Jurnal Teknologi

Full paper

Analysis of Physicality Aspects in Physical User Interfaces of Embedded Systems

Mahmood Ashraf[a], Masitah Ghazali[b*]

[a]*Department of Software Engineering, Faculty of Computer Science and Information Systems, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*
[b]*Department of Software Engineering, Faculty of Computer Science and Information Systems, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*

*Corresponding author: masitah@cs.utm.my

Article history

Received :23 October 2012
Received in revised form :10 January 2013
Accepted :12 February 2013

Abstract

Embedded systems are becoming more significant in our daily lives with the advent of ubiquitous computing. The increasing demands of multifarious functionalities and other factors lead to an increased focus of development on internal software issues. Negligence towards the interaction aspects of physical interface is resulting in the generation of interaction complexities for the user. This work evaluates, compares, and highlights the significance of physicality aspects of embedded system interfaces using five subjects including; washing machine; camera; oven; sound system; and MP3 player. The quantitative evaluation approach helps in a simple investigation by applying the numeric values for each aspect. The result analysis highlights the significance of exposed state, tangible transition, and inverse action over other physicality aspects. This study is especially valuable for the embedded system developers who may not have exposure or expertise to Human-Computer Interaction or its sub-field, Physicality. Managing and incorporating physicality aspects in embedded systems is a key factor for producing natural interaction products.

Keywords: Human-computer interaction; physicality; embedded systems; interaction; complexity; physical user interface

Abstrak

Sistem tertanam menjadi lebih penting dalam kehidupan seharian kita dengan kemunculan pengkomputeran di mana-mana. Permintaan yang semakin meningkat kepelbagaian fungsi dan faktor-faktor lain membawa kepada peningkatan tumpuan pembangunan ke atas isu-isu perisian dalaman. Kecuaian terhadap aspek interaksi antara muka fizikal mengakibatkan kerumitan generasi interaksi untuk pengguna. Kerja ini menilai, membandingkan, dan menekankan kepentingan aspek physicality antara muka sistem terbenam menggunakan lima subjek termasuk mesin basuh; kamera; ketuhar; sistem bunyi dan pemain MP3. Pendekatan penilaian kuantitatif dapat membantu dalam penyiasatan yang mudah dengan menggunakan nilai angka bagi setiap aspek. Hasil analisis menekankan kepentingan keadaan terdedah, peralihan ketara, dan tindakan songsang berbanding aspek physicality lain. Kajian ini adalah amat berharga untuk pemaju sistem terbenam yang mungkin tidak mempunyai pendedahan atau kepakaran terhadap Interaksi Manusia-Komputer atau sub-bidang, fizikaliti. Pengurusan dan penggabungan aspek physicality dalam sistem tertanam adalah faktor utama untuk menghasilkan produk interaksi semula jadi.

Kata kunci: Interaksi manusia-komputer; fizikaliti, sistem tertanam; interaksi; kerumitan; antara muka fizikal pengguna

■1.0 INTRODUCTION

Embedded systems (ESs) are becoming major part of our daily requirements. As compared to a general purpose computer, an ES is application-specific, invisible, inseparable, and integrated part of real life objects having small size, intelligence, quick response and light weight.[1-4] ESs encompass various areas including telecommunication, consumer appliances, medicine, transportation, built environment. A microprocessor chip is the fundamental part of an ES providing it the processing power [1]. Approximately 98% of 32-bit microprocessors currently in use worldwide are used in ESs and it is estimated that the common household or a modern car comprises of more than hundred processors each [5,6].

The fast expansion of ESs increases the significance of their interface and interaction aspects with the users [7]. The human senses of vision, touch, and hearing are more frequently used for interaction. On the other hand, the ES' visual, physical, and audible features of interface offer means of interaction. Complex physical user interfaces (PUIs) result in cognitive and hence physical burden on user. The products that offer usage difficulty are considered as complex or complicated by their users. Although, usability (a non-functional requirement in software engineering) is considered to be a candidate solution however, it does not address the physical aspects of interaction, if indeed applied properly at the first place.[8] There are many other factors especially physicality aspects, besides usability, for improving the natural interaction with ESs. The working of ES is subject to physical interaction constraints including reaction to a physical environment, and execution on a physical platform [9,10]. Natural interaction results by managing the combination of human innate abilities and the physical visceral aspects of ESs [10]. Physicality, a sub-field of Human-Computer Interaction (HCI), deals with augmenting the natural interaction with embedded artefacts.[11] Currently in practice, the methods or techniques aiming at increasing the naturalness of interfaces solely address the usability aspects while ignoring the detailed physicality aspects [31-34,37]. This work investigates and evaluates the existence of physicality aspects in ESs that include exposed state, compliant interaction, tangible transition, bounce back, inverse action, and compliant interaction. This investigation generates the numerical results by comparing the overall PUIs of ESs and it is not a comparison of the individual controls of each ES or the controls of different ESs.

