Evaluation Of A Kinaesthetic Feedback System

Abdouslam M. Bashir
Higher Institute of Industrial Technology,
Tripoli-Libya
bash74 {at} hotmail.com

Abstract—**This This paper discusses a study carried out on different visual/tactual feedback modes for a novel virtual object manipulation task was undertaken to evaluate the VisiTact system and assess the influence of haptic, visual and augmented feedback on a conventional assembly task. 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 study was conducted with two objectives in mind: to determine the number and order of trials required for any further study, and to determine the number of participants needed for the advanced study. A Mental Rotation Test (MRT) was used in the study. The study recommended that any further study should consider no less than four trial repetitions for each task. Additionally, any extra 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 deemed not to be significant. It was hypothesized 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- Kinaesthetic feedback system, Mental Rotation Test.

I. INTRODUCTION

The importance of making the visual images as realistic as possible has been emphasized, so that the users are comfortable in this abstract world, however, these images allow objects to be seen but not felt. This object recognition process can be further enhanced by providing a direct or indirect means of interaction, as most of human tasks involve not just a visual representation of the surroundings but also touching and manipulating.

An increased level of research is being directed towards developing techniques that give users the ability to interact with a virtual environment in a natural and realistic manner. Virtual reality technology has provided several approaches to visualise and interact with virtual objects by allowing them to be reached, grasped, and carried [1]. Significantly, it has also been established that when the user is also allowed to touch and feel rigid objects, their performance is markedly improved by about 50% [2].

Aaron et al [3] combined feedback from multiple sensory modalities to enhances brain–machine interface control, in which significant improvement in the performance of paralyzed patients was shown particularly when visual and proprioceptive feedback were matched. Williams et al [4] focused their studies on image registration. As a human vision system is very sensitive to visual error; which may result to that the virtual scene appears either unstable or positioned incorrectly. However, human skills during task performance may influence the kinesthetic feedback when linked with visually-directed action [5].

The focus of this study is on a device that allows several combinations of immersed or desktop vision feedback devices to be integrated with a three degree-of-freedom force-feedback device previously known as the 'VisiTact [6] and currently known as the ' Visitact' . The Visitact 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. In essence, the Visitact [7] allows a combination of various immersed or desktop visual solutions to be integrated with a three degree-of-freedom force-feedback device.

II. SYSTEM EVALUATION

The VisiTact is designed to detect collisions when the virtual object contacts another static or movable virtual object. The forces exerted between two bodies in contact with each other, are easily modelled in terms of the normal and friction force components when there is a relative motion between them. A simple test was performed in which a 1kg aluminium block was slid across a physical surface. The equivalent virtual test was conducted using the VisiTact with the control algorithm set up to match the attributes of the physical system, including gravitational, inertial and frictional (static as well as dynamic) forces. An integral part of the VisiTact performance evaluation involved a careful assessment of the human factors issues [8]. The following section describes the design and execution of a study, which was carried out to determine the extents of any advanced.

III. THE STUDY DESIGN

The design of the study was based largely on discussions with statisticians from the Industrial Statistical Research Unit (ISRU), and the School of Mathematics and Statistics (MAST) at the University of Newcastle upon Tyne. McGeeney (ISRU) outlined the importance of undertaking a study, to assist in the formulation of the advanced study [9]. 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 future study [10].

During the course of their involvement in the test programme, each of the participants were subjected to different kind of visual cues and different levels of immersion, and accordingly it was considered that their visual and spatial ability be subjectively evaluated, prior to undertaking the test programme. There are several techniques to test human' spatial ability, among which are Guilford-Zimmerman Orientation Test and Mental Rotation Test (MRT).

The Guilford-Zimmerman Orientation Test is used as an indicator of three different experimental conditions with respect to spatial ability [11], while the MRT assesses how quickly and accurately a person can rotate a two [12] or three-dimensional object. In this study, the participants' spatial abilities were recorded and evaluated using a Mental Rotational Test based on that of Crawford and Christensen [13]. The Latin Square design methodology was subsequently 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, [11 and 14]. The EDGER calculator was used to generate a balanced Latin Square design to determine the order of the task setup, [15]. 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. The sequence terminology of the task is briefly noted as follows:

- 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 jth task order.
- S_k = the kth subject.

