Usability Heuristics and Qualitative Indicators for the Usability Evaluation of Touch Screen Ventilator Systems

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Abstract. A ventilator system provides respiratory support to critically ill patients in the Intensive Care Unit. Increasing complexity in the user interface, features and functionalities of ventilator systems can cause medical errors and cost the life of a patient. Therefore, the usability of ventilator systems is most crucial to ensure patient safety. We have evolved a specialized set of heuristics combined with objectively defined usability indicators for the usability evaluation of touch screen based ventilator systems. Our study presents the heuristic evaluation of three touch screen based ventilator systems manufactured by three different companies. The heuristic evaluation has been performed by four different usability evaluators to ensure the reliability of heuristics proposed in this paper. The specialized set of heuristics linked with user interface components and the objectively defined usability indicators are found more reliable in identifying specific usability problems of ventilator systems.

Keywords: Touch Screen Ventilator System, Intensive Care Unit, Specialized Heuristics, Usability Indicators, Usability Evaluation, Patient Care

1 Introduction

Modern healthcare is supported by variety of complex medical equipments like ventilator system, multi-parameter monitoring system, defibrillator, ECG analyzer, etc. Mechanical age medical equipments are now undergoing major technological upgradation with the advent of embedded electronic equipments, small size displays, information technology and ubiquitous applications wherein the equipments can be networked together. This effort is directed at reducing process inefficiencies, improving the quality of patient care and controlling the healthcare costs. Increasing complexity of functionalities and features in healthcare systems is also resulting in potential usability and design errors.

Medical error is a leading cause of death along with motor vehicle accidents, breast cancer and AIDS [14]. Many medical devices have user interfaces that are so poorly designed and difficult to use that they cause a variety of human errors. Usability of

medical devices is most crucial to ensure safety and to enable physicians to focus on their patients rather than technology [1, 4]. Therefore, it is necessary to consider all such aspects of device design in a practical sense to ensure the optimal usability as well as performance of the medical device.

During our discussions with physicians, many of them highlighted the criticality of ventilator systems from the point of view of usability and recommended it for our usability evaluation. A ventilator system gives respiratory support to critically ill patients [5]. Ventilators can be classified as: mechanical, electronic or touch-screen based. We have specifically considered touch-screen based ventilator systems for our study.

There are many techniques available for usability evaluation [10] such as cognitive walkthrough, expert reviews, focus groups, Delphi technique, heuristic evaluation etc. We observed three ventilator systems manufactured by different companies to find major design problems in all touch screen interfaces. It lead us define a specific set of heuristics for evaluating the usability of ventilator systems.

Fig. 1. Touch screen ventilator system and the environment in the Intensive Care Unit

2 Related work

Nielsen proposed 10 broad heuristics of interface design [11]. Also, Ben Shneiderman has described eight golden rules [13] that all good user interface designs should follow. Based on their work, Zhang et al. [14] selected a set of 14 heuristics called as Nielsen-Shneiderman heuristics for evaluation of patient safety of medical devices. They also conclude that such adaptation of heuristic evaluation for medical devices is very useful, efficient and cost effective for evaluating patient safety features.

We have come across several usability evaluations which are carried out using the Nielsen-Shneiderman heuristics. Some examples of these are briefly presented here. Graham et al. carried out heuristic evaluation of infusion pumps [7] using Nielsen-Shneiderman heuristics. The evaluation exercise carried out by 3-5 evaluators is reported to have captured 60-70% of the usability problems [14]. Edwards et al have applied Heuristic Walkthrough (HW) method to evaluate and improve the usability of the Electronic Health Record (EHR) system [4]. In another case study, the usability evaluation of Automatic External Defibrillators (AED) was conducted according to Nielsen-Shneiderman heuristics [2]. Diabetes tele-management system is also evaluated using Nielsen-Shneiderman heuristics [9]. For usability evaluation of this system, they have used 1-5 Likert scale and applied it uniformly to all heuristics.

