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Developing User Interface Design Guideline for Flexible Display and Case Studies of its Application

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Abstract

This research has been conducted to develop the user interface design guidelines that are effectively applicable with the characteristics of the flexible display's physical shape change and to verify the applicability through design case studies. To do so, the design considerations that were determined in the preceding researches were categorized, organized and integrated into the flexible display's form factors of Flexibility, Shape, Size, Multi-Surface, Texture, and Transparency. From this process, 23 detailed types and 43 subordinate design guidelines have been derived for the six form factors. Moreover, through the case studies of the interface design in which the guidelines are applied to each display type; it has been proved that these guidelines are effectively applicable to various flexible display types. This research has integrated the existing studies and systematized for various types of the flexible displays. It has a significant meaning that this research has offered the base on which the proposed system to build more in the future.

Keywords: *Flexible Display, User Interface, Design Guideline, Rollable Display, Bendable Display*

1. Introduction

Different from the flat displays, newly rising flexible display interfaces recognize multi-touch or both hands gestures and as the results of the output, these new interfaces physically transform with completely different interaction or interface presentation methods from the existing displays. So, based on the displays' new features, some researches on how to effectively design with the maximum strength are in progress. The researches regarding the user interface design are the references that offer or evaluate the prototype designs for the flexible displays or those that offer or evaluate the suitable usage method for the particular flexible display types. However, because the existing flexile display interface design researches are way too specific, it is sometimes hard to apply to different cases leading to the individual case study exclusively without having systematized the design principles and guidelines.

Good design guidelines help good design choices as well as design process efficiencies. Especially, since the flexible display field is still at its early stage and the designers do not have much experiences with the new interface, the design guidelines that can be applicable to various examples are in need. Therefore, the aims of this research are to develop the design guidelines that can be utilized in various flexible display types and to examine the applicability of the design guidelines developed through the case studies.

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2. Flexible Display Design Reference Consideration

2.1. Flexible Display Preceding Research

A number of researches are being executed regarding the flexible display designs which can be classified into Curved Display, Bendable Display, Rollable Display, Foldable Display, and Stretchable Display depending on the level of its flexibility and the different types of each of these displays are being studied as well.

When the flexible display is a curved type, the user will confront an interface that is curved and in its fixed position; it could be concave, convex, bent at 90 degrees, cylindrical, spherical shapes. These shapes are all used as the main topics of many researches. In this type of display, utilizing it as much as it can to best deliver the functions by the display shape and using the appropriate view angle and the possible field of vision depending on the display's curvature are discussed to be the key considerations when designing it.

When the flexible display is a bendable type, the user will confront an interface that they can bend or flatten at a certain curvature. There are studies going on regarding offering suitable designs for the different level of flexibility or size as well as those regarding the new method of designing depending on how the display is bent. Besides, since there is a possibility of replacing papers, understanding the effective way of using the books or several pages of documents and supporting these methods are being studied.

When the flexible display is a foldable type, the user will confront an interface that they can fold or unfold to have it in various shapes and sizes. In other words, as the display can change its shape and size by the number of folds, providing the appropriate shape and functions for the specific situation is being discussed. Especially, the researches in this field are mostly focusing on the method of designing as the display is divided into several sides by folding.

When the flexible display is a stretchable type, the user will confront an interface that can be extended due to the elastic characteristics of the display. In this field, there are some studies regarding the designs that manipulate the area or depth of the display with an added pressure on it to expand the surface. In particular, based on the fact that the surface expands, the designs that use the tactile techniques are significantly discussed. The summary of the preceding researches by the display types are as in the following Table 1.

Table 1. Summary of the Preceding Research with Different Types of Flexible Display

Type	Researcher	Research Summary
C*	Weiss et al. (2010)	Studied the designs that utilized the divided sections from the display's bent shape for the proper functions of the interface in the context of using the desk where the flexible display had been applied
	Beyer et al. (2011)	Studied the designs that took into account the pedestrians' possible view range on a cylinder type of display to suggest a prototype to be used in public
	Benko, Wilso, & Balakrishnan (2008)	Understood that a spherical type would provide the users a view range of 360° and researched on the designs that several users could cooperatively use
B*	Schwesig, Pouyrpev, & Mori (2004)	Developed a prototype with the flexibility and size of a credit card, and understood the interaction techniques and studied on the contents designs appropriate for bendable displays
	Watanabe, Mochizuki, &	Studied the dual/single display designs by using the metaphor of flipping through a book to search the