Each participant was required to carry out a Mental Rotation Test (MRT), adopted from Crawford and Christensen [13], to measure their ability for visual thinking. Fig 1 illustrates an example of one of the MRT questions.

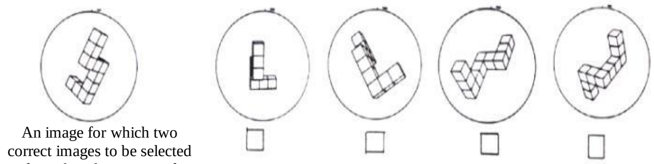

Figure 1. on set of the MRT questions

Having completed the MRT, each participant was given instruction and shown a short video sequence of each mode of operation. Other studies have used maps and tours to help participants to become familiarised with the related task, [11]. Furthermore, 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.

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.

The MRT was evaluated using the participant's mean completion time to establish whether there is any correlation between their participant's spatial awareness and the time taken to complete the test. Completion time was also used to measure the participants performance for the block in hole task. In this instance completion time is the time taken for the participant to grasp the object, to the time it is released on successful insertion.

IV. RESULTS OF THE STUDY

The MRT data sheet comprised several questions, and for each question there were four possible answers, of which only two were correct; the probability is that random responses would have given a 50% chance of being correct (2 out of 4). For each subject guessing, half of the numbers that were wrong were then subtracted from the correct answers [13]. The Pearson correlation analysis of MRT test showed little correlation between the participant's scores and time to complete the MRT (the correlation coefficient is only 0.008).

Fig 2 shows a scatter diagram of the completion time of the test versus the corresponding MRT score in percentage.

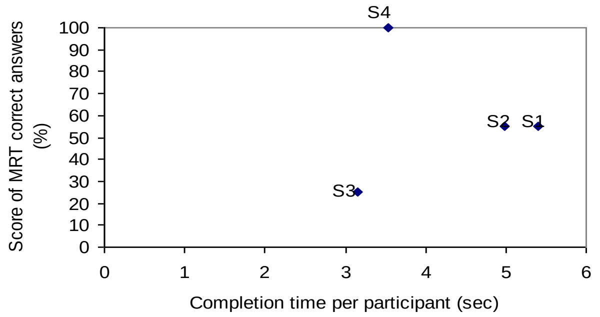

Figure 2. Relationship between MRT and completion time

As mentioned earlier, the task completion time will be measured for every subject with them repeating each task four times, summarised in table 1 (including the corresponding standard deviation).

TABLE I. TABLE OF TASK COMPLETION TIME (SECONDS)

Order	T1	T2	T3	T4
	Subject S1			
C	6.85	6.05	5.25	4.74
A	5.55	5.45	4.92	4.94
B	6.08	5.85	4.85	5.45
D	5.61	5.47	4.96	4.49
Mean	6.02	5.71	5.00	4.91
STD	0.60	0.29	0.18	0.41
	Subject S2			
Order	T1	T2	T3	T4
A	5.35	4.75	4.24	3.90
C	5.66	5.22	5.05	4.35
D	5.61	5.18	4.97	4.08
B	4.85	5.92	4.96	5.75
Mean	5.36	5.27	4.81	4.52
STD	0.84	0.48	0.38	0.84
	Subject S3			
Order	T1	T2	T3	T4
B	4.36	3.80	3.35	3.69
D	3.25	2.95	2.92	2.89
A	2.93	2.92	2.91	2.50
C	3.20	3.05	2.87	2.79
Mean	3.44	3.18	3.01	2.97
STD	0.63	0.42	0.23	0.51
	Subject S4			
Order	T1	T2	T3	T4
D	3.25	2.77	2.97	3.09
B	5.27	4.57	4.07	4.56
C	4.09	3.09	2.99	3.03
A	3.97	3.04	2.96	2.66
Mean	4.15	3.37	3.25	3.34
STD	0.84	0.81	0.55	0.84

The results from the MRT indicated that the spatial awareness of the participants and their performance with the virtual environment were less strongly and positively correlated. It was postulated that the spatial ability of a subject might affect their performance completion time.

