Model-Based Approaches to Quantifying the Usability of Mobile Phones

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Abstract. Several factors make it difficult to quantify the usability of mobile phones. Nevertheless, a quantified value of the usability could be used for several purposes, such as design innovation and benchmarking. This paper proposes three approaches (task centred, usability indicator-based, and design area-based quantification) to quantifying the usability of mobile phones on the basis of a hierarchical model of usability factors. Each of them provides process and rules for calculating the usability score of a mobile phone by applying weighting value assignment methods. Through two case studies, we could obtain empirical data to be used for determining the weighting value for quantification and confirm the usefulness of the proposed approaches.

1 Introduction

It is well known that usability is a critical attribute affecting the quality-in-use of mobile phones [4]. To assess and manage the usability in a more objective way, there has been an increasing need for usability quantification [3]. However, it is not easy to assign certain score to the usability. The difficulty is due to the fact that usability is a kind of emergent property and could be susceptible to users' subjective preferences [2]. Nonetheless, a quantified value of the usability could be used for several purposes, such as design improvement and benchmarking.

Very few attempts have been made at developing a method for quantifying usability. Rauterberg [6, 7] developed a concept to describe user interfaces on a granularity level and distinguish different types of interaction points. Based on this concept, he developed four measures (functional feedback, interactive directness, application flexibility, and dialog flexibility) and their relevant formula to quantify user interface characteristics. Sauro and Kindlund [10] proposed a method to simplify all the ANSI and ISO aspects of usability into a single, standardized and summated usability metric (SUM). Rubinoff [8] developed a methodology to quantify the user experience in websites. This methodology quantifies the user experience by measuring four

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interdependent, intangible elements: branding, usability, functionality, and content. They are measured with the use of a series of statements or parameters, each of which has a scale of 1 to 20. Lohse and Spiller [5] used a regression model to predict store traffic and dollar sales as a function of cyberstore interface design features, such as image sizes and store navigation features. Although the main purpose of several usability questionnaires like SUMI [11] is not to produce single usability score, many usability engineers have used them as a tool for quantification. Keinonen [3] claimed that quantification of usability should reflect users' preference on specific tasks or interface features with the use of weighting value assignment methods.

While most of earlier studies on quantification have addressed interactive software or websites, little attention has been given to information appliances like mobile phones. The purpose of this study is to propose model-based three approaches to quantifying the usability of mobile phones. Each of them is based on a hierarchical model of usability factors we developed [1]. Additionally, each approach uses various weighting-value assignment methods to reflect the relative importance of variables to be used for quantification. Firstly, we describe the hierarchical model and concepts for quantifying usability. Then each approach is explained in detail in terms of its quantification process and required information, and primary usages. Lastly, two case studies are explained, which were conducted for collecting data to be used for the weighting values and examining the usefulness of the approaches.

2 Hierarchical Model of Usability Factors

Quantification of usability proposed in this study is based on a multi-level hierarchical model that we developed to identify and organize various usability factors in terms of goal-means relations [1]. This model consists of five abstraction levels, each of which represents different aspect of mobile phone usability (Fig. 1).

Usability (Quality in Use)	Emergent feature to be characterized with several context factors
Usability Indicator	Hypothetical, abstract conceptual constructs that are not directly measured
Usability Criteria	Sub indicator that can be directly measured through at least one specific usability property
Usability Property (Metric)	Metrics that can be obtained by observing usability data or using a formula that defines a function
Usability Data	Usability Variable that can be obtained from mobile phones, user manual, user tasks, and so on

Fig. 1. Five abstraction levels of hierarchy model

It is not easy to have the accurate, absolute usability score of mobile phones. However, it can be estimated by combining some usability indicator factors, which measure how human users perceive the usability. Five principal factors we assume include

effectiveness, efficiency, learnability, satisfaction, and customization. Usability factors at the level of usability property measure observable features of a particular mobile phone. Usability data below this level provide actual value for usability property. One example of usability property factor is colour and its relevant usability data can be blue, red, and so on. Usability factors related to usability criteria evaluate how well usability property is designed to enhance the usability mobile phone in consideration of task scenarios. Usability criteria link usability property to usability indicator; they provide information to assess how actual, observed features of a mobile phone contribute to usability indicator. For example, we can measure 'minimalism', which can highly influence on 'effectiveness' and 'efficiency', by considering softkey mapping, menu contents, and scrolling method at the level of usability property.