The paper is organized as follows. The next section discusses the related work followed by an introduction to physicality principles. Subsequently, we assign the numeric values to these principles and then investigate the physical user interfaces of subject ESs. We discuss the results prior to conclusion.

■2.0 RELATED WORK

The physical interface or interaction complexity has not considerably addressed by researchers [1,24,26,29,35,47-52] as compared to the aspects of software complexity [12,13]. The significance of user interface (UI) is increasing due to various factors including the demand for multi-functionalities in a single product.[7] The contemporary electronic devices are replacing the physical controls (like buttons, dials, and knobs) with digital screens or displays that are resulting in difficulty of use for common users and especially users with some vision problems. The physical controls recruit tangibility and feltness that helps in easier manipulation[28]. An empirical study [14] highlights that the information complexity on ES's UI affects the user performance. Likewise, a strong users' trend of preferring the simpler UIs is observed. Another recent study [24] discovers various complications of use with the thermostats at homes. The contemporary digital thermostats with sophisticated touch screens are consuming more energy than older manual counterparts with physical controls. The physical buttons, knobs, dials, slider bars and other controls help user in anticipating not only the underlying functionality attached to them but also the handling of these controls themselves.

Due to the spread of ubiquitous computing, physical controls like buttons, sliders, and knobs are experiencing a restoration phase and can be augmented by incorporating and exploiting the visceral emotional features in them [25]. Another study [26] reports the complexity of home appliances (e.g., remote controls) is becoming saddling and elevating the cognitive burden on users. Cavett *et al*., [27] empirically discover the need to redesign the existing interface for the operator of unmanned aerial vehicles (UAVs) for reducing the operator's cognitive workload.

A series of studies [15-18] empirically report the usage complications present in mundane daily use electronic devices or ESs (e.g., table clock, camera etc.). These complications depend on prior experience and age of user, and appearance of ES. The appearance of ES's interface and its components effect naturalness of interaction more than their location. Moreover, the older adults find more difficulty of use with ESs than younger ones.

Various studies highlight the need to develop tools and methods to improve the physical interaction aspects in ESs [7,15,19]. For example, a study [7] points out the cause of interaction complexities in ESs as the designing of UI after defining the requirements. The proposed solution suggests for eliciting and incorporating the user-experience envisioned during product planning phase into UI prior to other activities. The proposed process is evaluated by two experiments; one in a manufacturing equipment maker; and other in a home appliance maker company. Results show that time limitations in requirement defining phase, the UI design is often left unevaluated by the actual users and implemented as it is.

A series of studies [19-23] empirically address some of the causes of naturalness in ES interaction. In addition to age and prior experience, these studies highlight the need for ES designers to match their perceptions (mental models [38-41]) of ESs' use with the perceptions of users. Designers need to be educated as well as equipped with certain tools and methods that can be employed earlier in the design process. Daily use ESs like microwave oven, simple and smart toaster, car controls, washing machine and laserplus show lack of natural interaction features [19-23]. Their proposed modeling approach named Goal-Action-Belief-Object (GABO) compares the similarities and differences between each user model and the designer model, checks the degree of compatibility, and takes appropriate design decisions. Although, this method is an example of developing tools and techniques for the ESs designers and developers however, it does not address the physicality aspects of interaction.

Perry *et al*., [29] discover few causes of interaction complexities in PUIs of ESs including actions with no effect; false affordances; and perceived interaction motions. However, this work focuses on the interface of touch screen only. The study also points the need for a standardized interface design approach. Kang and Kim [35] emphasize on the use of minimal, intuitive, and consistent controls. They conclude that intuitive use of ESs strongly depends on their PUI besides non-physical user interface (NPUI). The ESs offering both PUI and NPUI should use the more frequently used functions on PUI while the less frequently used functions should be included as part of NPUI. However, the study does not mention the specific physicality properties. Likewise, Han *et al*., [30] generally mention the physical aspects of consumer products as significant part of its interface but do not discuss these in depth. Kim *et al*., [32] include the PUI as part of their proposed framework for the development of ubiquitous computing device but do not address the reasons behind better or poor PUIs with respect to physicality aspects.

There are plenty of studies that evaluate the usability of ESs but ignore the physicality aspects [31-34]. It is important to note that traditionally usability deals with overall effectiveness, efficiency, and satisfaction of use [32,36]. For example, a study [33] checks the usability and acceptance evaluation of cardiac rehabilitation system consisting of various medical hardware devices (in addition to a software interface). Although, in this environment, it is more significant to address physicality because both physicians and patients are the users of the system but the study only measures the "overall" likeness of the system while ignoring the aspects of physicality.

