Development of an Information-Task-Interface Framework for Informative UI

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Abstract

This study aims to establish a model-based approach for user interface design that simultaneously considers the system's information hierarchy, users' task procedure knowledge, and system interfaces. The approach is based on a framework that contains multiple interaction models to express both system elements and users' knowledge. In evaluation processes, the framework, referred to the CDI (Combined Difficulty Index), evaluates system interface by the relation structure of users' task knowledge, information acquisition, and users' task procedure. In the design process, the information structure of a designed system is validated according to whether or not it matches users' task knowledge, and the interface is evaluated by its contribution to the users' task performance and navigation of the system information structure. Through the crosscheck process of models, the relation between information, interface, and task procedure is calculated. A user test was conducted for the validation of the CDI. The difficulties of the interface of a mobile healthcare system were predicted with the CDI, and the predictions were compared with the experimental results, where the users' performance showed consistence with the prediction.

1 Introduction

Usability problems of designed systems are often caused by the gap between the designer's knowledge and user's knowledge. In the goal-means abstract space, users adopt bottom-up knowledge of the system while designers adopt top-down knowledge for the system design process (Rouse, 1991). Designers are already aware of all the functions of the system and just relocate them into the interface, but users must get the information and infer the location of functions from the interface (Nielsen, 1993). It is necessary for an interaction model to express the system sides and user sides simultaneously. The usability problems users experience during the navigation of the information devices are similar with the users' cognition problems in the navigation of the physical space.

The main goal of this study is to explain the difficulty of a system interface as a combined effect of various elements in the system design. For this purpose, we considered the task procedure model, the information structure model and interface model of interface of a system. The three basic models are selected based on the users' space cognition model of Wickens (1999). The user's tasks are divided into cognitive operations and physical operations. The usability of a system is expressed with a difficulty index, which refers to the sum of difficulties users experience while performing both cognitive and physical tasks. If a design change occurs in the interface, task procedures, or information structure, the difficulty index is also changed. This change indicates the effect of the design change on usability. Thus, designers can easily predict the result of the design and the usability of a system.

2 Background

During the navigation in the physical space, users gather the landmark knowledge to their destination first. Next, they composite the route knowledge of the place based on their trajectory of navigation. Finally, users gather all the fragments of the landmark knowledge and route knowledge and build up the mental model on the whole area, the survey knowledge. This knowledge acquisition is performed with the bottom-up direction (Wickens, 1999). The landmark knowledge, the route knowledge, and the survey knowledge affect each other and define the degree of users' cognition and understanding of space. The knowledge acquisition process that users make during the navigation of an information system is as same as the knowledge acquisition process in the physical space.

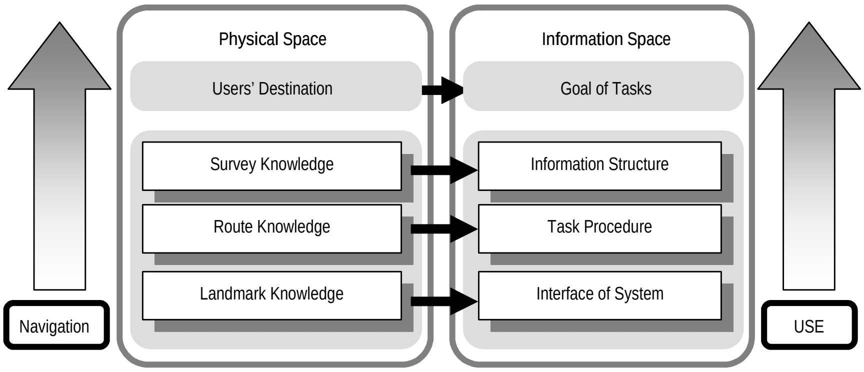


Figure 1: Knowledge acquisition process of the usage process and design process.

