



Interface Design Optimization by an Improved Operating Model for College Students

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ABSTRACT

A method was proposed in this study for assessing the interface operating efficiency of a remote control. The operating efficiency of a product interface can be determined by the proposed approach in which the related dimensions of human palms were measured. The reachable range (blue zone) and the most comfortable range (green zone) were investigated when a user used a single hand (right hand) to operate the remote controls. After that, new remote control designs were created based on the measurement results and the operating efficiency of commercially available remote controls were determined for comparison. The operating efficiency is determined by calculating the overall distance of finger movements when manipulating the buttons and the overall operation time was recorded. The subjects who joined the body measurements and performed the experiments are right-hander Asian college students between the ages of 22 and 28. After further optimization, the reachable range became more average during one-handed operations and those frequently used keys were included into the comfortable range. The resulting operating efficiency performance is higher than commercially available products. The results serve as a good reference for detailed modifications of the products or for the decision making of design proposals.

Keywords: interface configuration, human body measurements, usability assessment, efficiency assessment

INTRODUCTION

As technology advances, the common electronic products in our life are continuously innovated and upgraded, helping us to complete many jobs and making life more convenient. However, with the enhancement of functions, many complex functional buttons and operational options are added to the operating interface, increasing the difficulty the users experience in operating the more complex equipment. To improve the operating comfort level and safety of the products, the designer refers to relevant human body measurement data for product design to avoid users' limb injuries caused during the operation. Currently, a

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State of the literature

- The use of discount usability engineering helps identify individual usability problems for the typical configuration of a task. This approach can resolve the problem for professional users and determine the real tasks of a user. The effectiveness in ecology also reveals the real tasks of the user so that desired functions can be developed and characteristics can be described.
- A simple approach was proposed for determining the models for evaluating usability and it can be used to determine the range of assessing the interface of an audio/video electronic product and to measure its usability.
- The theory of space allocation was applied to the measurement of human palms so as to determine the optimal layout of a remote control within a limited area for arranging the buttons.

Contribution of this paper to the literature

- A method that can be used to assess interface operating efficiency was proposed.
- The comfortable and accessible areas of an interface for given palm dimensions can be determined based on the approach that is proposed in this paper.
- An optimized remote control that can be operated by a single hand is proposed based on the investigation results.
- The results of this study indicated that the operating efficiency of the proposed new remote control is higher as compared to those existing products.

considerable amount of research on body dimension measurements is available. However, maintain consistency with modern body dimensions, the measurement database needs to be updated on a regular basis. To facilitate the updating and application of existing body dimension data, Fernström and Ericson (1997) proposed conducting evaluations aiming at the human-machine interaction models of four types of input devices. Johnson et al. (2000) measured finger force exposure during regular computer work and simulated mouse use with a button and grip force-sensing mouse.

Woods et al. (2003) proposed identifying factors of a good design in relation to operations, performance and comfort of non-keyboard input devices (NKID). Gustafsson and Hagberg (2003) proposed that the positions of the forearms and hands influence the exposure, comfort, exertion, and productivity of the operational equipment. Jindrich et al. (2004) measured finger joint kinematics during voluntary finger tapping on a keyboard keyswitch using miniature electro-goniometers and high-speed photography. Sutter and Ziefle (2004; 2006) proposed the differences between the work efficiency of human-machine interactions using the technical characteristics between the change of feelings and the hardware (the change of hand movements and cursor movements). Lee et al. (2008) proposed a method to reduce the resulting musculoskeletal sensation of pain from finger gestures when using mice-like input devices. Herring et al. (2011) proposed the modification of equipment shapes and dimensions, such as good handle design and easy-to-use control mechanisms, to enhance the comfort, practicability, and accuracy of handheld tools.

Wang and Chao (2010) developed a method for acquiring new data using pairwise body dimension ratios (PBD ratios) to determine constant body ratio benchmarks (CBR benchmarks), which are least affected by gender and age. In addition to human body dimension measurement, a designer will employ various methods to assess whether the product satisfies customers' needs and comfort requirements to select the most appropriate design at the design stage. The most commonly used method is the usability assessment, which employs a user survey with a number of pre-determined assessment criteria. Finstad (2010) developed the Usability Metric for User Experience (UMUX) using a Likert scale and four items to evaluate the usability cognitive process. This assessment provides possible results obtained from the ten items of System Usability Scale (SUS), which are defined based the usability of ISO 9241-11. Park and Lim (1999) used an Analytic Hierarchy Process (AHP) to select the evaluation items that included the quantitative criteria, such as user evaluation, user testing, etc. Then, the usability evaluation methods were written into computer software to build a database system of assessment interface design. Han et al. (2001) applied the notion of usability to the design and evaluation of software interface and proposed a new definition for the interface assessment of consumer electronic products. Smith and Dunckley (2002) proposed that the use of a prototype for synchronous design and iteration allows designers to receive earlier evaluation feedback from the users in the design process.

Accordingly, this study developed an "Assessment Method of Product Operating Interface Efficiency," which contains human body measurements and the application of use evaluation, and the products have been evaluated in accordance with operating efficiency calculations. Currently available DVD players are mainly characterized by a concise, lightweight, and thin design, whereas remote control designers primarily focus on the conventional function of controlling with less emphasis on the appearance design. In general, a remote control is often regarded as an accessory to electronic products and is often neglected in the process of product design. However, a remote control is the most important medium of communication when the user operates the product as the device has the closest and most frequent contact with the user. Therefore, we selected the remote controls of DVD players as the case study. New remote control products were designed in this study and efficiency evaluations were conducted based on the proposed designing method to select new designs that are comfortable and easy to use.

THEORETICAL BACKGROUND

The assessment procedure for product operating interface efficiency proposed by this study is primarily based on Nielsen's (1993) Discount Usability Engineering to perform the usability assessment. The case in this study was designed with reference to the space configuration design principles proposed by Sanders and McCormick (1993). Then, the assessment method of operating efficiency proposed in this study was employed to calculate the product operating efficiency and the degree of efficiency improvement, and the aim is to assist designers in creating products that are more efficient.

Usability Engineering

Usability engineering was proposed for the first time in the early 1990s. It has since been applied in the field of interface, product, and system design. Nielsen's (1993) usability testing is a technique used to evaluate a product by testing it with representative users. In the test, users attempt to complete typical tasks while observers watch, listen, and take notes. Heuristic-based design and evaluation are general rules based on design principles that can be used to guide the design of a usable GI product or to aid in working prototype assessment or evaluation.

According to ISO (International Standards Organization) DIS 9241-11, the definition of usability refers to the user's goal, function, efficiency, and satisfaction achieved under specific circumstances. It states that to determine usability, user performance and satisfaction must be measured. Usability measures are important given the complexity of interactions among the user, the task characteristics, and other elements within the context of use. A product can have significantly different levels of usability when it is used in various contexts. The standard also states that measures of user performance and satisfaction can provide a basis for comparing the relative usability of products having different technical characteristics used in the same context (ISO 9241, part 11, 1998).