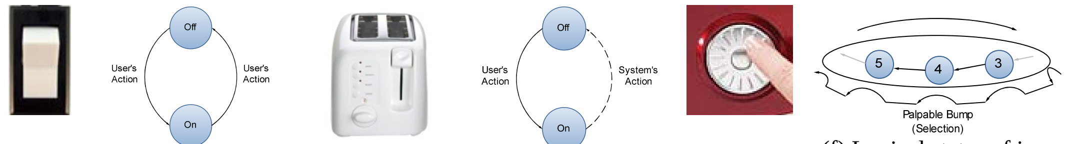
Therefore, it is necessary to develop tools and techniques addressing physicality aspects for the assistance of ES designers and developers for producing better interaction solutions.

■3.0 PRINCIPLES OF PHYSICALITY

This section introduces some of the key principles of physicality related to UI of ESs. Norman [11] states that physicality is the latest UI breakthrough by re-addressing the physical and mechanical controls that are now equipped with intelligent embedded processing and communicating facilities. Therefore, it is more significant now to produce intuitiveness in PUIs for the ease of users since they have to deal with those controls that offer more features in various ways than the conventional controls. Additionally, in order to produce intuitive PUI, the number of controls should be minimum [35] leading to the need of multiple functionalities per control and compactness of the overall interface. Therefore, it is significant to investigate the principles of physicality to produce natural interaction aspects in the ESs. This will guide the ES designers and/or developers in producing natural interfaces of their products. Six principles of physicality are discussed subsequently with the help of state transition diagrams including exposed state, compliant interaction, tangible transition, bounce back, inverse action, and compliant interaction [8].

3.1 Exposed State

When the physical state of the control reveals and exposes the underlying functionality then it is called an exposed state. The exposed state property helps the user in understanding the manipulation of control. A light switch (Figure 1a), for example, offers two physical states that is switch up and switch down. Each physical state has an attached logical state. Switch up is linked and associated with light off functionality while switch down is linked with light on functionality (Figure 1b). This one-to-one mapping of physical and logical states provides naturalness prior to and during interaction.



(a) Physical state of switch

(b) Logical states of switch

(c) Physical state of toaster lever

(d) Logical states of toaster lever

(e) Physical state of jog dial

(f) Logical states of jog dial

Figure 1 (a)(b) Exposed state, (c)(d) Controlled state, (e)(f) Tangible transition

3.2 Controlled State

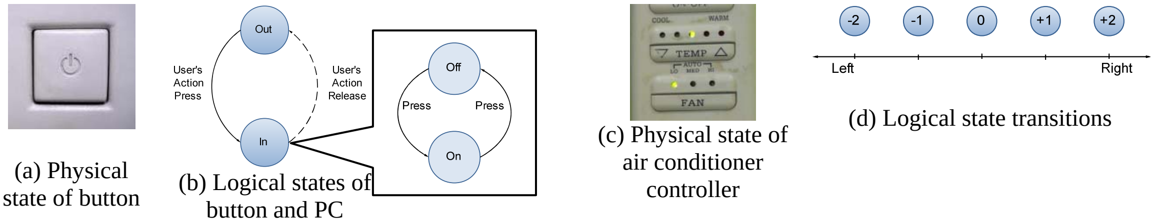
After moving a physical control from its initial position to a new position, if the control stays there and the device restricts the user from taking it back to its original position, then this property of the control is called the controlled state. The handle of a mundane toaster (Figure 1c), for example, once pressed down to an on state cannot be pulled back up by the user, instead the device itself releases the handle (Figure 1d). Although, this seems to restrict the user's control over the device but it helps in completing the job in various ways. Firstly, it informs the user that the device has accepted user's input. Secondly, it also shows the user that the device is now busy in executing the job and the user may wait. Thirdly, during the operation, anytime the user may know the internal (logical) state of the device by looking at the physical state. Lastly, on job completion the device releases the control and allows it to reach its initial position while indicating the end of job to the user.

3.3 Tangible Transition

The distinctive tangible feltness like subtle bump offered by any control at each logical state transition helps the user by informing about the state change without the need to look and focus at the control. This property is called tangible transition. For example, the dials of sound system (Figure 1e), MP3 players, car audio controls, etc. During the manipulation of a jog dial, a number of logical states can be traversed (Figure 1f). Tangible transitions provide eyes-free interaction with the control that is specifically useful for the mobile and compact devices.

3.4 Bounce Back

Some controls offer physical bounce back reaction after contact. When the physical state of the control returns back to the original state as soon as the hand pressure is released then this property is called bounce back. When the physical state of the control returns back to the original state as soon as the hand pressure is released then this property is called bounce back. PC power button (Figure 2a), for example, and joysticks. The underlying logical state during the physical manipulation may be triggered on or off at any point like start, during or after pushing the control to its fullest or at any point on the returning path. Figure 2b shows an example where one physical state of a button is mapped to two states of PC (on and off) in a toggle fashion.