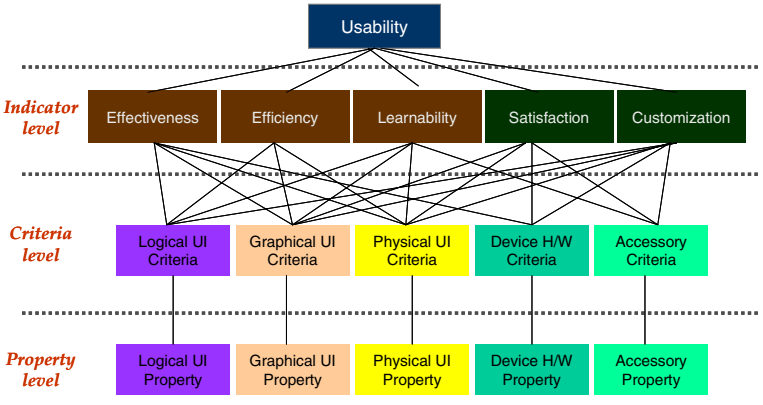

Fig. 2. Hierarchical model of usability factors

Fig. 2 shows hierarchical model consisting of four abstraction levels, excluding usability data level. Main characteristics of this model are many-to-many goal means relations between adjacent levels and distinction of design areas. In general, a mobile phone has six design areas: LUI (Logical User Interface), PUI (Physical User Interface), GUI (Graphical User Interface), device hardware, accessory, and service [1, 4]. LUI is interface concerned with information contents and structure for carrying out tasks. GUI means interface devoted to graphical or visual items presenting information needed for users to conduct a task. PUI is tangible interface supporting physical operation needed for executing a task. The hierarchical model takes account of five areas, without considering service. It can be said that the model seeks to elucidate how the invisible relations between different user interface types or design areas affect the usability of mobile phones.

3 Three Approaches to Quantification

Fig. 3 depicts three quantification approaches and their relationships. It can be regarded that this figure shows a context of use of a mobile phone. To consider the context of use, we can think of two aspects of users' model (cognition or emotion and physiology) and

environment surrounding them. User's tasks lie between users' world and mobile phones. Seven arrows reflect meaningful, distinctive paths of user-mobile phone interaction. Although there are other paths influencing the context of use, our stance is that these seven paths are most significant to measure the usability. These paths are related to two aspects of user model and three design areas of mobile phones. For example, a path formed by users' cognition and LUI represent the interaction between logical aspects of user interface like menu contents and structure and users' cognitive aspects like knowledge structure.

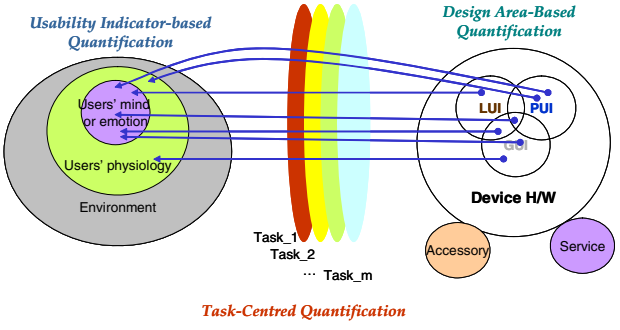

Fig. 3. Three approaches to quantification

3.1 Task-Centred Quantification

Fig. 4 shows the process of task-centred quantification. To use this approach, a set of tasks to be evaluated ($TS = \{T_1, T_2, \ldots T_m\}$) are firstly chosen. Then the usability score of mobile phone is calculated as follows, where $W(T_i)$ is the weighting value of T_i and $U(T_i)$ is the usability score of T_i.