According to Bevan et al. (1991), usability exists in the interactions between a user and a product or a system; at the same time, usability can be measured through the user's performance, satisfaction, and acceptance. For a product, usability is the user's evaluation of the product quality. Therefore, any change in the product, system, user, the work, or environment will affect its usability. The characteristics of usability in design mainly involve efficiency, effectiveness, safety, comfort, and satisfaction, taking into consideration "who are the users", "what is it used for", and "under what environment is it used". Collectively, these factors build the framework of the entire usability engineering. Nielsen (1993) suggests that describing the merits or drawbacks of a product or system in terms of usability is considerably objective and impartial. He also suggested that instead of being single-dimensional, the usability evaluation of a system or a user interface consists of the following five criteria:

- (1) Learning ability: A user can easily learn to use the interface or system.
- (2) Efficiency of use: The interface or system can be effectively used and can significantly enhance the operating efficiency of the interface or system.
- (3) Memorability: The user can easily remember the usage of the interface or system and does not forget how to use it over time.
- (4) Few or no catastrophic errors: The interface or the system should have a low error rate, and those errors that do occur should not have a catastrophic outcome.
- (5) Subjective satisfaction: The user should have a high satisfaction level upon using the interface or system, thus increasing the usability of the product.

At the same time, Nielsen also proposed using the discount usability engineering program in the process of product design. The four phases of assessment process are as follows:

- (1) Develop appropriate scenarios,
- (2) Select appropriate tasks,
- (3) Perform user/work observations,
- (4) Conduct a heuristic evaluation.

The program includes the user's subjective response and objective performance, the observation of the user's operating method, and the discovery of problems as well as suggestions. Discount usability engineering could discover individual usability problems by means of the configurations of typical tasks. It could account for the problems of professional users, show the true tasks of users in the effectiveness in ecology, and recommend function developments and characteristics descriptions.

In addition, usability tests represent an important and widely used tool in product development (Jordan, 1998). These tests aim to identify design shortcomings throughout the product development process by evaluating a product or a product prototype with prospective or real users and realistic tasks (Gould and Lewis, 1985). The typical measures collected in usability tests are the effectiveness (extent to which typical user tasks are successfully completed) and efficiency of task completion (amount of resources that have to be spent to reach a task goal) as well as the satisfaction a user experiences by using the product. More recent approaches in usability evaluation have enlarged the concept of usability and consider the whole user experience in product evaluation (Marcus, 2003; Norman, 2004). Sonderegger and Sauer (2013) proposed five typical user tasks in the context of coffee machine usage, measuring performance, perceived usability, and emotion.

Kwahk and Han (2002) proposed a methodology of usability evaluation through a simple and structured framework, and they put forward a usability assessment model to establish the assessment range of audio and video electronic products' interfaces and to test the usability. Lee et al. (2006b) presented a systematic evaluation methodology for cell phone interfaces, SEM-CPU, which has been exclusively used to integrate the user interface design of mobile phone and facilitate the processing and understanding of the content structure of a unique hierarchical menu system. Lee et al. (2006a) proposed and validated quantitative and predictive models on the human response time in the user interface with the concept of similarity. They proposed forecasting the response times of the model and the user by quantitatively examining the similarities of the interfaces. These researchers created a simple window-based GUI for visual search tasks, with which various text boxes were arranged purposely to detect the elapsed time from a notification message indicating the correct button being pressed by human operators. The results of the experiment indicated that the use of similar interfaces can improve the reaction speed of the user, and this information is helpful during the stages of user interface design and evaluation. Heo et al. (2009) indicated that when

an engineer develops a software system, the typical usability assessment and enlightening assessment would be adopted in most cases; however, these features cannot be effectively applied to the design of handheld cell phone interface. Therefore, Heo et al. (2009) developed four checklist sets and three different interface types (Logical User Interface (LUI), Physical User Interface (PUI), and Graphical User Interface (GUI)) in support of both task-based and interface-based evaluation approaches. These researchers proposed a framework for evaluating the usability of a cell phone based on a multilevel and hierarchical model of usability factors. The proposed framework specifies an approach to quantifying usability to allow usability practitioners to more easily use the system. Jin and Ji (2010), Park and Han (2010), and Ryu et al. (2013) proposed a quantitative approach to measure the assessment criteria of cell phones, suggesting the introduction of the usability risk level evaluation in the early stage of concept design because an early design will affect the phone's user interface. Other scholars such as Chao et al. (2016), Chou (2016), and Shi et al. (2016) also proposed the evaluation criteria or operating efficiency data of various user interfaces for the applications of different products.

Theories of Space Allocation

To make users feel comfortable during the operation, today's remote controls are designed with a width and size suited to the human hand. Studies by earlier scholars primarily focused on the body measurement related to the grip force of hands (Kitagawa and Miyashita, 1978; Miyatake et al., 2000; McGorry, 2001; Hulens et al., 2001; Rolland et al., 2004; Fogelholm et al., 2006; Wu et al., 2009; Cavuoto and Nussbaum, 2013). Garrett (1971) conducted the measurements aimed at the measurement model of hands by means of conventional tools. Garmer et al. (2002) and Kwon et al. (2009) subsequently conducted the correction of hand measuring technology. Yu et al. (2013) proposed to conduct accurate measurements of hand dimensions using 2D and 3D methods. For custom-made gloves, direct measurement tools, such as flexible measuring tape, calipers, measuring boards, and rulers, are traditionally used to obtain hand dimensions for glove design and pattern development (Garrett, 1971). Yu et al. (2013) reported that the objective of the present study is to propose a new approach of obtaining hand anthropometric measurements using 2D and/or 3D image analyses and comparing the new method with the conventional direct measurement method. This research work aims to provide a useful reference for the development of hand anthropometry.

However, the accommodating space for buttons on a remote control is very limited. Therefore, the button locations should be optimized in the smallest space to make the remote control's functions be easier to operate. Regarding the spatial allocation, Sanders and McCormick (1993) proposed two stages and four configuration guidelines (see [Table 1](#)). The summarized contents are as follows:

Table 1. Allocation Principles

Principles	Descriptions
Importance principle	Important components should be placed right before the eyes.
Frequency-of-use principle	The frequently used components should be placed in the most convenient positions
Function principle	Component groups with similar functions should be placed together, to form a similar group.
Sequence-of-use principle	The components used in sequence should be placed together.

- (1) Stage one involves the general location of the components. For a fixed operating procedure, the overall framework arrangement is based on the configuration of larger components within the space (such as mode selection groups in the interface).
- (2) Stage two concerns the location arrangement of small components. The positions should be allocated and specified, and allocation principles should be advanced. An interface contains a number of components. If the optimal location between these components can be achieved, the entire system will naturally achieve the highest effectiveness.

