DATA ACQUISITION FOR CIG DATABASE DEVELOPMENT

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ABSTRACT

Hardware developments are rapidly increasing the capacity and reducing costs of Computer Image Generation (CIG) Systems to process and create real-time visual simulations. Hardware costs continue to decline with recent developments resulting in low cost CIG workstation technology. However, software development costs for visual databases have not kept pace with the hardware cost reductions.

Database development costs represent one of the most important cost factors on future overall visual system cost reductions. One of the most important tasks, and one often inadequately addressed, is acquisition of 3-D visual data for incorporation into visual environments. The problem is lack of data necessary to generate realistic simulation databases.

This paper discusses the results of SBIR Topic N86-167, Contract N61339-89-C-0071 with MANDEX, Inc., "Digital Representation of Solid Objects" during 1989 through 1991 which include new techniques and methodologies for acquisition of 3-D data for CIG databases.

ABOUT THE AUTHORS

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INTRODUCTION

Computer Graphics Simulation is widely used by the U.S. Military services, especially for training, tactical planning, system design, concept evaluation and testing. Personnel develop their understanding of a weapons system and become familiar with important aspects of its operation and function without incurring the costs of wear and tear, depreciation or loss of military assets, consumption of supplies (fuel, ammunition, targets, etc.), amortization of costly facilities (e.g. a test range), or the risk of injury to the trainee and others. Furthermore, the training process can be accelerated by numerous repetitions of important or new sequences, while spending less time on sequences already learned. For example, a pilot can practice approaches, landings and takeoffs without the intervening and time consuming climb to altitude. Similarly, engineers can study alternative design concepts prior to final selection, and actually develop evaluation prototype simulations to aide in the selection process. Tactical planners can study alternative strategic scenarios in depth before actually involving personnel and equipment in live fire exercises.

While computer graphics simulation can achieve large cost savings for the military, its potential is limited by the degree of realism that is achievable and by the off setting costs and time involved in developing simulator graphics. Major limitations on realism are the visual detail with which real environments and objects can be depicted in a computer image, and the speed with which the image can be changed to simulate motion, either of the objects in the image, the viewer, or both.

Currently, hardware developments are rapidly increasing the speed and capacity of computers to represent visual detail and to modify images rapidly. Most graphics software tools are also seeing an improvement, and hardware and software prices continue to decline. These trends are supporting improvements in the quality of computer graphics in many applications, as well as stimulating new types of applications. In contrast, however, development of 3-D graphics data for simulation is almost at a stand still. The use of graphics-based simulation for military applications is impeded by the cost of developing accurate and realistic 3-D models of terrain, architectural and engineering structures, vehicles, military equipment, etc. Thus, imaging research is limited by the lack of numerous detailed and accurate models of potential targets, and flight simulators lack detailed and accurate topography, vegetation, buildings, streets and highways, ground equipment, etc., that are needed for instructional realism.

Ideally, these various 3-D objects would be developed directly from photographic or video images of real entities. Instead, they are usually developed indirectly from photographs by artists, or from engineering drawings by CAD operators. The former approach results in models that lack detail and accuracy, and the latter can be enormously expensive.

This is the problem addressed in our work for the Naval Training Systems Center (NTSC): Rapid Imaging of Real Objects and 3-D Model Development. Prior to our Phase I effort, MANDEX had already developed techniques for developing accurate and detailed models of military vehicles from orthogonal vehicle outline drawings, and a photogrammetric procedure for developing models from photographs of vehicles. In Phase I of our work for NTSC we showed how the imaging and modeling processes could be sped up for small real objects and scale models, by use of a video process. We also showed that the vehicular photographic and modeling process could be sped up and made applicable to a much broader range of objects, from small vehicles to buildings, building complexes and architectural/ engineering structures.

PHASE I RESEARCH OBJECTIVES

In Phase I we demonstrated the feasibility of rapidly producing 3-D models of small objects, such as scale models, using a video technique, and of rapidly and accurately modeling objects from photographs without the need for targeting, scaling or orientation aids visible in the photographs. This section briefly summarizes the methodology and findings. Detailed accounts of the methodology and results are contained in a Phase I report submitted to NTSC in December 1987.[1]

The advantages of the video technique are its potentially low labor requirement, its use of inexpensive hardware and software, and its low overall cost. The advantages of photogrammetry without targeting, scaling or orientation aids within the field of view are that, the costs of obtaining photographs are minimized for large objects such as a building complex and that accurate modeling becomes feasible for objects where close physical access is not possible.