In the evaluation phase, many quantitative and qualitative measures are used including time and error. In addition, the quantity of information (Fitts, 1954), system complexity caused by the number of interfaces or parts of a system (Rouse, 1979), the meaning of labels evaluated by the card sorting method (Nielsen, 1994), and the user's knowledge procedure evaluated by PetriNet or OCD (Park and Yoon, 2000) are also used as a measure for system usability. Yoon and Lee (1998) proposed the entropy value, the cognitive complexity of a system interface, to determine the complexity of system interface. The usability measures mentioned above are useful to evaluate system interface, but some measures are so qualitative that the result of evaluation depends on a subjective decision. Models mentioned above deals with the system interface from different viewpoints. As a result, the data of a specific model is hardly sharable with other models.
Previous research on interaction modeling shows that a unified measure on system interfaces is necessary and the users' space cognition process should be treated as an important factor in the system design.

3 Combined difficulty index and the interaction models

The Combined Difficulty Index (CDI) is a tool to calculate the difficulty of a system interface that users might experience during their task performance. CDI is extracted from the size of information structure, the complexity of task procedure and the complexity of the system interface.

3.1 Key dimensions for the CDI modeling

3.1.1 Information structure

Information structure is defined as a vertical and horizontal relation of information within a system. Information structure is a system-centered model that describes the elements of system sides. The information structure can be regarded as the survey knowledge of the physical space. The information structure of a system is the same as the structure of interface, and both information and interfaces are correlated with each other.

3.1.2 Task procedure knowledge

In CDI, the task procedure is defined as a description of the user's knowledge of the process to achieve his/her goal through the system functions. The task procedure in the information space could be regarded as same as the route knowledge in the physical space.

3.1.3 Interface

Interface refers to the cognitive parts of a system that users recognize when they perform tasks. Interface is as same as the landmark knowledge in the physical space. It is the same with the set of interfaces that users control in a specific state of a system. Interfaces are located in the structure of the system information and are affected by the system structure. In contrast, interface also affects the information structure or task procedure.

3.2 Relation of three models

When a user performs the same task in two different systems, the difficulty and the efficiency of a user's behavior are different in the two systems although the goal and procedure are the same, The factors that cause these differences exist on various levels of system elements, from information structure to the design of the interface, including labels, icons, color, font, and the size of buttons. Usability problems are a synthesis of multi-leveled problems, and the three basic models of the CDI enable designers to detect the problems of various levels.

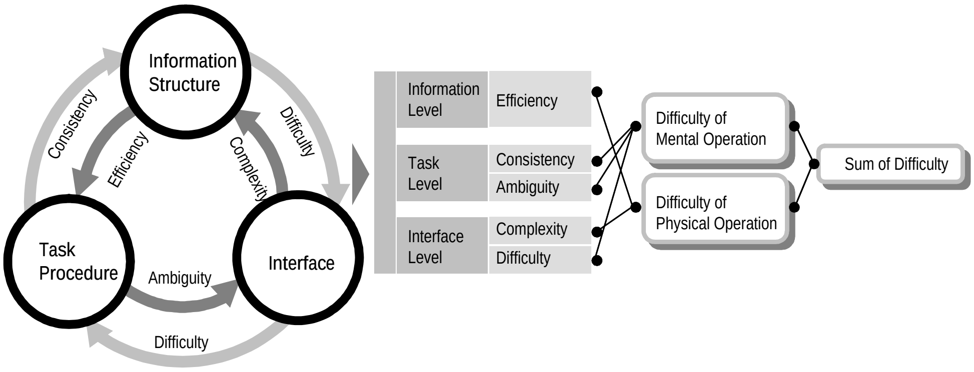


Figure 2: Three basic interaction models for the calculation of the CDI.

3.2.1 Hypothesis for the CDI

Users perform two kinds of activity during task performance: cognitive operations and physical operations. The cognitive operation is to interpret interface and to set the strategy for the next activity, and the physical operation is to control the physical parts of the system interface. Task difficulties are also classified into cognitive and physical difficulties. The difficulty of the system interface is measured by the number of errors and task performance time.