Research Methods and Procedure Flowchart

The decision-making regarding a design plan typically involves a number of pros and cons. The decision might simultaneously account for marketing, cost, functionality, aesthetic quality of appearance, usability, and even the environmentally friendly factors of a product. Using usability as the starting point, the “Assessment Procedure of Product Operating Interface Efficiency” proposed by this study recorded and observed the operation of the products by the subjects or users and then used simple equations to calculate the product operating efficiency and the improvement degree of operating efficiency. This method enables designers to use the measured improvement degree of operating efficiency as one of the reference points in design decision. The flowchart of the design procedure in this study is presented in **Figure 1**, and the operating steps are as follows.

Step 1: Determine the target product.

Step 2: Collect reference information related to the target product.

Step 3: Measure human body dimensions that are needed for the design of the target product.

Step 4: Select products for comparison. Observe the users’ operation.

Step 5: Design new products with reference to the measured dimensions and the operations of comparison products.

Step 6: Assess the operating interface efficiency of newly designed products and comparison products.

Step 7: If the improvement of the operating efficiency of a new product exceeds that of the comparison product, the design procedure is complete. If not, perform detail modifications on the new product and then compare it with the comparison product again. If re-design is required, return to Step 5.

Step 8: The design process is complete. This step is the end of the efficiency assessment stage of the design process. Further decisions can be made in accordance with other methods according to the designer's requirements.

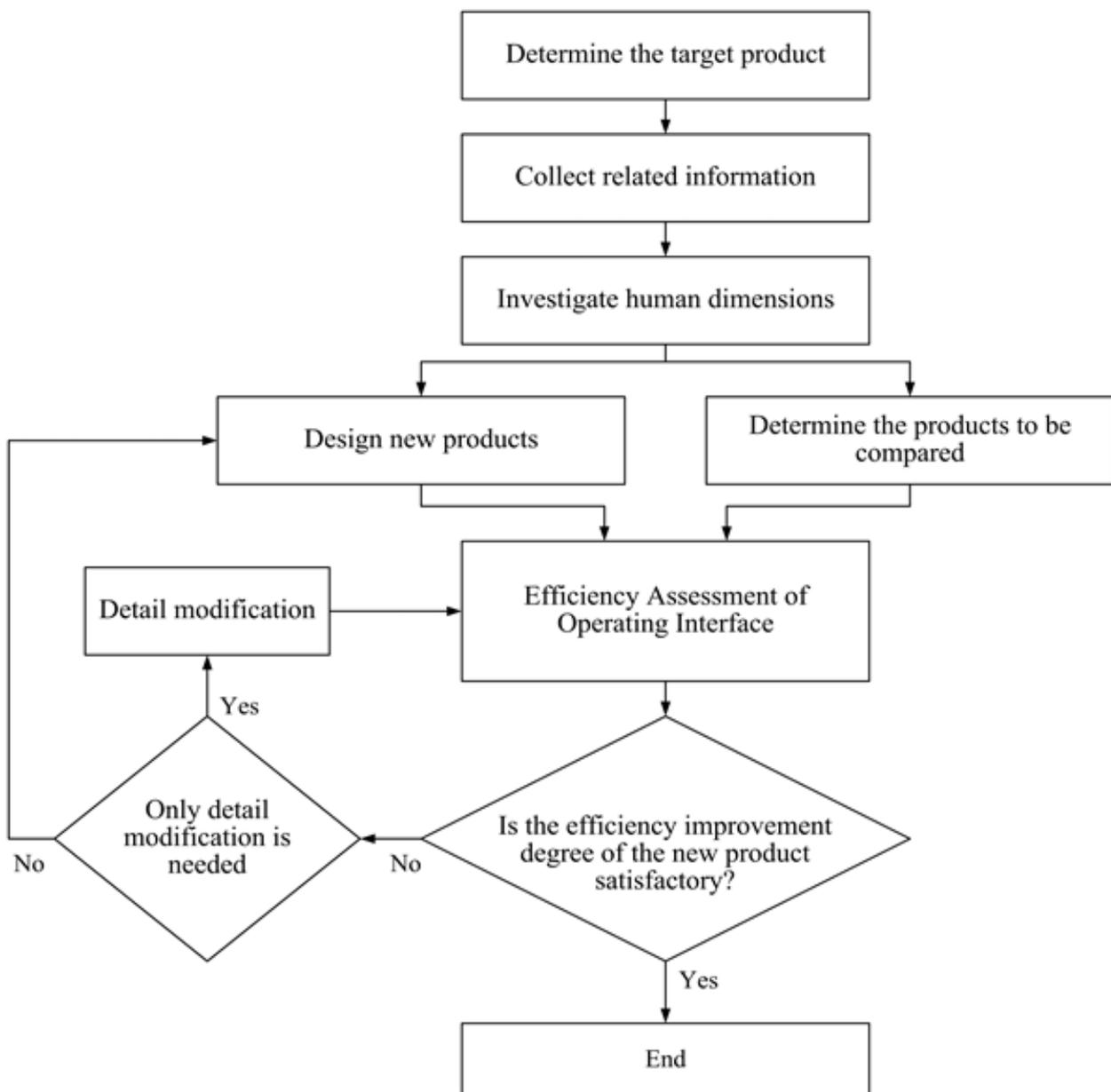


Figure 1. Evaluation Procedure of Product Operating Interface Efficiency

Efficiency evaluation methods of the operational interface

The operating efficiency assessment method proposed by this study enables a designer to know whether a subject's operational efficiency is improved due to spatial configuration upgrading. Also, the designer could refer to the improved efficiency degree to select a better design. The implementation of the operating efficiency assessment method was divided into four steps. Using the remote control as the case of study, the four steps are as follows:

- (1) Step one: Configuration of typical tasks.
- (2) Step two: Measurement of the length of the total operating distance of each task item. The measured distances between buttons on different product interfaces are not the same, so the operational distances should be measured separately. A task item is likely to involve traveling between two keys; therefore, the calculation equation for total operational distance uses the distance between two keys multiplied by the operation frequency. Next, the sum of these values were obtained to reflect the length of the total operational distance the subject moved when he or she operated the remote control interface according to the requirement of the task item as shown in Eq. (1):

$$OD_{total} = \sum_{ij}^n (d_{ij} \cdot F_{ij}) \quad (1)$$

OD_{total} = Total operating distance

n = The number of button combinations

d_{ij} = The distance between two buttons

F_{ij} = Operating frequency between two buttons

- (3) Step three: Operating efficiency calculation. Using the total operating distance measured in Step two along with the operating time that the subject spent on the operation according to the task item, the subject's operating efficiency can be calculated. The calculation method of the operating efficiency is shown in Eq. (2) below.

$$ED = \frac{OD_{total}}{s} \quad (2)$$

s = Operating time (sec)

- (4) Step four: Calculation of the improved efficiency degree of the new product. Designers can determine whether a new design exceeds the comparison products (old designs) in terms of the operating efficiency improvement degree. Eq. (3) presents the calculation of the improvement degree of the new product's operating efficiency as follows:

$$E_j = \frac{E_{new} - E_{old}}{E_{old}} \quad (3)$$

E_j = Improved operating efficiency degree of a new product

E_{new} = Operating efficiency of the new product

E_{old} = Operational efficiency of the comparison products.