Photogrammetric Methodology

All of the methods studied for generating 3-D models are generally referred to as photogrammetric methods.[2] They depend on obtaining multiple 2-D images of objects (perspective photographs or images) and computing the positions of objects or points and positions in 3-D space, utilizing triangulation algorithms. To understand the problems that must be overcome in using photogrammetry for 3-D modeling, it is essential to understand the spatial relationship that exists between a photograph or video image, and the object being modeled.

The fundamental characteristic of a 2-D image is that every point on the image corresponds geometrically to a unique point in the object scene. The size of the image compared with the object depends on the distance from the camera to the object, and also on the focal length of the camera lens. The focal vector defines the direction a camera is pointing as it passes through the focus and the optical center of the lens. The focal vector is perpendicular to the image plane. The view vector for a point on the 3-D object extends from the point, through the lens, and to the focus. The corresponding point on the 2-D image occurs where the view vector passes through the virtual image plane. *Figure 1* illustrates these characteristics.

If we determine, for each camera, its location in space, its focal vector (i.e. the direction it is pointed),

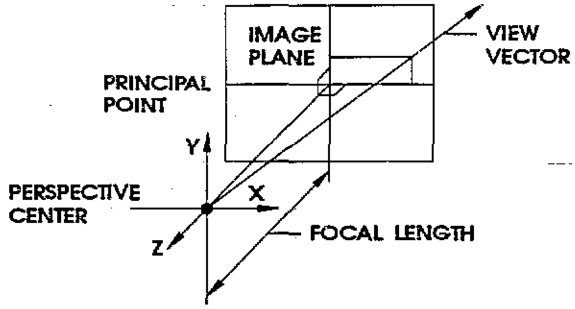

FIGURE 1 2D IMAGE CHARACTERISTICS

and the focal length of the lens, all the data needed to define each view vector and, thus, the triangle connecting a point on the object and the corresponding points on two 2-D images is know. Therefore, for any point on the object, visible to both cameras, its location in 3-D space can be computed. This is what is meant by "triangulation."

Photogrammetric methods based on triangulation differ mainly in how two essential tasks are performed, the determination of correspondence, or, how to identify points on an object in two or more images, and the determination of camera location and direction of aim.

Determination of correspondence is almost always done by a human operator. The video technique demonstrated in Phase I depends instead on a computer technique (referred to as space coding). Determination of camera location and direction of aim usually depends partly on reference points or other aiming and scaling aids placed in the field of view of the cameras. The method devised and demonstrated in Phase I for modeling large objects does not depend on such aids.

Finally, the methods of developing 3-D models demonstrated in Phase I depend, for efficiency, on CAD techniques and software previously developed by MANDEX. These were further developed in Phase II.

Space Coding

In Phase I, most new experimental work went into developing an automated method for identifying points in two or more video images of an object, and using the resulting data to generate a 3-D model. The method used was referred to as "Space Coding". The object of interest (a scale model airplane) was illuminated with an array of lighted dots projected through a series of shutters and viewed from two positions through a CCD video camera.

Each of the resulting video images was captured using an AT computer equipped with a video frame grabber. The overlaid shutters caused the object of interest to be illuminated by a different subset of the array of dots, in such a way that each dot of the array could be identified with a unique on-off sequence. By determining the sequence for each dot in an image, the computer identified the originating dot in the projected array. With precise data on the locations of the cameras and the object of interest, the computer software determined, through triangulation, the 3-D location of each dot striking the object of interest.

Close Range Photogrammetry

Our experimentation with photogrammetry for large objects involved both data acquisition and data input. Data acquisition required procedures for obtaining photographs that were of photogrammetric quality, and instrumentation and survey procedures to obtain accurate data on camera locations and orientation. Data input and model creation required a new software program and procedures for entering the photographic and survey data into the computer for each photographic view.

Data acquisition equipment consisted of a photogrammetric camera, a surveying instrument with an electronic distance meter, range poles with prisms, and tripods. Several locations around a building were selected as viewpoints. At each location, the camera was set up, a photograph made of the building, and the location determined relative to other camera locations utilizing standard survey techniques (a surveying traverse). The camera's azimuth aim was determined at each location relative to points on the traverse, and its inclination relative to horizontal was determined by a gimbal vernier scale. A simple procedure was devised to assist the operator in setting up the equipment at each location and to easily record the necessary data.