$$Usability\ Score = \sum_{i=1}^{m} (W(T_i) \times U(T_i)) \ . \tag{1}$$

The weighting value of each task can be determined by several methods. In this study we use one of the following seven methods: no weighting value, expert opinion, rank sum weight or rank reciprocal weight based on task usage frequency or task importance, KANO model, entropy model using the usability score of each task, geometric mean of pair-wise comparison result in AHP (Analytic Hierarchy Process), and statistical data from usability problems collected. The usability of each task can be obtained as follows, where $W_L(T_i)$ is the weighting value of LUI when conducting task T_i, $U_L(T_i)$ is the usability score of LUI when conducting task T_i, $W_G(T_i)$ is the weighting value of GUI when conducting task T_i, $U_G(T_i)$ is the usability score of GUI when conducting task T_i, $W_P(T_i)$ is the weighting value of PUI when conducting task T_i, and $U_P(T_i)$ is the usability score of PUI when conducting task T_i

$$U(T_i) = W_L(T_i) \times U_L(T_i) + W_G(T_i) \times U_G(T_i) + W_P(T_i) \times U_P(T_i) \ . \tag{2}$$

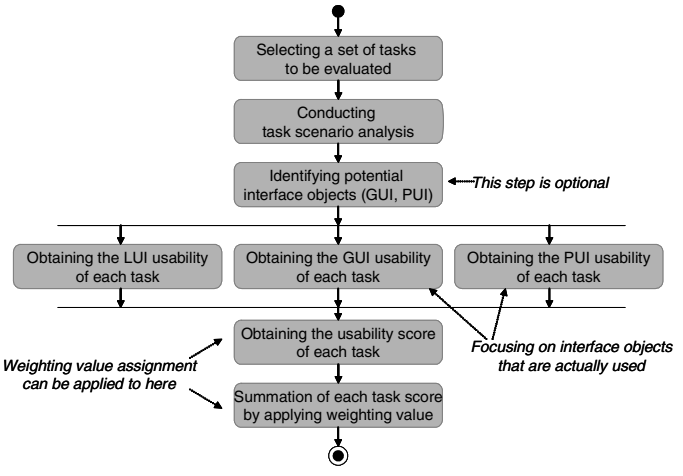

Fig. 4. Process of task-centred quantification

The weighting value of each interface area can be obtained by using the same methods as those used when calculating the weighting value of each task. The usability of each interface area uses the value of usability criteria, which are in the hierarchical model described in section 2, as follows, where $CL_j(T_i)$ is the rated value of the j^{th} criterion related to LUI when conducting task T_i, $CG_j(T_i)$ is the rated value of the j^{th} criterion related to GUI when conducting task T_i, and $CP_j(T_i)$ is the rated value of the j^{th} criterion related to PUI when conducting task T_i.

$$U_L(T_i) = \sum_{j=1}^{n_L} CL_j(T_i),\ U_G(T_i) = \sum_{k=1}^{n_G} CG_k(T_i),\ U_P(T_i) = \sum_{l=1}^{n_P} CP_l(T_i)\ . \tag{3}$$

Fig. 5 shows the usability factors of each design area at the level of usability criteria. In order to make it easier to rate the value of usability criteria factors, we developed a checklist on the basis of the hierarchical model. This checklist associates

