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Abstract. In 3D gesture interaction, people engage in contactless interaction with computers through arm and palm movements. The aim of this study was to develop and verify a reasonable evaluation scheme for 3D gesture usability through empirical methods and finally form an efficient, natural, and standard gesture library for 3D interaction. Two experiments were performed. In the first experiment, an evaluation scheme for 3D gestures with different weighted indexes of usability was developed, and then the ratings of the usability dimensions of 30 gestures within 10 operations in the 3D interaction were compared with one another. The purpose of this comparison was to summarize a set of 3D gestures with the highest usability. In the second experiment, the validity of the gesture set acquired in the first experiment was verified by comparing the usability differences between the high- and low-rated 3D gestures. An optimal set of 3D gestures was obtained by comparing the usability ratings of the different gestures and then verifying the superiority of the operation performance and users' satisfaction of this 3D gesture set in a real operation task.

Keywords: 3D gestures, Usability, Human–computer interaction.

1 Introduction

Gesture interaction has gradually become a meritorious mode owing to its natural and efficient attributes and to the maturation of recognition technology. Meanwhile, 3D gesture interaction, also called gesture somatosensory interaction, refers to a new way in which people engage in contactless interactions with computers through arm and palm movements (Pallotta, Bruegger, and Hirsbrunner 2007). In comparison with the 2D interactive mode, the current 3D gesture interaction mode is more adaptable and enables a more natural form of interaction with a machine. It can also reduce people's cognitive load because it is not limited to the form of hardware (Pantic et al. 2006).

Although new products or new recognition algorithms were used in previous studies for the design and evaluation of specific actions, most of them failed to include all the gestures that a platform may use. Considering the previous 3D gesture studies mentioned before, which mainly investigated the optimization of the gesture recognition algorithm or the usability for single or multiple gestures, it is necessary to use a reasonable multi-metric usability assessment method and obtain a set of gesture combinations with a high level of availability. Moreover, as the unified and effective evaluation criteria have not been formed yet, neither the specific index system of the evaluation of 3D gesture nor the weight of each index in the system is consistent. Thus, the existing standards or guidelines of 3D gesture design need to be improved to match the high requirement for human–machine interaction especially in complex tasks (Nielsen 2010).

The aim of this study was to develop and verify a reasonable evaluation scheme for 3D gesture usability through empirical methods and finally form an efficient, natural, and standard gesture library for 3D interaction. Two experiments were performed. In the first experiment, an evaluation scheme for 3D gestures with different weighted indexes of usability was developed, and 30 college students with minimal experience in using 3D interactive devices were recruited to rate the usability of 30 gestures within 10 operations by comparing with one another. The purpose of this comparison was to summarize a set of 3D gestures with the highest usability. In the second experiment, another 60 novices were recruited, and the validity of the gesture set acquired in the first experiment was verified by comparing the usability differences between the high- and low-rated 3D gestures. An optimal set of gestures was obtained by comparing the usability ratings of the different gestures and then verifying the superiority of the operation performance and users' satisfaction of this 3D gesture set in a real operation task.

2 Experiment 1

The aim of this experiment was to develop an optimal 3D gesture combination. The usability of 30 alternative gesture motions corresponding to 10 operations were compared with one another.

2.1 Method

Participants A total of 30 Chinese undergraduates (mean age = 22.4 years, SD = 1.2 years) participated in this study, who have minimal experience in using 3D interactive devices, such as Leap Motion or Xbox.

Experiment design A within-subject design with one independent variable was conducted. The independent variable was the gesture motion for various operations, and each operation included three corresponding gesture motions. The dependent variable was the usability evaluation of gestures, which included four aspects, namely, learnability, metaphor, memorability, and comfort (Table 1). We presented the experimental materials randomly to avoid the order effect that may influence learning, evaluation, and recall of different gestures.

Table 1. Evaluation indexes of 3D gesture usability.