Data input to the computer was performed on a MANDEX designed CAD workstation which included an E-size digitizing tablet. Enlargements of the photographs were mounted on this tablet. Using specially developed software, the photographs were positionally registered to the tablet using the field data acquired during the traverse.

An operator then developed a 3-D wireframe model of the building, on the computer, by using the digitizer cursor to identify points on the building, one at a time, common to at least two photographs. Using CAD software interfaced with the data entry software, the operator also connected the points with lines. Upon completing the wireframe, the operator used polygonizing software to add colored surfaces to the wireframe.

TRIANGULATION ALGORITHM

With any single 2-D image there is not enough information to generate depth measurements. Only the direction to a point in the image, not how far into the scene the point is, is indicated. However two photographs taken of the same point from different locations provide enough data to calculate the depth information. ***Figure 2*** demonstrates the mathematical coordinate system that allows calculation of 3-D points from two photographs.

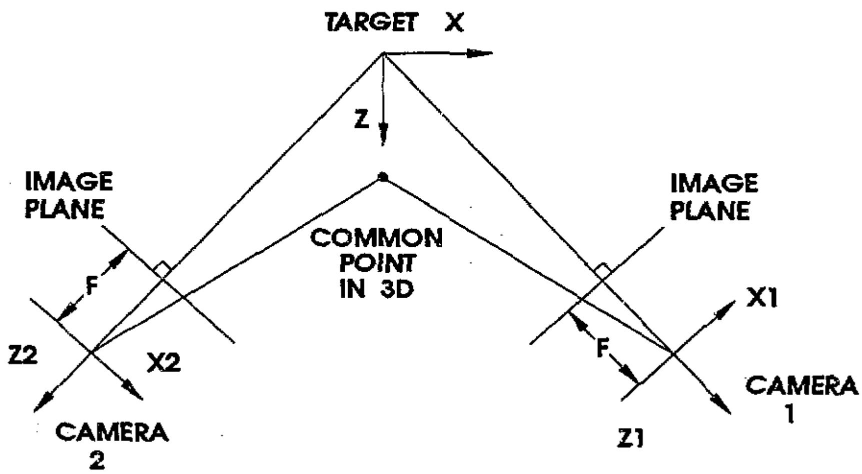

FIGURE 2 3D POINT DETERMINATION

With this system a point on an object is identified in both photographs. Next, a transformation is performed to convert the two view lines from the two local camera coordinate systems into a common coordinate system. This transformation utilizes information about the camera locations and the direction of the principal line of view of each camera. Finally, the 3-D point location is calculated by determining the closest passing of the two view lines.

The algorithm used for the calculation of the 3-D point from two view vectors does not actually calculate the intersection of the two vectors but calculates the location of the closest passing of the vectors. The closest passing of the two vectors can be defined as a line passing between the two vectors which is normal to both vectors. ***Figure 3*** shows the definition of the variables used in the development of the closest passing algorithm.

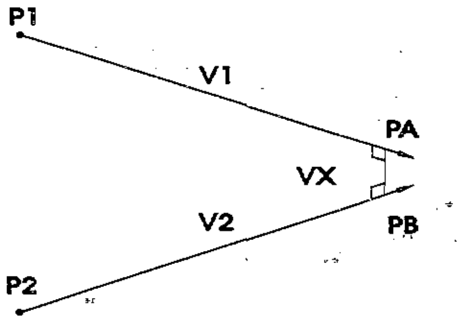

FIGURE 3 TRIANGULATION CONVERGENCE SETUP

The variables are as follows:

P1 Is the location of the focal point of camera 1 in global coordinates

P2 is the location of the focal point of camera 2 in global coordinates

V1 *is the view vector of the point from camera* 1 in global coordinates

V2 is the view vector of the point from camera 2 in global coordinates

PA is the point along the line defined by P1 V1 in which one of the end points of VX is found. Where VX is normal to both view lines.

PB is the point along the line defined by P2 and V2 in which one of the end points of VX is found. Where VX is normal to both view lines.

VX is the vector normal to both view lines defined by P1, P2, V1, V2.

The points PA and PB are defined as follows:

$$PA = (P1 + t1 * V1)$$
$$PB = (P2 + t2 * V2)$$

Where t1 and t2 are scalars.