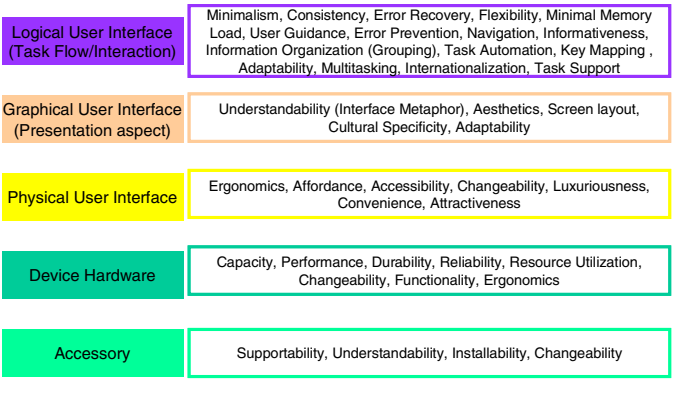

Fig. 5. Usability factors at the level of usability criteria

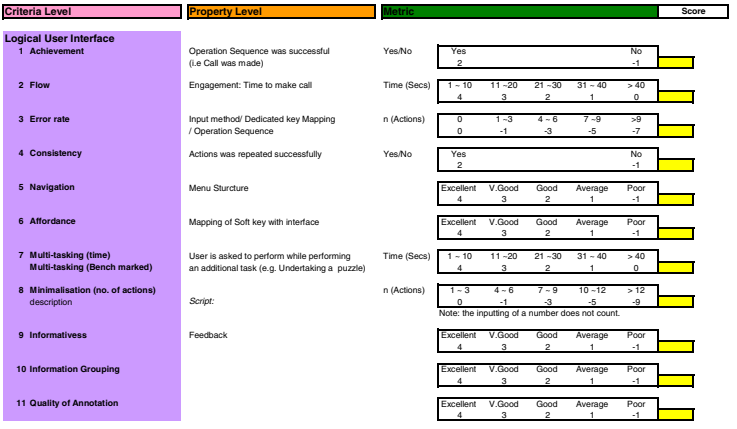

Fig. 6. Checklist to evaluate LUI

usability criteria with their relevant usability properties and metrics in a systematic way. Fig. 6 shows a part of the checklist, which is concerned with LUI.

3.2 Usability Indicator-Based Quantification

Fig. 7 shows the process of usability indicator-based quantification. This approach assigns weights to the value of usability indicators and combines the weighted value into a single score. Identification of indicators to be measured varies from evaluator to evaluator. Our recommendation is however to use five indicators, as suggested in the hierarchical model of usability factors. The value of each usability indicator can be

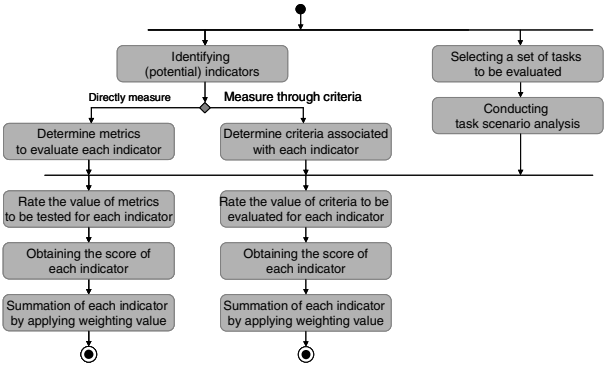

Fig. 7. Process of usability indicator-based quantification

determined in two ways: direct measurement and indirect measurement by using usability criteria. Weighting value assignment can use one of the methods described in section 3.1.

Measurement by using usability criteria can also employ the checklist that is used in task-centred quantification. To use this method, evaluators should identify potential goal-means relations between each usability indicator and its relevant usability criteria, as well as a set of tasks to be used for this measurement. But it is prohibitive to define the relations in terms of time and effort required. Thus a questionnaire survey like SUMI can instead be used [11]. Each indicator can be directly measured by using metrics. For example, effectiveness can be measured by several metrics such as task completion time, error rates, and recall accuracy [2].

3.3 Design Area-Based Quantification

This approach focuses on the usability value of eight design areas (interaction paths) affecting interaction between users and mobile phones. Fig. 8 illustrates the process of design area-based quantification. It calculates the usability of device hardware area and seven areas (seven arrows in Fig. 3) influencing on the context of use and the usability of mobile phones. Although there are other design areas to be concerned, we assume these eight areas are most relevant and sufficient to obtain the usability score. Weighting value assignment can also use one of the methods in section 3.1.