When the size of a system interface is too small, the gap between users' evaluation and execution is large. Users must perform the large number of task steps and keystrokes. Big screen systems provide more information in one state and reduce physical difficulty, but the cognitive difficulty increases because users must find the appropriate controls among a large number of interfaces. In contrast, if a small screen system provides a smaller quantity of information on one state, the cognitive difficulty decreases while the physical difficulty increases due to increase in the number of task steps.

3.2.2 Combination of three basic models

The CDI calculates the difficulty of a task by the sum of the cognitive and physical difficulty on every task step that users make. A high difficulty value indicates that the state is difficult for users. The three basic models of the CDI represent the levels of interaction problems, and as a result, the CDI also classifies the difficulty index into three levels: the task level, operation level, and interface level. The difficulty of the task level is caused by the complexity of the task procedure and goal-means structure. Table 1 shows the elements of the task difficulty index in CDI. For the prediction of the difficulties of a system state, all interfaces and keystrokes are counted. Then the complexity of the interface is calculated by the ratio of the feedback and control interface. The calculated complexity is multiplied by the number of keystrokes to elicit the total difficulty value of physical operations.

Table 1: The elements of the difficulty index

Difficulty Level	Attributes	Explanation	Equation	Code
Task level	Task steps	Sum of the cognitive and physical operations	∑(Om + Op)	T
	Ambiguity	The number of available operations that users can perfo rm in a state. The sum of interfaces and all operations.	n(Operation)	A
	Consistency	The number of states that can appear after the current st	(Post-condition/	C

		ate as a result of a user's control. The larger the consiste ncy value, the lower the actual consistency in the CDI.	Pre-condition)	
The operation level	Efficiency	The number of keystrokes a user makes to move to a ne w state.	n(keystrokes)	E
The interface level	Difficulty	The number of interfaces available in a state. The meas ure for the cognitive difficulty to make a decision for th e next operation	n(interface)	D
	Complexity	The ratio of the number of feedback interfaces and the c ontrol interfaces in a state.	(Feedback/Control)	X

The sum of the cognitive difficulties consists of the interface difficulty, the ambiguity of the task, and the consistency of the system states. The sum of physical difficulties and cognitive difficulties indicates the total difficulty of a state. The state of high difficulty value requires users to perform more complex operation. The difficulty index of a state calculated in the task level is converted into the information structure. The modeled CDI value represents the location of possible usability problems which exist on the information structure of a system. The equations for task complexity in the CDI are as follows:

Table 2: Calculation of the difficulty index

Difficulty Index	Equation	Code
Physical difficulty	= Complexity of interface * Number of keystrokes = [Complexity (F/C)* Efficiency]	[X * E]
Cognitive difficulty	= Number of feedback interface + Task ambiguity + Consistency of system state	[D +A + C]
Total difficulty of a state	=Physical difficulty + Cognitive difficulty	[X * E] + [D + A + C]

4 Rationale of the CDI

A user test was conducted to verify the reliability of the CDI. In this experiment, the CDI was used to predict the usability of a mobile system, and the predicted result was compared with the result of the user test.

4.1 Experiment material

The simulation of a diabetic management system produced by LG Corporation in 2004 was selected as the experiment material. This mobile – PC unified healthcare system aims to support diabetic patients to measure and manage their blood-sugar level anywhere, at any time. Users insert a chemical sensing-strip into a slot on the side of phone, and add a drop of blood to the strip for the measure of their blood- sugar level. After seconds, the phone calculates the blood-sugar level and the results are simultaneously transmitted to a main server and to a doctor. The patients can easily review the list of measured data via either mobile devices or homepages.

The participants of the experiment were informed about the test and were asked to download the simulator of the diabetic management phone and RIO browser, a remote mouse tracking system (Oh and Lee, 2002) from the homepage of the experiment.

4.2 Experiment material

Participants were asked to perform two task selected for the experiment with the simulator. Then the simulator recorded whole track of participants' mouse movement and the task performance time. The optimal paths of each task are shown in Table 3.

