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The effects of screen size on rotating 3D contents using compound gestures on a mobile device

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ABSTRACT

The development of mobile devices nowadays shows an increasing trend toward interacting with 3D digital content on a 2D touch screen. However, many issues regarding the appropriateness of the control mode require further exploration. The experimental design in this study designates displays of two sizes—five inches and seven inches—with three groups of hand gestures controlling the *X*-, *Y*-, and *Z*-axis, respectively. The three groups of gestures are compared in terms of how they interact with the 3D content. In the experiment, 30 adult research subjects twice completed a task that involved rotating three 3D immersive-heritage models. Their characteristics, completion time, subjective evaluation, and frequency of gesture change were measured and examined. The results from the experiment and the statistics from a two-way Analysis of Variance (ANOVA) indicate: (1) the display size and the task-completion time are inversely related. Under the effect of the Control–Display ratio, using a smaller display results in a shorter completion time while using a larger display results in a longer completion time; (2) tasks with obvious characteristics for the 3D objects require a shorter time to complete, but those with no obvious characteristics require more time; and (3) using familiar hand gestures leads to a shorter task-completion time, while using unfamiliar hand gestures leads to a longer completion time. The findings of this study show that the Control–Display ratio is an important factor that affects the operational performance of the 3D immersive-heritage model's rotation tasks completed with hand gestures on small displays. In addition, adaptability and familiarity should be taken into consideration when introducing new hand gestures. Hence, the suggestions in this study constitute important guidelines for museums designing technology for the interaction between mobile devices and 3D immersive-heritage models.

1. Introduction

Given the richness of information in today's digital content, and the social educational responsibilities of museums and art galleries, the use of machines for reading and browsing is the best solution for insufficient manpower at the lowest cost. Due to the advancement and popularization of modern smartphones and other mobile devices, as well as multimedia technologies, research on the interaction of 3D objects in mobile communication has become a trend [1]. This is like creating an immersive interaction method on a virtual museum platform, which help the public understand and appreciate cultural heritage. Therefore, the interactive browsing content of museums can be expected to be closer to users [2]. As animation software matures, designers can produce a simulation of 3D objects with the relevant software. In such a case, interacting with artifacts without physical contact by using a mobile device is highly anticipated, and in-depth studies of 3D space display, gesture control, and natural interaction with 3D objects are of great importance [3].

The motivation for this study is to replace the mouse and keyboard—with which we have been accustomed for a long time as input tools—with touch control, because touch-control technology is becoming increasingly advanced and popular. Manipulating text and graphics with this technology is easier and more intuitive. However, when manipulating 3D objects on a 2D display, the restriction of the small screen size may cause disruptions when using touch gestures, resulting in frustration and a deterioration of the operational performance.

Thus, in consideration of the above-mentioned circumstances, this study aims to analyze the performance of manipulating

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3D-simulated artifacts on 2D displays of different sizes with hand gestures in an experimental design. In addition, a quantitative method is adopted to analyze the statistics, and suggestions are made to help designers improve the rotational touch gestures for controlling 3D immersive heritage.

2. Literature review

To facilitate natural and rapid communication between humans and machines with current touch-screen technology, we rely on the operational interface for touch gestures [4]. A touch gesture is defined as the act of touching the display while moving over the display's surface without losing contact before releasing. Windows Touch includes eight standard gestures, namely Panning, Press and tap, Press and hold, Select and drag, Rotation, Zoom in/out, Flicks & Two Finger tap. Standardized gestures reduce the difficulties in product development and allow users to have a more consistent experience.