That was not the case with the four participants. In other words, the Pearson correlation method showed that there was a poor correlation between the correct answers per subject and the task completion time. Furthermore, the method demonstrated that the subjects who performed the task in a shorter time would not necessarily score the highest number of correct answers in the MRT.

In order to determine the number of trials for any advanced study, the mean time and standard deviations from table 3 were used. Fig 3 shows the mean completion time versus trial number, and it can be noted that with the orders O1, O2 and O4 there were significant differences in the mean completion time.

A paired t-test comparison (one tailed) indicated that in the first order there was a difference between trial 2 and 3 ($\mu 2 = 5.70$, $\mu 3 = 4.99$; $t(2,3) = 6.06$, $p = 0.004$), in the second order the t-test also showed that there was a significant difference between the trial 2 and 3 ($\mu 2 = 5.26$, $\mu 3 = 4.80$; $t(2,3) = 2.53$, $p = 0.04$). The t-test also proved that there was a significant difference between trial 1 and 2 in the fourth order ($\mu 1 = 4.14$, $\mu 2 = 3.36$; $t(1,2) = 6.58$, $p = 0.003$). After the third trial no significant difference in the mean completion time was recorded.

A one-way ANOVA method, followed by Tukey's HSD post-hoc test [16] were used to determine whether there is a significant difference in the test order. There was no significant difference in the first and second orders ($F(3,12) = 0.82$, $p = 0.5$, and $F(3,12) = 1.27$, $p = 0.3$), whilst the third and forth orders showed a significant difference among the 4 modes ($F(3,12) = 11$, $p = 0.001$, and $F(3,12) = 9.86$, $p = 0.001$) respectively. The ANOVA results are detailed.

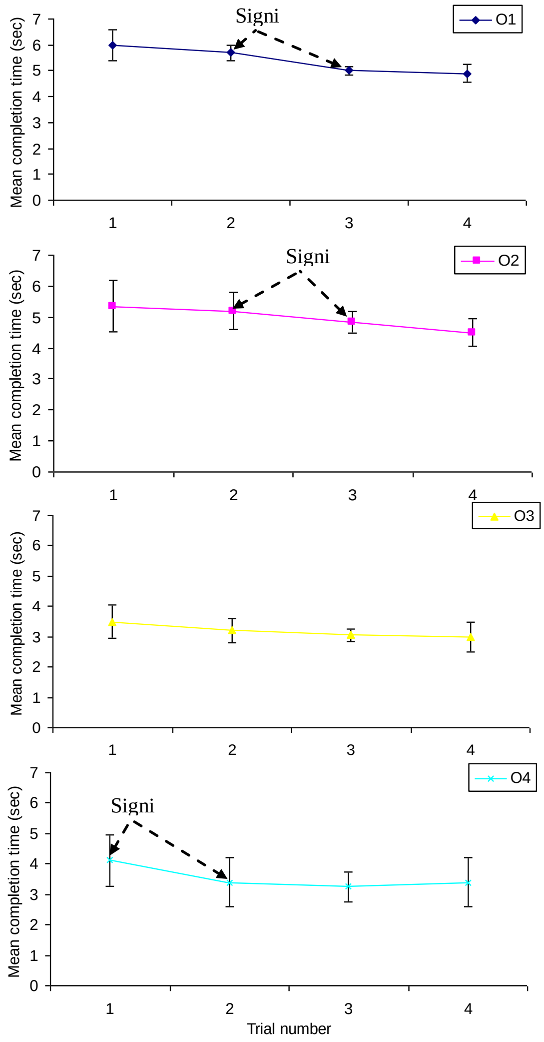

Figure 3. Trial Vs. Mean completion time for all 4 orders, Oi

To determine the number of subjects, a power analysis was used, which is normally used for determining the number of subjects assigned to different treatment conditions. Although it is recommended that the greater the number of participants involved the more sensitive the results become, the power analysis procedure can provide an indication of the minimum number of participants to be involved in a scientific study experiment [16].

