Subjective Evaluation Of A Force Feedback Subsystem

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Abstract— **This paper discusses a subjective evaluation on different visual/tactual feedback modes for a virtual object manipulation task known the VisiTact system. The task consists of grasping an object, placing it against a vertical surface, sliding it over the surface and inserting it into a horizontal hole. The main objective is to determine the number and order of trials required for any further study, and to determine the number of participants needed for such advanced study. The study recommended that any further study should consider no less than four trial repetitions for each task. Additionally, any further research on the VisiTact should employ at least thirteen subjects to ensure that the results are adequate for such contact type tasks. However, the order, or randomisation, in which each of the modes is executed, was thought not to be important. It was assumed that the real task would yield a superior performance over all other modes, and that the participant's performance will degrade as the user's level of presence decreases.**

Keywords—Force feedback, Subjective evaluation.

I. INTRODUCTION

A wide range of VR, touch/force feedback, and AR systems have been successfully developed and have been incorporated into the human-computer interaction model. Most of them, however, have one major drawback, which is related to the nature of interaction, i.e. the user must be attached to a device at all time [1]. This continuous contact between the user and the device's stylus (or thimble) damages the user's sense of presence as it prevents the user from experiencing new tactile sensations upon contact with the virtual objects [2].

The Phantom device, for example, uses a stylus or thimble to provide the reactive forces to the user's finger when touching or moving over a surface. These forces can only be applied to fingers [3]. The Cybergrasp, on the other hand, provides haptic interface for the entire hand but there is nothing to stop the hand passing through a virtual object, besides, no feedback of inertial forces as the object moves [4]. Another example of continuous interaction device is the exoskeleton. Although it provides force feedback to the fingers, hand and elements of the arm and wrist, it still hinders the user from having new tactile sensations when contact with virtual objects takes place [5] . There have been some attempts to overcome such problems but these attempts are either complex or else limited to a small workspace [6].

II. THE HAPTIC SUBSYSTEM

An extensive work on, touch/force feedback, and AR systems have been successfully developed and have been incorporated into the human-computer interaction model. Non the less there is a major disadvantage, concerning the nature of interaction, i.e. the user must be attached to a device at all time. The VisiTact system, allows some combinations of immersed or desktop vision feedback devices to be integrated with a three degree-of-freedom force-feedback device previously known as the 'Reactabot'[5]. The devices is a haptic display robot that provides and receives kinaesthetic information from the user, who can touch and manipulate a surrogate object, and feel external forces exerted upon it by obstructions, within a virtual environment. The mechanical interface senses the forces applied by the user and the haptic control system generates a reaction force that moves the surrogate object in the direction of the applied force [3].

The device provides force feedback over a large proportion of the user's workspace and enables virtual objects to take on user-specified physical properties such as mass, gravity, weight and drag, and was implemented with force/velocity control to allow the robot to interact with an operator, and to share the same working volume. The 'VisiTact' system is divided into two major subsystems: the haptic/tactile subsystem and the visual subsystem. The primary objectives of the study were:

1. To determine the number and order of trials required for any advanced study.
2. To determine the number of participants needed for future study.

III. THE STUDY DESIGN

The design of the study was in consultation with statisticians from the Industrial Statistical Research Unit (ISRU), and the School of Mathematics and Statistics (MAST) from the University of Newcastle upon Tyne. Other relevant sources of information on the design of experiments have also been studied.

McGeeney (ISRU) outlined the importance of undertaking a experimental study, to assist in the formulation of any advanced study . Several well-documented and recognised

methods for designing experiments, including both the Latin Square and Factorial Design methodologies, were discussed at length. Additional discussions with Fawcett (MAST) again endorsed the significance of a study through which the number of participants, the number of trials and the order of the tasks to be determined for the main study [7].