Regarding the interaction between a mobile device and 3D immersive heritage mentioned in this study, consensus was reached based on studies of smartphone-users' touch gestures to establish classification standards and to compile a touch-gesture reference guide that can be referenced for future designs and explorations in touch-gesture technology [5]. In light of racial and cultural differences, the sample size should be enlarged such that the touch-gesture classification is more comprehensive, and customized touch gestures can be explored in the future to accommodate the demands of different tasks. Moreover, an increasing number of studies are available concerning interactive touch gestures for 3D objects. For instance, the introduction of a calibration program to deal with vertical or horizontal offsets returned by vertical or horizontal drag gestures when rotating 3D objects with touch gestures is recommended in order to meet user expectations. In addition, in the descriptions of a lasso or rotational-drag touch gesture, adding circular guiding lines to the outline of an object that correspond with the different rotating axes or adding control interfaces for switching different axial modes is recommended in order to address the difficulties in matching the axes from 2D touch gestures with 3D content [6]. However, the adaptability to small touch screens still requires further exploration. Dibber et al. developed a mobile 3D-gaming prototype based on the concept of using touch gestures to perform 3D-gaming motions on the 3D display of a handheld device [7]. However, more in-depth studies on 3D perceptual and navigational technologies are needed. Moreover, the games require testing with different display devices. This technology will be conducive to the interaction between mobile device and 3D artifacts. Liang et al. asked their research subjects to interact with 3D objects using hand gestures on handheld devices with bigger screens. They analyzed the gestures and the relevant issues with an experimental design and proposed recommendations that were later used as a reference for designing a hand-gesture interaction interface [8]. Because screens of only one size were used in the experiment, however, it is recommended that comparisons be drawn by introducing screens of different sizes in the future and with more than one operational object. The issues mentioned above should be included in the discussions of similar studies. Marco et al. made use of camera technology and large mobile devices to interact with 3D sculptures, and as a result they developed a network-based systems that was humanized, flexible, and expandable [9]. Considering the differences in the shapes and functions between heritage from the East and that from the West, the feasibility of sharing the same system calls for further investigation. This paper researches different areas targeting artifacts from the East. Nils et al. offered a 3D-interactive experience using 3D Web technology that was novel to users [10]. As a result, mobile devices such as smartphones and tablets together with Web applications facilitate interaction with 3D artifacts on 2D displays. Museums in particular can build databases of 3D immersive-heritage models using the Web, and such models are not bound by geography, time, or distance and can be browsed at any time. Vlad proposed highly efficient 3D-object interaction and portrait-rotation techniques for mobile devices [11]. However, their rotation techniques are still constrained by thumb occlusion, display size, specific functions, etc. When the degree of rotation increases for complex tasks, the effectiveness depreciates because users are more likely to suffer from fatigue. Apart from rotational interaction, other issues including the coordination of tasks such as dragging and zooming are yet to be resolved. Nonetheless, rotational tasks are indeed an important factor in the interaction with 3D immersive-heritage models, making rotational hand gestures a focus for research.

Discussions of related issues such as the display size and the Control–Display ratio are also available. An increase in information has led to an increase in the display sizes of smartphones and tablets. Yet, mobile devices remain limited. Cuong found that controlling the navigational system with the cursor and fingers on a touch screen is the solution to the problem of dragging on touch screens for users with large fingers [12]. Given the limited number of research subjects, more in-depth studies are needed. This issue reflects the diversity of digital content in museums, and there is vast room for development in areas outside heritage interaction, such as in the area of augmented reality. Two-mode target selection (TMTS) was proposed after conclusions were drawn from a study on improving the selection of small virtual targets on handheld touch screens. TMTS was compared with other solutions in terms of practicality, and attempts were made to raise the satisfaction levels of small-touch-screen users under specific target layouts [13]. Suggestions for the future included a further examination of gestures such as scroll and drag to ensure that the task command is easy to interpret. This should be helpful when selecting digital content displayed in museums. Device miniaturization and content enrichment exacerbate the problems of finger occlusion and imprecision in touch-control interaction. Ying proposed a technique that uses a dynamically sized finger probe for on-screen object selection and displays magnification with visualization scaling to solve the above-mentioned problems [14]. Assessments were made on only a single type of operational task, however, and it is hence recommended to include tasks that are more realistic. This may be the approach to solving the problems arising from increased digital content in museums and the constraints of the display size. Yong and Sung investigated the impact of touch-key size and location with one-handed thumb control as a mobile-phone input. Statistics concerning the practicality of touch-key locations were collected and analyzed to confirm the availability of desirable and usable locations [15]. The differences between races and sexes result in variations to the design of touch-key sizes and locations. For 3D heritage interaction, the touch-key locations are defined with a flagpole method, and tasks were presented in portrait form. After studying the results from mobile devices, Nils et al. discovered that text orientation, display size, and font size had an impact on the time required to perform a search. Among these factors, a larger display makes content easier to read [10]. Different approaches to studying the display size can be seen in the above-mentioned literature. The display size should be further discussed with regard to experimental designs in the future.

In recent years, studies on the coordination of hand gestures with 3D immersive heritage have been on the rise. In particular, the development of digital content for museums is a coming trend. In light of this situation, incorporating gesture recognition with such content development involves innovative techniques that facilitate user interaction in the 3D environment. Therefore, the