2.1 Need for a specialized set of usability heuristics and indicators

As per our assessment, the interface design heuristics proposed by Nielsen and Shneiderman are meant for general-purpose software applications. Previous research by Nielsen and Molich has already shown that there is vast difference in the findings of usability evaluation by different evaluators [12]. Furthermore, these heuristics tend to miss out the unique nature of user interfaces of ventilator systems such as-

- **Combination of touch screen interface and physical interfaces like touch buttons, knobs and LEDs**
- **Direct, precise and immediate communication and control (less scope for metaphoric representations)**
- **No scope for trial and error and exploratory approach to figure out the user interface**
- **Always used in time and life critical situations**
- **Fatal consequences in case of errors and delay**

In case of ventilator systems, we need to specify the user interface components, a set of usability heuristics supported by objectively defined usability indicators [8] so that at least the major usability problems are not missed out during the evaluation. It is an imperative for medical usability because patient safety cannot be compromised and the consequences can be fatal. We have directly mapped the evaluation ratings with the usability indicators. We have attempted to reduce the vagueness and subjectivity in heuristic evaluation.

3 Methodology

- **Involvement of a physician**

The usability experts have limited medical knowledge despite of putting sufficient effort in understanding the functionality and actual usage of a ventilator system. Therefore, it was an imperative step in our usability evaluation to involve a physician with the required medical expertise. The physician was to also help in sharing their expectations, priorities and experiences.

- **Ventilator systems**

Three touch screen ventilator systems by different manufacturers were selected for usability evaluation. The names of manufacturers and equipment models of these ventilator systems are not disclosed to maintain confidentiality.

- **User interface and usage scenarios**

The usability experts developed adequate familiarity of the ventilator systems [6] with the help of the physicians and medical staff. It was very difficult to observe and evaluate the ventilator systems in the intensive care unit. Therefore, the physician was requested to perform the tasks while explaining the significance of use and this was video recorded for further observations. The video recording was helpful in noting the minute observations and the final usability evaluation. Ethical practices were observed while video recording the ventilator systems in intensive care units.

- **Usability heuristics and indicators**

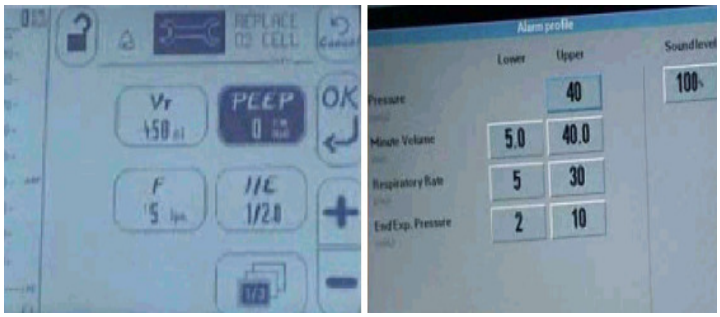
Usability problems and design deficiencies commonly prevalent among all three ventilator systems were identified based on which the heuristics were formulated. The design priorities and medical priorities were fused together wherever applicable through deliberations between the design / usability experts and the physician. The user interface components and qualitative usability indicators [8] were identified to measure the compliance. Instead of applying the 1-5 Likart scale [9] uniformly across all parameters, we have chosen a indicator based evaluation method. Some heuristic indicators are checked in term of their absence or presence and some are elaborated in terms of their qualitative attributes. Each indicator is rated between 0 and 1.

- **Usability Evaluation**

The heuristic evaluation has been performed by four different usability evaluators to ensure the reliability of heuristics proposed in this paper.

4 Introduction to heuristics

4.1 Value input interface



A B

Fig. 2. Value input interface of ventilator systems

The input values for related parameters can be provided to the system through interface shown in Fig. 2A after selection of ventilator mode. The interface does not indicate valid range of values for parameters with proper upper and lower limits. It does not provide a selection of measuring units for corresponding parameters. Abbreviations are used for describing the parameters like PEEP or I/E and it does not visually represent those values. We found that some of the abbreviations and parameters were unfamiliar to the physicians. For alarm settings shown in 2B, units are not placed next to corresponding values. **Most of the time, the physicians have to input variety of values in the ventilator system and therefore the interface for inputting the values must be error free and user friendly.**

The list of heuristics for evaluating the touch screen interface for value inputting is elaborated in table 1.

