of UFuRT



Note. This figure was adapted from Zhang and Butler 2007 publication and it visualizes the the four pillars of UFuRT framework. From *A Work-Centered Framework and Process for Design and Evaluation of Information Systems*, by J. Zhang and K. Butler, 2007. Copyright 2007 by Zhang and Butler

Figure 7

Operationalization of UFuRT framework in the Metered Solar Home Systems case study

UFuRT Framework	Solar Home Systems Case Study
USER	Owners of metered solar home systems
FUNCTION	Checking status of the device and activating the device
REPRESENTATION	LED light behavior for device or activation status
TASK	System is ON/OFF and Keycode is Accepted, Rejected or Repeated

Data Collection and Study Design

Data collection was done via observation and in-person interviews using questionnaires. To show how different solar home systems relay feedback, the devices were observed.

To highlight challenges arising from interacting with non-standardized LEDs, a questionnaire was used in the first phase of the study during in-person interviews of the 111 users. This exercise was consistent with past research that conducted usability testing to understand user challenges and effectiveness of systems through UFuRT framework (Assila, 2016). The questionnaire included questions that directly addressed challenges faced by the user as well as questions that covered understanding of the different representative functions of the device. Examples of questions included;

I. What information do you deduce from the LED signals of the device you own?
II. What do you think is represented by a red fast blinking light?

The second phase of the study was based on explicit user suggestions and analyzed feedback from the first phase of the study. The first part of the second phase of the study applied HCI principles in determining the design considerations that define standardized LED feedback mechanism. This process also utilized the feedback from the user in the challenges they faced and their understanding of feedback.

The second part of the second phase of the study aimed at comparing the effectiveness of standardized and non-standardized LED point lights. This process was conducted by presenting the designed standardized interface to 43 users. To measure effectiveness of the standardized interface users were asked of their understanding of the interface. The questionnaire contained questions such as;

i. What do you think is represented by 6 green slow blinks?
ii. What do you think is represented by a red stable light next to the money symbol?

Finally, a comparison was conducted between the understanding of various interfaces and types of communication among users in the first phase of the study and the understanding of the standardized interfaces among users in the second phase of the study.

All the data collected in the questionnaires was eventually coalesced into a central spreadsheet for analysis.

Data Analysis

The study consisted of qualitative and quantitative data. The data was first coded and grouped along the four objectives of this paper. A Google spreadsheet was used to tabulate the quantitative data per objective. The summaries were then presented in the form of charts and summarized tables.

Ethical Approval

This was provided by Kenya Methodist University Scientific, Ethics and Review Committee (approved 9th July 2019) and from the National Commission of Science and Technology and Innovation (License No. NACOSTI/P/19/1739). Informed consent was also sought from the participants of the study hence involvement was on a voluntary basis.

3.0 Results and Discussions

Results are presented and discussed as per each research objective of this paper.

Device Ownership

The results obtained from the first phase of in-person interviews indicated that 78% of the 111 users owned one solar home system and 22% owned more than one device. Of the users who owned just one solar home system, 59% owned the Sunking Pro and 41% owned the SunKing Home. Of the users who owned more than one solar home system, majority owned 2 devices from different manufacturers, while 1 owned 4 devices, and 1 owned 10 devices.

Out of the 111 participants, 47% had owned the device for a year while 26% had owned the device for 2 years. The rest had ownership durations ranging from 2 months to 5 years. The average solar device ownership among all the 111 participants is 1.3 years.

How do different solar home systems relay feedback to the user?

It was observed that each of the four devices studied exhibited a different LED feedback for all the five feedback modes. Table 1 shows how the four devices exhibited feedback. This variance was the case even for products that were made by the same manufacturer. For example, the Sunking Home 60/120 displayed twelve green slow blinks when *keycode was accepted*, whereas the Sunking Pro displayed the same behavior complimented with blinking bulb light when *keycode was accepted*. On the hand the JUA Home System displayed six slow blinks with the dollar sign light on for *keycode accepted*. Another example is exhibited for the *device enabled* feedback. The JUA Home System showed a green dot LED light, while a Forsera home system displays a green battery.

These results indicate that there is a difference in the LED representation of feedback mechanisms across the systems, even for devices from the same manufacturer.

