Advances in Display Technology V

ADVANCES IN DISPLAY TECHNOLOGY V

Elliott Schlam

Chairman/Editor

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ADVANCES IN DISPLAY TECHNOLOGY V

Volume 526

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INTRODUCTION

As the information age progresses, display technology advances. For the first time products with distinct identities such as personal computers and automobiles are being marketed with the aid of "better," "brighter," "flatter," and more "colorful" displays. Cathode ray tubes are advancing with higher resolution, better color and sharper images. Plasma, liquid crystal and electroluminescent displays are becoming more plentiful while developmental activities in these areas promise improved, larger, higher resolution, better quality displays. In addition to the technological display advances, there is increasing recognition of the technology of how to use displays. As the prime man-machine interface in many systems, the information that appears on a display and the way in which the user interacts with it are critical to effective system operation. The papers presented at this conference represent a sampling of the many technological areas now being pursued by the display community.

This 1985 conference was divided into four sessions. The first session, Display Human Factors, presented a selection of papers relating to choice criteria for displays, the use of touch panels as display interactive devices, and the effect that luminance and color have on the recognition of images on a display screen. Session 2, CRT and Projection Display Systems, had papers discussing effects of rastering in television display, announced a 2048 × 2048 line color raster CRT display, and discussed large screen projection displays using both CRT and liquid crystal technology. The third session, Electroluminescent Displays, announced a new personal computer using a TFEL display, discussed sunlight legible TFEL displays as well as the development of a 10" × 12" TFEL display, and concluded with a discussion on the design of a single board display monitor. The final session, Passive Displays, discussed the advances expected from silicon TFT addressed liquid crystals, contrast effects in guest-host liquid crystal displays, a new LC display mechanism based on zero order diffraction effects and a large viewing area LC display.

Next year's conference promises more exciting news on advances in display technology.

Elliott Schlam
U.S. Army Electronic Technology and Devices Laboratory

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Session 1

Display Human Factors

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SELECTING THE 'BEST' VISUAL SYSTEM: A GUIDE FOR MANAGERS

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Abstract

Choice of the "best" visual system for a given set of simulation training tasks is considered by many as a black magic process. Considerable confusion, misunderstanding and misapplication of visual requirements exists within the simulation community. Several elementary mistakes are frequently made, so that the simulation visual system is unsatisfactory for the simulation user.

This paper presents management methodology for selection of the optimum visual system for a given set of simulation training tasks. Discussion of several current "pitfalls" in visual system use is given to increase confidence in choice methodology. Comparison tables are developed for current state-of-the-art visual systems to provide understanding of visual systems strengths and weaknesses.

Introduction

Training as a force multiplier has been demonstrated throughout recorded history, since the ancient Greeks learned to march in step, and a handful of Roman legions ruled the world. The advantages that training confers is even more apparent today, with the increased complexity of weapon systems and the disparate strengths of national forces. Unfortunately, limitations in "real world" training are imposed today because of fiscal, environmental and hazard pressures. Fortunately, simulation systems exist that can largely "fill the gap" and produce training results that equal real world efforts.

Training has always been divided into two methodologies: Training the individual with weaponry and training as a team (unit or crew). Simulators can easily accomplish both aims. To do this, however, the simulator/simulation must be incorporated into the training system as an integral part of the program. The determination of the real world weapon system requirements and the associated simulation requirements must be thoroughly worked out and integrated with the training program capabilities and final aims. This is the first area of concern and a prime requirement of the manager (see Figure 1).

The visual system is the principal source of sensory information in the real world, perhaps as much as 90% of our information derives from this source. Any observer's visual system has available a very large number of redundant cue sets which are used to establish orientation to, motion through, and detail of the real world. Each observer selects a set of cues, dependent upon his personal equation, experience, and conditions of current operation [1]. The importance of the visual system in the simulated training process cannot be overstated. It represents the real world environmental space (and conditions) through which the simulated vehicle (aircraft, ship, tank, etc.) is maneuvered by the operator (observer). The level of effective training that can be achieved is dependent in large measure upon the quality of the visual display [2]. The performance of the operator relative to the real world vehicle and his progress in competency is a function of the completeness of the cue sets presented by the simulator visual system [3].

Visual System Design Algorithm

The Visual System Design Algorithm is presented in two parts: 1) Deriving the visual system simulation requirements from the weapon system real world requirements and the real world training requirements (Figure 1), and 2) The visual system test algorithm (Figure 2).

As was noted in the introduction, the determination of the visual system simulation requirements is the first concern and a prime requirement of the manager of the training/simulation program. The simulator visual system requirements are derived from the simulator training requirements and other simulator systems and interfaces; these in turn are derived from the real world training and mission operation requirements of the weapon system in question (Figure 1). The simulator/simulation must be an integral part of the training process, the design and use of the simulator can only be effective to the extent this is done. The procedure of visual design is broken at this point to emphasizes that the real world mission and training requirements drive the visual system requirements and not that available systems drive the training requirements. It is too often the case that unnecessary restrictions on training are produced by a too facile acceptance of current visual system parameters or the "pushing" of a favorite visual device.

The visual system test algorithm (Figure 2) defines the actual design process to be followed for the visual system. Not specifically shown, at all stages of the algorithm, is the constant concern for the interrelationship of the visual system to the other simulator systems, in particular to the training system and instructor station. These interfaces should be a continual factor in all efforts.