To assess the usability of each design area, evaluators should identify usability factors concerned with the area. Taking into consideration the abstraction level of these factors, most of them pertain to usability criteria or property. In this regard, the hierarchical model can be a useful reference when selecting the factors. For example, one factor of 'PUI↔user's physiology' area is 'comfortable size', and one factor of 'LUI+GUI↔user's mind or emotion' area is 'menu contents and structure'. As Fig. 8 shows, the eight areas are classified into two groups, depending on whether or not they can be evaluated without conducting tasks.

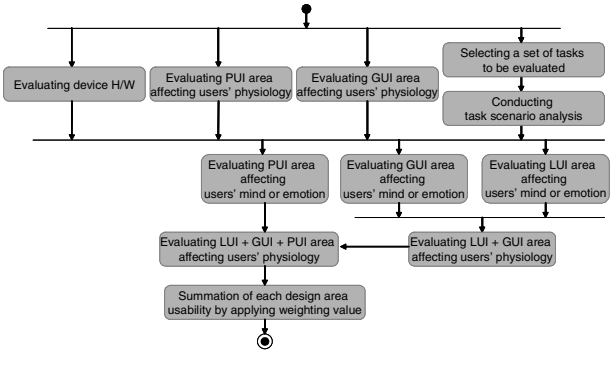

Fig. 8. Process of design area-based quantification

4 Case Studies

We conducted two case studies in order to obtain empirical data to be used for determining weighting values for quantification and examine the practicality of the three

quantification approaches. Another purpose of the studies was to verify the usefulness of the hierarchical model of usability factors (this is beyond the scope of this paper).

In the first study in which twenty-one people participated and conducted eleven tasks, we collected the data which were used for examining task usage frequency, classifying tasks by KANO model, and determining the weighting value of usability indicators and the importance of usability criteria. Table 1 shows the rank of tasks by task usage frequency and classification of tasks by Kano model. Kano model is known to be useful for characterizing customers' preferences by dividing product features into five categories (one-dimensional, attractive, one-dimensional, must-be, and reverse) [12]. In this study the eleven tasks were grouped into one of three categories. As space is limited, we don't describe this categorization in detail.

To obtain the weighting value of usability indicators, we applied pair-wise comparison method, which has much been used in AHP (Analytic Hierarchy Process) [9]. The weighting values were calculated by using 'geometric mean' of each pair-wise comparison result, and consistency ratio indicated the obtained values are reasonably reliable. They were: 0.213 for effectiveness, 0.240 for efficiency, 0.190 for learnability, 0.247 for satisfaction, 0.109 for customization.

In the second study, five usability professionals participated and examined the practicality of the three quantification approaches, with particular emphasis on the task-centred quantification method. The conducted three tasks and compared the usability of four mobile phones. The tested tasks include: making a call, sending in text, and adding contact information. Considering that these tasks are mainly concerned with logical aspects of interaction, we focused on usability factors related to LUI

Table 1. Rank by task usage frequency and classification of tasks by Kano model

Task	Rank by task usage frequency	Classification of tasks by Kano model
Call	1	One-dimensional
Message	2	One-dimensional
Telephone book	3	One-dimensional
Setting	4	Attractive
Camera (photo)	5	Attractive
File manager	6	Indifferent
MP3 player	7	Attractive
WAP & Connectivity	8	Attractive
PIM	9	Indifferent
Mobile commerce	10	Indifferent
Mobile TV	11	Indifferent

at the level of usability criteria. Using the set of checklist, we tested the usability of the three tasks at eleven factors: achievement, flow, error rate, consistency, navigation, affordance, multi-tasking, minimalism, informativeness, information grouping, and quality of annotation. To apply task-centred quantification approach, we used five different methods for assigning weights to the task. Fig. 9 shows the task usability of each mobile phone, weighting value of each task by five methods, and the usability

Usability of Task			
	Task_1	Task_2	Task_3
Phone-A	20	7	16
Phone-B	22	6	16
Phone-C	20	13	13
Phone-D	25	15	15