A Latin Square design methodology was selected and used to formulate the basis of the design of more advanced study experimental programme. Gender was not considered in this study and accordingly 4 male participants, aged between 20 and 40 years, were employed for the study tests.

a) Test Sequence Order and Design

Similar studies have identified the need for each participant to undergo some form of equipment and task familiarisation before beginning the trials, [8 and 9]. The EDGER calculator was used to generate a balanced Latin Square design to determine the order of the task setup [10]. Each participant was required to undertake four trials for each of the four modes, and the assignment and order of the tasks was randomized, according to the schedule in table 1.

TABLE I. THE STUDY TASK SEQUENCE

		Participants															
		S_1				S_2				S_3				S_4			
	Trials	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4
Order	O_1	C_{11}	C_{12}	C_{13}	C_{14}	A_{11}	A_{12}	A_{13}	A_{14}	B_{11}	B_{12}	B_{13}	B_{14}	D_{11}	D_{12}	D_{13}	D_{14}
	O_2	A_{21}	A_{22}	A_{23}	A_{24}	C_{21}	C_{22}	C_{23}	C_{24}	D_{21}	D_{22}	D_{23}	D_{24}	B_{21}	B_{22}	B_{23}	B_{24}
	O_3	B_{31}	B_{32}	B_{33}	B_{34}	D_{31}	D_{32}	D_{33}	D_{34}	A_{31}	A_{32}	A_{33}	A_{34}	C_{31}	C_{32}	C_{33}	C_{34}
	O_4	D_{41}	D_{42}	D_{42}	D_{44}	B_{41}	B_{42}	B_{42}	B_{44}	C_{41}	C_{42}	C_{42}	C_{44}	A_{41}	A_{42}	A_{42}	A_{44}

Key to table 1

A – Real mode (previously designated R)

B – Fully Immersed Augmented Reality mode (FIAR)

C – Fully Immersed Virtual Reality mode (FIVR)

D – Partially Immersed Virtual Reality mode (PIVR)

T_i = the ith trial.

O_j = the j^{th} task order.

S_k = the k^{th} subject.

The sequence that each participant subscribed to, in undertaking the tests, is best illustrated using a flow-diagram, as shown in figure 1.