(a) Physical state of button

(b) Logical states of button and PC

(c) Physical state of air conditioner controller

(d) Logical state transitions

Figure 2 (a)(b) Bounce back, (c)(d) Inverse action

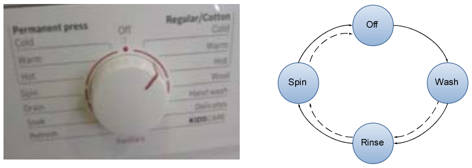
When the physical state of the control returns back to the original state as soon as the hand pressure is released then this property is called bounce back. PC power button (Figure 2a), for example, and joysticks. The underlying logical state during the physical manipulation may be triggered on or off at any point like start, during or after pushing the control to its fullest or at any point on the returning path. Figure 2b shows an example where one physical state of a button is mapped to two states of PC (on and off) in a toggle fashion.

3.5 Inverse Action

Inverse action is present in a control if the underlying logical functionality maps to the physical opposite states of the control. For example, when the temperature of a cooling system can be decreased by rotating the dial anticlockwise then the temperature must increase by rotating the dial clockwise. Likewise, the up/down or right/left movements of slider controls (Figure 2c and Figure 2d). The shape of the control also plays an important role. This is a powerful principle that helps the user during an interaction.

3.6 Compliant Interaction

Compliant interaction is the mutual symmetrical role of user and the control. A common example is the main washing dial of programmed washing machines (Figure 3). The solid arrows represent the user's action while dashed arrows represent the system's action. User sets the dial (by rotating it) at a particular setting; the washing starts; and the dial starts rotating back (to initial position), providing current state information to the user, lapsed and remaining time, and the speed of progress.



(a) Physical state of washing machine program dial

(b) Logical state transitions

Figure 3 Compliant interaction

Some controls restrict the user to rotate backwards (against the direction of rotation) or forward (in the direction of rotation) depending on the requirement that may result in better understanding between the control and the user.

■4.0 ASSIGNING VALUES TO PHYSICALITY PRINCIPLES

The quantitative evaluation of PUIs can offer more advantages than qualitative approach for the developers of ESs [47-52]. The resultant distinctive numeric values make it easier for the developers to better understand and apply the physicality aspects properly. There are various studies that have assigned numeric values to evaluate the usability of UIs [10,42-46] and not physicality. Therefore, we have firstly assign values to physicality principles according to the level of their existence in a control as listed in Table 1.

The numeric values of two, one, and zero are assigned for the full existence (in all controls of an ES), partial existence (in half controls of an ES), and absence of a principle, respectively. There are cases when more than half and less than all controls support a principle and less than half of the controls support a principle. Therefore, values of 1.5 and 0.5 are also used for the former and latter cases, respectively, for precise rating.

The partial existence (value one) can be of various types in between full existence and absence of a principle. For an exposed state, for example, refer to Figure 1b, if the user can perform one of the two actions then it implicates that exposed state property half exists. In other words, if the control offers toggle function having two state transitions but the user can perceive only one of these transitions then this control exhibits partial exposed state. The physical state transition is there but unperceivable to user until the user's finger actually engages the control. Likewise, for controlled state, referring to Figure 1d, if the pressed lever at its fullest (down) can be lifted back up towards initial position at some intermediate point then the control offers partial controlled state.

When the distinctive tangible feltness offered by a control (like dial) do not equally map to the underlying logical state changes then the dial supports partial principle of tangible transition. If a control offers bounce back but returns back to initial position after some delay, with slow motion, or with play (violating a straight path), then this control is classified as having partial bounce back effect. For inverse action, if the two sides of a control (left/right, up/down) have vague or unequal physical-digital mappings compared to each other means the control offers partial inverse action.

Table 1 Physicality analysis ratings

#	Principles	Values	Description
1	Exposed State	0 1 2	Absent Partially supported i.e., only half number of exposed states Fully supported i.e., all exposed states
2	Controlled State	0 1 2	Absent Partially supported i.e., intermediate state Fully supported i.e., no intermediate state
3	Tangible Transitions	0 1 2	Absent Partially supported i.e., missing mappings Fully supported i.e., no missing mappings
4	Bounce Back	0 1 2	Absent Weakly supported i.e., delay and play on the return path Strongly supported i.e., no delay at return
5	Inverse Action	0 1 2	Absent Vague and/or unequal number of mappings at each side Clear and/or equal number of mappings at each side
6	Compliant Interaction	0 1 2	Absent Weak compliance i.e., no means available for user to go back during symmetric motion Strong compliance i.e., user has some means available to go back
For all principles		0.5	For conditions between values zero and one
		1.5	For conditions between values one and two

If a user, in case of compliant interaction, can be able to move the control to any previous or forward state, directly or indirectly, then it is strong compliance while if a control does not allow user by any means to return to any previous or forward state, then it is weak compliance. An example of the indirect return to a previous state, mentioned in former case, is the availability of forward movement of a washing machine dial by the user all the way around returning to previous position.