The study considered four treatment conditions (i.e. modes, or $a = 4$) and by estimating the expected minimum treatment effects as population treatment means μ_i (the average of 4 modes per subject). Table 2 depicts the means completion times of four modes and their deviation from the grand mean ($\mu = 4.2$).

TABLE II. MEAN AND STANDARD DEVIATIONS FOR ALL FOUR PARTICIPANTS

Mean of mode	Deviation from μ
$\mu_1 = 5.4$	$\mu_1 - \mu = 5.4 - 4.2 = 1.2$
$\mu_2 = 4.9$	$\mu_2 - \mu = 4.9 - 4.2 = 0.8$
$\mu_3 = 3.1$	$\mu_3 - \mu = 3.1 - 4.2 = -1.1$
$\mu_4 = 3.5$	$\mu_4 - \mu = 3.5 - 4.2 = -0.7$

By assuming that an accurate estimate of the population variance $(\sigma^2_{S/A})$ is available, equal to 4.2. The available information in table 5 is substituted into the formula

$$\phi_A^2 = \frac{s'\left[\sum(\mu_i - \mu)^2\right]/a}{\sigma^2_{S/A}} \quad (1)$$

$$\phi_A^2 = \frac{s'\left[\sum(1.2)^2 + (0.8)^2 + (-1.1)^2 + (-0.7)^2\right]/4}{4.2} = 0.2s' \quad (2)$$

$$\phi_A = \sqrt{\phi_A^2} = \sqrt{0.2s'} = 0.5\sqrt{s'} \quad (3)$$

Assuming s' = 13, $\phi_A = 0.5\sqrt{13}$ = 1.71. From the power , with the numerator degree of freedom of F-ratio is equal to 3, the power function is drawn for 11 different values of the degree of freedom denominator, df_{denom} as follows:

$$df = a(s' - 1) \quad (4)$$

df is calculated to have a value of 48. As the df_{denom} has certain values on the power chart (i.e. 6,7,8,9,10,12,15,20,30,60) the power function was shifted towards 60 ($df_{denom} = 60$), the power associated with $\phi = 1.71$ is approximately 0.81, which is, according to Keppel a reasonable level of power for such scientific experiments.

This can be illustrated by drawing a horizontal dotted line at the power level of just over 0.8 (on the Y-axis, Fig 4) then reading off through a vertical doted line the number of subjects required (along the X-axis). Thus, it is clear that the sample size is slightly greater than 12, and accordingly the future study should not involve fewer than 13 participants.

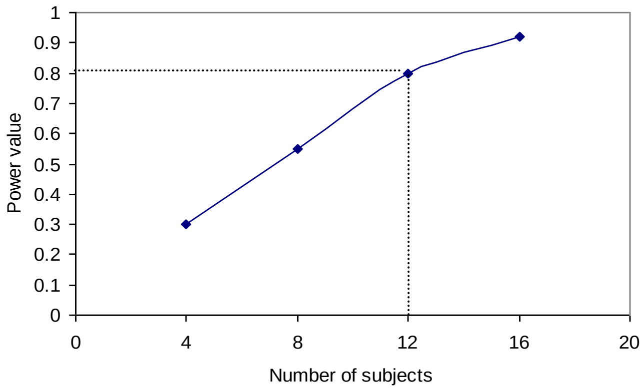

Figure 4. Number of subjects required for future study

It should be pointed out that as the number of subjects' increases beyond this level the predicted benefit is lower, for the test results. This is in broad agreement with previous findings in [14].

CONCLUSIONS

The paired t-test results showed that there should be at least 3 trials (repetitions) for the task by every subject. The task order was participant dependent.

Reference [16] thought that 0.8 would be a reasonable level of power to derive the number of subjects. This level has been achieved in this study. Reference [14] argued that exceeding this level may only show a little benefit from the results.

There was little correlation between the correct answers per subject and the task completion time, and furthermore, subjects with high levels of spatial ability should not necessarily perform a contact type task better than those without.

Any future 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.

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