DEVELOPMENT OF A LOW-COST 3-DIMENSIONAL COMPUTER GRAPHICS TRAINING SYSTEM

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ABSTRACT

An experimental simulation training system was developed using the latest microcomputer hardware and firmware technology combined with a new 3-dimensional graphics software program. The purpose of this system is to provide a realistic representation of the 3-dimensional geometry involved in aircraft intercept missions for Air Force Weapons Directors. The advantages of this system are its relatively low cost, small size, and ability to be used as a stand-alone, interactive, high performance 3-dimensional computer graphics training device. Training and human factors issues are addressed, along with a presentation of the visual display and control capabilities of this experimental system. In addition, guidelines for use in similar programs are offered, along with recommendations for future research.

KEYWORDS: 3-Dimensional Computer Graphics, Computer Graphics Training Systems, Animation and Modeling, Computer Simulations.

INTRODUCTION

This paper describes a relatively inexpensive and simple hardware and software approach to the development of 3-dimensional computer graphics simulators. The initial application of this unique system was in the development of a training device for possible use by Air Force Weapons Directors. As part of an occupational category which also includes Federal Aeronautical Administration (FAA) Enroute and Terminal Air Traffic Controllers and Navy Air Intercept Controllers, these personnel direct the flight of aircraft in a 3-dimensional airspace using symbolic graphics displays presented on a 2-dimensional Cathode Ray Tube (CRT).

It was believed that training for this occupation would be more effective if it included experience with a simulation device which presents a 3-dimensional display of aircraft flight characteristics and aircraft intercept concepts and techniques.

Historically, most 3-dimensional graphics simulators have been expensive, bulky, and difficult to program. They have been especially difficult to develop for occupations in which an operator must continually interact with an animated, real-time graphics display and simultaneously perform many information-processing and decision-making tasks.

For the application described here, a stand-alone microcomputer with a new 3-dimensional graphics package resident in Programmable Read Only Memory (PROM) chips in the computer formed the basic hardware/software configuration. Additional software, stored on a 10 megabyte disk drive, was developed to provide the high-resolution, color, animated, real-time display of three aircraft flying in a defined airspace (see Figures 1-4).

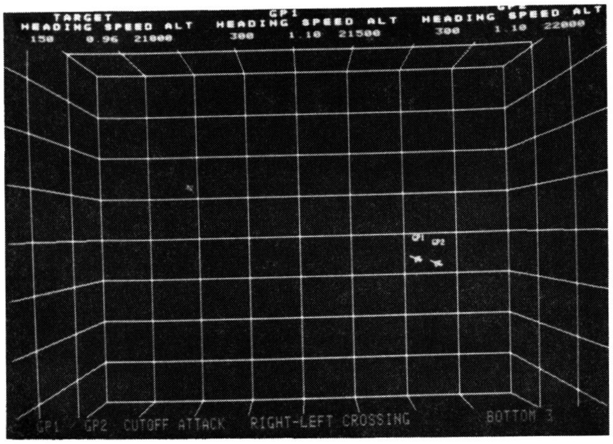

Figure 1. Long-range view of cube and aircraft (Top view)

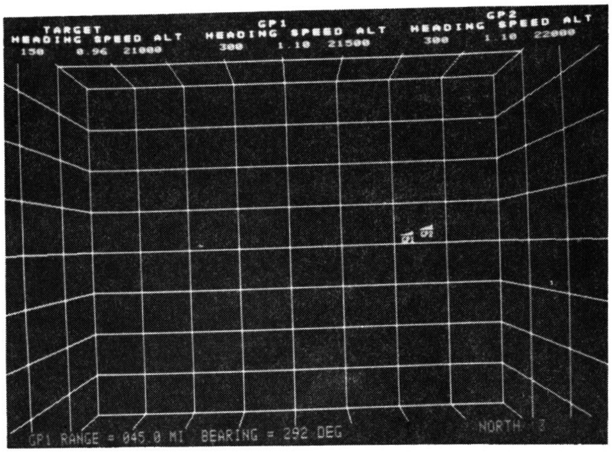

Figure 2. Long-range view of cube and aircraft (Side view)

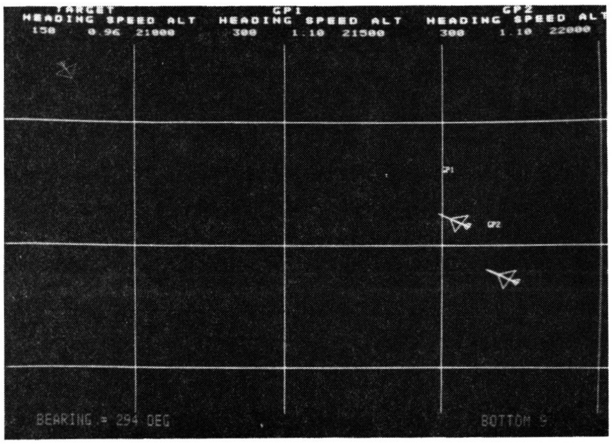

Figure 3. Close-up view of aircraft (Top view)