Once the visual system performances parameters are established, the candidate visual systems can be evaluated. This process has two major and several minor "gates" (see Figure 2). The major gates are system capabilities and system costs.

System capabilities are defined by the critical performance parameters (established by mission operational requirements and training needs). These would include: field of view, scene resolution and detail, brightness, contrast, scene dynamics and management, color, stability, and lack of scene defects and distractions (and perhaps others).

Cost factors are acquisition (recurring and nonrecurring) and life cycle costs for the specified lifetime of the simulator system. Cost balance for acquisition recurring and nonrecurring factors can often be struck. Life cycle costs are an important factor and should be given careful attention.

Any acceptable visual system must pass these two major "gates", and then be evaluated for the several minor "gates" (summarized in one box of Figure 2), so as to establish a possible visual system design that satisfies the training task requirements. This process may produce alternate visual system designs or several cycles through the process may be required to obtain a single satisfactory design.

The final selected visual system is then treated as a unit and integrated into the simulator system to be tested as a complete simulation system. The final simulation system design is then ready for modification (or production) and so is ready for training.

Discussion I (System)

Evaluation of alternate visual systems may be conducted as illustrated in Figure 3, System Matrix Table. Here the risk evaluation of performance and failure mode effects can be compared for various visual systems. Areas of concern are the mission operation modes (actual training requirements), off the shelf capabilities, cost, schedules, expansion and concurrency capabilities, gaming areas, etc. The evaluation criteria are established by the visual system requirements obtained from the unified training and mission requirements of the simulation system. The mission operational modes should be separated on the basis of the common, unique, or special visual system requirements. Typical would be taxi; takeoff (including MITO); climb out; high altitude cruise (sole); companion aircraft; aerial refueling; descent; low level flight, slow (landing) speed; low level flight, high speed; low level flight, attack; etc., all of which define data base requirements. Risk evaluation should include critical factors; i.e. what percentage of training can be accomplished despite failure, as well as MTBF and MTTR values. Expansion of the simulation system and maintenance of concurrency are becoming more important due to budgetary limitations. Commonalities of displays with other imaging systems (LLTV, IR, RADAR, etc.) is also a primary requirement of increasing importance in the training of full mission capabilities. The cost factors are, of course, obvious.

Discussion II (Performance Parameters)

A set of "design goal" performance parameters [4] [5] is given in Figure 4. These parameters were selected by an international body of simulation experts to define a set of performance parameters for a simulation visual system that would be the minimum acceptable as a "real world" system. This does not infer that acceptable training levels cannot be attained with lower quality visual systems. These values can be compared to the parameters of visual systems discussed below (see Figure 5).

The remainder of this section discusses the five types of visual systems currently in todays state of the art, and summarizes their performance parameters. Visual systems consist of two major subsystems: image generator (IG) and image display (ID). These systems can be further categorized on the basis of modeling technique for the data base and methodology of image formation.

1) Computer Image Generation (CIG): The scene model is within the computer memory, and is processed, structured computationally, and output to the display subsystem, either raster or calligraphic. Considerable confusion exists within the simulation community because of the various descriptional terms used to express the CIG system capabilities (triangles, polygons, edges, etc.). For purposes of evaluation here the equation 1 polygon = 2.4 edges is used (trangle = polygon). This equation is based upon geometric processing and display qualities of the various CIG systems. (Note: The number of edges required to construct N polygons within a bounded planar area converges to 2N as N increases). CIG systems can produce mathematical points and lines and so have excellent resolution (limited by and should be matched to the ID subsystem because of aliasing problems), but have poor scene detail (data base storage limitations), saturated colors, and incorrect scene dynamics. Because of the linear construction of scene detail and saturated colors, such systems produce "cartoonish" visual scenes. These systems have gaming areas limited only by storage capacity of the computer data components which is the principal reason for their current wide spread use (see also ref 3). Recent improvements in CIG systems where texturing is inserted into polygon "blocks" of the display increases the illusion of detail in the scene and so produce more visually acceptable scene displays. Changing models is relatively easy (new program/data base).

Advantages: Large gaming area (world wide possible); highly flexible data base; good special effects; considerable current effort in improvement and expansion.

Disadvantages: High cost (acquisition and life cycle); "cartoonish" display, low scene level of detail, straight line construction and limited (largely saturated colors; complex computer; scene management difficulty.

2) Camera/Model: The scene is produced from a physical model (data base), generated by a television camera viewing the model and output to the ID subsystem. The resolution is limited by the display parameters (compounded by the sampling of the camera). The scene detail is limited by the detail of the model (in practice by the resolution of the ID). These systems are severely limited in gaming area, but produce good results where such limitations can be accepted. Changing models can be difficult (must be constructed physically). It is difficult to provide lighting other than "high noon" type.

Advantages: Good scene detail; moderate cost (acquisition and life cycle) good maintainability; good color.

Disadvantages: Limited gaming area; limited variation of data base; limited growth; "high noon" shadow effects.

3) Direct View: The scene is produced from a physical model and presented directly to the observer by the ID subsystem without (usually) further processing. The resolution and scene detail are limited by the model and the optics (in practice by the observer's eye). Scene dynamics, colors, and illumination levels are as presented by the model (neglecting optical train effects). These systems can present stereoscopic displays limited only by observers eye, but are severely limited in gaming area (useful in aerial refueling particularly) and by the positioning requirements relative to the cockpit. Cost and maintenance of such systems can be very low (relative to other discussed systems).