	Horry. (2008)	contents
	Lee, Lim & Lee (2012)	Designed the bendable displays in two different sizes and compare them to observe the user's usage and satisfaction
	Kildal, Paasovaara, & Aaltonen (2012)	Researched on the new interaction designs where bending techniques were used with both hands on a landscape smart phone interface and also studied the flexibility related to it
	Girouard, Tarun, & Vertegaal (2012)	Suggested a system which allowed the physical lump of the digital documents and case studied regarding the interface that could appear on a paper type display with several pages
	Burstyn, Banerjee, & Vertegaal (2013)	Studied the interaction techniques to search for Z-axis on a smart phone type interface and the navigation designs to support it
R*	Khalilbeigi et al. (2011)	Studied the possibility of the effectiveness of a physical size change of a rollable display to the digital contents and the interaction methods
	Steimle, & Olberding (2012)	Studied on the rollable display prototype that an individual can carry around by hand and that several people can use it together
	Nagaraju (2013)	Defined the physical structure which might appear on a rollable display as well as the single or multi-screen from each structure, and studied the interface using the screens
F*	Lee, Hudson, & Tse (2008)	Studied the various shapes of a possible display design by suggesting four different designs of a foldable display that did not have only straight lines
	Khalilbeigi et al. (2012)	Researched on how the users recognized and use it by reviewing the number and overlapping shape of a display by how it is folded
	Ramakers, Schöning, & Luyten (2014)	Realized the mobile prototypes that can be transformed into various types like a big or small book type or a ring type, and studied new interaction methods through comparisons of the physical limitation methods or touch methods to manipulate
S*	Sato et al. (2009)	Studied the possible designs using the elasticity and transparency through technical studies on the elasticity and transparent tabletop prototype
	Yun et al. (2012)	Discussed the interaction method of pushing it hard with a hand by using the elasticity, and also studied the navigation and interface designs effective for complicated multi-dimensional data structure search
	Lee et al. (2014)	Discussed on the designs depending on the possibility of incorporation of tactile techniques on a stretchable display

* C=Curved Display, B=Bendable Display, R=Rollable Display, F=Foldable Display, S=Stretchable Display

2.2. Flexible Display's Form Factor

Since the designs that have applied the flexible display's various form factors come in many different types; such as, Cylinder type, Spheric type, Book type, Rollable Type, Folded type, Smartphone type, Desktop type, Fan type, etc., the design considerations that were discussed earlier are interpreted at individual levels. Thus, researches to establish the

common factors to thoroughly understand the various types and the characteristics of different shapes of the flexible display are being executed.

Form factors are the characteristics of the display shape that can be differentiated from each other and these characteristics have been discussed as the analytical system for the flexible display designs. Rümelin *et al.*, (2012) discussed on the form factors as the main analytical system that was related to the non-flat interactive display designs and suggested shape, size, curvature and structure[1] as form factors. However, his research was focused on the Curved Display only; other types of the flexible display were not fully explained. Chung *et al.*, (2015) have incorporated and redefined the factors that were mainly discussed in various types of flexible display design reference based on the form factors in the typical industrial design fields to suggest flexibility, shape, size, multi-Surface, texture, and transparency[2](Table 2).

TABLE 2. The Form Factors of Flexible Display [2]

Form Factor	Definition
Flexibility	The characteristic of the hardness or softness of the display
Shape	The characteristic of the appearance by connecting the display's sides
Size	Size The characteristic that defines how big or small the display is
Multi-Surface	The characteristic of the partition of the surface that appear when the display is bent or folded
Texture	The visual or tactual sense of characteristic added to the display surface
Transparency	The characteristic that the display light penetrates without scattering which makes the back of the display visible

3. Flexible Display Design Guideline Development with Different Form Factors

In spite of the continuous researches on the flexible display designs, the structure has not been established due to various forms of the flexible displays. Thus, in this research, the design considerations collected from the 22 studies were categorized, organized and integrated by form factors - Flexibility, Shape, Size, Multi-Surface, Texture, and Transparency. First, the considerations regarding the form factors were categorized, and excessively detailed contents were rephrased into more general sentences focusing on the factors and related context. Then the sentences with similar ideas were integrated again, and if the ideas are similar but have different important considerations, these were broken into more detailed types. Flexibility is divided into Bendable, Rollable, Foldable, Stretchable. Shape is broken into more detailed groups of Curve-sided 2.5D, Straight-sided 2.5D, Cylindrical 3D, Spherical 3D, Complex in the shape of an object, and Expression of the 3D data. Size is categorized into Responsive screen, Size suitability, Contents arrangement for many users, and Multi-interaction application. Multi-Surface is categorized into detailed types-The shape and number of the divided surfaces, Division of functional role, Division of sequential role, Division of hierarchical role, Separation and combination of the surfaces. Texture is divided into Visual and tactile texture, Feedback, while Transparency is divided into Overlapping and Visibility. Lastly, the six form factors have been divided into 23 detailed types and 43 guidelines have been developed as in the following TABLE 3.