The vector VX is defined as follows, in terms of PA and PB:

$$VX = PA \bullet PB$$
$$VX = (P1 + t1 * V1) \bullet (P2 + t2 * V2)$$

The closest passing of the two view lines occurs when the dot product of VX and V1 = 0 and VX and V2 = 0

$$0 = VX \bullet V1$$
$$0 = VX \bullet V2$$

Substituting for VX and combining terms,

$$0 = (P1 \bullet P2 + t1 * V1 - t2 * V2) \bullet V1$$
$$0 = (P1 \bullet P2 + t1 * V1 - t2 * V2) \bullet V2$$

Distributing the dot product,

$$0 = P1 \bullet V1 - P2 \bullet V1 + t1 * V1 \bullet V1 -*t2 \bullet V1$$
$$0 = P1 \bullet V2 - P2 \bullet V2 + t1 * V1 \bullet V2 - t2 * V2 \bullet V2$$

With two equations, the two unknowns, t1 and t2 can be solved using substitution. Solving the top equation for t1 and substituting into the lower equation yields;

$$t1 = \frac{(P2 - P1) \bullet V1 + t2^{*} V1 \bullet V2}{V1 \bullet V1}$$
$$t2 = \frac{[(P1 - P2) \bullet V2](V1 \bullet V1) - [(P1 - P2) \bullet V1](V1 \bullet V2)}{(V1 \bullet V1)(V2 \bullet V2) - (V1 \bullet V2)}$$

Substituting variables for common repeated terms,

$$A = (V1 \bullet V1)$$
$$B = (V2 \bullet V2)$$
$$C = (V1 \bullet V2)$$
$$D = (P1 \bullet P2)$$

$$t1 = \frac{D \bullet V1 - t2^{*}C}{A}$$

$$t2 = \frac{D \bullet V2 \bullet A - D \bullet V1 \bullet C}{A \bullet B - C \bullet C}$$

Once the variables t1 and t2 are calculated, these values are substituted back into the formulas for calculating PA and PB. Lastly, the 3-D point is calculated by finding the midpoint between PA and PB.

By defining the 3-D point as the closest passing of the two view vectors, some error checking can be performed. If the distance between PA and PB is above a certain value, the 3-D point may be thrown out. In the software program, this value is referred to as the convergence tolerance.

PHASE II DEVELOPMENT OBJECTIVES

In phase II we proposed to bring together the techniques investigated in Phase I as an integrated system of data acquisition and modeling procedures, hardware and software, for use in rapidly developing realistic simulator models.

Our intent was to make maximum use of existing cost effective computer equipment and proven user-friendly commercial software, as well as custom software developed during Phase I. The resulting system would be demonstrated by developing a 3-D model for inclusion in the Naval Training Systems Center's simulator database.

Ultimately, the system would be developed to include data acquisition systems for ground-based architectural photogrammetry, aerial, and video photogrammetry, and a simulation workstation equipped with software for developing 3-D models from this acquired data.

The emphasis in Phase II was on developing the capabilities demonstrated in Phase I, architectural photogrammetry using land based cameras, and video photogrammetry. Architectural photogrammetry is the application for which demand appeared to be most immediate' In Phase II, it was to be developed as a fully functional package for developing accurate, detailed models.

The video photogrammetry (Space Coding) capability was also to be developed so that it became a practical tool for modeling, but major improvements to the system's resolution, while desirable, were to be left as an enhancement further developed in a Phase III effort or later.

An aerial photogrammetry capability, appeared to be feasible and was considered to be extremely useful. However, this application was not contemplated in the Phase I research and required a design effort before specific development plans could be made. Phase II would include an initial design effort and feasibility study with a view to full development in Phase III.

3-D Modeling Workstation

The main hardware requirement for this system was a computer with the power to store, rapidly display, and manipulate a database containing a very large number of polygons. This was required because in 3-D polygon modeling, it is necessary for the computer to manage much more graphic data than appears on the screen at any instant.

The machine proposed was the Silicon Graphics 4D/120 GTX Super Workstation. We also proposed to acquire a GTCO high resolution E-size digitizing tablet for data input purposes.

MANDEX had previously developed software for creating wireframe computer models from photographs using a digitizer for other military applications. This software, which existed in two versions (for an Auto-trol Apollo CAD workstation and the AT/Matrox computer workstation) was ported to the IRIS workstation. This software was written in FORTRAN for a DOS environment and had to be converted to C on a UNIX system. This constituted a major programming effort.