5.0 INVESTIGATING THE PUIs

Five ES PUIs are used for this study including washing machine; camera; oven; sound system; and MP3 player shown in Figure 4.

(a) Washing Machine (b) Camera (c) Oven (d) Sound System (d) MP3 Player

Figure 4 Subject ESs

Washing machine PUI has four controls; all dials. Camera has six controls; all push buttons. Oven has three controls; a toggle button and two dials. Sound system has four controls; a push button and three dials. Lastly, MP3 player has a slider and five buttons of various types. Table 2 introduces the subject ESs by listing the number and types of controls present in them.

Table 2 Controls of subject ESs

Controls	Embedded Systems (ESs)				
	Washing Machine	Camera	Oven	Sound System	MP3 Player
Push Button	-	5	-	1	2
Surface Button	-	-	-	-	3
Toggle Button	-	-	1	-	-
Dial	4	-	2	3	-
Slider	-	1	-	-	-
Total Controls	4	6	3	4	5

As mentioned in the Introduction section that this investigation generates the numerical results by comparing the overall PUIs of ESs and it is not a comparison of the individual controls of each ES or the controls of different ESs. Using expert analysis method the values are applied on subject ES and the results are listed in Table 3.

Table 3 Physicality analysis results

#	Principles	Embedded Systems				
		Washing Machine	Camera	Oven	Sound System	MP3 Player
1	Exposed State	2	1	2	1.5	1
2	Controlled State	0	0	0	0	0
3	Tangible Transitions	2	0.5	1	1	0.5
4	Bounce Back	0	1	0	0.5	0.5
5	Inverse Action	2	0.5	2	2	0.5
6	Compliant Interaction	0.5	0	0.5	0	0
	Total	6.5	3	5.5	5	2.5

The controls of washing machine and oven offer strong exposed states. The controls of sound system offer exposed state but due to the strong similarity of shape and orientation between push button and dials, it takes time to distinguish them from each other. All camera controls offer weaker exposed state compared to washing machine and oven. The surface buttons at the front panel of MP3 player afford partial exposed state. Additionally, it is difficult to operate them without looking at them or in low light context. The slider and push buttons offer better exposed state. However, taking an average of all six controls, the exposed state of overall interface (of controls) is rated with value one.

None of the controls of all devices offer controlled state, therefore, all PUIs are rated as zero. All the dials of washing machine offer tangible transitions, so rated with a value two. So, the score of this principle for washing machine is two, whilst others are ranked zero. Meanwhile, camera controls do offer tangible feedback at transitions, yet with a very subtle feedback, so it is rated with a value 0.5. Two out of three controls of oven offer tangible transitions i.e., toggle button and a dial. However, the number of tangible transitions offered by the said dial is so large in number that their purpose approximately vanishes as user cannot recognize the two adjacent setting values displayed with the dial. Therefore, overall a value of one is assigned. Two out of four controls of sound system i.e., power push button and volume dial, offer tangible transitions while other two dials for bass and treble does not offer tangible transitions. Therefore, a value of one is assigned. Among all controls of MP3 player, only slider control (for power) offers sufficient tangible transition while other controls offer meager and insufficient tangible transitions.

For the bounce back, the dials of washing machine do not offer bounce back hence rated zero. The controls of camera and some controls of MP3 player offer weak bounce back hence assigned value one and 0.5, respectively. Oven controls does not offer bounce back, so rated zero while one of four controls of sound system offers bounce back, so overall rated 0.5. The controls of washing machine, oven, and sound system offer strong inverse action. The camera's quad-button is a multi-purpose button hence offering weak inverse action, so overall camera's inverse action is rated with value 0.5. Similarly, the forward and backward buttons of MP3 player, two out of six controls, offer weak inverse action while the slider offers strong inverse action, so an average value of one is assigned to overall PUI. One control of washing machine offers compliant interaction; the main wash dial; therefore an average value of 0.5 is assigned. Similarly, a control of oven offers compliant interaction; the baking dial; therefore an average value of 0.5. Other PUIs do not offer compliant interaction hence rated zero.

According to these results, washing machine PUI offers highest and MP3 player PUI offers lowest value of physicality principles. Exposed state, tangible transitions, and inverse action play significant role in the ratings of washing machine. On the other hand, MP3 player lacks in strong exposed state, bounce back, and inverse action. Oven and sound system PUIs offer strong exposed state and inverse action principles. Camera PUI is slightly better than MP3 player due to comparatively better bounce back effect. Overall, washing machine PUI offers highest physicality value than other subject PUIs.