Table 3. Design Guidelines for Flexible Display

No.	Factor	Type	Guideline	References
FL-1	Flexibility	Bendable	Bendable Display should be interacted by bending or unfolding gestures by hands and should be operated by one or both hands depending on the size.	[3], [4]
FL-2			Bendable Display's gesture interactions have detailed standards (position, direction, time, number of times), and the executive functions can be defined according to its combinations.	[5]
FL-3			Bendable Display can offer navigation functions which moves in Z-axis through bending and unfolding interactions.	[3]
FL-4		Rollable	Rollable Display can be interacted by rolling or unrolling gesture by hands and the rolling or unrolling direction and the size when it's unrolled should be reviewed.	[6]
FL-5			Rollable Display size can be expanded by unrolling and using it alone and with a few people at the same time should be considered.	[7]
FL-6			Rollable Display can be divided into three types of mode-Cylindrical mode as the whole body is rolled like a cylinder, partially rolled mode with the rest flat, or just all flat mode-and their appropriate display formation should be considered for each situation.	[8]
FL-7		Foldable	Foldable Display can be interacted by folding or unfolding gestures by hands and folding or unfolding methods or position of the hands should be reviewed.	[6]
FL-8			Foldable Display's gesture interactions have detailed standards (folding or unfolding position, direction, number of times, angles, and time), and the executive functions can be defined according to its combinations.	[9]
FL-9			Physical operating methods of the foldable display, like turning the pages over, help memory of space and understanding the contents and should be used properly.	[10]
FL-10			Foldable Display can be modified by folding in half, folding partially or folding in various combinations (1), and horizontal-vertical, or atypical folding is also possible (2). Display formation for each situation should be considered.	[6], [11]
FL-11		Stretchable	Stretchable Display can be interacted by pushing or pulling gestures.	[12]
FL-12			Stretchable Display allows adding the depth and softness to the contents.	[12]
FL-13			Stretchable Display is defective to express the multi-dimensional data (time dimension, 3D space search), and by adjusting the Z-axis by the extent of pushing, it can provide visualized data at various stages.	[13]
SH-1	Shape	Curve-sided 2.5D	The gently curved shape is effective to maximize the visual quality of the user and allows to provide the suitable curve variations according to the contents.	[14]
SH-2		Straight-sided 2.5D	The sharply curved shape looks like it is divided into two or more sides and should be considered for applicability for multi-sided display.	[15]

SH-3		Cylindrical 3D	Since the field of vision for the cylindrical shape changes depending on the size, the size should be considered when providing an interface. Also, because there is no boundaries of left-right (or top-bottom), the contents should not be fixed at a point.	[16]
SH-4		Spherical 3D	The sphere shape has 360° of sight range so it can provide the interface with which many users can cooperate at omni-directions.	[17]
SH-5		Complex in the shape of an object	As the display can express objects in various shapes, it should provide the interface according to the various shapes of the objects.	[11]
SH-6			It helps the user to use the display intuitively by using the interaction methods that utilize the physical usage experiences from the existing objects	[18]
SH-7		Expression of the 3D data	As the 3D shape of the display allows expressing data in three dimensions, it is effective to match the shape of the data and the display.	[19]
SI-1	Size	Responsive screen	The size of the interface should be changed according to the physical size of the display as it can be folded and unfolded or rolled and unrolled.	[6], [7]
SI-2		Size suitability	The display size should be presented in accordance with its purpose of use. If the purpose changes, the size should be modifiable by rolling or folding it.	[6]
SI-3		Contents arrangement for many users	If the display size becomes larger, it should be considered that the display is being shared by several users simultaneously and the arrangement (position, size, direction) of the contents should be modified accordingly.	[7]
SI-4		Multi-interaction application	Concerning the interaction methods, if the display size becomes larger no matter whether one hand or both hands are used, the touch input function should be applicable.	[20]
MU-1	Multi-Surface	The shape and number of the divided surfaces	The shape and number of divided surfaces depending on the bending shape, rolling shape, and folding shape should be considered.	[15], [8], [6]
MU-2		Division of functional role	It can provide different interfaces on each surface with different functions to work separately.	[15]
MU-3		Division of sequential role	It can provide different interfaces on multi- surfaces to work in a consecutive order.	[15]
MU-4		Division of hierarchical role	It can provide many hierarchically separated interface as menu and contents or main contents and sub-contents.	[18]
MU-5			Each surface is suitable for division of work; especially the smaller surface is suitable for summarized list.	[6]
MU-6		Separation and combination of the surfaces	The surface can be divided by folding or bending the display; it can also be combined and extended by unfolding and spreading out the divided surfaces.	[11]
MU-7			Through combining interaction by placing divided displays side by side, it can have physically extended surface.	[21]
TE-1	Texture	Visual and tactile texture	It can deliver the visual and tactile texture of the actual objects; the stretchable display can adjust the height of the surface.	[22]