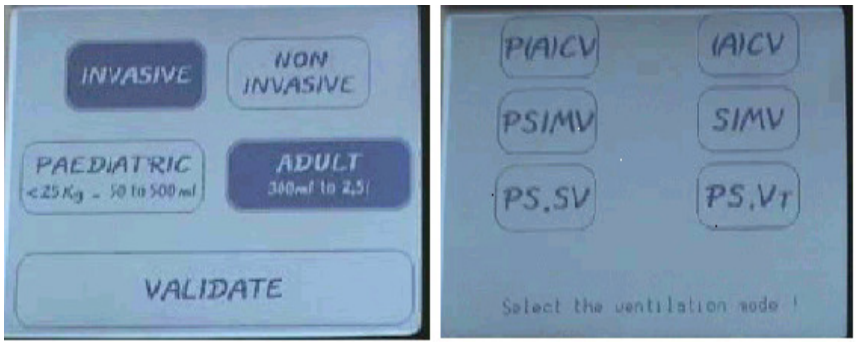
Table 1. Heuristics for evaluating the touch screen interface for value inputting

Interface for input of values		
H1	Indicate valid range (maximum and minimum thresholds) of values for various parameters	Indicated (1) Not Indicated (0)
H2	Allow selection of units for measurement	Allowed (1) Not Allowed (0)
H3	Validate the inputs before acceptance	Validated (1) Not Validated (0)
H4	Confirm in case of proceeding with default values	Confirmed (1) Not Confirmed (0)
H5	Highlight the selected text input area and gray out the other text input areas	Highlights (1) Grays out (1) Does not highlight or gray out (0)
Interface for controlling the value input		
H6	Both on screen controls and physical knobs be provided for adjusting the values	Both Provided (1) One is provided (0)
H7	(Applicable in case of on screen interface) The input box and controls for adjusting the values to be co-located for every parameter	Co-located (1) Not co-located (0)
Labeling of value input interface		
H8	Use full form expressions for describing the parameters	Used (1) Not used (0)
H9	Use full form expressions for describing the units	Used (1) Not used (0)
H10	Units to be placed next to the value	Placed (1) Not placed (0)
Visual Representation		
H11	Form a visible group of related parameters	Common color (1) Boundary (1) Proximity (1) Scattered (0)
H12	Visually represent the values	Represented (1) Not Represented (0)
H13	Use unique colour code for quick identification and recall	Used (1) Not used (0)
Culture Specific Preferences		

H14	Date format (dd/mm/yyyy or mm/dd/yyyy)	Given (1) Not given (0)
H15	Weight measurement unit (Pounds or Kilograms)	Given (1) Not given (0)
H16	Height measurement unit (Feet or Centimetres)	Given (1) Not given (0)

4.2 Interface for selection of option

Fig. 3A shows the screen for setting the patient configuration that provides two pairs of options namely "invasive or non-invasive" and "pediatric or adult". From each of these pairs one option needs to be selected. But this expectation is represented in a very ambiguous manner. Fig. 3B provides options for selecting the ventilator modes like (A)CV or PSIMV. Such abbreviations are obscure and unclear for the medical staff. Proper understanding of options and their selection is important. The heuristics for evaluating the touch screen interface for selection of options are enlisted in table 2.



A B

Fig. 3. Interface for selection of options

Table 2. Heuristics for evaluating the touch screen interface for selection of options

Interface for structuring of options		
H17	Logical sequence of options	Logically arranged (1) Randomly arranged (0)
H18	Form visibly proximate groups of related options	Common color (1) Placed a boundary around the group (1) Closeness by distance (1) Scattered (0)
Visual Representation of option		

H19	Consistent sizes of buttons by following a grid	Consistent (1) Inconsistent (0) Grid followed (1) Grid not followed (0)
H20	Use appropriate symbols or icons for related options	Used (1) Not used (0)
Description of option		
H21	Use full expressions for describing the options	Used (1) Not used (0)
H22	Describe the screen / groups of options by precise title	Title given (1) Title not given (0)
H23	Provide tool tips for explaining the options, their implication and the number of options one can select at a time	Tool tips provided (1) Tool tips not provided (0)
H24	Avoid all capital letters for normal text (Acronyms to be excluded)	Upper-lower case (1) All capital letters (0)
H25	Legibility of text	Legible (1) Not Legible (0)
Feedback		
H26	Highlight the option(s) to indicate the selection	Highlighted (1) Not highlighted (0)
H27	Ask for confirmation before accepting the inputs	Provided (1) Not provided (0)