Table 1

Differences in feedback mode exhibited by four devices

Feedback Mode / Device	Keycode Accepted	Keycode Rejected	Keycode Repeated	Device Enabled	Device Disabled
Sunking Home 60/120	Twelve slow blinks (green LED)	Twelve rapid blinks (red LED)	Twelve slow blinks (green LED)	Battery indicator (green LED)	Battery indicator (red LED)
Sunking Pro/Boom	Twelve slow blinks (green LED simultaneous with bulb)	Twelve rapid blinks (red LED simultaneous with bulb)	Twelve slow blinks (green LED simultaneous with bulb)	Battery indicator (green LED simultaneous with bulb)	Battery indicator (red LED simultaneous with bulb)
JUA Home System	Six slow blinks (keypad) dollar sign lights up	Rapid blinking for 2secs (keypad)	Three slow blinks (keypad)	Green dot LED light	No LED indicator
Fosera Home System	Six blue dot LED blinks	Three blue dot LED blinks	Three slow blinks (blue dot) LED blinks	Green battery LED	Orange dot and battery LED light up

LED feedback use and understanding

To understand how solar home system owners use the device they were asked two questions: (i) what feedback mechanism they interacted with while using their solar devices; and (ii) if they understood the LED signals of the feedback mechanisms in devices they own and those they do not own.

Figure 8 shows the distribution of the feedback mechanisms that users interacted with. 91% of users interact with at least one of the feedback mechanisms on their solar devices. This result shows that users actually utilized the solar devices that they own. Of the users who utilize at least one feedback mechanism, 68 % indicate that they utilized the *keycode feedback (accepted, rejected, repeated)*, with 22% using the LEDs to identify the *device status*. The remaining 2% used the device to check *device issues*. The 8% of users who indicated they ignore the LEDs of the devices, claimed they either understood how the device was supposed to work or sought help from somebody if they needed it. These results indicate that majority of users actively rely on the feedback of the device.

The users were then presented with all five feedback mechanisms and their related LED signals then asked if they understood each related LED signal. Figure 9 shows that the LED signals for *Keycode Rejected* were the most understood feedback, with 76% of the users correctly deducing its meaning.

Figure 8

Distribution of the feedback mechanisms that users interacted with

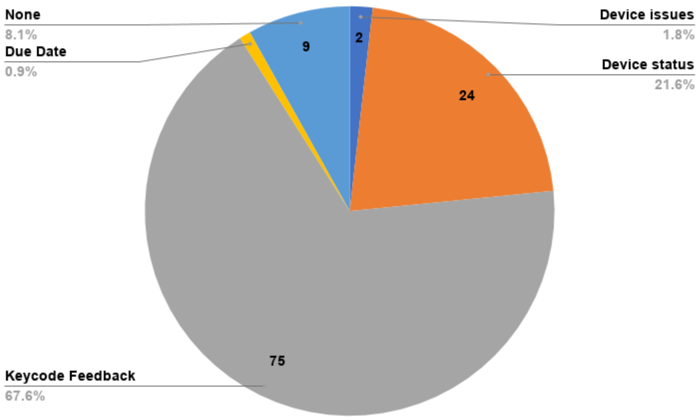
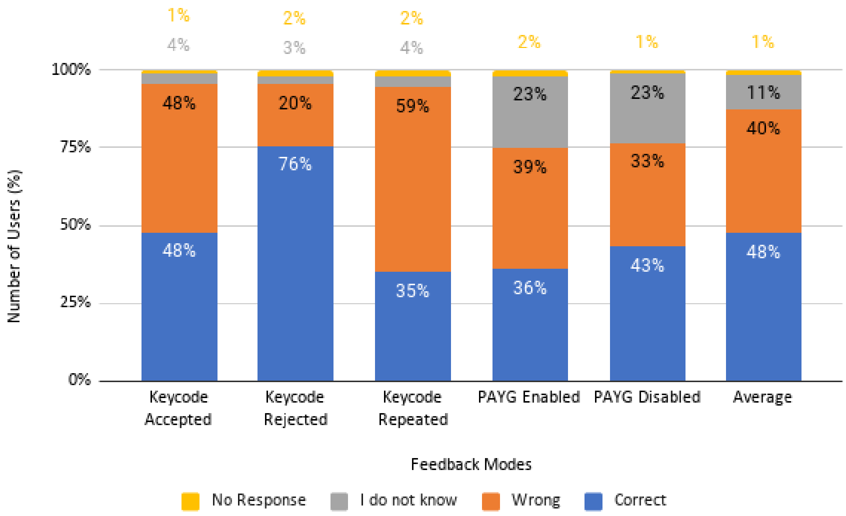