TE-2		Feedback	By providing tactile feedback through three-dimensional variations, it can induce the user to carry out the exact action.	[23]
TR-1	Transparency	Overlapping	By overlapping the real world with a transparent display, it can provide the mixture of the meta-information on the screen and the information of the physical object in the background.	[24]
TR-2		Visibility	With higher visibility through the display, it is necessary to adjust the brightness of color and font size which affect the user's realization.	[25]

4. Design Case Studies

The guidelines developed in this research have been established applicable for various types of the flexible display design by organizing the form factors that are considered to be essential in the flexible display design. In order to verify the applicability of the developed design guidelines, two case studies were executed. In this research, the designs were mainly focused on the rollable and bendable display types.

4.1. Case Study 1 – Rollable Display Type

For this research, the scenario based design method[26][27] has been used to offer the appropriate interface for the detailed usage context in the given scenario. In this case study, the flexible display user experience scenario has been created to be used in the work environment in the near future. Through the preceding survey for this scenario, the situation where the device needs to be moved to outside of the office has been chosen and the problems and needs have been derived along with a suggestion of the product that can solve the problems. The suggested product is a rollable device which can be easily carried around; specifically, it is a digital device on which the architectural drawings can be seen. To design the interface that is needed in each situation, the guidelines developed earlier have been applied. The applied situations are as in TABLE 8 and the related images are in Figure 1.

Table 8. The Case Study Applying Guidelines for a Rollable Display Type

No.	Situation	
	Guideline	User Interface Design Applicaion
#01	Architectural designer (A) and Client (B) moves to the construction site with the design drawing device which is rolled.	
	SI-3	The design drawing device is a digital device that shows architectural drawings and it can be down-sized by rolling when moving.
#02	A searches for the one that he wants from many blueprint documents that are saved in the device.	
	FL-2	Using Bending gesture interaction: by holding the edge of the right side of the device (location) for a long pause (duration) and bend it backwards (direction), several blueprints appear as if the pages of a book are being flipped through. When the device is bent backward even deeper (degree), it scrolls through even faster.
#03	A and B look are the blueprint from the device on a table. A turns around the blueprint little so that B can have a better view of it.	
	FL-5	With a hand gesture as if turning a door knob above the device, the screen turns around so that the person

		in the opposite side can see it in the correct direction.
#04	At the construction site, they can only look at the half of the blueprint while standing.	
	SI-1	When the device is spread out only a little bit with one side is still rolled in, the size of the blueprint is adjusted into the appropriate size so that the whole blueprint is shown.
#05	A enlarges a part of the blueprint while explaining to B.	
	FL-2	When the device is bent twice (frequency), the screen enlarges itself. Depending on how long it is hold at the second time, the enlargement level can be chosen.
#06	A shows B the work schedule.	
	MU-4	The menu appears when the rolled part of the device on the left hand side is dragged down with a left thumb. When schedule icon is clicked, the schedule appears on the right hand side of the device.