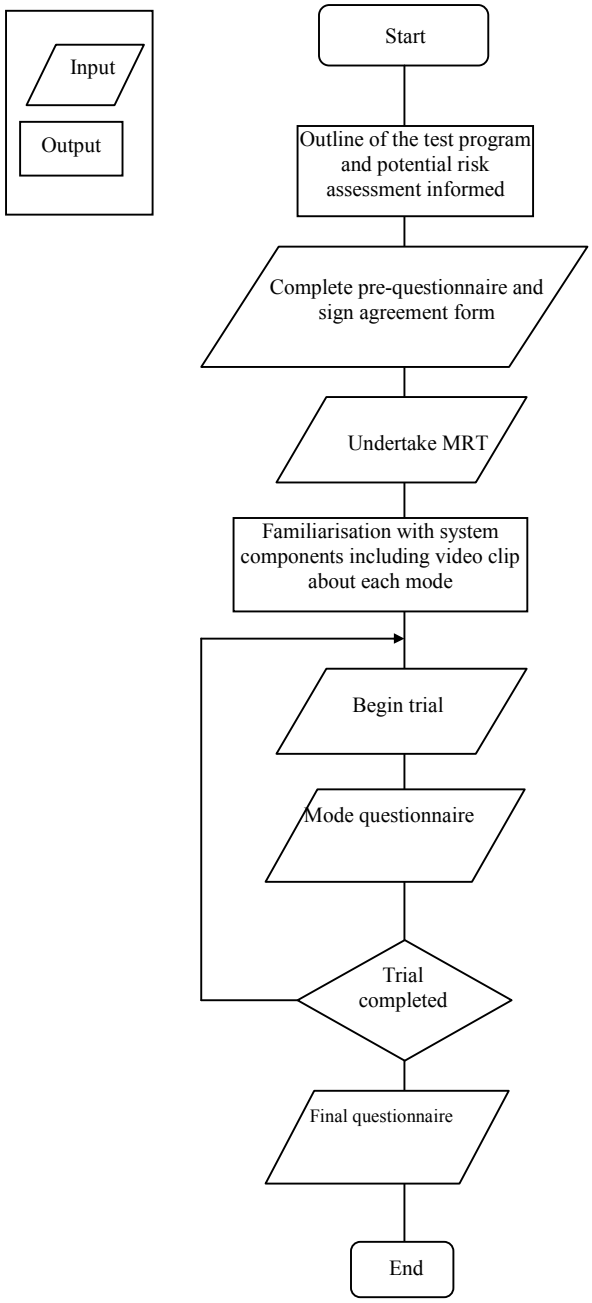

Figure 1. Test Sequence

Table 2 provides an estimate of the time taken for each of the participants to complete the preliminary evaluation and all tests.

TABLE II. TIME ESTIMATE FOR THE STUDY (IN MINUTES)

No.	Event	Estimated time (minutes)
1	Preliminary questionnaire	2
2	MRT	3
4	Familiarization with equipment	5
5	Briefing	1
6	4 tests plus 4 mode related questionnaire	4x2+4x1=12 (max)
7	Post-tests questionnaire	4
8	Total	27

b) Subjective Assessment Measures

All participants were required to undertake a series of questionnaires at key stages of the test programme. The subjective assessment was extracted from the questionnaires to include the ease and accuracy by which the tasks were performed; the quality of the virtual environment through comparison with the real condition with the visual and haptic feedback, and the preferred VR solution.

A preliminary questionnaire was given to each of the participants in order to establish their general knowledge of computers, and their experience of VEs with visual/force feedback systems.

In terms of the participant's age, it has previously been reported that differences in performance were evident, especially for those aged over 55 when tested on new technologies [9]. The visual and physical impairment questions were concerned with the participant's health.

The question about hand dexterity is to discriminate, though not to screen out, participants since the test is valid for both right and left handed subjects, provided they use only one hand. The level of computer experience and virtual environment, including experience with computer games might affect the task performance [8]. Also experimenting with VR as well as force feedback related equipment could influence the learning curve of participants, especially if they were used recently.

Each of the subjects were given the opportunity to get familiarised with the equipment and allowed to practice as many times as they wished prior to beginning the tests. They were also instructed to abandon the session at any time if they felt uncomfortable. In these cases the results were discarded and the experiment repeated. Before the test begins, however, each participant was asked to agree to the following:

- Performing the tasks to the best of their capabilities.
- Providing honest answers to all questions asked.
- Providing honest answer to feedback questions.

At the end of each session, each participant completed a questionnaire giving their subjective opinion of each mode. The first mode related question tries to establish whether the participant experiences any difficulty when interacting with equipment. Another question attempts to establish whether there is a correlation between determining number of trials (based on each test result) and participant opinion towards the number of repetitions, and furthermore to determine whether the participant has some difficulty in the task (or in one part of the task) .

At the end of the test, subjects were asked a series of open-ended questions related to comparing the different modes, and to establish their 'preferred' mode; it was considered that this rating may be of value in subsequent task design. There were specific, yet important, rules against which the participants performed the tests as well as possible, including:

- Only one hand is allowed to dexterously grasp an object, using three fingers and thumb to help during the insertion phase.
- Twisting or turning the object upside down is not allowed.
- The participant's elbow was not allowed to rest during the time from grasping the object to releasing it.

The health of the participant is duly considered, as he or she might experience motion-sickness whilst carrying out a task, and it was accepted that a small proportion of the participants are likely to be susceptible to simulation sickness, or more precisely motion sickness. This is most likely to occur when the participants are wearing the HMD. Possible symptoms include headache, nausea and in some cases vomiting.

To reduce the likelihood of this, the task has been kept simple which helps to minimize the VE exposure time. The participants were required to read the operating instructions and safety sheet before beginning the task. The data from the study was kept confidential and stored anonymously by reference number. The arrangement for encoding and storage of data was explained to each participant prior to testing, and analyzed using SPSS to obtain frequency tables and percentages.