4.3 Interface for screen locking

A **B**

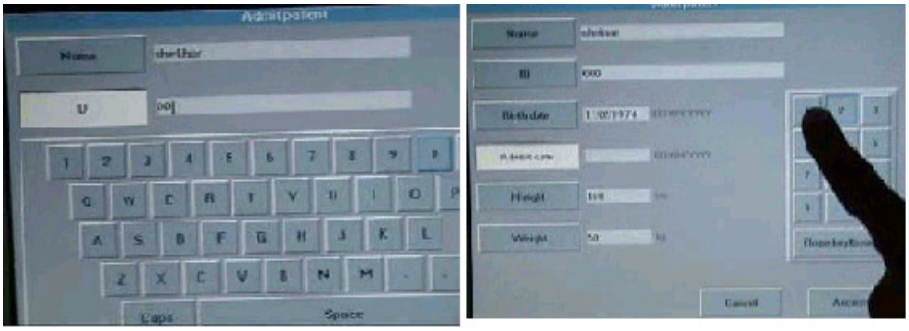
Fig. 4. Interface for screen locking

Screen locking feature can protect the settings from unintended changes. The touch screen ventilator systems without screen lock facility are prone to the danger of undesired changes in the settings. The touch screen lock is shown in fig. 4. It is obvious that the 'locking and unlocking' icons are not located in a consistent place. The heuristics for evaluating the screen locking interface are enlisted in table 3.

Table 3. Heuristics for screen locking interface

Availability of Lock		
H28	Screen locking / unlocking provision at any stage	Provided (1) Not provided (0)
Location of Lock		
H29	Screen Lock / Unlock toggle buttons to be located in a unique place	Unique (1) Not unique (0)
Visual Representation		
H30	Clearly visible and understandable iconic representation	Provided (1) Not provided (0)
Functional Behavior		
H31	Store the settings selected till the stage of locking	Stores (1) Does not store (0)
H32	Resume from the stage of unlocking	Resume (1) Does not resume (0)
Feedback		
H33	Visible feedback after locking and unlocking the screen	Provided (1) Not provided (0)

4.4 Data entry



A B

Fig. 5. On-screen keyboard and patient record interface

Touch screen ventilator systems require to provide an on-screen keyboard interface for data entry as shown in Fig. 5A. Fig. 5B shows patient record screen with numeric keyboard. The ventilator systems evaluated by us do not provide the facility to store and manage multiple patient records. Also the settings can be stored only once, if you change the settings and save then it overwrites the earlier. The heuristics for evaluating the on-screen keyboard interface and patient records are given in table 4.

Table 4. Heuristics for the on-screen keyboard interface and patient records

On-screen Keyboard		
H34	Onscreen keyboard for alphanumeric input	Provided (1) Not provided (0)
H35	Separate onscreen keyboard only for numeric input	Provided (1) Not provided (0)
H36	Provision for closing the onscreen keyboard whenever necessary	Provided (1) Not provided (0)
H37	Key size to be adequately large for fingure touch	Large (1) Not large enough (0)
H38	Adequate distance between keys so as to avoid wrong key-press	Adequate (1) Not adequate (0)
H39	QWERTY keyboard layout (with minimum necessary keys)	Provided (1) Not provided (0)
H40	Allow onscreen movement of keyboard	Provided (1) Not provided (0)
Patient Data Input		
H41	Allow selection of data format for input	Provided (1) Not provided (0)
H42	Allow selection of units for measurement	Provided (1) Not provided (0)
H43	Check in case of proceeding with default values	Checks (1) Does not check (0)
H44	Validate the inputs before acceptance (e. g. admit date should not be prior to birth date)	Validates (1) Does not validate (0)
Patient Record		
H45	Patient ID must be assigned to the record	Assigns (1) Does not assign (0)
H46	Rules may be applied while forming the ID	Rule-based (1) Random (0)
H47	Every patient record should have unique ID	Unique (1) Not unique (0)
H48	Storage of patient records	Stores (1) Does not store (0)
H49	Retrieval / deletion / updation of patient records	Supported (1) Not supported (0)
H50	Updation and Deletion of record by authorized users only	Supported (1) Not supported (0)

4.5 System feedback

A ventilator system has to be extremely communicative with the physicians and medical staff. Changes in the settings, internal processing, consequences of actions, warnings, error messages, status updates, alarms, etc have to be communicated from time to time. It is possible to design effective communication with the help of audio, visual, text and mobile messaging. The heuristics for evaluating the system feedback are given in table 5.