Advantages: Low cost (acquisition and life cycle); real world detail, color; stereoscopic displays; no image distractions; realistic scene dynamics.

Disadvantages: Very limited gaming area; rigid mounting requirements; limited growth.

4) Electronic Data Store (EDS): The scene is produced by a physical model (or real world) as viewed by camera or by off line computer processing and converted to data base stored on photograph, video disk or tape, or within a computer data bank. The scene is reproduced under computer control, modification and/or processing and output to the ID system. Self contained EDS systems are useful if imployed in "close course" modes of operation (e.g. takeoff and landing, low level attack, etc.) due to data store and processing requirements. These systems produce high quality displays of limited gaming area. The brightest future would appear to be as components in a "hybrid" visual display system (see below).

Advantages: Excellent detail; highly flexible data base; good special effects; large gaming area possible; considerable current effort; combines with CIG systems.

Disadvantages: Data base costs are high; system development required; high cost currently suitable for "closed course" systems.

5) Laser Camera and Video Projector: These systems are similar to camera/model units described above, except the illumination and scanning operation is done by a laser camera. This produces better resolution and scene detail, as well as somewhat improved lighting effects. Considerations of eye safety may limit such systems and the possible use of laser projectors may be considered hazardous.

Advantages: As camera model with improved detail, better illumination.

Disadvantages: Eye safety; costs; limited gaming area.

6) Hybrid Systems: Combinations of CIG and EDS systems, currently under work by several companies, offer the potential of extremely high quality displays with huge gaming areas. As yet no systems are available, but the progress should be monitored.

Advantages: Combine best features of both (or more) systems.

Disadvantages: Development.

Image Display (ID) systems in current use consist of television type projectors, either raster or calligraphic used as CRT systems or as projectors. At the present time the displays are the limiting factors in visual simulation (resolution, scene detail, brightness contrast, color, stereo, etc.). In most cases the field of view is fixed at 48°h x 36°v (or slightly larger) per channel (due to resolution minimums), with multiple display units for increased field of view (e.g. 3 channel, 150-180°h and 38-60°v total display). A display system presenting a resolution of 3 arc minutes per TV line would allow the observers to detect detail of 6 arc minutes, and recognize or identify objects of 12-36 arc minutes. This is unacceptable for most advanced training applications and must be greatly refined.

Conclusions

To summarize the statements and conclusions of this paper:

- Training is essential as a force multiplier.
- Simulation training is a necessary part of the training task.
- Proper management is essential to proper training.
- Currently visual simulation systems exist that can satisfactorily accomplish some (possibly or eventually most) of the training task.
- Correct evaluation and use should be placed on the visual simulation task to accomplish the training task.

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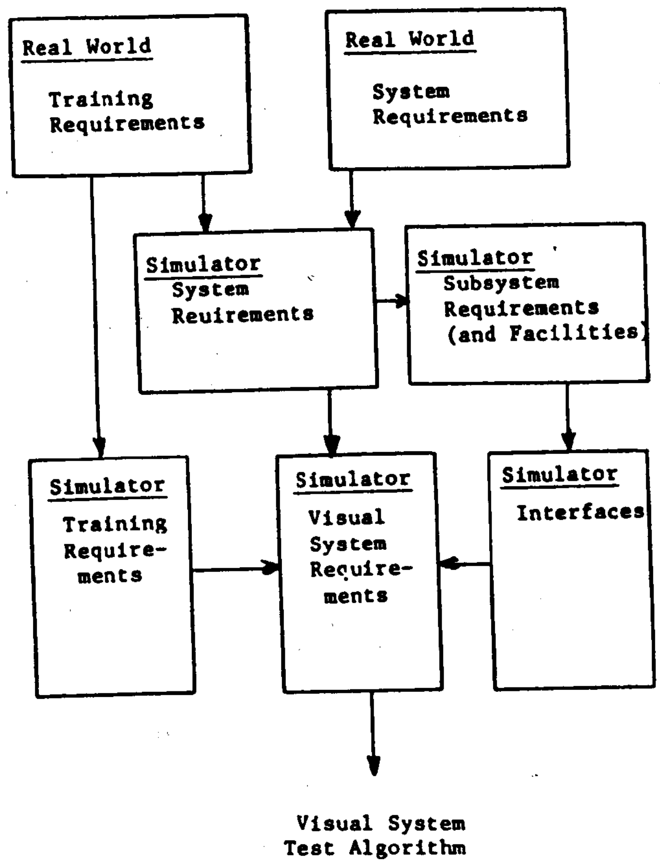