CASE STUDY

In accordance with the evaluation procedure of product operating interface efficiency (**Figure 1**), the remote control of a DVD player was selected as the case study for this study. We then collected data and human body measurements, compared product selection, and performed the industrial design and button allocation design of the new remote control. Then, based on the new design, operable experimental prototypes were produced by Computer Numerical Control (CNC), enabling the subjects to perform hands-on operation and accept the questionnaire assessment. Then, the improvement degree of the operating efficiency was calculated, and a detailed design was conducted according to the most easy-to-use product configuration prototype. The results were finally rendered in three-dimensional simulation.

Human body measurements

The operation of a remote control is mainly realized by the use of the hand. Therefore, this study wanted to investigate and measure the holding and manipulating areas of the remote control. In addition, to avoid the influence of other variables during the experiment, only right-handers were chosen as subjects in this study, and all of the subjects of this study were from Asian countries. In total, 20 males and 20 females participated in this study. The measurements were obtained using the right hands of subjects. The major range of measurements included the palm thickness, palm width, palm length, index finger length, and thumb length. Vernier calipers were used as the measuring tools. The measurement results of the subjects are presented in **Table 2**.

Table 2 reveals that although the discrepancy between the average height of male and female was as great as 14 cm, the maximum discrepancy between the two genders in terms of relevant hand measures of palm thickness, width, length, and the length of the index finger and thumb was only 1.2 cm. In this case, the average measurements from the right hands of females are used as the reference base for designing new remote controls (given that the easy-to-grasp dimensions for females are similar to the easy-to-grasp dimensions for males).

Table 2. Measurement Result of Males’ and Females’ Hand Dimension (Right Hand)

Human Body Measurement									
Sex	Sample	Age	Height (cm)	Weight (kg)	Thickness of Palm (mm)	Width of Palm (mm)	Length of Palm (mm)	Length of Index Finger (mm)	Length of Thumb (mm)
Female	Sample 1	19.2	150.31	49.23	36.15	74.3	147.23	77.12	107.14
	Sample 2	18.1	151.22	43.17	35.11	74.6	148.64	76.11	98.26
	Sample 3	19.0	152.30	54.21	37.43	75.2	144.82	78.31	99.42
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	Sample 20	18.4	165.60	52.20	44.01	83.15	155.63	78.42	116.02
	Average Value	19	159.61	53.25	37.95	72.25	150.45	77.1	106.85
	Sample 21	20.2	165.11	70.01	49.13	83.09	149.33	72.10	109.17
	Sample 22	19.5	166.27	65.21	36.29	80.22	160.76	82.20	118.38
	Sample 23	19.2	170.43	54.31	37.82	77.04	155.09	71.21	113.82
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Male	Sample 40	19.6	172.35	65.20	49.11	84.36	160.64	87.69	122.85
	Average Value	20	173.31	66.72	46.81	83.61	162.01	84.50	118.50

* The age averages have been rounded to the nearest integer throughout this study.

Deciding on the comparison products

The style of most remote controls on the market is rectangular with rounded corners. To avoid subject fatigue during the experiment, two remote controls (commercially available products) with differences in length and key layout were chosen in this study as the comparison target products of this case design. Among these remote controls, target product Old A is a common universal remote control with a slender body and more keys; target product Old B is a remote control made by a well-known brand with a shorter body and fewer keys. The target remote controls are portrayed as the line art presented in **Figure 2** (the length and width of squares of the base figure is 5x5 mm). We then observe and record the process of the subjects manipulating remote controls with one hand (right hand) on the reachable range (blue zone) and the most comfortable range (green zone).

The aggregate results of male and female subjects’ single-handed operations of the remote control are recorded in **Figure 3**. As shown in **Figure 3**, the green zone covered a small range concentrated at the upper-middle region of the control, which displayed the most comfortable area when moving the thumb. The blue area displayed the utmost accessible range when stretching the thumb. As shown in **Figure 3**, the color of the remote’s lower-middle region gradually faded, signifying that the finger could not touch this area. In addition, the gradation of colors of the green zone and the blue zone is composed of the overlapping measured results from a total of 40 individuals (males and females). Darker overlapping color

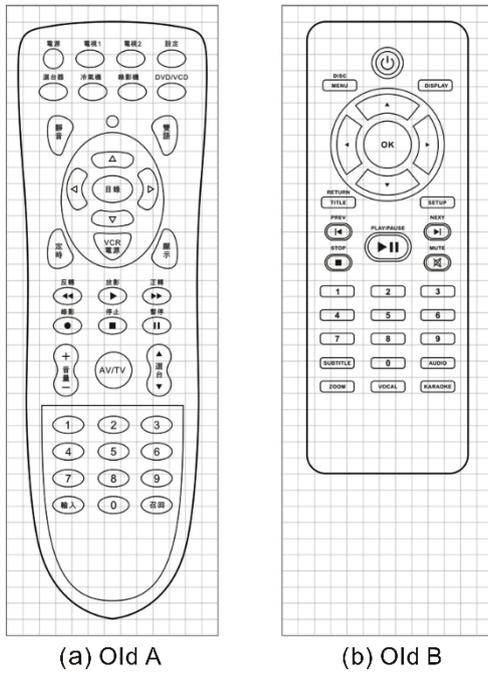


Figure 2. Black and White Grid Sketch of the Comparison Products

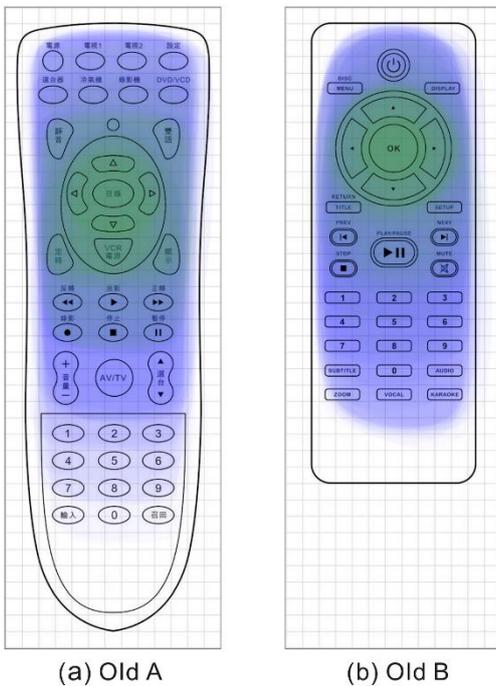


Figure 3. Subjects' Operational Areas on the Comparison Products

indicates that the operable range for most people concentrates in this zone; in contrast, lighter overlapping color indicates that fewer people could reach this zone via a one-handed grasp.