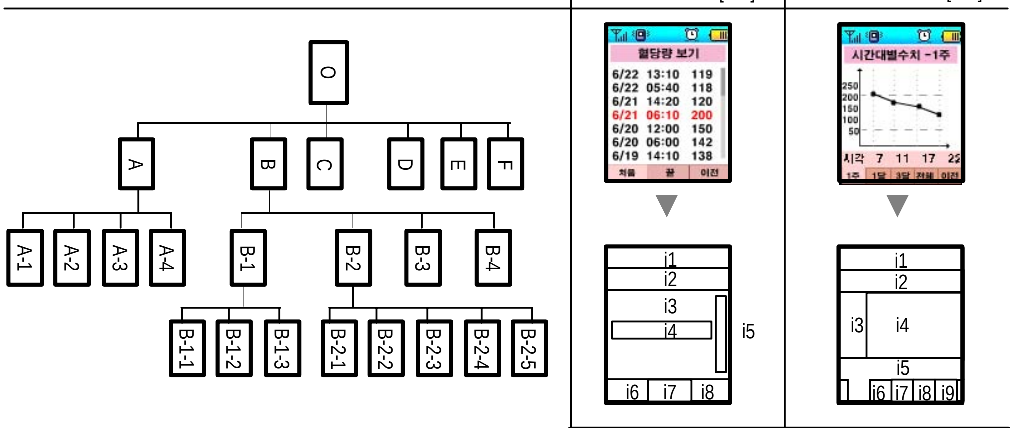
Table 3: Task list and the optimal path of the experimental task

Task			Detail	Task Procedure
Pilot test	0	Measure the blood-	Users insert a chemical sensing-strip into a slot on the	[O]-[A]-[A_1]-[A_2]-[A_3]-

	sugar level	side of phone, and add a drop of blood to the strip. After seconds, the phone calculates the blood-sugar level and sends it to the main server.	[A_4]
Main test	1 Review the list of blood-sugar level	The list of 100 recent data of blood-sugar levels	[O]-[B]-[B_1]-[B]-[B_2]
	2 Setting	Control panel of the private data	[O]-[F]-[F_1]-[F_1_1]-[F_1]

4.3 Modeling difficulty of a system interface with CDI

Figure 3 shows an example of state difficulty modeling with the CDI. The left column of the figure shows a part of the information structure of the mobile phone. On the right column, two different states of the mobile phone were selected and compared. State [B_1] contains 8 interfaces (the number of items of the list screen was not considered), and helps users to choose a desired item from a list. State [B_2] contains 8 interface elements and was mainly designed to provide a blood-sugar level data with a graph format. In both states, the semantic and the subjective factors such as colors, groupings of icons, appropriateness of labels and the metaphor of icons were not considered.