Figure 1 Establishing the Visual System Simulation Requirements

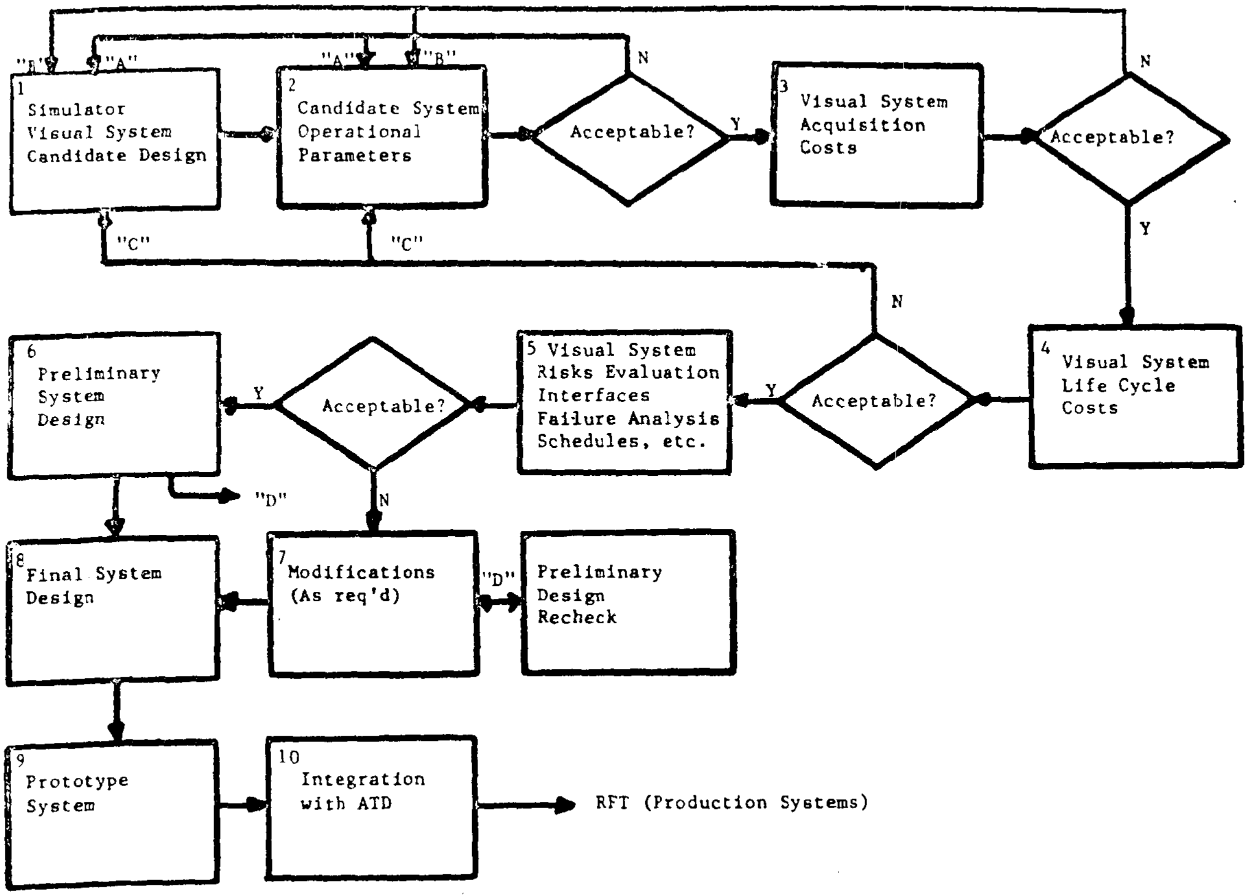

Figure 2 Evaluation of Candidate Visual System Designs

Criteria / Candidate (Class)	Performance								Risk						Misc.					
	Taxi	Take Off	Landing	Air Refueling	Low Level	Air to Ground	NOE	Etc.	Development	Schedule	Cost	Failure Modes	Logistal Support	Etc.	Gaming Area	Data Base Compt.	Proprietary	Subsystem Compat.	Concurrency	Etc.
CIG	Y	G	Y	R	Y	R	R	-	Y	Y	Y	Y	G	-	B	B	G	G	B	-
Camera/Model	Y	B	G	G	Y	Y	R	-	G	G	G	G	G	-	R	G	B	B	G	-
Direct View	Y	Y	Y	B	Y	Y	R	-	G	G	G	Y	G	-	R	G	G	B	G	-
EDS	G	G	G	B	Y	G	R	-	Y	Y	Y	Y	Y	-	B	G	G	B	B	-
Laser	G	B	G	Y	Y	G	R	-	Y	Y	Y	Y	Y	-	R	G	G	B	G	-

Repeat for individual systems in each class.
All performance tests are done for initial advanced, and continuation training.

B=exceeds; G=satisfies; Y=problem area; R=unsatisfactory.

Figure 3 System Matrix Table

Field of View	320° Horizontal + 100° to - 40° Vertical
Resolution Brightness	1 Arc Minute 125 ftL
Contrast Depth of Field	1000/1 5 m to 100 km
Color Perspective	1% (Real World) 1% (Real World)
Parallax (Stereo) Distortion	As Real World 1% (Real World)
Positional Accuracy	0.1 m
Picture Content	All Detail Larger than 10 mm Linear Dimension
Picture Control Gaming Area	Dynamic 300×10^6 km^2