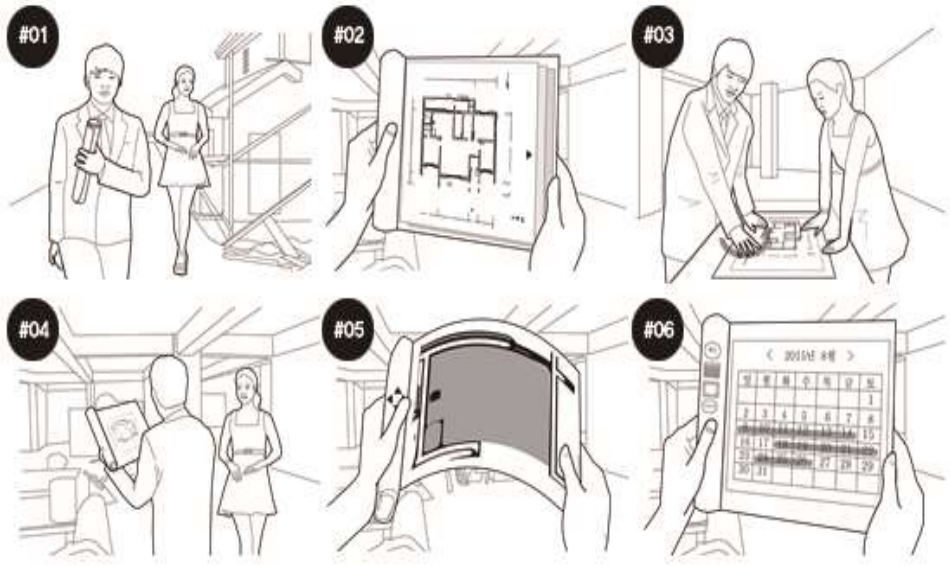

Figure 1. Images of the Usage Context and the Interface Design

4.2. Case Study 2 – Bendable Display Type

The designed product in this case study is a Bendable device which can be utilized in the educational environment in the near future. To be more specific, the device can be used as an admission ticket to public places and at the same time it can collect or edit information on it. The guidelines developed earlier have been applied to design the interface to make it appropriate for the field trip or cooperative learning context. The applied images are in the Figure 2 below.

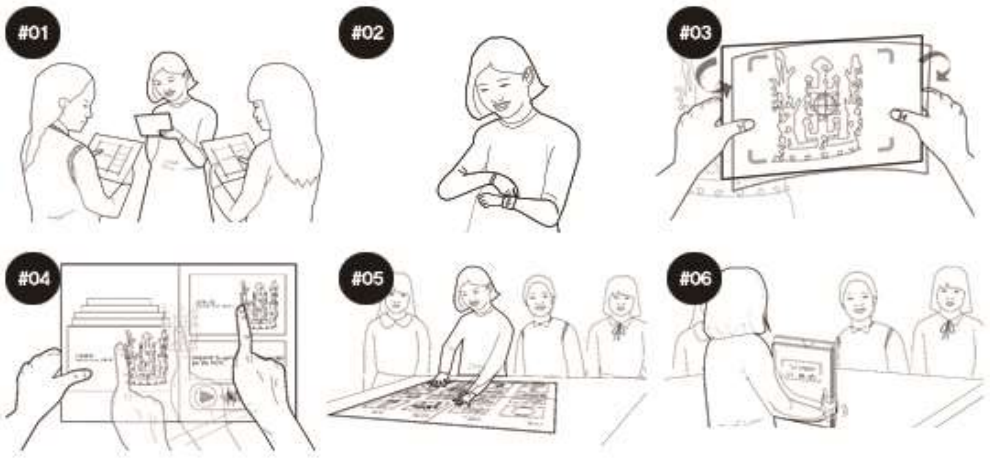

Figure 2. Images of the Usage Context and the Interface Design

5. Conclusion

In this research, the collected design considerations from 22 studies have been categorized, organized and integrated by the form factors - Flexibility, Shape, Size, Multi-Surface, Texture, and Transparency – to suggested design guidelines. Altogether 23 detailed types for six form factors have been categorized and 43 subordinate guidelines have been developed. Moreover, case studies have been executed in order to validate the applicability of these guidelines to various flexible display developments. The designers who participated in the case studies confirmed that the application of the developed design guidelines helped them define the design direction. It is also proved that these guidelines can be effectively utilized for various display types as demonstrated in the case study with the product on which the bendable and rollable display types are applied.

This research has been proceeded to help the designers' effective and proper decisions by offering guidelines for the flexible displays that have completely different physical characteristic from the existing flat display. The pre-existing studies have been integrated and systematized and the build-up base for the guidelines that can be applied with various types has been offered. The design considerations that are to be proposed by many different researchers in the future can be integrated in this guideline system. Through this, it is expected that these guidelines are to be expanded and developed with more elaborate contents and to be applied to a wider range of the design cases.

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