Knowing that a requirement of the graphic databases created with this system would be to transport them into the simulator software package used by NTSC, we developed a means for saving polygon data in a form readable by Multi-Gen. We also included on the IRIS, a 3-D CAD software package called, CADKEY. The significance of adding this is that data created using any one of the photogrammetry methods, can be loaded into CADKEY for easy editing, modification, or even to add polygons there, before sending the data to Multi-Gen.

CADKEY is also a full function CAD package that can be used for a multitude of graphic development applications. For instance, in Phase II we proposed to incorporate a means for creating terrain models' CADKEY makes this possible by allowing direct digitization of contour maps using the digitizing tablet, and by accepting commercially available Digital Elevation Models (DEM).

The Silicon Graphics software on the IRIS has the capability to produce polygons from a series of 3-D points. The software developed during this effort utilized that capability and has been included in all of the modules that comprise the system. These polygon models, like those that can be created using the CADKEY software, can be saved in a format readable by Multi-Gen.

Architectural Photogrammetry

The architectural photogrammetry procedure was already well developed at the conclusion of the Phase I effort. Phase II concentrated on simplifying the data acquisition equipment and the procedures for recording camera position data, and entering the data into the computer. The major part of the effort for Phase II was in transporting the original software developed in FORTRAN for a DOS environment, to the C programming language in the UNIX environment used by the Silicon Graphics IRIS-4D Series Workstation.

To improve the data acquisition portion of the Architectural Photogrammetry procedure, a photogrammetric workstation was designed, assembled, and tested. It consists of a lightweight metric camera (the same camera used by the Aerial Photogrammetry procedure) mounted and registered on top of a digital theodolite (survey workstation). This "total station" greatly simplifies the original equipment configuration which required three pieces of equipment, the theodolite, electronic distance meter, and camera, be mounted one after the other in sequence to acquire the desired data. The total station presents quickly to the user, all data required by the digitizing software to determine camera location and aim.

Aerial Photogrammetry

Phase II included initial design and feasibility study of a procedure for producing graphic models using low altitude, oblique, aerial photographs. The emphasis was on a technique for obtaining multiple photographs of an area of interest (say a building complex) along with data on the position and orientation of the camera at the instant each image was obtained. A software module similar to that used by the architectural photogrammetry method would have to be developed at some time, if the results from the feasibility study were promising.

Design consisted of devising a stabilized mounting rig for a camera, and a procedure for recording data representing the position and orientation of the camera relative to some known position (such as the position when the first exposure was taken). The possibility of using satellite position data was to be considered. Other possibilities for determining camera position included "dead reckoning based on airspeed, heading, wind speed and direction, and rate of climb or descent and altimeter readings.

The feasibility study consisted first of an error propagation analysis to determine if adequate accuracy was likely to be obtained. Results were favorable and development of a working system was started.

Video Photogrammetry

The technique demonstrated in Phase I involved forming light dot images of an object of interest as viewed from different directions, and then to combine these 3-D views to form a completed model of the object. Although we concentrated on the techniques for easily forming the model views and on obtaining an acceptable resolution, the most important developments needed were to make the procedure practical for routine application and to develop a simple and reliable procedure for registering the views so that they have a common 3D coordinate system, that is, a procedure for accurately "welding" the views to form a completed model. The quality of the model produced in the Phase I effort was greatly impaired by the lack of such a procedure.

For objects in the size range that could utilize the video technique, the appropriate approach to merge views seemed to be to improve the method used in Phase I, in which the object was placed on a turntable. The spindle of the turntable becomes the center of rotation of the coordinate system, the cameras remain in fixed positions, and the rotation of the turntable, and the angle of rotation for each partial model (relative to the starting position) was carefully measured and controlled.

The image capture hardware is similar to that used in Phase I. The same personal computer equipped with a video frame grabber board recorded the images obtained through a pair of CCD video cameras. (Use of the IRIS workstation for this task was considered wasteful, the AT computer was adequate for the purpose.)

The pattern projection system was improved with the purpose of making it simpler to operate. The overhead projector used in the Phase I effort was replaced with a 35-mm film strip projector that has the 64 x 64 array of dots fixed rigidly in the film holder. The shutters used to mask the light dot array, and thus project subsets of the array onto the object of interest, are a series of frames on a film strip that are quickly advanced into place.