■6.0 DISCUSSION

The analysis of five PUIs highlights the significance of exposed state, tangible transitions, and inverse action. The results of this study verified that these principles are more significant in augmenting the natural interaction. Additionally, even a single control offering good compliant interaction, depending upon device's underlying functionality, also helps in enhancing the overall performance of device. Although dials are powerful controls but do not offer bounce back that is more significant with other controls especially buttons. The PUIs with buttons should offer bounce back effect properly as it is missing in some of the subject ESs. Controlled state is not a frequently used principle and none of the subject interfaces offered it. These principles recruit users' innate subconscious abilities. Users' prior experience with other like devices also helps in building the abilities of use. The physicality principles help in building a kind of mutual understanding between the user and the control. This results in alleviating the cognitive requirements and visual concentration especially by tangible transitions, bounce back, and inverse action. The quantitative ratings help ES developers in easily managing these principles in their developed products. The introduction of physicality principles in PUIs of ESs helps in reducing the complexity of interaction and augmenting the naturalness of interaction. Previously, these principles were not applied to the ESs [8].

■7.0 CONCLUSION

There is a need to incorporate physicality aspects in PUIs of ESs. This study has investigated the physicality principles in the PUIs of various ESs including washing machine; camera; oven; sound system; and MP3 player. The results revealed that the washing machine interface offers most physicality principles while MP3 player offers the least. The principles of exposed state, tangible transitions, and inverse action are found to be more significant than other principles in producing visceral interaction. The quantitative analysis approach has helped us to easily highlight the key issues related to physicality of devices. This approach is especially helpful for the ES developers having less exposure to the techniques and methods of Human-Computer Interaction or its sub-field Physicality. The developers can use this approach to incorporate, manage, evaluate, and hence enhance the physicality aspects. This practice will result in the development of naturally interactive ESs since these aspects were not addressed before [8,47]. The evaluation of this approach by the ES developers is in progress.

Acknowledgement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

References

[1] A. Malinowski, and Y. Hao. 2011. Comparison of Embedded System Design for Industrial Applications. *IEEE Transactions on Industrial Informatics*. 7(2): 244–254.

[2] A. Sehmi. 2010. On Distributed Embedded Systems. *Architecture Journal*. 17.

[3] L. Józwiak, N. Nedjah, and M. Figueroa. 2010. Modern Development Methods and Tools for Embedded Reconfigurable Systems: A Survey. *Integration, VLSI Journal*. 43(1): 1–33.

[4] M. Sarrafzadeh, F. Dabiri, R. Jafari, T. Massey, and A. Nahapetian. 2006. Low Power Light-weight Embedded Systems. *Proceedings of the 2006 International Symposium on Low Power Electronics and Design (ISLPED'06), ACM*, NY, USA. 207–212.

[5] W. Ping. 2008. Research on the Embedded System Teaching. *IEEE International Workshop on Education Technology and Training & 2008 International Workshop on Geoscience and Remote Sensing*. 19–21.

[6] U. Meyer-Baese, G. Bottela, E. Castillo, and A. Garcia. 2010. A Balanced HW/SW Teaching Approach for Embedded Microprocessors. *International Journal of Engineering Education*. 26(3): 584–592.

[7] N. Hirasawa, S. Ogata, and K. Yamada-Kawai. 2010. Integration of User Interface Design Process. *Proceedings of the 11th International Conference on Product Focused Software*. 39–42.

[8] M. Ghazali. 2007. *Discovering Natural Interaction of Physical Qualities to Design Fluid Interaction for Novel Devices*. Research Monograph, Universiti Teknologi Malaysia, Malaysia.

[9] T. A. Henzinger, and J. Sifakis. 2007. The Discipline of Embedded Systems Design. *Computer*. 40(10): 32–40.

[10] S. Gelineck, and S. Serafin. 2009. A Quantitative Evaluation of the Differences between Knobs and Sliders. *Proceedings of the 2009 conference on New Interfaces for Musical Expression (NIME09)*, 13-18.

[11] D. Norman. 2007. The Next UI Breakthrough, Part 2: Physicality. *Interactions*. 14(4): 46–47.

[12] H. Nakagawa, N. Yoshioka, A. Ohsuga, and S. Honiden. 2011. IMPULSE: A Design Framework for Multi-agent Systems based on Model Transformation. *Proceedings of the 2011 ACM Symposium on Applied Computing (SAC'11)*. ACM, NY, USA. 1411-1418.

[13] M. Unterkalmsteiner, T. Gorschek, A. K. M. M. Islam, C. K. Cheng, R. B. Permadi, and R. Feldt. 2011. Evaluation and Measurement of Software Process Improvement - A Systematic Literature Review. *IEEE Transactions on Software Engineering*. X: 1–29.

[14] E. Coskun, and M. Grabowski. 2005. Software Complexity and its Impacts in Embedded Intelligent Real-time Systems. *Journal of System and Software*. 78(2): 128–145.