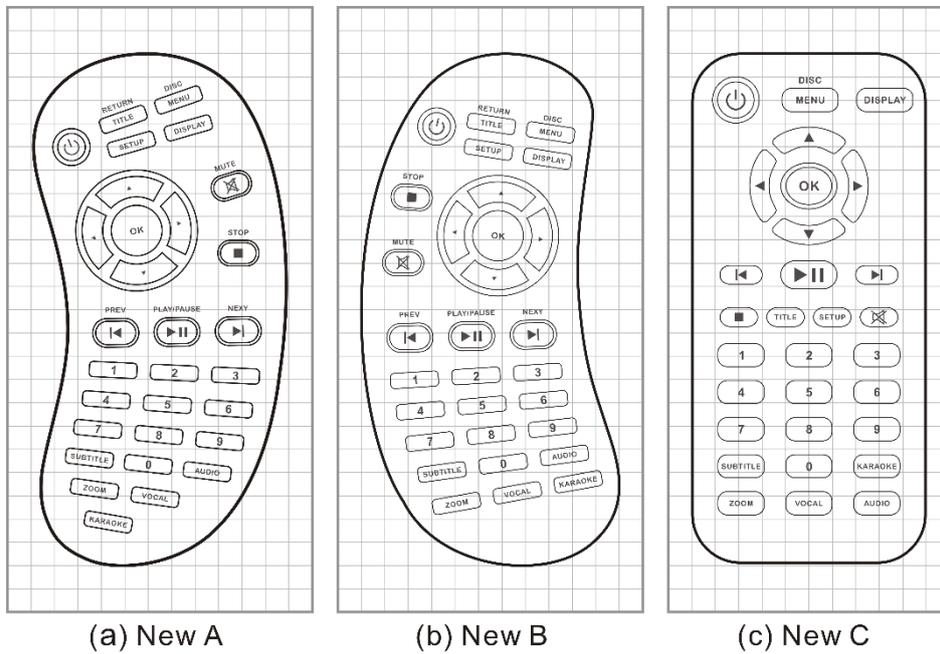


Figure 4. Black and White Grid Sketches of the Three New-designed Remote Controls

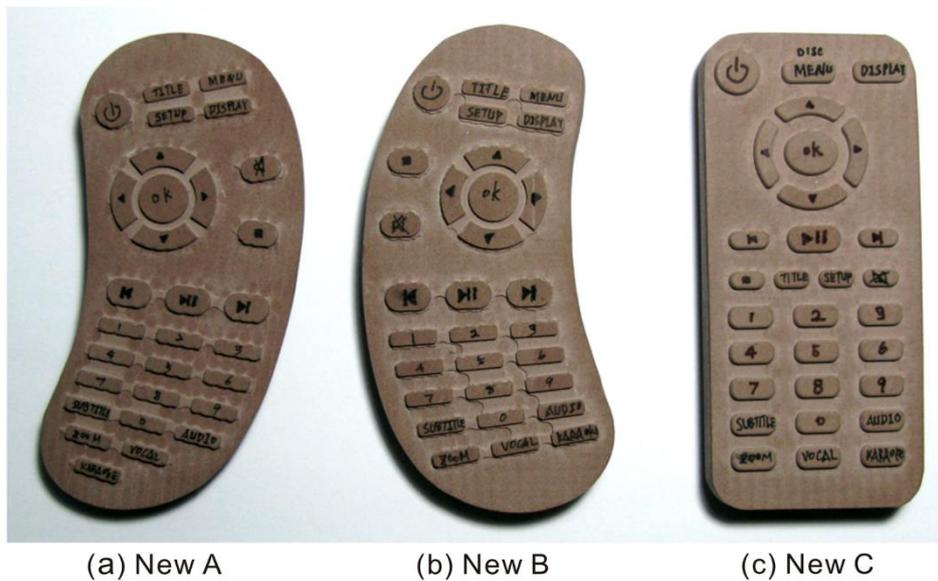


Figure 5. Experimental Prototype of the Three New-designed Remote Controls

Design of New Products

After referring to the body measurement dimensions (**Table 2**) and the operable range of the target products (**Figure 3**), this study refers to the spatial arrangement theories of Sanders and McCormick (1993) in the *Theories of Space Allocation* section. Using the four

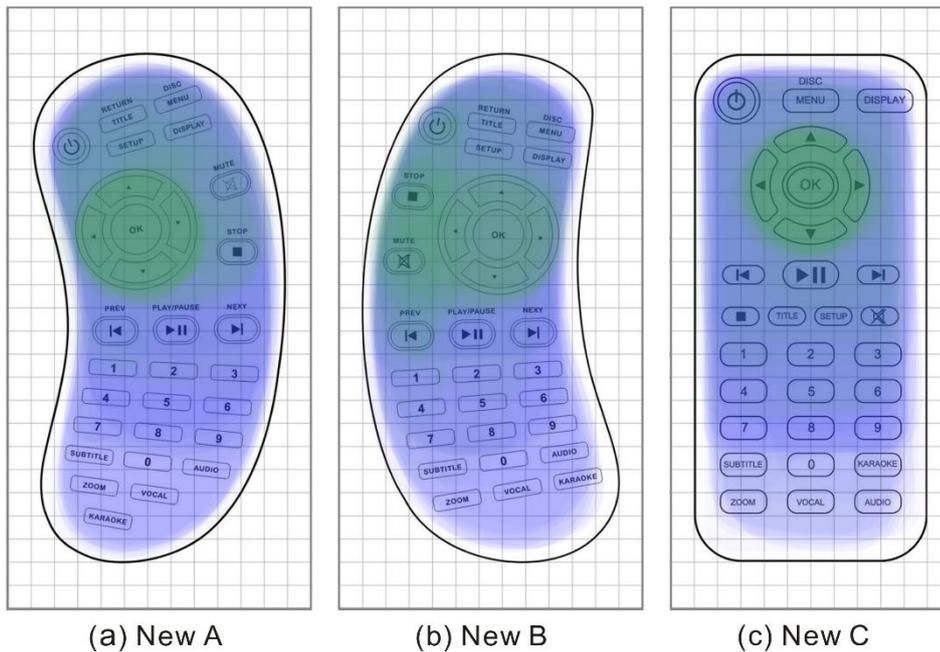


Figure 6. Subjects' Operating Zones on the New-designed Remote Controls

principles of the spatial arrangement (Figure 1), the button positions are re-allocated and the length of remote control is reduced to design three remote controls with different configuration. Two remote controls were designed to fit to the curve of the holding hand to investigate whether the curved shape would affect the degree of comfort and efficiency of operation. The black and white grid sketches of the three new remote controls are presented in Figure 4. In addition, operable experimental prototypes of the three new controls (New A, New B, and New C) were created (Figure 5) to enable hands-on operation of the new remote controls and perform the later efficiency assessment. The comfortable operating areas were observed and recorded.

The single-handed operating results of male and female subjects using new remote controls were recorded. The summarized results are presented in Figure 6. As shown in Figure 6, the green zones spanned greater than half of the interface area of the remote controls. However, the comfortable operating zones displayed on the newly designed remote controls covered more buttons compared with comparison products Old A and Old B. Based on the blue zones that indicate the furthest area reachable with a stretched thumb, the entire area of the new remote controls could be accessed, and the color distributions on products New A and New B are the most similar.