Minor improvements were made to the image capture and processing software to accommodate the image registration procedures and simplify the acquisition process. Many cosmetic changes were made to the menu system to improve its use and make it more understandable.

PROJECT RESULTS

The results from the SBIR program Phase II effort are described below. Overall, the concept of developing a complete system for acquiring and creating data to use in constructing visual databases has been achieved. Some of the methods developed are more practical than others, but all meet specific data acquisition requirements and needs.

Architectural Photogrammetry

The Architectural Photogrammetry process is definitely the most complete and accurate method developed. It is also the most efficient and practical. It's use of off-the-shelf hardware for data acquisition, which is sure to come down in price, make it an excellent tool for reverse engineering now, and in the future. It does however have a few drawbacks.

For our purposes on this effort, we used some rather expensive equipment, particularly the surveying instrument and metric camera. The cost of this equipment could potentially limit the number of users, although, through the experience we have gained from this work and other photogrammetric studies, this drawback can be overcome. An inexpensive 35mm camera could be substituted in place of the metric camera. The only requirement would then be the inclusion of a Reseau plate in the camera which is necessary to apply markings on the photograph that are used for registration. Information about lens distortion is also a requirement but not extremely critical unless high accuracy is necessary in the resultant computer model.

A lesser expensive surveying instrument should also be available that will accomplish the same tasks as the TOPCON used on this effort. An alternative to purchase, of course, would be to rent the equipment. Most surveying supply companies have top quality equipment available for rental purposes and can supply all of the necessary tripods, prisms, and training for a relatively small daily or weekly rental fee.

The Architectural Photogrammetry procedure also requires some degree of access to the object being photographed. A minimum of four photographs are required to make the software work properly, and eight photographs are recommended. In cases where access is limited, we have allowed in the procedure the ability to take multiple photographs from a single camera station. For example, if the camera station is too close to the object to get the full view in the camera frame, a shot can be taken of half of the object and then rotate the camera to get a shot of the rest of the object. The software has been designed to accept photographs taken in this manner which effectively alleviates this drawback.

Once the procedure and equipment are understood by the user, a data acquisition session takes only a couple of hours to perform but will vary depending on the number of camera stations required to traverse the object of interest. After the photographs are developed and enlarged, a session on the computer is also relatively short depending on the level of fidelity desired. For the models created during this effort, to test the method, our operator required four to five hours to construct each. This time included a substantial amount of starting and stopping to identify and eliminate minor problems in the software and input procedure. An estimate for a fully trained operator with properly functioning software should therefore be two to three hours per model.

As stated earlier, this acquisition and modeling technique is the most efficient and practical of those developed. It is most useful for objects that range in size from an automobile to a building and allows for a high level of fidelity in the model. To reverse engineer or document objects in this size range, it is definitely the method of choice.

Aerial Photogrammetry

The Aerial Photogrammetry technique has the potential to be the most useful of the methods developed, but at this time, still has a few obstacles to overcome. This acquisition technique and software was the least tested of those developed under the contract due to the limited amount of field data that was acquired. Additional flights to acquire data were not made, due in part to time constraints associated with the delivery of the GPS receiver. There are also significant costs associated with making these flights which could limit use of the entire process.

Aerial Photogrammetry captures the greatest amount of data in the least amount of time over any of the other developed techniques. It is also the most appropriate data source for developing large database models to the level of fidelity currently used by NTSC. Our test flight lasted only one hour, including flight time from the airport to the UCF campus and back. Although this could be considered a short flight, two passes were made around the campus, and an additional pass over the adjacent research park. This was done after much experimentation with different elevations and distances from the object of interest was performed. Without this experimentation time, substantially more data could have been acquired in the same amount of time.

The major drawbacks to using this method are the cost for the metric camera and GPS receiver, and the cost for aircraft rental. As described with the Architectural technique, the expense of the camera could potentially be reduced. This obstacle is easily overcome. The cost of the GPS receiver should drop over time and could possibly be integrated into the Architectural technique to eliminate or reduce the cost of the surveying instrument required there. As for aircraft rental, our one hour flight cost about $750.00, which included some labor charges for installation of the GPS antenna. This cost may be prohibitive for some, but considering the amount of data that can be acquired in a short period of time, the cost may prove to be inconsequential when compared to alternative data acquisition methods.