Figure 9

User understanding of the different LED feedback from devices they own



For the remaining feedback mechanisms, the understanding rate was between 35% and 48%. On average, the understanding rate among all users for devices they own across the 5 feedback mechanisms was 48%. 51% of the users could not correctly deduce or did not know the related LED signals across the feedback mechanisms. Of these 14% could not correctly deduce the related LED signals for all five feedback mechanisms. Figure 10 shows that there was not much difference in understanding rate for devices that the users owned compared to those that they did not own. Across all feedback mechanisms the understanding rate is between 32% and 62%. %. On average, the understanding rate among all users for devices they did not own across the 5 feedback mechanisms was 46%. This could be a factor of the devices being conceptually the same in the sense that they all seem to exhibit some similar patterns such as fast blinking for keycode rejection.

Design features that improve user understanding of LED feedback

Using UFuRTs HCI framework by introducing competing/similar devices, users were presented with solar home systems they did not own and those they owned. When asked about their thoughts on what design features would help improve their experience, most users stated that they were out of their depth in terms of design but would struggle with the devices if customer support was non-existent.

From an analysis of the devices that the users did not own, Figure 11 indicates that an average of 31% of the users understood the feedback modes of the JUA home system. This percentage was higher than the average of users who understood the feedback modes of the other three devices.

Figure 10

User understanding of the different LED feedback from devices they did not own

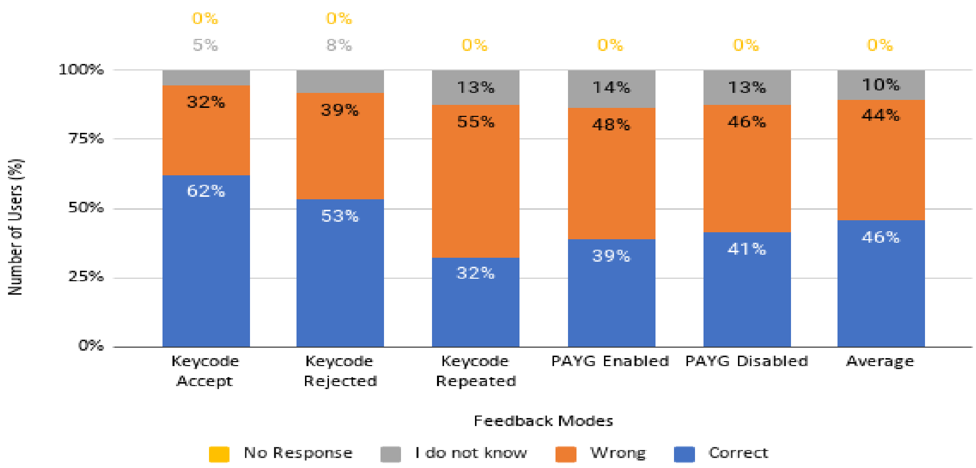
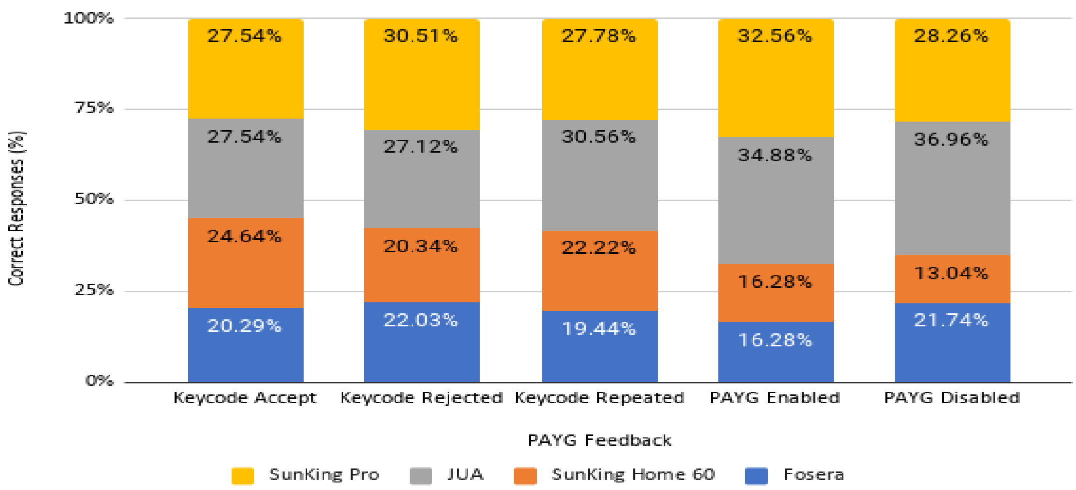