IV. RESULTS

Since all participants completed all questions, the response rate was 100%. The SPSS results, detailed in , shows that all participants were under 40 years of age (mean =30.5, standard deviation =3.5), and that up to 75% had a good knowledge of using computers.

All of the respondents were students, right handed, with no physical/visual problems. Furthermore, the majority of participants (3 out of 4) had some experience in the past with desktop-based games, using joysticks. Table 3 summarises the results from the preliminary questionnaire.

TABLE III. PARTICIPANT DETAILS FROM PRELIMINARY QUESTIONNAIRE

		Frequency	Percent	Cumulative Percent
Age	Between 21and 30	2	50.0	50.0
	Between 31 and 40	2	50.0	100.0
Major	Student	4	100	100
	Staff	0	0	100
Vision Related Problems	Yes	0	0	0
	No	4	100.0	100.0
Physical Problems	Yes	0	0	0
	No	4	100.0	100.0
Dexterous Hand	Right	4	100	100
	Left	0	0	0
Experience With VE	Yes	3	75	75
	No	1	25	100.0
Experience With force feedback systems	Yes	3	75	75
	No	1	25	100.0

As expected, for the real task, 75% of the participants found it was easy to interact with. Furthermore, all of the respondents have agreed that four attempts should have been enough to perform the contact-type task. The majority of participants accomplished that task successfully; hence all favoured this mode, though the mode was not exciting for them according to their comments. Table 4 summarises the participants' feedback on the real task.

TABLE IV. PARTICIPANTS FEEDBACK ON THE REAL MODE (R)

		Frequency	Percent	Cumulative Percent
Interaction with the real mode	Fairly easy	1	25.0	25.0
	Too easy	3	75.0	100.0
Four attempts were enough	Strongly agree	4	100.0	100.0
How well you accomplished the task	Well	3	75.0	75.0
	Very well	1	25.0	100.0
Overall reaction	Good	2	50.0	50.0
	Excellent	2	50.0	100.0

As far as the use of VisiTact with augmented reality is concerned, all of the participants found it at least fairly easy to interact with the augmented scene, and they all thought that it was not that difficult in learning to use the system, even though most of them have agreed that the augmented reality scene was realistic, and had done at least quite well with the four attempts. This mode in particular was preferred by all of the subjects. Table 5 summarises the participants' feedback on mode FIAR.

TABLE V. PARTICIPANTS FEEDBACK WITH THE IMMERSED AUGMENTED REALITY MODE (FIAR)

		Frequency	Percent	Cumulative Percent
Interaction with the surrogate object and HMD	Fairly easy	2	50.0	50.0
	Easy	2	50.0	100.0
Learning to use the system	Not bad	2	50.0	50.0
	Fine	1	25.0	75.0
	Too easy	1	25.0	100.0
The appearance of the simulated world	Quite realistic	1	25.0	25.0
	Realistic	3	75.0	100.0
Four attempts were enough for this mode	Quite agree	1	25.0	25.0
	Agree	1	25.0	50.0
	Strongly agree	2	50.0	100.0
How well you accomplished the task	Quite well	3	75.0	75.0
	Well	1	25.0	25.0
Overall reaction	Good	4	100.0	100.0

Concerning the VisiTact and the fully immersed FIVR mode (i.e. using HMD) each subject described a certain level of interaction. Those difference reactions were reflected on how participants completed the test and on their decisions to whether prefer this mode or not. Nonetheless the majority still agreed on four attempts as being a sufficient number to conduct the test. A summary of the participant's feedback is in table 6.