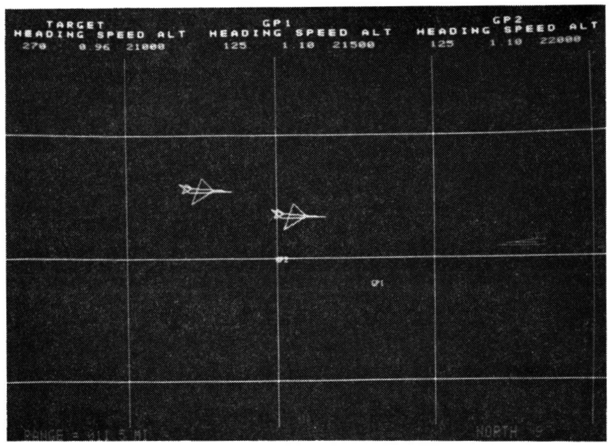

Figure 4. Close-up view of aircraft (Side view)

By selecting a set of specific training issues for this experimental system, it was possible to add special graphics subroutines to provide training-related aircraft control information and intercept performance feedback to the student on a real-time basis.

In its present configuration, this training system allows a student full interactive control, via a keyboard, of all the major flight variables of two interceptor aircraft and one target aircraft. The scene can be viewed from virtually any angle, including from the cockpit of the interceptor aircraft. In addition, the flight path of the target aircraft can either be controlled from the keyboard or chosen from a set of preprogrammed flight plans, allowing the student to concentrate on controlling the interceptor aircraft.

The remaining sections of this paper will address the training and human factors issues involved in the development of this system, the hardware and software which comprise the system, general guidelines for the development of other low-cost, 3-dimensional computer graphics training devices, and recommendations for further research.

TRAINING ISSUES

The basic principle behind the development of this training system was that the performance of Weapons Directors on the 2-dimensional CRT used in controlling aircraft would be improved as a result of a better understanding of the 3-dimensional intercept geometry involved in aircraft intercepts. A feasible way to improve training is to expose students to a visual simulation of aircraft flying in a 3-dimensional airspace. In this manner, a student can view intercepts with realistic looking aircraft and, with the aid of supplemental graphics, understand issues such as 3-dimensional intercept geometry, airspace utilization techniques, air-battle tactics, and flight safety considerations.

A series of discussions with academic instructors and an examination of the current training syllabus led to the development of an initial set of training issues and a set of flight scenarios similar to those actually encountered during missions with operational aircraft. At the same time, special 3-dimensional graphics display software was designed to depict the geometry involved in aircraft intercepts, including: vector lines to forecast aircraft flight paths, differences between interceptor and target headings (heading crossing angle), places in space where the interceptors change from approach to attack flight parameters (transition points), places where the interceptors change attack headings (offset points and turn points), and recognition of a successful intercept.

Because the applications software is contained on a single disk, both experimental research and software development efforts can continue outside of the training setting, with periodic replacement of the disk for a new version. In this manner, this type of training system can be incorporated into a training program early in the development of the applications software as a supplemental training device or part-task trainer. For additional training capability, special graphics routines would be designed around the specific 3-dimensional issues to be addressed.

HUMAN FACTORS ISSUES

There were two categories of human factors issues to be addressed during the development of this experimental training system. The first involved the presentation of alphanumeric information and graphics displays on the CRT. The primary display issues were the appropriate level of realism, perceptual fidelity, and complexity needed in the displayed imagery. Since the training issues were not dependent on the characteristics of any specific aircraft or specific operational equipment, a moderate level of realism was chosen for this system. Whenever possible, the display characteristics were designed to reflect those of actual operational equipment in order to minimize the amount of new learning required for students to understand the visual display.

The second major human factors issue concerned the manner in which the graphics display would be presented to, and controlled by, a student. A high priority was given to simplifying the physical-manipulative tasks required for its operation in order to allow students to concentrate on the visual scene.