Figure 4
Visual System Display Parameters

Parameters	#1 CIG/Raster	#2 Camera/Model Raster	#3 Direct View	#4 EDS/Raster	#5 Laser Camera/ Raster
Off the shelf Req'd Develop Demo Possible	Yes No Yes	Yes No Yes	Yes (Comp) Possible Yes	Yes (Comp) Yes Possible	Yes (Comp) Yes Yes
Schedule Lead Time Risk Evaluation Initial Cost	12-18 mo Low V High	12-15 mo Low Mod	12-15 mo Low Low	18-24 mo Mod V High	18-24 mo Mod V High
LCC Cost Growth Potential Field of View	V High V Good 48°Hx36°V	Mod Low 48°Hx36°V	V Low Low 90°Hx90°V	V High Excellent 48°Hx36°V	V High Low 48°Hx36°V
ID Type Resolution Scene Detail	TV Proj 8 arc min 9000 obj	Raster CRT 8 arc min 691,200 obj	Direct Proj 2 arc sec 5.6×10^9 obj	Raster CRT 8 arc min 691,200 obj	Raster CRT 6 arc min 691,200 obj
Scene Texture Scene Brightness Scene Contrast	Yes 6 ftL 15/1	Not Required 20 ftL 25/1	Not Required 200 ftL 200/1	Not Required 20 ftL 25/1	Not Required 20 ftL 25/1
Scene Dynamics Scene Management Scene Stability	Good Dev Reqd Good	Good Good Good	Excellent NA Excellent	Good Dev Reqd Dev Reqd	Good Dev Reqd Dev Reqd
Special Effects Gaming Area Data Base Size	Excellent As Data Store V Large	Excellent Limited Limited	Excellent V Limited V Limited	Good As Data Store V Limited	Good Limited Limited
Computer Complexity Scene Defects Color	V High 3 per 5 min Saturated	Mod 3 per 5 min Sat - Unsat	Low None Excellent	V High Dev Reqd Excellent	High 3 per 5 min Good
Stereo Display Comments	No Linear Const	No Quality as model	Yes Quality as model	No Requires parallel processing	No Quality as model

Figure 5 Visual Parameter Comparison Table

Effects of touch key size and separation on menu-selection accuracy

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Abstract

Two experiments were performed to assess the effects of touch key design parameters on menu-selection error rates. The first experiment determined that the optimal design consisted of touch keys 10.16-mm high, either 10.16- or 20.32-mm wide, and separated vertically by less than 10.16 mm. The second experiment extended the investigation by including the effects of viewing angle. These latter results replicated the first experiment, but also favored the 20.32-mm wide key for off-axis viewing conditions. In both experiments, the horizontal separation between touch keys did not affect menu-selection accuracy; however, subjective selection favored a 20.32-mm horizontal separation.

Introduction

Recently, numerous attempts have been made to engineer efficient interfaces between computer systems and their human operators. Typically, these efforts have proposed the use of ancillary devices to augment the traditional keyboard and the use of structured formats for the display of complex information. For example, the touch panel and the "information menu" have been suggested as standard design layouts for applications involving item selection.[1] Similarly, devices such as thumb wheels and "joydisks" have become standard additions to many computer terminals to aid the user in certain elementary operations.

Despite the widespread work to develop newer and better computer interfaces, relatively little effort has been invested toward the full use of existing interface designs. This problem is evident in the research literature, where comparisons of human performance are often made among different input devices rather than across different configurations of a *single* device technology.[2,3] Moreover, it has become increasingly important to understand and optimize existing interface designs, because the application of computer-based systems into new market places has surpassed the development of new input device technologies.

Research to investigate the human interface of touch panels indicates that they are an alternative to other existing input devices.[4] However, little information is available that recommends key size and layout on a touch panel. This paper reports two experiments in which the physical design parameters of a touch panel system were varied. The specific concern of this work was to uncover the size and spacing of touch keys for menu-selection accuracy.

Experiment 1

This experiment examined the relationships among menu-selection performance and four design parameters that determine the configuration of touch keys.

Method

Subjects: Twenty-one subjects (6 females) voluntarily participated in the experiment. These subjects were engineers and other staff personnel employed at Tektronix. Each subject participated individually in an experimental session that lasted about 45 minutes. Twenty-four percent of the subjects were between the ages of 20 and 29 years, 52% were between 30 and 39 years, 14% were between 40 and 49 years, and 10% were between 50 and 59 years. More than half of the subjects (56%) claimed to have had no previous experience using touch panel systems, while none of the subjects claimed to use touch panels on a regular basis.

Apparatus and stimuli: A conductive-film touch panel (TSD Products, Model TF-19H) was used in the experiment. The touch panel was mounted on a graphics display terminal (Tektronix Model 4115B), and an aluminum bezel was placed over the touch panel to restrict the usable surface to an 11-cm square area. A laboratory computer (Tektronix Model 4052A) was used to control the experimental trials and to collect the output of the touch panel.

A 10.16-cm square region of the usable surface was defined as the active touch area. Within this area, the resolution of the touch panel was 70 units horizontally by 80 units vertically, while the graphics resolution was 1280 by 1024 pixels. Thus, the minimum quantization error in mapping the touch panel units into pixel units was 0.73-mm horizontally and 0.64-mm vertically. When added to calibration errors, this device error produced a touch panel system that was accurate to within 1.5 mm, on the average.

Each stimulus used in the experiment consisted of 12 touch keys arranged in a four-row by three-column matrix. The physical dimensions of this key matrix were determined by the factorial combinations of four variables: key height (5.08, 10.16 mm), key width (10.16, 20.32 mm), horizontal separation between touch keys (0.0, 10.16, 20.32 mm), and vertical separation between touch keys (0.0, 5.08, 10.16, 15.24, 20.32 mm). Each touch key was outlined by a one-pixel wide black border, and the entire key matrix was presented on a white background of 51.39 cd/m^2.

During the experimental trials (described below), each touch key was labelled with a random CVC (consonant-vowel-consonant) trigram and a target CVC was presented in a small window located directly above the touch area.

After the experimental trials, each subject completed a questionnaire as part of the debriefing procedure. The questionnaire asked for subjective preference ratings for each level of four independent variables.