Weighting values

	Rank sum weight	Rank reciprocal	Kano(I)	Kano (II)	Entropy
Task_1	0.500	0.545	1.000	0.400	0.055
Task_2	0.333	0.273	1.000	0.950	0.902
Task_3	0.167	0.182	1.000	0.947	0.043

Usability score of mobile phones by different weighting values

Usability Score	Rank sum weight	Rank reciprocal	Kano(I)	Kano (II)	Entropy
Phone-A	15.00	15.73	43.00	29.81	8.10
Phone-B	15.67	16.55	44.00	29.66	7.31
Phone-C	16.50	16.82	46.00	32.67	13.39
Phone-D	20.00	20.45	55.00	38.46	15.55

Fig. 9. Application of task-centred quantification in the 2nd case study

score of each mobile phone. As expected, the usability score is dependent on the method of determining weighting values.

5 Conclusion

This paper proposed three approaches to quantifying the usability of mobile phones based on a hierarchical model of usability factors. We described the process and rules of each approach to calculate the usability score of a mobile phone. To take account of users' preference on specific mobile phone features or context factors, these approaches employ several methods for assigning weighting value. We could confirm their practicality through case studies. Lastly, what should be noted is that quantified usability score should only be a reference point for design improvement or benchmarking, not an absolute value for judging the quality of mobile phone. It would be more useful when it is used in combination with other usability testing methods.

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References

1. Ham, D-H., Heo, J., Fossick, P., Wong, W., Park, S., Song, C., Bradley, M.: Conceptual Framework and Models for Identifying and Organizing Usability Impact Factors of Mobile Phones. In: Proceedings of 2006 Annual Conference of the Australian Computer-Human Interaction Special Interest Group (OZCHI 2006), Sydney, Australia (November 2006)
2. Hornbæk, K.: Current Practice in Measuring Usability: Challenges to Usability Study and Research. Int. J. Human-Computer Studies, 64(2) 79–102 (2006)
3. Keinonen, T.: One-Dimensional Usability-Influence of Usability on Consumers' Product Preference. Unpublished Doctoral Dissertation, University of Art and Design and Helsinki (1998)
4. Ketola, P., Röykkee, M.: The Three Aspects of Usability in Mobile Handsets. Paper Presented at the Workshop of ACM Conference on Human Factors in Computing Systems (ACM CHI 2001), Seattle, USA, March-April (2001)

5. Lohse, G.L., Spiller, P.: Quantifying the Effect of User Interface Design Features on Cyberstore Traffic and Sales. In: Proceedings of ACM Conference on Human Factors in Computing Systems (ACM CHI 1998), Los Angeles, USA, April (1998)
6. Rauterberg, M.: An Empirical Validation of Four Different Measures to Quantify User Interface Characteristics Based on a General Descriptive Concept for Interaction Points. In: Proceedings of IEEE Symposium and Workshop on Engineering of Computer-Based Systems, Friedrichshafen, Germany, March (1996)
7. Rauterberg, M.: How to Measure and to Quantify Usability of User Interfaces. In: Özok, A., Salvendy, G. (eds.) Advances in Applied Ergonomics, West Lafayette, USA Publishing. pp. 429–432 (1996)
8. Rubinoff, R.: How to Quantify the User Experience (2006) Available online via http://www.sitepoint.com/article/quantify-user-experience
9. Saaty, T.L.: How to Make a Decision. The Analytic Hierarchy Process. Interfaces 24(6), 19–43 (1994)
10. Sauro, J., Kindlund, E.: A Method to Standardize Usability Metrics into a Single Score. In: Proceedings of ACM Conference on Human Factors in Computing Systems (ACM CHI 2005), Portland, USA, April (2005)
11. SUMI (2006) Available online via http://sumi.ucc.ie
12. Yang, C-C.: The Refined Kano's Model and Its Application. Total Quality Management 16(10), 1127–1137 (2005)