Building the model database from the photographs acquired using this method is relatively simple. It follows the same procedure as the Architectural technique but is not used to achieve the same level of detail. Roads, water bodies or any desired ground feature is easily created to form the model base. Buildings and structures are accurately located and drawn as a footprint that can be extruded into the third dimension or used as a guide to pop into place a model from another database previously created from any other model building method (e.g. Architectural, CADKEY).

The model of the UCF campus, which can be viewed on the IRIS, was created in about sixteen hours. Included in that time were several interruptions for minor programming changes and evaluations of the input technique, which when subtracted, would substantially reduce the modeling effort. The buildings in the model are also more detailed than is necessary for the NTSC database.

Comparing this method to others, based on time, indicates that it is most economical when used to create models at the level of detail currently used on the NTSC databases. Developing the same model using two dimensional maps and conventional aerial photographs would definitely take more time and would not be as accurate, both in position and data, due in part to the source acquisition dates of the data. This judgment is based on our experience in graphics development over the past six years and the records we have compiled and use when developing cost estimates for proposals.

Additionally, our experience indicates that three dimensional model development using commercially available CAD software is cumbersome and time consuming. The methods that have been developed during this effort have been designed to make three dimensional modeling as simple as possible. They eliminate the need for measuring a drawing and keying in dimensional data. Direct digitization in 3-D is a significant improvement that substantially reduces time and effort, thereby reducing cost.

Of the methods developed during this effort, Aerial Photogrammetry is the most directly applicable to the needs of NTSC's database development requirements.

Video Photogrammetry

The Video Photogrammetry system, though improved greatly over the Phase I system, is still a time consuming process. The accuracy and ability to more effectively merge views to form a complete model are the most significant improvements to come out of our efforts.

Capturing images for a single view of the object of interest using this method takes nearly an hour. Images from at least four views are necessary to create a model and when multiplied by the time, results in a significant effort. The resulting model is also not of much use. Hand editing by the user is still necessary to clean up the model before polygonizing and the number of polygons created to approximate the object surface is much too great to allow inclusion of the model into a larger database.

Although we accomplished the goals set down in the contract for this task, our recommendation for use or continued development of this modeling technique would be to divert any efforts to a more applicable and promising technique such as the Aerial Photogrammetry method. The complexity of the equipment setup, cost of the equipment and amount of effort required to create a poor model are major detriments to the use of this method as a tool for use by NTSC in simulator database modeling.

Terrain Modeling

The development of a Terrain Modeling capability is a useful asset to the total system. This coupled with the CADKEY software, serve to round out the 3-D Modeling Workstation capabilities.

With the number of commercially available Digital Terrain Modeling databases increasing, the inclusion of a method for accepting, manipulating and polygonizing that data was an essential component to be included in this total system. The method utilizes software previously developed for the Video technique thereby making some further use of the effort spent on that task.

The models created from DTM's cover a large area of terrain and are useful as a base for the larger model. Roads and buildings created using the Architectural and Aerial techniques can be laid directly onto the terrain to complete the model. We have supplied on the IRIS, four DTM quads of the Central Florida area that can be used in conjunction with the NTSC database.

SUMMARY

In summary, Architectural and Aerial Photogrammetry are useful and economic tools for database development. These have definite and direct uses by NTSC. Terrain Modeling is certainly useful when you consider the source data available that can be utilized and the resulting images that can be created and used. The Video Photogrammetry technique does not have a direct application for use by NTSC and should not be explored further.

Recommendations for further additions to this system should include the incorporation of methods and software to utilize and manipulate remotely sensed imagery data. This appears to be the only technique left to explore that could potentially be added to the system. Satellite data is also commercially available and can be used to automatically generate 3-D models. Commercial software packages have recently been introduced, at a reasonable price, that will perform this function using SPOT imagery in stereo pairs.

With the exception of a module to utilize remotely sensed data, the 3-D Modeling Workstation developed under this Phase II effort is a complete package of computer hardware, data acquisition equipment and procedures, software modeling tools, and documentation that greatly aide in the rapid development of computer models for simulator database development, through the use of photographic, video, and commercially available data.

REFERENCES

1. James, G., Craig, S., and Couts, D. "3-D Representation of Solid Objects With Minimum Human Intervention", N61339-86-R-0066, Dec., 1987.

2. Slama, C., Theurer, C., Henriksen, S. "Manual of Photogrammetry" Fourth Edition, American Society of Photogrammetry, 1980.