Fig. 6. Right-handed design of interface

Table 5. Heuristics for evaluating the system feedback

Feedback		
H51	Give feedback to communicate confirmation, status of progress, consequence of action, warnings and errors	Provided (1) Not provided (0)
H52	Effective use of visual communication	Appropriate use of signs & symbols (1) Color code (1) Animation (1) Culture-specific depiction (1) No visual communication (0)
Alarm		
H53	Provide alarms in audio, visual and mobile messaging forms	Audio (1) Visual (1) Mobile (1) None (0)

4.6 Neutral interface

Most medical equipments are designed only for right-handed users as seen in Fig. 6. It is clearly reflected in the layout of control panel, placement of knobs and buttons. Such design may not prove efficient for left-handed users. Therefore, neutrality for both left and right-handed users and ergonomic design are most desirable. The heuristics for evaluating neutrality of user interface are provided in table 6.

Table 6. Heuristic for evaluating neutrality of interface

Neutrality		
H54	Neutrality towards left and right-handed users	Neutral (1) Left-handed design (0) Right-handed design (0)

4.7 User manual / online help in local language

Mostly the user manuals are provided in English. Help is not provided as part of the software of ventilator system. The physicians are proficient in English but the assistive staff in the hospitals, which usually operate the ventilator systems are not familiar with English. Therefore, provision of user manuals and online help in English as well as local language is a must for reducing the possible medical errors.

Table 7. Heuristics pertaining to user manuals and online help

User manual and online help in local language		
H55	User manual in local language	Available (1) Not available (0)
H56	Online help in local language	Available (1) Not available (0)

5 Evaluation of ventilator systems

We have evaluated the usability of three different touch screen ventilator systems using the heuristics and usability indicators with following objectives.

i. Measure the usability and overall efficacy of touch screen ventilator systems
ii. Compare the quality of touch screen interfaces
iii. Study the reliability of the heuristics by involving three more usability evaluators to carry out the evaluation of same set of ventilator systems

This heuristic evaluation was carried out by totally four Usability Evaluators (UE). In this, UE1 are the authors of this paper who have formulated the heuristic guidelines. UE2, UE3, UE4 are other usability evaluators who used our heuristic evaluation method for evaluating the same set of ventilator systems.

We ensured that the usability evaluators had adequate understanding of Human Computer Interaction (HCI). They were sensitized about the proposed heuristics, criticality in the ICU environment and the usability evaluation of ventilator systems. Their queries about the heuristics and related evaluation were discussed and then they carried out the heuristic evaluation of all the three ventilator systems individually.

The total scores of usability evaluations by all four usability evaluators are consolidated in table 8.

Table 8. Heuristic evaluation of three Ventilator Systems (VS) by four different usability evaluators

* UE1 are the authors of this paper who have formulated the heuristic guidelines.

User Interface for	Max. Score	Usability Evaluators	Scores of Touch Screen Ventilator Systems		
			VS-I	VS-II	VS-III
1. Value Input	21	**UE1**	**03**	**05**	**09**
		UE2	04	07	11
		UE3	05	05	09
		UE4	04	04	09
2. Options	14	**UE1**	**07**	**08**	**11**
		UE2	06	11	9
		UE3	05	8	10
		UE4	06	8	11
3. Screen Lock	06	**UE1**	**05**	**00**	**06**
		UE2	06	00	05
		UE3	05	00	05
		UE4	05	00	06
4. Data Entry	17	**UE1**	**00**	**07**	**02**
		UE2	00	07	00
		UE3	00	07	01
		UE4	00	10	01
5. System Feedback	08	**UE1**	**02**	**03**	**05**
		UE2	04	05	03
		UE3	04	04	04
		UE4	03	04	05
6. Neutrality	01	**UE1**	**00**	**00**	**00**
		UE2	00	00	00
		UE3	00	00	00
		UE4	00	00	00
7. Help in local language	02	**UE1**	**00**	**00**	**00**
		UE2	00	00	00
		UE3	00	00	00
		UE4	00	00	00
Total	**69**	**UE1**	**17**	**23**	**33**
		UE2	20	30	28
		UE3	19	24	29
		UE4	18	26	32