Efficiency Assessment of Operating Interface

The assessment of operational interface efficiency can be divided into four steps, including (1) establishment of the typical task, (2) measurement of the length of the total operating distance, (3) calculation of operating efficiency, and (4) calculation of the improved

Table 3. Typical task for Usability Assessment

Task Items	Task Contents
T1	Power → Play → Fast Forward → Play
T2	Power → Play → Menu → Section Selection → Play
T3	Pause → Fast Rewind → Play → Volume → Stop → Eject → Power
T4	Power → Menu → Section Selection → Play → Volume → Pause → Fast Rewind → Play → Stop → Play → Eject → Power

efficiency degree. In accordance with the four steps, the assessment was implemented as detailed below:

Establishment of the typical task

The major purpose of configuring the typical task is to ensure that the subjects are capable of operating products of different styles following the same task items. The operation time of each product is obtained by measurements, and then the excellence or inferiority of performance in the operating efficiency of products is ranked. It is beneficial to follow the same task items to conduct testing to observe the difference between the performances of subjects against the same topics.

However, numerous combinations for the arrangement of the control sequence of remote controls are possible. In this case study, keys commonly used by typical people (e.g., the power switch, play, stop, volume, pause keys, etc.) were selected to set the task items. The contents of the task are arranged at random. To prevent subjects from feeling tired of the operation of experiments, only four typical task items were defined in this study, and the task contents executed are described in **Table 3**.

Measurement of the Length of Total Operating Distance

In different typical tasks, it is necessary to measure the length of the total operating distances on the new and old remote controls. For example, to calculate the total operating distances on New C in Task Item 3 (New C-T3), the distance between two buttons and the number of button combinations (5 combinations in total) are observed (**Figure 7**), and the functions of pause and play share the same button "a"; therefore, the operation frequency of \overrightarrow{ab} is recorded as 2 (Note: The distance between keys 'PAUSE→FAST REWIND' is a→b. In contrast, the distance between the 'FAST REWIND→PLAY' keys is b→a because the distance of a→b equals b→a; therefore, the operation count of \overrightarrow{ab} is recorded as two times).

Eq. (1) was used to calculate the total operating distance (moved distance) of New C-T3, and the resulting value is $OD_{total} = \overrightarrow{ab} \bullet 2 + \overrightarrow{ac} \bullet 1 + \overrightarrow{cd} \bullet 1 + \overrightarrow{de} \bullet 1 + \overrightarrow{ef} \bullet 1 = 209.63$ (mm).

In accordance with the above equation, the measured results of total operating distances on two comparison products (old) and three new controls in different typical tasks are presented in **Figures 4** and **5**, respectively.

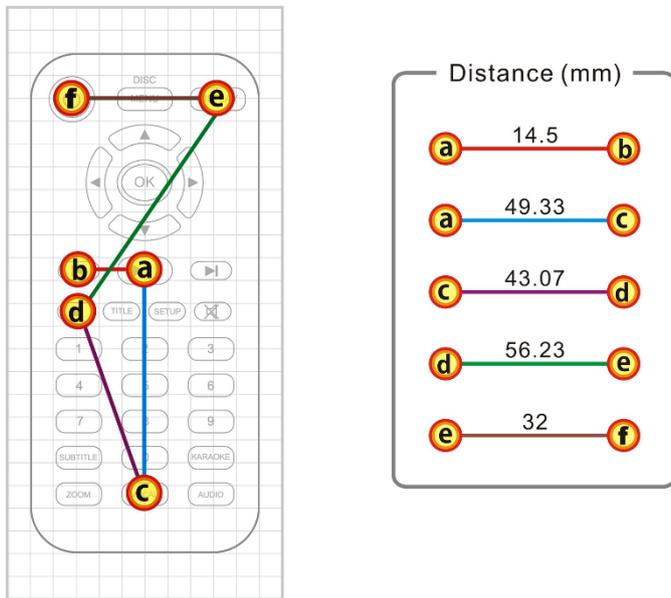


Figure 7. Distance between Buttons and Number of Button Combinations

Calculation of Operating Efficiency

To calculate the operating efficiency, it is necessary to first obtain the length of the total operating distance and operating time. In the previous step, the measurements of the length of the total operating distance were completed. The operating time was measured in this step by recording and observing the subjects' operations on the experimental tools.

The requirements for conducting the experiments include the following: (1) Subjects must be right-handed; (2) Subjects should grasp experiment tools with one hand, using thumbs to control; (3) Subjects must operate the following task items, and each key should only be pressed one time (according to task contents as listed). The details of the experiment are described below.

The subjects in this study are college students between the ages of 22 to 28. There were 40 subjects in total, including 20 males and 20 females. The experimental tools include two types of comparison remote controls (Old A and Old B), the experimental prototypes of three new-designed remote controls (New A, New B, and New C), and a stopwatch timer. An operator who extensively practiced used a stopwatch to record the time when the subjects pressed the button. A video camera also recorded the entire process. At the end of the experiments, video clips were reviewed to observe the timing error when the subjects pressed the button to start the experiments and when the operator pressed the button of the stopwatch timer. For an operator with adequate practices, the average timing error is approximately 0.3 seconds, which is considered acceptable.

Table 4. Subjects' Operating Time and Operating Efficiency on Comparison Products

Subject	Comparison Product Remote Control A				Comparison Product Remote Control B			
	Old A-T1	Old A-T2	Old A-T3	Old A-T4	Old B-T1	Old B-T2	Old B-T3	Old B-T4
Subject 1	5.49	10.01	15.35	20.37	4.01	5.11	8.04	15.46
Subject 2	4.11	7.33	10.42	17.22	5.05	6.22	7.21	13.23
Subject 3	4.31	3.41	6.32	15.31	6.32	6.25	10.52	11.31
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Subject 40	6.52	10.22	15.23	25.41	7.47	7.38	25.04	14.10
Average Operating Time (sec)	6.23	8.40	12.78	18.35	5.53	8.28	12.45	15.80
Total Operating Distance (mm)	101	152	175	286	89	175	156	240
Operating Efficiency (mm/sec)	16.22	18.10	13.70	15.59	16.11	21.14	12.53	15.19

Table 5. Subjects' Operating Time and Operating Efficiency on New Products

Subject	New Remote Control A				New Remote Control B				New Remote Control C			
	New A-T1	New A-T2	New A-T3	New A-T4	New B-T1	New B-T2	New B-T3	New B-T4	New C-T1	New C-T2	New C-T3	New C-T4
Subject 1	5.20	8.24	10.15	18.28	4.08	5.51	8.61	10.71	5.60	13.10	9.10	17.10
Subject 2	6.22	7.82	11.26	17.46	4.82	5.22	6.73	12.59	4.91	5.92	10.21	14.30
Subject 3	2.53	3.12	5.04	7.82	1.81	2.53	6.86	8.38	2.64	3.73	6.40	10.10
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Subject 40	4.02	5.40	7.81	12.91	4.73	2.64	10.50	11.47	4.28	6.09	10.90	17.10
Average Operating Time (sec)	3.98	5.11	9.31	12.57	3.88	4.34	8.26	11.74	4.16	6.26	9.47	12.98
Total Operational Distance (mm)	71.77	145.36	171.52	248.23	71.99	141.26	183.42	256.53	69.06	121.29	209.63	292.93
Operational Efficiency (mm/sec)	18.03	28.47	18.42	19.75	18.55	32.53	22.22	21.85	16.61	19.38	22.14	22.57

Before launching the experiment, the experiment methods and procedures were first explained by the operators. The subjects could first browse through the contents of task items and the prototype remote controls of the experiment but could not attempt to operate the devices in advance. In contrast, the operators simply observe the subjects and count the time and are prohibited from guiding the subjects through any of the operation.