[15] A. L. Blackler, V. Popovic, and D. P. Mahar. 2010. Investigating Users' Intuitive Interaction with Complex Artefacts. *Applied Ergonomics*. 72–92.

[16] S. Lawry, V. Popovic, and A. L. Blackler. 2010. Identifying Familiarity in Older and Younger Adults. *Proceedings of Design Research Society International Conference 2010: Design & Complexity*, School of Industrial Design, Université de Montréal, Montréal.

[17] A. L. Blackler, D. P. Mahar, and V. Popovic. 2010. Older Adults, Interface Experience and Cognitive Decline. *Proceedings of the 22nd Annual Conference on the Australian Computer-Human Interaction Special Interest Group: Design - Interaction - Participation, ACM & CHISIG*, Queensland University of Technology, Brisbane, Queensland.

[18] R. R. Gudur, A. L. Blackler, D. P. Mahar, and V. Popovic. 2010. The Effects of Cognitive Ageing on the Use of Complex Interfaces. *Proceedings of the 22nd Annual Conference on the Australian Computer-Human Interaction Special Interest Group: Design - Interaction - Participation, ACM & CHISIG*, Queensland University of Technology, Brisbane, Queensland.

[19] P. Langdon, J. Clarkson, and P. Robinson. 2010. Designing Inclusive Futures. *Universal Access in the Information Society*. 9(3): 191–193.

[20] P. Biswas, and P. Langdon. 2011. Standardizing User Models. *Universal Access in HCI. Users Diversity*. C. Stephanidis (Ed.), Springer Berlin / Heidelberg. 6766: 3–11.

[21] C. Wilkinson, P. Langdon, and P. Clarkson. 2011. Evaluating the Design, Use and Learnability of Household Products for Older Individuals. *Universal Access in HCI. Users Diversity*. C. Stephanidis (Ed.), Springer Berlin / Heidelberg. 6766: 250–259.

[22] U. Persad, P. Langdon, and P. Clarkson. 2011. Investigating the Relationships between User Capabilities and Product Demands for Older and Disabled Users. *Universal Access in HCI. Design for All and eInclusion*. C. Stephanidis (Ed.), Springer Berlin / Heidelberg. 6765: 110–118.

[23] A. Mieczakowski, P. Langdon, and P. J. Clarkson. 2011. An Approach Towards Considering Users' Understanding in Product Design. *Universal Access in HCI. Design for All and eInclusion*. C. Stephanidis (Ed.), Springer Berlin / Heidelberg. 6765: 90–99.

[24] T. Peffer, T. Pritoni, M. Meier, A. Cecilia, and D. Perry. 2011. How People Use Thermostats in Homes: A Review. *Building and Environment*. 46(12): 2529–2541.

[25] C. Swindells, K. E. MacLean, K. S. Booth, and M. J. Meitner. 2007. Exploring Affective Design for Physical Controls. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. San Jose, California, USA, ACM. 933–942.

[26] A. Ferscha, S. Vogl, B. Emsenhuber, and B. Wally. 2007. Physical Shortcuts for Media Remote Controls. *Proceedings of the 2nd International Conference on Intelligent Technologies for Interactive Entertainment*, Cancun, Mexico, ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering). 1–8.

[27] D. Cavett, M. Coker, R. Jimenez, and B. Yaacoubi. 2007. Human-Computer Interface for Control of Unmanned Aerial Vehicles. *Proceedings 2007 IEEE System Information Engineering Design Symposium*. 1–6.

[28] J. Packer, and M. Blubaugh. 2011. Left to Your Own Devices: Results of a Study on the Usability of Everyday Household and Electronic Products for People with Vision Loss. *Accessworld: Technology for Consumers with Visual Impairments*. 12(11): 6–22.

[29] D. Perry, C. Aragon, A. Meier, and M. Pritoni. 2011. Developing Standards for Affordances on Embedded Devices: Poster Abstract. *Proceedings of the 2011 iConference '11*, New York, USA, ACM. 746–748.

[30] S. H. Han, M. H. Yun, K. Kim, and J. Kwahk. 2000. Evaluation of Product Usability: Development and Validation of Usability Dimensions and Design Elements based on Empirical Models. *International Journal of Industrial Ergonomics*. 26(4): 477–488.

[31] C. Harvey, N. A. Stanton, C. A. Pickering, M. McDonald, and P. Zheng. 2011. A Usability Evaluation Toolkit for In-Vehicle Information Systems (IVISs). *Applied Ergonomics*. 42(4): 563–74.

[32] H. J. Kim, J. K. Choi, and Y. Ji. 2008. Usability evaluation framework for ubiquitous computing device. *Proceedings of Third International Conference on Convergence and Hybrid Information Technology (ICCIT '08)*. 164–170.