Figure 11

Number of correct answers by users who did not own the devices



The findings align with the conclusion of other researchers that users tend to better understand communication if it is unique and easy to recall (Kim et al., 2014). The JUA home system has four LED lights, which is double the number on the other devices that have two each. Thus, in using the four LEDs the JUA manages to display more unique feedback combinations than the other devices.

With the above data, the study focused on task success as a component of UFuRT framework for each of the five feedback mechanisms. Since most users seemed to better understand the feedback from the JUA home system, it was hypothesized that creating clear distinction between the different feedback behaviors would be more effective in improving user understanding.

This hypothesis is also supported by Punchoojit and Hongwarittorn's research that reviewed several studies that compared a number of existing systems in design of usable Mobile User Interfaces (Punchoojit & Hongwarittorn, 2017). Another study compared the benefits and drawbacks of information systems and found that getting user requirements for a new design from existing or competing systems is a more effective way of addressing current problems and identifying new features/acceptance criteria (Maguire et al., 2002).

The standardized interface was created using Adobe Creative Studio and Microsoft Paint 3D and featured animations showing the five feedback patterns.Figure 12 shows the standardized interface, and Table 2 summarizes the LED signal for all the five feedback mechanisms.

Design of Device Enabled Feedback

To match the dollar sign on the JUA system, the *device status* feedback mechanism was created and marked with a *money symbol*. Further, the money symbol was designed to only show *stable green light* to indicate *device enabled*. The color of the LED signal was designed to match similar signals exhibited in the stable LEDs

Figure 12

Mockup solar home system with refined LED feedback

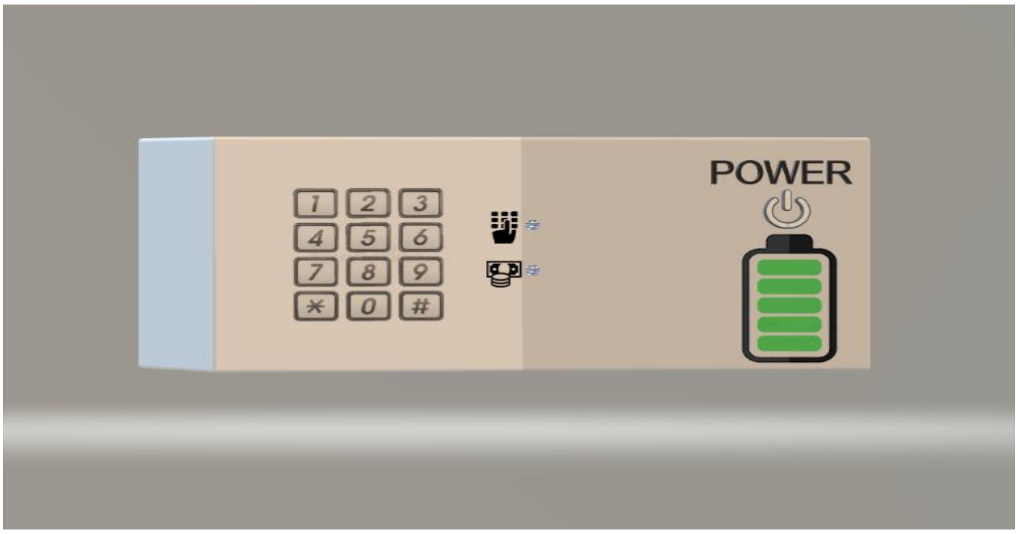


Table 2

Mockup Solar Home System LED feedback behavior

Feedback / Mode / Device	Keycode Accepted	Keycode Rejected	Keycode Repeated	Device Enabled	Device Disabled
Mockup Solar Home System	Six slow green blinks next to the Keypad icon (green LED)	Eight rapid red blinks next to the keypad icon (red LED)	Three slow green blinks next to the keypad icon (green LED)	Green steady light next to the money icon (green LED)	Red steady light next to the money icon (red LED)