The initial configuration utilized a standard microcomputer keyboard which allowed both executive control of the training program and interactive control of the flight of the aircraft. It was felt that this keyboard system would be too difficult for students to operate and, instead, video-tapes were made of the flight scenarios as a temporary media for presenting the 3-dimensional graphics. Although this configuration does not allow the student to exercise interactive control of the aircraft, it does eliminate the problem of teaching students to operate a new device and increases the likelihood that the 3-dimensional relationships between the aircraft will be understood.

One possibility being considered for the future is to introduce voice recognition and speech synthesis technology into this training system. This would allow the student to practice controlling the simulated scenario using spoken language identical to that used in controlling operational aircraft. This technology has met with a moderate level of success in similar aircraft controller training systems with 2-dimensional graphics display systems, notably the efforts being conducted by the U.S. Naval Training Equipment Center (Breaux, McConley & Van Hernel, 1981; Halley, Hooks, Lankford & Nowell, 1981; Hicklin, Barber, Bollenbacher, Frady, Harry, Meyn & Slemon, 1980).

HARDWARE AND SOFTWARE FOR THE SYSTEM

Visual Display.

The scene presented to the student consists of a screen divided into three areas (See Figures 1-4). The top 15% of the screen is devoted to alphanumeric status information relating the current flight parameters of each of the three aircraft. The middle 70% of the screen contains an interior representation of a 3-dimensional gridded cube containing three aircraft represented by 3-dimensional outlines. Two of these aircraft are colored green to represent interceptor aircraft under the direction of the student. The third aircraft is colored red to represent a target aircraft. The goal of the student is, of course, to guide the interceptor aircraft through a successful mission and "kill" the target aircraft. It is essential that this middle area of the screen update in such a fashion as to present a moderately realistic display of the three aircraft maneuvering in 3-dimensional space. In addition, the status area at the top of the screen must update at the same rate. This requires a relatively high performance, animated, 3-dimensional display capability.

The bottom 15% of the screen area is devoted to keyboard input and instructional prompts. All student interaction is directed through an ASCII keyboard with function keys. The student may enter English language commands to direct the interceptor aircraft with the same terminology that a Weapons Director would use in an operational setting. The system either responds by accepting the command and causing the aircraft to maneuver accordingly or informs the student of a potential error. Since the aircraft take a finite time to execute each maneuver, compound commands are allowed only to the extent that is actually possible with real aircraft.

There are a number of special function keys available to the student during the mission. These are divided into two logical areas: those keys which relate to the viewing of the flight scenario, and those which relate to the control of the mission. The viewing control keys allow the student to view the mission from a variety of perspectives. In this simulation, the "viewer" or "camera" is on one of the six surfaces of the gridded cube, facing toward the opposite surface. By use of six corresponding function keys, it is possible to view the mission from any of the six cube walls (four sides, top, or bottom). In addition, the student may pan from side to side or vertically along each of these walls, as well as zoom in through ten possible steps to expand the detail of the mission activities.

The second group of function keys allows the student or instructor to start and stop the mission at any time for instructional purposes, to receive graphic and alphanumeric information concerning various aspects of the required intercept procedures, or to inquire as to the possibility of success or failure of the intercept with the target.

Hardware and Firmware

The display and control requirements were satisfied by the use of a stand-alone, full color, raster scan microcomputer display system based on a high level 3-dimensional graphics instruction set. The actual application was programmed using this disk based display system as a development system. The display hardware consisted of an AYDIN CONTROLS model 5216 display computer. This system is a 1024 by 1024 color raster display system utilizing an 8086 microprocessor and a disk based operating system. Internal to this system are a number of hardware modules designed to enhance the graphic and alphanumeric display capabilities. The selection of this display system provided a relatively low cost alternative to traditional host bound simulators. Also, this system provided software controllable scan formats which allow the rapid adaptation to standard TV scan rates for videotaping.

The programming required to achieve the above requirements was implemented in two phases: development of a general purpose 3-dimensional graphics instruction set, and development of the specific Weapons Director application. The 3-dimensional instruction set was developed in conjunction with the hardware manufacturer as a standard product and contains features in accition to those presented in this paper. The standard instructional set is contained in firmware on board the computer, while the applications programs are stored as disk based software.

The 3-dimensional instruction set consists of a group of approximately fifty subroutines which may be directly activated from a keyboard or called by an applications program. These instructions are grouped into a number of categories: graphic primitives, data base control, image and viewing transformation control, and interactive control. These instructions form a very powerful graphics nucleus to which the application routines were added.