Index	Explanation	Operational definition
Learnability	Whether the gesture is easy to learn or not	The number of practice attempt when the gesture motion is completed twice correctly
Metaphor	Whether the gesture is consistent with users' intuition and expectation or conform to users' cognition in daily life	The result of assigning the gesture to one operation
Memorability	Whether the gesture is easy to remember	Accuracy of recognition task
Comfort	Whether the gesture can be effortlessly completed	Grade of subjective comfort

Material and Procedure In order to determine the most frequently used gesture operations in 3D gesture interactions field, we first listed the gesture operations that exist on common 3D interactive devices (Leap Motion, Xbox and Kinect). Then, based on the 3D gesture interaction design principles proposed in previous studies, three expert users rated the listed gesture operations, considering their importance and frequency in actual use. Finally, the most typical 10 gesture operations and the most common three gesture motions for each operation were selected.

Experiment 1 consists of six tasks: evaluation task, learning task, practice task, gesture comfort rating task, recognition task, and index weight assignment task. All the materials for the tasks were presented with E-Prime in one Laptop except the material for the gesture motion practice task, which was presented with Leap Motion application in another Laptop. Fig. 1 shows the entire procedure of this experiment.

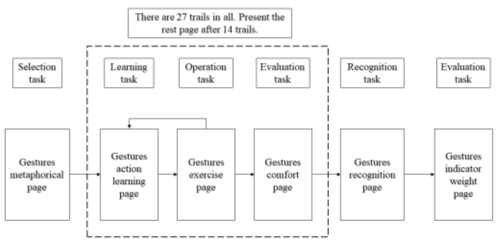

Fig. 1. Experiment 1: Schematic diagram of experimental procedures.

2.2 Results

Outliers outside three standard deviations were removed for each experimental treatment, and the sifted data accounted for 1.18% of the total data.

Considering that the data of memorability was enumerative, we performed chi-square tests to test the differences in memorability among the three schemes. Table 2 shows the results. We used one-way ANOVA to compare the three schemes with respect to learnability, comfort, and metaphor for each gesture task (Table 3).

Table 2. Results of chi-square tests for memorability.

Operation	Gesture 1		Gesture 2		Gesture 3		$\chi 2$
	True	False	True	False	True	False	
Left click	16	14	18	12	11	19	3.467
Right click	17	13	18	12	10	20	5.067
Page up/down	18	12	16	14	26	4	8.400*
Page left/right	25	5	25	5	26	4	0.180
Zoom	11	19	11	19	23	7	12.800**
Max/min	18	12	11	19	4	26	14.067**
Switch	27	3	29	1	1	29	70.048***
Volume control	25	5	8	22	20	10	21.020***
Double click	24	6	13	17	16	14	8.904*
Pause/start	17	13	23	7	29	1	13.260**

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

The analysis of the three gestures of *Page up/down*, *Zoom*, *Max/min*, *Switch*, *Volume control*, *Double click*, *Pause/start* showed significant differences in memorability, but no difference in memorability was observed among the three gestures of *Left click*, *Right click* and *Page left/right* ($p_s > 0.05$).

Table 3. Results of one-way ANOVA for learnability, comfort, and metaphor.

Operation	Gesture	Gesture evaluation dimension					
		Learnability		Comfort		Metaphor	
		Mean	D[a)]	Mean	D[a)]	Mean	D[a)]
Left click	1.1	.0676	A	.2945	B	-.6039	A
	1.2	-.2563	A	.4915	B	.9128	B
	1.3	1.8405	B	-1.1969	A	-.3006	A
	F	46.460***		35.988***		27.282***	
Right click	2.1	-.0858	A	.3508	B	-.5212	A
	2.2	.3404	A	.1820	B	.1682	B
	2.3	.3915	A	-.7466	A	-.3833	A
	F	2.124		14.289***		5.851**	
Page up/down	3.1	-.7166	A	.6041	B	.3888	A
	3.2	-.5290	A	.4915	B	.3613	A
	3.3	-.1369	B	-.9999	A	-.1075	A
	F	9.972***		37.162***		2.491	