Procedure: A menu-selection task was employed. Each trial began with the empty background field in the touch area. An auditory signal (bell) informed the subject to press a "start" button to initiate the presentation of the target CVC and the labelled key matrix. The subject's task was to search the key matrix for the key containing the same CVC as the target CVC and, then, to touch that key to indicate a response. Immediately following this response, the target CVC and the key matrix were replaced by the empty background field. After a seven-second delay, the auditory signal indicated the beginning of the next trial. No feedback concerning the accuracy of response was given to the subjects.

Before beginning the experimental trials, each subject received a series of practice trials. The practice consisted of blocks of 10 trials in which representative key matrices were presented. The purpose of the practice trials was to familiarize the subjects with the touch panel system and to stabilize their responses. Each subject reached an 80% correct response level before starting the actual trials.

Following the practice, each subject received 60 total trials, each of which consisted of a single presentation of each factorial combination of two key heights, two key widths, three horizontal separations, and five vertical separations. On each trial, the X, Y touch panel coordinates of the subjects' response were recorded. During these trials, the subjects were seated in a dimly lit room to avoid glare from the touch panel. Also, the subjects were allowed to choose a comfortable viewing distance ($\bar{x} = 45.0$ cm, $\sigma = 9.1$); however, they were positioned so that their horizontal line-of-sight remained normal to the center of the touch area.

Results and discussion

The X, Y touch panel coordinates recorded for each subject in the 60 treatment conditions were transformed into X, Y pixel units. These transformations were implemented with first order least-squares mapping functions developed for each axis during device calibration. Next, the pixel units were compared with the border coordinates of the touch key that contained the target CVC. If the touch coordinates were outside of the correct key area, an error was coded into the data set by a numerical value of 1; otherwise, a value of 0 was coded into the data set.

The error data were subjected to a fixed-effects four-factor analysis of variance procedure. The only significant main effect involved the key height factor $\{F(1,20) = 107.91, p < 0.0001\}$. As shown in Figure 1, the error rate associated with the 5.08-mm high key was twice as great as that with the 10.16-mm high key. The effect of key height, however, was involved in two significant higher-order interactions.

Figure 2 represents the significant two-factor interaction between key height and vertical separation $\{F(4,80) = 4.51, p = 0.0025\}$, while Figure 3 presents the significant three-factor interaction among key height, vertical separation, and key width $\{F(4,80) = 4.27, p = 0.0035\}$. In general, these higher-order effects do not change the finding that 10.16-mm high keys lead to lower error rates than do 5.08-mm high keys. However, the interaction effects point up an additional data trend.

As seen most clearly in Figure 2, the factor of vertical separation differentially affected the error rate between the two key-height conditions. For the 10.16-mm high keys, the error rate decreased with increasing vertical separation. The opposite trend occurred for the 5.08-mm high keys, where the error rate decreased with increasing vertical separation. At the extreme vertical separation, 20.32 mm, the error rate did not differ between the two key height conditions. This pattern of results was verified by a *post hoc* Newman-Kuels test at the 0.05-alpha level.

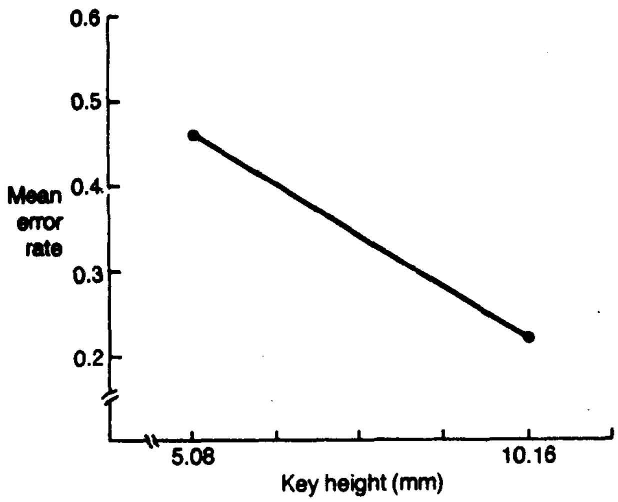

Figure 1. Main effect of touch key height, averaged over 21 subjects, on the mean error rate in Experiment 1.

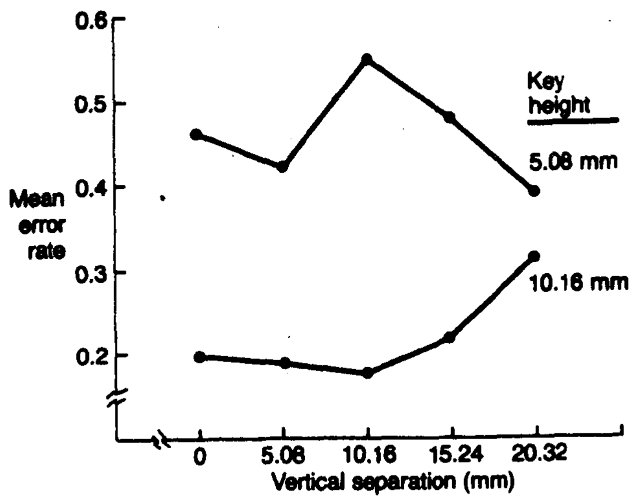

Figure 2. Two-factor interaction between touch key height and vertical separation between touch keys, averaged over 21 subjects, on the mean error rate in Experiment 1.