All graphic primitives are described in a 3-dimensional coordinate space. These primitives are surfaces, vectors, prisms, spheres, and text. The aircraft are drawn with prisms and surfaces, and the cube is gridded with vectors. These primitives are logically grouped together into display lists known as "graphic objects". In this application, each aircraft and the gridded cube is described by its own graphic object. Associated with each graphics object is an image transformation which causes the data in the graphic object to rotate, translate, and scale in 3-dimensional world coordinate space. Thus it is possible to orient and position each individual aircraft within the cube without altering the graphics primitives which describe the aircraft, but rather alter its associated image transformation, translation, and rotation factors.

These graphic objects may be nested in the form of a tree structure, providing a heirarchical structure for the building of complex data bases. This tree structure causes an interesting action to occur to each of its graphic objects (nodes). For each node in the tree, the image transformation through which the primitives in that node undergo is the concatenation of the image transformation of that graphic object and the transformations of all other graphic objects above that node. This makes it possible to model complex transformations by the successive concatenation of simple transformations. Thus, a tree may be built containing four graphic objects, the three aircraft and the gridded cube, each of which will have different and complex transformations.

The ability to position the viewer (camera) and control how that viewer looks at a scene is referred to as a viewing transformation. This is controlled by several parameters in the 3-dimensional instruction set. First the user must specify the location of the viewer in 3-dimensional space and in which direction to look. If we imagine the viewer to be looking through a window, we must specify the height and width of that window and the distance from the viewer to that window. These last two factors control the amount of "zoom" apparent in the view of a particular scene. In this application, the horizontal and vertical position of the viewer is controlled by a cursor device on the keyboard, and the distance to the window is controlled by ten zoom function keys.

Lastly, in the 3-dimensional instruction set, the ability to easily create interactive programs is paramount. This system provides the capability to assign user written or package supplied commands to individual function keys. Complex routines may be written and tested and then, by the inclusion of a single command, be logically attached to a particular function key. Thus, it is possible to dynamically assign various interactive responses to each function key for student control during a mission.

Applications Software

The actual applications software is organized as two tasks under a multitasking operating system. The first task is a timer driven task to accomplish the actual animation of the scene. It calculates the path and rate of change of each aircraft for each frame and requests the 3-dimensional instruction set to update its image transformations and create a new frame of picture data on the screen. The second task is concerned with student interaction. It accepts student input from the keyboard, or the function keys, and generates the appropriate responses. In particular, the interactive task will direct commands to the animation task to alter the characteristics of the aircraft flight or the viewing transformation through which they are displayed. It also provides all of the user friendly interpretation and messaging necessary for the student.

A special technique is utilized to achieve smooth animation using the raster scan system. Each successive frame image is built in alternate frame buffers so that, while a given frame is displayed, the next frame is being built into refresh memory by the graphics routines and hardware. When the entire next frame is built, the old frame is made invisible and the new frame is made visible through the use of video lookup tables. This achieves a smooth transition between frames, without the student being forced to watch each frame being built.

GUIDELINES FOR RELATED PROGRAMS

A set of general guidelines applicable to other programs involving low-cost, 3-dimensional computer graphics training devices were compiled as a result of the present effort, and are offered here:

1. Specification of training issues must be made as early as possible so that graphics application routines can be designed which address the critical 3-dimensional issues. Continual discussions with the eventual user during the development of the system are necessary in order to provide a system which satisfies their actual training requirements.

2. If animation is used, a high priority must be given to maximizing the raster scan refresh rate. One way to help this effort is to use firmware chips to store the basic 3-dimensional display package, rather than to have it stored as disk based software.

3. Every effort should be made to enhance the motivation of the student to use the training system. One advantage of using graphics simulators with displays that are easy to understand and simple to operate is that they have the same intrinsic appeal to students that modern graphics "Arcade" games have for the general public.

4. In an interactive training system, special attention must be given to providing accurate and timely performance feedback to the student in order to maximize the effectiveness of the training.

5. Human factors issues which affect the intelligibility of the visual display and the ease of use of the system must continually be given a high priority. There currently exist many technical guides for the design of 2-dimensional displays and controls for training systems, as well as information on the display and perception of 3-dimensional images (Biberman, 1973; Christ, 1975; Farrell & Booth, 1975; Huggins & Getty, 1981).

FUTURE RESEARCH NEEDS

In the graphics display area, future research possibilities include investigations into the level of fidelity required for this type of training system, the optimal size and method of presentation of alphanumeric information, methods to decrease visual flicker in the display, and choice of colors for each displayed item. In addition, research is needed on better ways to enhance the 3-dimensional perspective through the use of a rotatable cube or a representation of a moving ground beneath the flight path of the aircraft.

Finally, the capability for including an intelligent, evasive target needs to be developed, using an artificial intelligence (AI) programming approach. Another needed product, using the AI approach, is a more extensive performance measurement system to provide more detailed feedback to the student.

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