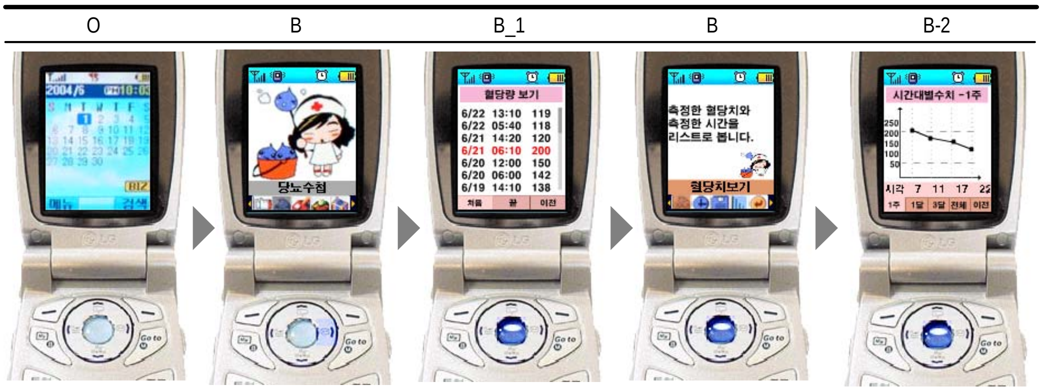


	Elements (B-1)	Value (B-1)	Elements (B-2)	Value (B-2)
Ambiguity : Number of available tasks	i1, i2, i3, i4, i5, i6, i7, i8	8	i1, i2, i3, i4, i5, i6, i7, i8, i9	9
Consistency : Pre condition/ Post conditions	1/3	0.33	4/4	1.0
Efficiency : Number of keystrokes to move to next state	Set cursor on i6	1	Set cursor on i5	1
Difficulty : Number of available interfaces	i6, i7, i8	3	i5, i6, i7, i8, i9	5
Complexity : Ratio of the feedback interface/control interface	4/10	0.4	2/8	0.25

Figure 3: Comparison of two different states with different interface.

The difficulty index of the two states was modeled with the CDI, as in Figure 3. State [B_2] contains more interface (1) than state [B_1], thus, the cognitive difficulty of the state [B_1] is lower than the state [B_2]. The physical difficulty to get state [B_1] was same with the state [B_2]. With the same method, the difficulty index of five states was calculated and Figure 4 shows the modeling data of task and the difficulty index.

For the next step, CDI modeling data in Figure 4 was normalized and converted into the physical and cognitive difficulties as follows. Table 4 shows that calculated complexity of state [B_2] is much higher than the state [B_1]. According to the CDI data, the difficulty of state [B_2] increased up to the highest value (2.076) among the five states of Task 1. It was also predicted that the cognitive difficulty would be more serious than the physical difficulty in state [B_2]. In addition, the ambiguity, the number of available operations in state [B_2] was nine, larger than the ambiguity of other states. State [B] was found to be the state with the lowest difficulty value (-1.134).



State		O	B	B_1	B	B_2
Task	[A]mbiguity	8.000	7.000	8.000	7.000	9.000
	[C]onsistency	0.200	0.250	0.330	0.250	1.000
Operation	[E]fficiency	3.000	3.000	1.000	3.000	1.000
	[D]ifficulty	6.000	5.000	3.000	5.000	5.000
Interface	[F]eedback	2.000	2.000	4.000	5.000	2.000
	Comple[X]ity	0.220	0.250	0.400	0.250	0.250

Analysis of Task 1	mean [complexity]	Number of states	Difficulty Value
	0.424	5.000	2.120

Figure 4: CDI modeling: complexity of task [Review the list of blood-sugar level]

Table 4: CDI value and the complexity of the information structure of task

State		O	B	B_1	B	B_2
Task	[A]mbiguity	0.239	-0.956	0.239	-0.956	1.434
	[C]onsistency	-0.614	-0.465	-0.227	-0.465	1.772
Operation	[E]fficiency	0.730	0.730	-1.095	0.730	-1.095
	[D]ifficulty	1.193	0.447	-1.043	-1.043	0.447
Interface	[F]eedback	-0.730	-0.730	1.095	1.095	-0.730
	Comple[X]ity	-0.619	-0.528	-0.073	1.748	-0.528

CDI Index of Task 1		O	B	B_1	B	B_2
Physical	[X * E]	-0.452	-0.386	0.080	1.276	0.578
Cognitive	[D +A + C]	-0.152	-0.748	-0.175	-0.413	1.488
Sum	**[X * E] + [D + A + C]**	**-0.604**	**-1.134**	**-0.095**	**0.863**	**2.067**

With the same methods, the difficulty index of the Task 2 was also analyzed. The CDI data in Figure 5 shows that the difficulty value of Task 2 was the higher (3.070) than Task 1(2.120). The difficulty values of the two tasks are converted into the information hierarchy in Figure 5. The state difficulty value of each task is not summed because the state difficulty value means not the absolute difficulty of a state, but the comparative difficulty among the states used for a task.