The time spent by subjects on operating remote controls (sec), the total operating distance (mm), and the operational efficiency (mm/sec) in accordance with the content of the typical task is presented in **Tables 4** and **5**. The operating efficiency was calculated using Eq. (2).

Table 6. Improved Operating Efficiency Degree of New Remote Controls in Comparison with the Comparison Products

Existing Remote Controls	Improved Degree of New Remote Controls (%)		
	New A	New B	New C
Old A-T1	11.16	14.36	2.40
Old A-T2	57.29	79.72	7.07
Old A-T3	34.45	62.19	61.61
Old A-T4	26.68	40.15	44.77
Old B-T1	11.92	15.15	3.10
Old B-T2	34.67	53.88	-8.33
Old B-T3	47.01	77.33	76.70
Old B-T4	30.02	43.84	48.58
Overall Improvement	253.21	386.64	235.91
Percentage	28.91%	44.15%	26.94%



Figure 8. Detailed Design Simulations of New B Remote Control Design

Calculation of Improved Operating Efficiency

Using Eq. (3), the improved efficiency degree of the product was obtained by calculating the operating efficiency values for the new and old comparison products. Using the calculation of the operating efficiency of the remote controls New B and Old A in Task Item 2 (T2) as an example (Tables 4 and 5), the improvement degree of operating efficiency can be obtained as follows: $E_i = (32.53-18.1)/18.1 = 79.92\%$.

The detailed calculated results of the degree of operating efficiency improvement of the new remote controls are listed in Table 6. As evident in Table 6, the remote control New B exhibited the highest degree of improvement with an overall improvement degree of 44.15%, which is substantially increased compared with the other two designs. Therefore, detail modifications have been made on the basis of the experimental prototype of remote control New B. Its three-dimensional simulation is presented in Figure 8.

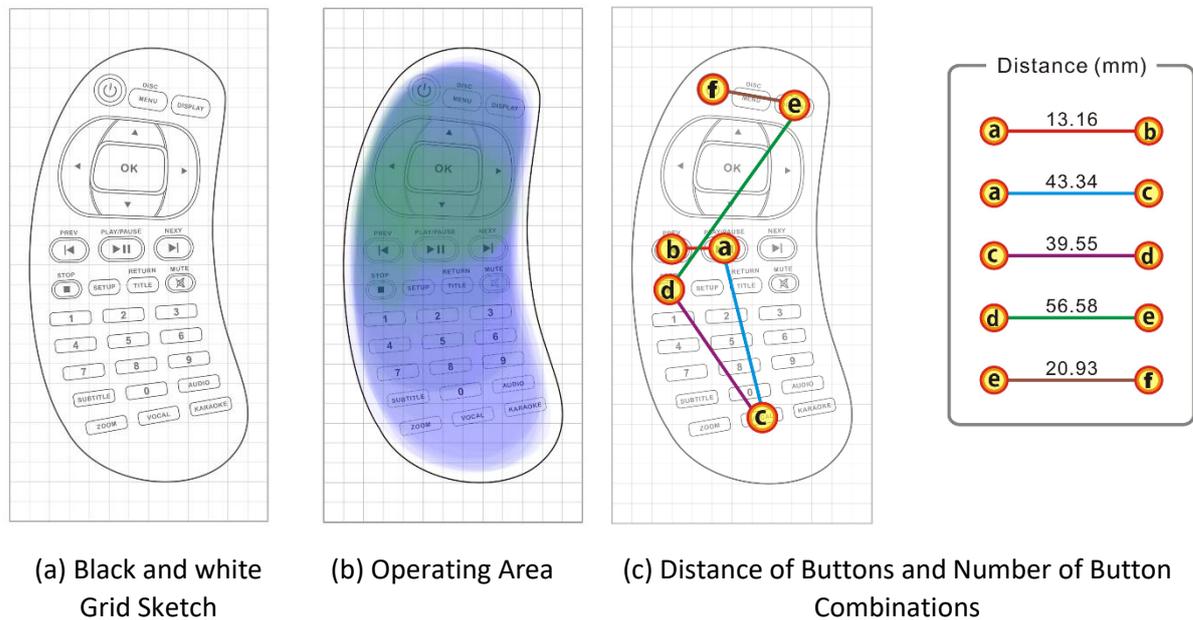


Figure 9. New Design Plan of Remote Control New D

DISCUSSION

With a high overall improvement degree of 44.15%, remote control New B possesses the best performance in the experiment. If the designer is satisfied with such an improved efficiency degree, the “Assessment Method of Product Operating Interface Efficiency” proposed by this study could end here.

However, if the designer is not satisfied with the improved efficiency degree of the newly designed product, then how could the designer use this design method to assess the modified new product? An explanation of the re-designing process is provided in the *Efficiency Assessment of Operating Interface* section that follows.

Re-design of the Case: Remote Control New D

As presented in [Table 6](#), the New B, which possesses a left-tended curving shape, has the best operating efficiency improvement degree. Therefore, when redesigning the new product New D, the appearance design of New B was maintained, and the buttons was reallocated. By referring to layout principles of Sanders and McCormick (1993) ([Table 1](#)), the design of key layouts for remote control new D was conducted. The mute and stop keys were moved to the bottom (similar to the layout position of remote control New C), and the direction key was enlarged. During the design process, the basic principle to follow is to place frequently used keys within the most comfortable range (green zone). The black and white grid sketch of remote control New D is presented in [Figure 9 \(a\)](#).

Given that the appearance and shape of New D is the same as that of New B, the reachable area figures of both male and female subjects' operations are the same. These results are presented in **Figure 9 (b)**. With the redesigned product New D, the efficiency assessment of operational interface was conducted, and the procedures are described below.

- (1) The configuration of a typical task: The operating efficiency improvement degree of the redesigned product New D was obtained via comparison with the assessment results of Old A, Old B, New A, New B, and New C. Therefore, the content of a typical task must be consistent. As a result, the content of New D's typical task should be the same as that presented in **Table 3**.
- (2) Measurement of the length of total operating distance: For measuring the operating distance on New D in Task Item 3 (New D-T3), the measurement results listed in **Figure 9 (c)** were used for calculation.

The total operating distance (distance moved) of New D-T3 was calculated based on Eq. (1) as follows: $OD_{total} = \overline{ab} \bullet 2 + \overline{ac} \bullet 1 + \overline{cd} \bullet 1 + \overline{de} \bullet 1 + \overline{ef} \bullet 1 = 186.72$ (mm).