observed in all of the devices (shown in Table 1.

A money symbol was aimed at achieving the goal of users understanding that they needed to pay for usage of the device. So, if the device had not been paid for then a red light will be shown while if it had been paid for then a green light will be shown.

Design of Keycode Acceptance Feedback

Once the user enters the keycode on the large keypad, *the keycode accepted* feedback is designed to show 6 slow green blinks. The area that blinks was designed next to a keypad icon to make it clear that the signals are only applicable to keycode acceptance.

Design of Keycode Rejected Feedback

To be consistent with existing devices the *keycode rejected* feedback was designed to show 8 red blinks. The area that blinks was designed next to a keypad icon.

Design of Keycode Repeated Feedback

Keycode repeated feedback was designed to show three slow green blinks. The area that blinks was designed next to a keypad icon.

Design of Device Disabled Feedback

A stable red light blinks to indicate Device disabled. The area that blinks is next to the money symbol.

Additional Features

The new design featured a separate battery indicator to separate charging and battery states from the five feedback mechanism to have the distinction shown in the JUA home system. All the other devices did not consider this separation and therefore confused many users. For example, one user of the Sunking Home asked, “why does a battery shaped light blink when I enter the keycode?” To alleviate such confusion, the new design made sure that the battery symbol was separated from the five main feedback mechanisms.

Effectiveness of standardized LED light feedback mechanism

The second phase of the study involved 43 participants. This number of participants falls well within the number mentioned by other researchers as a good measure of saturation in qualitative research (Guest et al., 2006 and Crouch & McKenzie, 2006).

Users were shown the interface in Figure 12 and asked to describe what they thought each symbol meant. Figure 13 shows that 86% of the users were able to correctly identify the *device enabled* and *device disabled* LED feedback mechanisms.

56% of the users were able to correctly deduce the *keycode acceptance f*eedback on the standardized interface. In comparison, 48% of users were able to understand the keycode acceptance mechanism for devices that they owned (Figure 14). These results demonstrates an increase in the understanding rate *from devices users' owned* to the standardized interface.

67% of the users were able to correctly deduce the *keycode rejected f*eedback on the standardized interface. In comparison, 76% of users were able to understand the keycode rejected mechanism for devices that they owned (Figure 14). These results demonstrates an increase in the understanding rate *from devices users did not own* to the standardized interface.

Figure 13

User understanding of the LED light feedback of a mockup solar home system

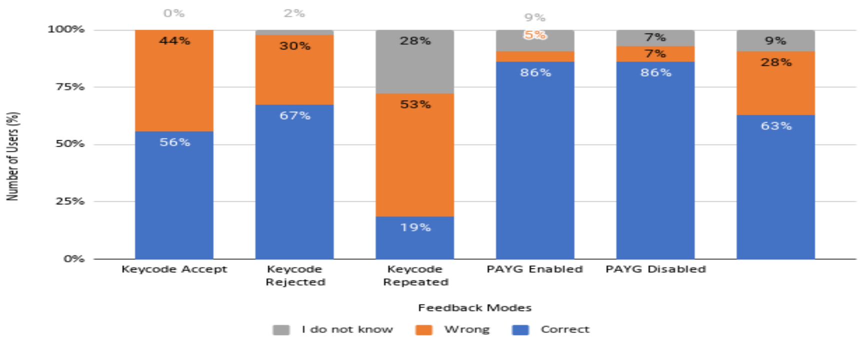
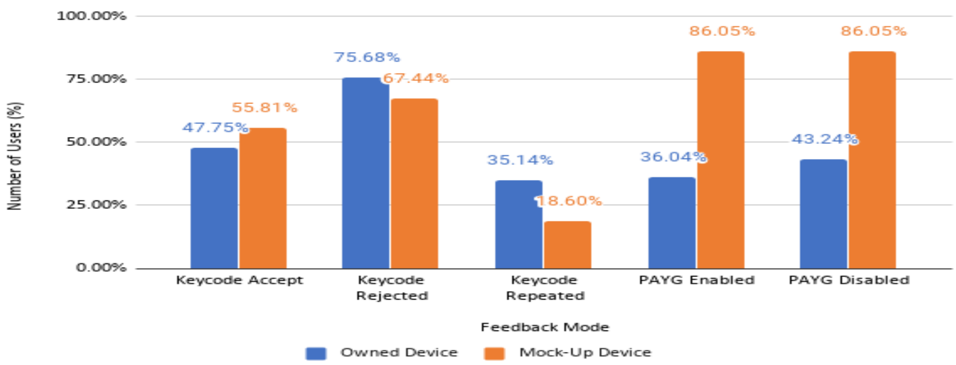