Table 5: The modeling data of Task 2 [Setting]

State		O	F	F_1	F_1_1	F_1
Task	[A]mbiguity	0.447	0.447	0.447	-1.789	0.447
	[C]onsistency	0.730	0.730	-1.095	0.730	-1.095
Operation	[E]fficiency	1.129	0.695	-1.043	0.261	-1.043
	[D]ifficulty	0.539	-0.135	1.214	-1.483	-0.135

Interface	[F]eedback	-0.850	-0.850	1.082	-0.464	1.082
	Comple[X]ity	-1.030	-0.951	1.009	-0.037	1.009

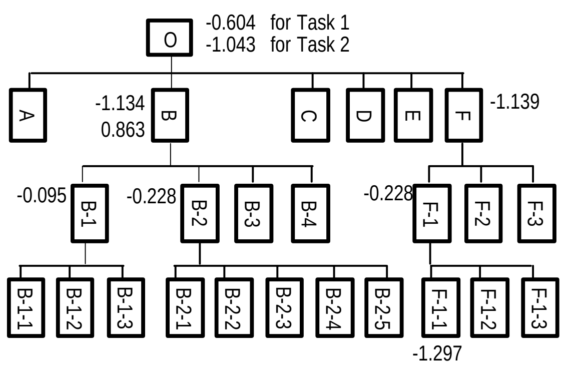
▼

Analysis of Task 2	mean [complexity]	Number of states	Difficulty Value
	0.614	5.000	3.070

CDI Index of Task 2		O	F	F_1	F_1_1	F_1
Physical	[X * E]	-1.163	-0.661	-1.051	-0.010	-1.051
Cognitive	[D +A + C]	-0.119	-0.478	-0.823	-1.287	-0.823
Sum	[X * E] + [D + A + C]	-1.043	-1.139	-0.228	-1.297	-0.228

The difficulty of state [O] in Task 1 was -0.604, but the difficulty of the same state in Task 2 was -1.043. This difference implies that the interface design of state [O] is more suitable for Task 2 than Task 1. In the evaluation of the difficulty of frequently used states like [O], the balance of the interface should also be considered. Therefore, the less the mean and standard deviation of difficulty values, the better the quality of a state's usability.

Information structure



Task 1		Task 2	
State	CDI	State	CDI
O	-0.604	O	-1.043
B	-1.134	F	-1.139
B-1	-0.095	F-1	-0.228
B	0.863	F-1-1	-1.297
B-2	2.067	F-1	-0.228

Figure 5: Linking the procedure of Task 1 and the information hierarchy.

4.4 User test

An online user test was designed to verify the result of the CDI during 5 days. The number of participants was 40, the ages of participants ranged from 20 to 40, and they consisted of 25 males and 15 females. All of the participants had over three years of previous contact with mobile devices, but no knowledge of the medical treatment of diabetes. Participants were asked to perform two tasks including pilot test. The order of two tasks in the experiment was same for all users without consideration of the learning effect. When users failed to follow the optimal procedure of a task presented in Table 3, that task was classified as a fault.

Table 6: The time and errors of the two tasks in the user test

TASK	Task 1			Task 2		
Time	134.235			67.237		
Error	0.125			0.05		
Click	48.571			19.036		
	State	Time	Error	State	Time	Error
	O	5.785	2	O	1.97	0
	B	10.96	0	F	4.10	0
	B_1	22.26	3	F_1	8.16	0
	B	33.21	0	F_1_1	5.22	1
	B_2	39.50	0	F_1	15.73	1

The mean time for Task 1 was the longer at 134.235 seconds, and the error rate was lower in Task 2. The time required for the state [F_1], the second and the last state of the Task 2, was much more than for other states, and this result shows that the interface of [F_1] is difficult for users to understand. On the second step of the Task 2, the state [F_1] contains too many interfaces, and the amount of information required users to spend more time to select the right interface and proceed. On the last step of the Task 2, participants spent long time on state [F_1] even after they arrived to the final state. This situation means that the design of state [F_1] was too complicated for users to realize that they finished the task successfully.