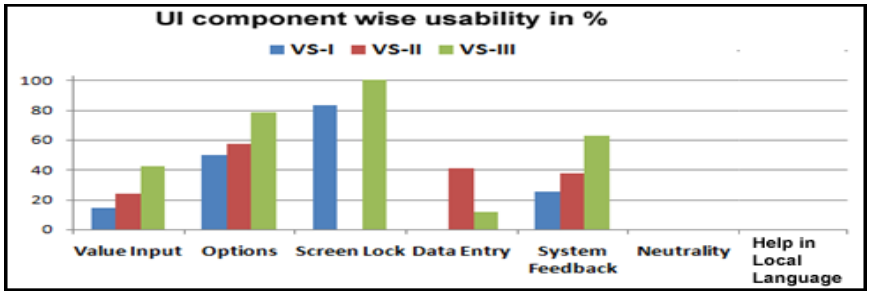


Fig. 7. UI component wise usability of all three ventilator systems as per the evaluation of UE1

Considering that UE1 have formulated the usability heuristics and the indicators, their evaluation score is compared with the evaluations by other usability evaluators to find the closeness in their results.

6 Reliability of usability heuristics

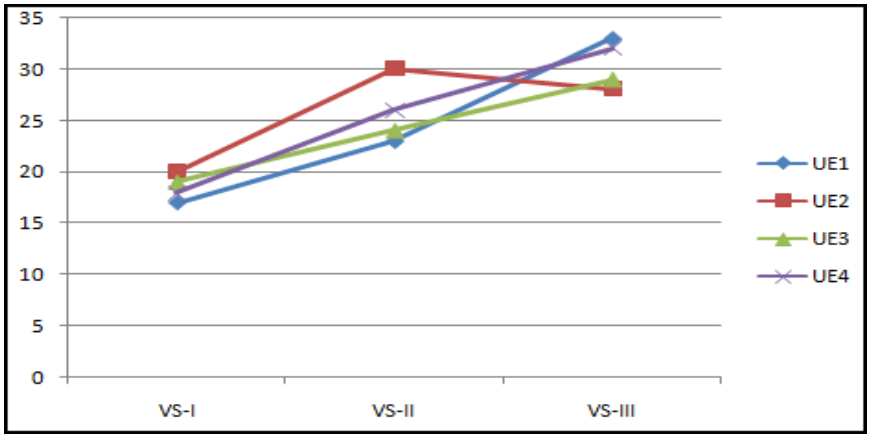


Fig. 8. Comparison of usability evaluation of ventilator systems by four usability evaluators (UE1,2,3,4)

The usability evaluation by other usability evaluators differs from UE1 by 11.77% for VS-I, 16.09% for VS-II and -10% for VS-III. The evaluation by UE2 is significantly different than the other usability evaluators because his interpretation of some heuristics (H18, H21, H27) and the importance given is slightly different than expected. On an average the evaluation of other usability evaluators has differed by 5.95% (addition of all % / 3) which is not very significant if compared with the results of Nielsen-Shneiderman heuristics in the context of medical devices [2,7,9,14].

7 Conclusion

Our observations of several ventilators systems available in Indian hospitals and the outcomes of heuristic evaluation show that the interface design of touch screen ventilator systems need significant design enhancements.

The specialized set of heuristics linked with user interface components and the objectively defined usability indicators are helpful in identifying specific usability problems of ventilator systems.

Heuristic evaluation in medical context cannot afford to be very subjective and open ended as in case of general-purpose software applications. It must identify specific usability problems in order to ensure patient safety and accuracy of treatment otherwise the consequences can be fatal.

The reliability of our approach in terms of reduced subjectivity and objective definition of UI components, heuristics and usability indicators specifically designed for ventilator systems is much higher.

Future Work

The UI components and the corresponding heuristics logically seem to be applicable to variety of medical devices. However, which subset of heuristics is more relevant to which medical devices and their significance needs to be explored separately.

We propose to design the prototypes of user interface for a ventilator system which will comply with the heuristic guidelines. We would like to collaborate with the manufacturers of ventilator systems to design more usable interfaces.

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