Figure 14

Comparison of user understanding of LED feedback on owned and mockup devices



19% of the users were able to correctly deduce the *keycode repeated f*eedback on the standardized interface. In comparison, 35% of users were able to understand the keycode repeated mechanism for devices that they owned(Figure 14). These results demonstrates a decrease in the understanding rate *from devices users owned and did not own* to the standardized interface.

4.0 Results and Discussion

Figure 13 shows that on average, the understanding rate among all users for the newly designed standardized interface, across the 5 feedback mechanisms, was 63%. In comparison, the average understanding rate of LED feedback mechanisms among users for devices they own is an average of 48%, while the average understanding rate is 47% for devices they do not own.

A higher percentage of users of the standardized interface correctly deduced the *keycode accepted* feedback than the percentage of users who owned their own devices, for a similar feedback mechanism. Similarly, a higher percentage of users of the standardized interface correctly deduced the *device enabled* and *device disabled* feedback than the percentage of users who owned their own devices, for similar feedback mechanisms. These results show that using a HCI framework to standardize the interface design of LED-touting devices increases the expressivity and user understanding of feedback relayed by these devices.

A lower percentage of users of the standardized interface correctly deduced the *keycode rejected* and *keycode repeated* feedback than the percentage of users who owned their own devices, for a similar feedback mechanisms. The result for the *keycode rejected* could indicate that because most of the users owned the Sunkin system, which blinked twelve times with a red light, they could not correctly deduce the eight-time blinks in the standardized interface. Therefore, it is recommended that further training and exposure to the new standardized interface be conducted, or the twelve-time blink could be adopted for a standardized interface showing the *keycode rejected* mechanism.Also, further investigation among users is necessary to understand if the placement of the *keycode rejected* icon next to a keypad icon was confusing.

Similarly, the result for the *keycode repeated* could indicate that because most of the users owned the Sunking system, which blinked twelve times with a green light, they could not correctly deduce the three-time blinks in the standardized interface. Therefore, it is recommended that further training and exposure to the new standardized interface be conducted, or the twelve-time-green blinks could be adopted for a standardized interface showing the keycode repeated mechanism. Also, further investigation among users is necessary to understand if the placement of the keycode repeated icon next to a keypad icon was confusing.

5.0 Conclusion

Light Emitting Diodes (LEDs) are used in a variety of devices ranging from watches to solar home systems, as status indicators or communicative tools. They are typically designed to produce light in different colors and intensities. However, the communicative output varies across devices of similar or different functions. This variation and the sense that there is a wide array of expressions that can be employed, makes it hard for users of the devices to deduce the feedback easily. However, the findings in this paper suggest that standardized LED-based interfaces can increase the rate of understanding, of standard feedback mechanisms, among owners of solar home devices.

Further, the results show that the integration of LED feedback designs from devices that users own and use frequently could increase the effectiveness of standardized LED interfaces. With these findings, the study concludes that using a HCI framework to standardize the interface design of LED-touting devices increases the expressivity and user understanding of feedback relayed by these devices. Thus, manufacturers and industry governing bodies need to consider a universal vocabulary of light-based design that can be widely adopted to solve device usage challenges.

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