In accordance with the above equation, the calculated results of New D's total operating distances in different task items are as shown in **Table 7**.

- (3) Calculation of operational efficiency: To ensure the accuracy of the experimental results, the subject group for New D should be the same as the group used to assess Old A, Old B, New A, New B, and New C if possible. The detailed process of the experiment is described below. There are 40 subjects in total, including 20 males and 20 females. The experimental tools include the experimental prototype of New D and a stopwatch timer. Before the start of the experiment, an operator explained the methods and procedures of the experiment. During the experiment, the subjects operated the remote control in accordance with the content of the typical task, while the operator observed the subjects and calculated their operating time. The operating time and operating efficiency of subjects on New D are presented in **Table 7**.

Table 7. Subjects' Operating Time and Efficiency on Remote Control New D

Subject	New-Designed Remote Control D			
	New D-T1	New D-T2	New D-T3	New D-T4
Subject 1	3.02	3.27	7.69	9.93
Subject 2	3.82	4.78	8.07	11.32
Subject 3	3.75	4.34	8.24	12.71
⋮	⋮	⋮	⋮	⋮
Subject 40	3.04	3.12	8.01	10.62
Average Operating Time (sec)	3.97	5.05	8.36	12.50
Total Operating Distance (mm)	66.73	125.65	186.72	263.9
Operating Efficiency(mm/sec)	16.82	24.87	22.34	21.12

Table 8. Improved Operational Efficiency Degree of New Remote Controls and New D in Comparison with the Comparison Products

Improvement Degree of Operating Efficiency (%)				
New-Designed Remote Controls and Re-designed Remote Control New D				
Existing Remote Controls	New A	New B	New C	New D
Old A-T1	11.16	14.36	2.40	3.70
Old A-T2	57.29	79.72	7.07	37.40
Old A-T3	34.45	62.19	61.61	63.07
Old A-T4	26.68	40.15	44.77	35.47
Old B-T1	11.92	15.15	3.10	4.41
Old B-T2	34.67	53.88	-8.33	17.64
Old B-T3	47.01	77.33	76.70	78.29
Old B-T4	30.02	43.84	48.58	39.04
Overall Improvement	253.21	386.64	235.91	279.02
Percentage	21.93	33.48	20.43	24.16

- (4) Calculation of Improvement Degree of Operational Efficiency: Using the operating efficiency of remote control New D and Old A in Task Item 2 as an example, the improvement degree of operating efficiency was calculated based on Eq. (3) as follows: $E_j = (24.87-18.1)/18.1 = 37.4\%$.

The detailed calculated results of the improved operating efficiency degree of the newly designed remote control in comparison with the comparison product are presented in **Table 8**. As evident in **Table 8**, remote control New B remains the best design in terms of the overall improvement. The overall improvement degree of the re-designed remote control New D was 24.16%, which is slightly better than New A and New C. When the improved operating efficiency degree of a certain plan is obviously better than other plans, it indicates that the plan was closer to the ideal state, and the designer is not required to spend more time on redesigning the product.

All of the above experimental results were obtained from the same batch of subjects, which are referred to as old subjects. To understand whether old subjects have already gained learnability during the experiment and subsequently enhanced the operating efficiency of remote control New B compared with New D, a new group of subjects, which are referred to as new subjects, were selected to conduct the experiments using New B and New D remote controls. The new subjects are all right-handers and were asked to operate the same task items.

New subjects' operating time and efficiency on remote controls New B and New D are listed in **Table 9**, which demonstrates that the operating efficiency of New B still exceeds New D. From the results, it is evident that the users did not become skilled after operations on several remote controls in the first experiment; therefore, remote control New B remained the best design.

Table 9. New Subjects' Operating Time and Efficiency when Operating Remote Controls New B and New D

Subject	New-Designed Remote Control B				New-Designed Remote Control D			
	New B-T1	New B-T2	New B-T3	New B-T4	New D-T1	New D-T2	New D-T3	New D-T4
Subject 1	3.22	4.91	6.12	11.52	3.08	6.22	7.61	9.90
Subject 2	5.53	4.26	6.91	12.54	3.89	4.73	8.08	11.32
Subject 3	3.27	4.80	7.61	13.08	3.71	4.31	8.24	12.74
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Subject 40	3.80	6.94	8.70	13.01	2.30	4.34	5.81	8.26
Average Operating Time (sec)	3.38	4.60	7.13	11.67	3.57	5.38	8.64	13.03
Average Length of Total Operating Distance (mm)	71.99	141.26	183.42	256.53	66.73	125.65	186.72	263.90
Operating Efficiency (mm/sec)	21.28	30.73	25.73	21.98	18.70	23.36	21.62	20.25

CONCLUSIONS AND SUGGESTIONS

The assessment method of product operating interface efficiency proposed in this study was proven to be both practical and feasible. The proposed evaluation method of the operating efficiency of the product interface has been verified to be viable for Asian individuals by the experiments presented herein. According to the results of the case studies, the single-handed accessible operating area of new-designed remote controls are more uniform, and the most comfortable operating area covers more commonly used keys. Thus, the new design exhibits a higher operating efficiency than existing products on the market. The newly designed remote control New B exhibits 44.15% improvement degree of operating efficiency (Table 6), which is significantly higher than other remote controls. This finding indicates that the design of the rightward convex shape and the key arrangement method of New B were favorable for operation by subjects (right-handers).

During the experiment, when the subjects press the keys within the most comfortable range, they appear to feel easier and the keys are easy to press; outside of the comfortable range, the subjects appear to feel hampered (inflexible fingers). After finishing the questionnaire, most subjects indicate that under the state of gripping, keys used more often should be placed within the range of thumb movement. The angle of thumb movement is smaller, and the keys feel more comfortable and easy to press. The comments proposed by the subjects in the experiments of this study are similar to the proposed layout principles (frequency-of-use principle) of the spatial arrangement of Sanders and McCormick (1993), who suggest that frequently used components should be placed at the most convenient positions (in this study, namely the most comfortable range and the reachable range of operation).

In addition, if a designer wants to re-design the product, the following three principles should be considered: (1) the content of the typical task must remain unchanged; (2) the users should consist of the same individuals as much as possible; and (3) the redesigned proposal must be compared with the previous new designs and comparison products to ensure the overall improvement results. The analysis model that was developed in this study can be used by designers for repeatedly analyzing processes and for making further modifications. The overall degree of improvement can be enhanced further with a higher degree of usability due to the convergence of the resulting values.

In addition, it is important to note that when a designer uses the assessment method proposed by this study, the number or content of task items can be increased. Although this increase may prolong the experimental time, it will allow the designer to better understand the user's operating situation. For follow-up research in the future, the operating range and operating time of the index finger can be included and further investigated. Moreover, when researchers are using the evaluation method that was proposed in this study for follow-up research, they are recommended to increase the load or contents of typical tasks. The duration of experiments might be increased but this approach allows designers to understand better the users' operating conditions.

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