Page left/right	4.1	-.4779	A	.6604	B	.4991	B
	4.2	-.5461	A	.7729	B	.9955	C
	4.3	.6813	B	-1.3657	A	-.5763	A
	F	29.882***		101.049***		37.418***	
Zoom	5.1	-.5461	A	.6322	B	.4716	B
	5.2	-.1710	A	-.0994	A	.4164	B
	5.3	.2040	B	-.2683	A	-.6867	A
	F	6.316**		10.630***		13.213***	
Max/min	6.1	-.3074	A	.7448	C	.6094	B
	6.2	.0506	A	.1257	B	-.4109	A
	6.3	-.1029	A	-.9436	A	-.4109	A
	F	1.363		32.373***		15.033***	
Switch	7.1	-.0347	A	-.0713	A	.6094	C
	7.2	1.2439	B	-.2683	A	.1131	B
	7.3	-.2904	A	.0131	A	-.7142	A
	F	23.986***		.780		23.916***	
Volume control	8.1	-.2733	B	-.4371	A	.6922	B
	8.2	-.6995	A	.4352	B	-.3833	A
	8.3	-.6995	A	.3508	B	-.2454	A
	F	11.641***		14.541***		13.090***	
Double click	9.1	.5109	B	.3227	A	1.0507	B
	9.2	-.2222	A	.5197	B	-.5212	A
	9.3	1.5507	C	-.9155	B	-.3833	A
	F	22.447***		28.787***		29.746***	
Pause/start	10.1	-.3927	A	.8011	C	.1958	B
	10.2	-.3756	A	.2101	B	-.6867	A
	10.3	-.0176	B	-.6904	A	-.5488	A
	F	4.043*		34.164***		11.402***	

Note: D[a)], Duncan's multiple range test

The three gestures of each operation all presented significant differences in learnability ($p_s < 0.05$), comfort ($p_s < 0.001$), and metaphor ($p_s < 0.01$) except *Max/min*, *Right click* in learnability ($p_s > 0.05$), *Switch* in comfort ($p > 0.05$) and *Page up/down* in metaphor ($p > 0.05$).

Table 4 shows 10 optimal gesture designing schemes (the highest overall score of the three gestures of each operation).

Table 4. Gesture illustration and schematic of 10 optimal 3D gestures.

Task	Action description	Schematic
Left click	Open your palm, click downward with your index finger lightly	
Right click	Open your palm and turn it; bend your index finger, and then reverse it slowly	
Page up/down	Spread out your fingers, point upward to turn pages up, and point downward to turn pages down	

Page left/right	Slide your five fingers left and right	
Zoom	Extend five fingers to the screen (zoom in); shrink out five fingers off the screen (zoom out)	
Max/min	Open hand up /create a fist	
Switch	Turn the palm up and move upward	
Volume control	Point to the sound equipment, summon the menu, and move up or down to adjust	
Double click	Click twice with a single finger	
Pause/start	Supinate	

3 Experiment 2

The aim of this experiment was to verify the effectiveness and subjective satisfaction of gesture combinations developed in Experiment 1 in different operation tasks. The gesture combinations were compared with one another.

3.1 Method

Participants A total of 60 Chinese undergraduates (mean age = 22.1 years, SD = 1.4 years) participated in this study, who have minimal experience in using 3D interactive devices, such as Leap Motion or Xbox.

Experiment design A between-subject design with one independent variable was conducted. The independent variable is the grade of gesture combination: high- and low-rated groups. The high-rated gesture combination was developed by the 10 optimal gesture motions that had been verified in Experiment 1. The low-rated gesture combination was composited by 10 gesture motions that were randomly selected from one of the other two gesture motions of each operation.