Table 7: Comparison of the predicted difficulty value and the result of user test on Task 2

TASK				
Time	134.235		Difficulty Value	3.070
Error	0.125		Click	48.571
	State	Time	Error	CDI
	O	5.785	2	-0.604
	B	10.96	0	-1.134
	B_1	22.26	3	-0.095
	B	33.21	0	0.863
	B_2	39.50	0	2.067

The modeling data of the CDI was compared to the results of user test. Table 7 shows the comparison between the CDI, and the result of the user test. The value of error and time are the result of the user test and were normalized for comparison with the predicted difficulty value. According to the modeled data of the CDI, the difficulty value of state [B_2] was the highest among the states of the main task. The results of the user test also show that users spent the longest time on state [B_2], and this result coincides with the predicted value.

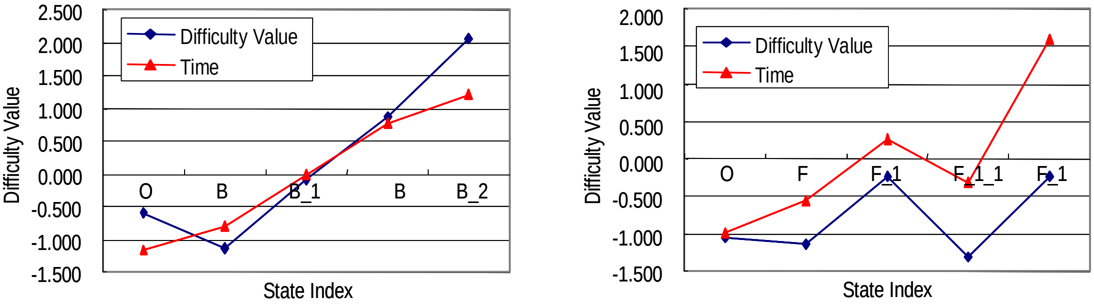


Figure 6: Graphical comparison of the difficulty data

In order to find the relation of the difficulty value and the user test result, a Pearson correlation analysis was conducted. There was a significant correlation between the two ($r = 0.935$, $n=5$, $p<0.05$). Therefore, it was found that the difficulty value, calculated by number of interfaces and operation, indicates the difficulty experienced by the users. In the comparison of Task 2, the correlation between the CDI and the result of user data was statistically significant ($r = 0.7981$, $n=5$, $p<0.10$). However, the total difficulty value did not show a significant relation with the result of user test.

5 Discussion

The comparison of the predicted difficulty of the CDI and the results of user test showed a close relation, meaning that the number of interfaces, the number of available operations, and interfaces affects on the cognitive operations of users. The complexity, described as the ratio of the feedback and control interface, is also proven to affect the physical operations of users.

The difficulty index of each state that the CDI predicted means not the absolute difficulty of the state, but the comparative difficulty of that state when users perform a task. The same state may have a different difficulty value according to the task.

The state difficulty value of the information hierarchy is the group of state difficulties for each task. The state difficulty is not an absolute value, so it cannot be calculated by the sum of task difficulties in the state. However, the mean of task difficulties and the standard deviation can serve as a guideline to evaluate a state in an information hierarchy. Large standard deviations mean that the interface of that state is optimized only for a specific task, and the difficulty of the other task increases greatly.
A limitation of the CDI was also found from the experiment. State [B] of Task 1 and state [F] of Task 2 contained few interfaces and keystrokes and exhibited a high level of consistency; thus, the CDI predicted that the difficulty values of these two states would be lower than other states. However, user test results discovered that users spent more time on those two states because the labels of icons used in states [B] and [F] were inappropriate for users to acquire adequate information. The usability problems related to the validity of abstract information on the interface level were not predicted by the CDI.

6 Conclusions

The main goal of this study was to establish the CDI, an interaction difficulty measure that links system information architecture, users' task procedure knowledge, and system interfaces. The CDI was used for the evaluation of the diabetic phone interface, and the difficulty value of each state caused by interface was calculated. After the prediction, user test was conducted on the same two tasks to verify the CDI. The time that users spent to perform a task was regarded as the amount of difficulty that users feel in a given state. It was proved that there was significant correlation between the modeled data and the user test results. This correlation also showed that the usability problem is not a simple problem, but a combined result of the system information, the interface, and users' task knowledge.

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