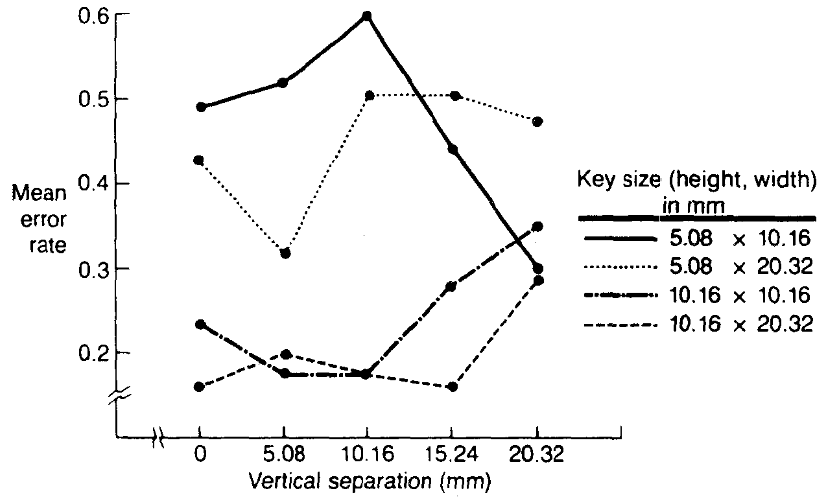

Figure 3. Three-factor interaction among touch key height, touch key width, and vertical separation between touch keys, averaged over 21 subjects, on the mean error rate in Experiment 1.

The questionnaire data, obtained after the completion of the experimental trials, indicated that most subjects preferred the 10.16-mm high by 20.32-mm wide touch keys (86%), a horizontal separation of 10.16 mm (82%), and a vertical separation of either 5.04 or 10.16 mm (86%). Aside from the horizontal separation preference, these subjective ratings strongly supported the trends observed in the objective performance data.

As investigated here, the optimal key-matrix design for menu selection consists of 10.16-mm high by 20.32-mm wide keys, separated vertically by no more than 10.16 mm. From these results, horizontal separation between touch keys does not influence menu-selection accuracy; however, this factor does influence subjective preference ratings. These conclusions, of course, must be tempered by the constraints of the experimental procedure employed and, in particular, by the fact that subjects used the touch panel system only in direct, or on-axis, viewing conditions. It is possible that viewing parallax may change the performance effects observed in the present experiment. This possibility was investigated in the next experiment.

Experiment 2

This experiment extends the approach taken in Experiment 1 by including the effects of viewing angle, as well as the physical key-matrix parameters, upon menu-selection performance.

Method

Subjects: Twenty-two subjects (2 females), who were employed at Tektronix, Inc., volunteered to participate in the experiment. Each subject participated individually in an experimental session that lasted about 45 minutes. Twenty-seven percent of the subjects were between the ages of 20 and 29 years, 55% were between 30 and 39 years, 14% were between 40 and 49 years, and 4% were between 50 and 59 years. Fifty percent of the subjects claimed that they had no previous experience with touch panel systems.

Apparatus and stimuli: The experimental set-up used was identical to that used in Experiment 1, with the exception that the vertical separation between the touch keys was held constant at 10.16 mm.

Procedure: The same menu-selection task used in Experiment 1 was employed for the second experiment. However, the procedure was implemented with subjects positioned at each of five viewing angles: 40° left of center screen, 20° left of center, 0°, 20° right of center, and 40° right of center. At each of these viewing positions, the subjects chose a comfortable viewing distance ($\bar{x} = 50.3$ cm, $\sigma = 6.3$) and maintained a horizontal line-of-sight that intersected the center of the touch area. As in Experiment 1, the subjects received blocks of 10 practice trials and were required to reach an 80% correct response level in the 0° viewing condition before starting the experiment. Once the experimental trials began, the subjects received 60 total trials that consisted of single presentations of each factorial combination of two key heights, two key widths, three horizontal separations, and five viewing angles. These treatment conditions were presented in a unique random order for each subject with the constraint that all 12 key height by key width by horizontal separation conditions were completed before changing the viewing angle.

Following the experimental trials, each subject completed a brief questionnaire to indicate their subjective preference for each level of the four independent variables.

Results and discussion

For each experimental observation, the X, Y pixel coordinates of the subject's response were compared to the border coordinates of the touch key containing the target CVC. If an error occurred, a numerical value of 1 was coded into the data set; otherwise, a value of 0 was coded into the data set.

The error data were subjected to a fixed-effects four-factor analysis of variance procedure. The significant main effects were key height $\{F(1,21) = 16.370, p < 0.001\}$, key width $\{F(1,21) = 11.461, p < 0.0001\}$, and viewing angle $\{F(4,21) = 11.707, p = 0.001\}$.

Figure 4 presents a replication of the basic finding in Experiment 1; that is, the significant main effect of key height indicates that 10.16-mm high keys produced nearly a two-fold increase in menu-selection accuracy as compared to 5.08-mm high keys. Although the absolute error rates are higher in the present experiment, this can be attributed to the use of only direct viewing in Experiment 1.

Figure 5 presents the effect of key width on touch accuracy. It is clear from this figure that the 20.32-mm wide keys led to fewer errors than did the 10.16-mm wide keys. Over the range of viewing conditions employed, the advantage of the wider keys is a 50% reduction in touch error rates.