Material and Procedure A The material and procedure of Experiment 2 was simplified in comparison with Experiment 2. In this experiment, we developed only three sets of materials (gesture learning materials, gesture task program materials, and gesture subjective satisfaction rating materials) for three corresponding tasks (gesture learning, gesture operation, and subjective satisfaction rating). Gesture learning material and task were identical to those in Experiment 1.

Five simulated operation tasks that may be encountered in real-life context were designed. Each operation task required four gesture operations to complete and must be performed twice in each operation task. The participants were instructed to use the gestures recently learned to perform the actual operation in accordance with the requirements of actual situations. The time of accurately completing an operation task was recorded.

3.2 Results

Outliers outside three standard deviations were removed for each experimental treatment, and the sifted data accounted for 1.52% of the total data. Table 5 shows the descriptive data and the results of comparing two groups.

Table 5. Operating performance and subjective satisfaction of high- and low-grade gestures.

	Operating performance			Subjective satisfaction score		
Task	High grade group	Low grade group	t	High grade group	High grade group	t
1	20.28±4.48	21.11±4.90	2.291*	4.46±1.04	3.81±0.92	2.541*
2	26.50±4.96	27.82±4.70	2.615*	4.07±0.96	3.13±0.92	3.831***
3	20.55±4.97	22.16±4.45	2.912**	4.15±0.93	4.09±0.95	0.241
4	32.95±6.42	35.54±7.31	2.536*	3.59±0.78	3.11±0.70	2.435*
5	25.85±5.92	27.99±5.65	2.723**	3.93±0.71	3.27±0.80	3.307**

The high-rated group performed significantly better than the low-rated group among all five operation tasks: Task 1, $t_{(58)} = 2.291$, $p < 0.05$; Task 2, $t_{(58)} = 2.615$, $p < 0.05$; Task 3, $t_{(58)} = 2.912$, $p < 0.01$; Task 4, $t_{(58)} = 2.536$, $p < 0.05$; and Task 5, $t_{(58)} = 2.723$, $p < 0.01$.

For the subjective satisfaction, the high-rated group performed significantly better than the low-rated group in the four tasks (Task 1, $t_{(58)} = 2.541$, $p < 0.05$; Task 2, $t_{(58)} = 3.831$, $p < 0.001$; Task 4, $t_{(58)} = 2.435$, $p < 0.05$; and Task 5, $t_{(58)} = 3.307$, $p < 0.01$), except Task 3 ($t_{(58)} = 0.241$, $p = 0.810$).

These results suggest that the optimal gesture combinations that were developed in Experiment 1 indeed show operational advantage to cope with simulated operation scenarios.

4 Discussion

Basing on previous studies and questionnaire surveys, we presented a comprehensive evaluation system, which included learnability, metaphor, comfort, and memorability as indicators with different weights for the 3D gesture design. In accordance with this comprehensive evaluation system, we conducted an optimal set of 3D gestures by comparing the usability of the different gestures and then verified the superiority of the operation performance and users' satisfaction of this 3D gesture set via a simulated operation task.

This study partially solves the lack of existing 3D gesture design proposed by (Norman, 2010). First, the 3D gesture motions suggested by our study is natural and can be easily learned and memorized and also with a high level of availability. Second, high-rated gesture combinations suggested by our study had been proven to be effective in terms of usability and user satisfaction in complex operations.

This study had the following limitations and prospects. The usability data of all gestures proposed in this experiment were collected from college students. Given that gesture movements are affected by physiological and psychological factors, people with different ages and cultures may have different attitudes toward each gesture. In the future, exploring the preference differences on 3D gesture interaction among different age and cultural groups is necessary. Previous studies have suggested that as a result of the deterioration of the mobility of the elderly or the lack of athletic ability of some disabled people, 3D gesture interaction without actual touching is suitable for these special groups (Kobayashi, et al., 2011; Leonardi, et al., 2010; Murata & Iwase, 2005). Moreover, using neurophysiological indicators, such as electroencephalogram or myoelectricity, may offer new insights into the design and usability test of 3D gestures.

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