TABLE VI. PARTICIPANTS FEEDBACK ON THE VIRTUAL IMMERSED MODE (FIVR)

		Frequency	Percent	Cumulative Percent
Interaction with the surrogate object and HMD	Fairly easy	2	50.0	50.0
	Easy	2	50.0	100.0
Learning to use the system	Not bad	2	50.0	50.0
	Fine	1	25.0	75.0
	Too easy	1	25.0	100.0
The appearance of the simulated world	Quite realistic	1	25.0	25.0
	Realistic	3	75.0	100.0
Four attempts were enough for this mode	Quite agree	1	25.0	25.0
	Agree	1	25.0	50.0
	Strongly agree	2	50.0	100.0
How well you accomplished the task	Quite well	3	75.0	75.0
	Well	1	25.0	25.0
Overall reaction	Fair	1	25.0	25.0
	Average	1	25.0	50.0
	Good		50.0	100

In terms of the mode with the use of VisiTact and desktop, two subjects managed to interact with the system too easily according to the SPSS analysis and similarly they thought that

four repetitions would be enough. In terms of the task completion 3 subjects thought that they did well and preferred this mode, as shown in table 7.

TABLE VII. PARTICIPANTS FEEDBACK USING THE HAPTIC FEEDBACK AND DESKTOP DISPLAY (MODE PIVR)

		Frequency	Percent	Cumulative Percent
Interaction with the block, desktop and VR	Fairly easy	1	25.0	25.0
	Easy	1	25.0	50.0
	Too easy	2	50.0	100.0
Four attempts were enough	Agree	3	75.0	75.0
	Strongly agree	1	25.0	100.0
Learning to use the system	Not bad	2	50.0	50.0
	Fine	2	25.0	100.0
How well you accomplished the task	Rather well	1	25.0	25.0
	Well	2	50.0	75.0
	Very well	1	25.0	100.0
Overall reaction	Good	3	75.0	75.0
	Excellent	1	25.0	100.0

With regard to the open ended questions, all subjects preferred the Augmented Reality mode (FIAR), and all agreed that it would be the best choice for any further studies. Table 8 summarises the participants' preference towards each mode.

TABLE VIII. PARTICIPANTS PREFERENCE FEEDBACK TO ALL MODES

		Frequency	Percent	Cumulative Percent
Mode R	Like it	1	25.0	25.0
	Don't like it	3	75.0	100.0
Mode PIVR	It is fine	4	100.0	100.0
Mode FIVR	Like it	4	100.0	100.0
Mode FIAR	The best	4	100.0	100.0
Do you think that mode R is helpful towards further studies	Agree	1	25.0	25.0
	Totally disagree	3	75.0	100.0
Do you think that mode FIAR is helpful towards further studies	Disagree	4	100	100
Do you think that mode FIVR is helpful towards further studies	Agree	3	75.0	75.0
	Totally disagree	1	25.0	100.0
Do you think that mode PIVR helpful towards further studies	Totally Agree	4	100	100

CONCLUSIONS

Most of the participants (75%) interacted well with all of the VisiTact modes owing to its spacious working volume, unrestricted grasping of the surrogate object, the simplicity of the task design, as well as finding the virtual environment relatively realistic. Hence all of participants felt that they accomplished the set tasks well.

Three quarters of the participants felt that the introduction of the augmented hand within the virtual environment improved the presence, which suggests that the augmented reality interface has assisted the user and improved the task performance. However most of participants found it difficult to interact with the purely virtual environment.

DISCUSSION OF RESULTS

- Any advanced study should consider no less than 4 trial repetitions for each task.
- From the power analysis methods, the future study should employ at least 13 subjects to ensure that the results are adequate for such contact type tasks.
- Based on the study, the order, or randomisation, in which each of the modes is executed, was deemed not to be significant. However for continuity and completeness, the study was conducted using the EDGER calculator to generate the Latin Square design for randomising the sequence of the tests.
- Based on the conclusions of the future study, the combination of haptics and a fully immersive environment is seen to offer some improvement in task performance as compared to a partially immersed setup, and can be interpreted in that the availability of haptics and that the level of presence does influence performance in undertaking contact type tasks.

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