[33] C. Vera-Muñoz, M. T. Arredondo, I. Peinado, M. Ottaviano, J. M. Páez, and A. D. de Barrionuevo. 2011. Results of the Usability and Acceptance Evaluation of a Cardiac Rehabilitation System. *Proceedings of the 14th International Conference on Human-Computer Interaction: Users and Applications - Volume Part IV (HCII'11)*. Julie A. Jacko (Ed.), Part IV. Springer-Verlag, Berlin/ Heidelberg. 219–225.

[34] P. J. Standen, C. Camm, S. Battersby, D. J. Brown, and M. Harrison. 2011. An Evaluation of the Wii Nunchuk as an Alternative Assistive Device for People with Intellectual and Physical Disabilities Using Switch Controlled Software, *Computers Education*. 56(1): 2–10.

[35] S. Kang, and W. Kim. 2007. Minimalist and Intuitive User Interface Design Guidelines for Consumer Electronics Devices. *Journal of Object Technology*. 6(3): 39–52.

[36] ISO, 9241-11. Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs). Part 1998.11.

[37] F. Yanxiang. 2012. The Study on Human Computer Interaction Design Method based on Unified Interactive Mode. *International Journal of*

Digital Content Technology and its Applications (JDCTA). 6(2): 180–187.

[38] P. N. Johnson-Laird. 1989. Mental Models. *Foundations of Cognitive Science*. M. I. Posner, (Ed.). Cambridge, MA: MIT Press.

[39] P. N. Johnson-Laird, V. Girotto, and P. Legrenzi. 1998. Mental models: A Gentle Guide for Outsiders. University of Michigan: http://www.si.umich.edu/ICOS/gentleintro.html

[40] D. A. Norman. 1983. Some Observations on Mental Models. *Mental Models.* D. Gentner, and A. L. Stevens (Eds.), Hillsdale, NJ: Lawrence Erlbaum Associates.

[41] S. J. Payne. 2003. Users' Mental Models: The Very Ideas. *HCI Models, Theories, and Frameworks.* J. M. Carroll. (Ed.). San Francisco: Morgan Kaufman Publishers. 135–154.

[42] T. Ikegami, H. Okada, S. Yoshizaka, and S. Fukuzumi. 2008. Proposal of Usability Quantification Method (1) –checklist for exclusion blurring among evaluators. *Annual Conference of Information Processing Society*, Japan. 248–251.

[43] H. Okada, T. Ikegami, S. Yoshizaka, and S. Fukuzumi. 2008. Proposal of Usability Quantification Method (2)–experiment for validation of a checklist. *Annual Conference of Information Processing Society*, Japan. 252–258.

[44] S. Kato, K. Horie, K. Ogawa, S. Kimura. 1995. A Human Interface Design Checklist and Its Effectiveness. *Transaction of Information Processing Society of Japan*. 36(1): 61–69.

[45] D. -H. Ham, J. Heo, P. Fossick, W. Wong, S. -H. Park, C. Song, and M. Bradley. 2007. Model-based Approaches to Quantifying the Usability of Mobile Phones. *HCI 2007. Lecture Notes in Computer Science*. J. A. Jacko. (Ed.), Springer, Heidelberg. 4551: 288–297.

[46] S. Fukuzumi, T. Ikegami, and H. Okada. 2009. Development of Quantitative Usability Evaluation Method. *Human-Computer Interaction. New Trends Lecture Notes in Computer Science.* 5610: 252–258.

[47] M. Ashraf, and M. Ghazali. 2011. Towards Natural Interaction with Wheelchair Using Nintendo Wiimote Controller. *ICSECS’11, III.* J. M. Zain (Ed.), Springer Berlin, Germany. 231–245.

[48] M. Ashraf, and M. Ghazali. 2011. Augmenting Intuitiveness with Wheelchair Interface Using Nintendo Wiimote. *International Journal on New Computer Architectures and Their Applications*. 1(4): 1000–1013.

[49] M. Ashraf, and M. Ghazali. 2011. Reducing the Complexity of Embedded System Interactions Using Physicality. *Proceedings of IEEE 2nd International Conference on User Science and Engineering: Beyond Usability (i-USEr2011)*, Extended Abstract, Malaysia. 14–19.

[50] M. Ashraf, and M. Ghazali. 2011. Interface Design for Wheelchair Using Nintendo Wiimote Controller. *Proceedings of the IEEE 2nd International Conference on User Science and Engineering: Beyond Usability (i-USEr2011)*, Malaysia. 54–59.

[51] M. Ashraf, and M. Ghazali. 2011. Taming The Complexity of Embedded System Interaction Using Principles of Physicality. *3rd Software Engineering Postgraduates Workshop (SEPoW2011)*, Malaysia. 58–62.

[52] M. Ashraf, and M. Ghazali. 2011. Investigating Physical Interaction Complexities in Embedded Systems. *Proceedings of the 5th IEEE Malaysian Software Engineering Conference (MySEC2011)*, Malaysia. 214–219.