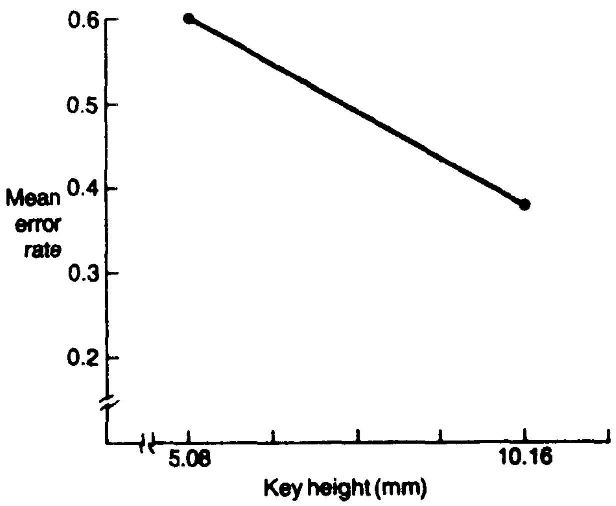

Figure 4. Main effect of touch key height, averaged over 22 subjects, on the mean error rate in Experiment 2.

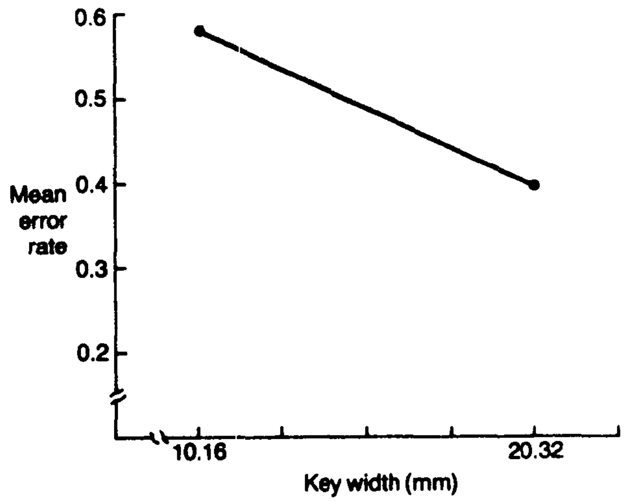

Figure 5. Main effect of touch key width, averaged over 22 subjects, on the mean error rate in Experiment 2.

Figure 6 shows the main effect of viewing angles; it can be seen that the on-axis, 0°, viewing condition was associated with the lowest error rate. As viewing angle increased, the error rate clearly increased. Moreover, the effects of viewing angle are quite symmetrical in either direction from the 0° position.

The latter two main effects of key width and viewing angle must be interpreted in terms of a significant two-factor interaction $\{F(4,84) = 2.838, p = 0.0151\}$. This interaction is shown in Figure 7; it is apparent that the general findings from the individual main effects are still valid. However, the interaction effect indicates that the 20.32-mm wide key maintains a lower error rate across a broader range of viewing angles than does the 10.16-mm wide key. A Newman-Kuels test indicated that performance remained constant within ±20° from center for the wide touch key, but significantly declined within this range for the narrow touch key.

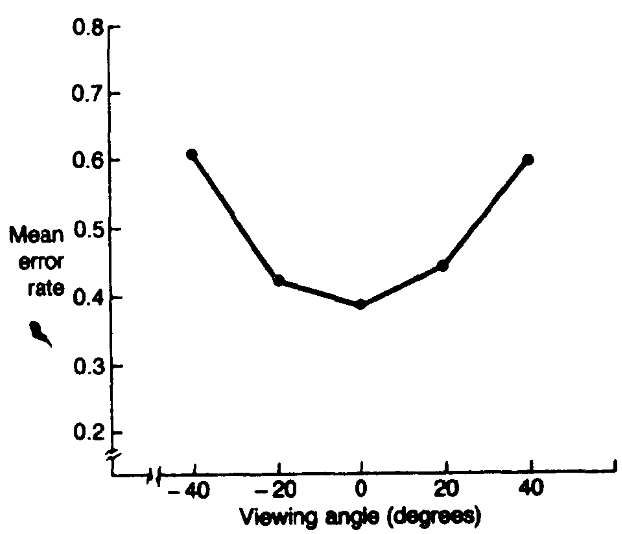

Figure 6. Main effect of viewing angle, averaged over 22 subjects, on the mean error rate in Experiment 2.

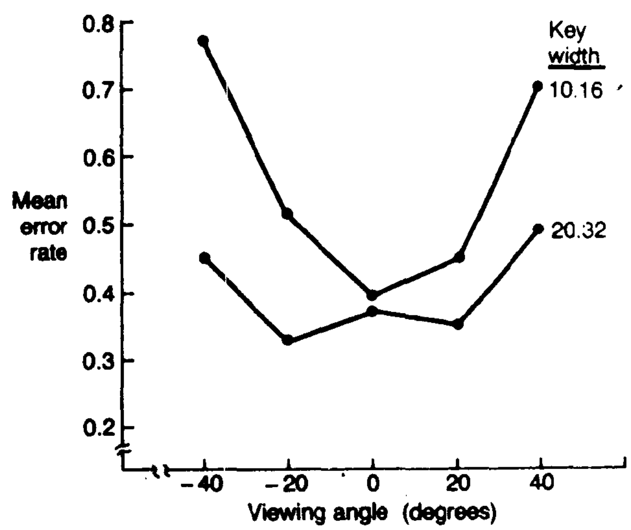

Figure 7. Two-factor interaction between touch key width and viewing angle, averaged over 22 subjects, on the mean error rate in Experiment 2.