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The U.S. Army Engineer Topographic Laboratories (USAETL) has initiated a program to design and develop a terrain Information Extraction System (TIES). This is a test-bed system which will integrate many diverse capabilities drawn from the fields of photogrammetry, remote sensing, automated cartography and geographic information systems; all within a distributed, digital environment. TIES will be an extensible, modular system which will be used to develop more responsive and reliable techniques to generate digital terrain databases. The system will provide a "beginning-to-end" mapping and exploitation capability utilizing a number of digital and digitized image source materials to collect data needed for various military and civilian activities, including wetlands delineation and water resources management. TIES is being developed on commercial off-the-shelf hardware, and will incorporate both proprietary and public domain software. Major components of the system include an image scanner, a digital stereo photogrammetric workstation and geographic information systems.

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DESIGN AND DEVELOPMENT OF THE TERRAIN INFORMATION EXTRACTION SYSTEM

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ABSTRACT

The U.S. Army Engineer Topographic Laboratories (USAETL) has initiated a program to design and develop a Terrain Information Extraction System (TIES). This is a test-bed system which will integrate many diverse capabilities drawn from the fields of photogrammetry, remote sensing, automated cartography and geographic information systems; all within a distributed, digital environment. TIES will be an extensible, modular system which will be used to develop more responsive and reliable techniques to generate digital terrain databases. The system will provide a "beginning-to-end" mapping and exploitation capability utilizing a number of digital and digitized image source materials to collect data needed for various military and civilian activities, including wetlands delineation and water resources management. TIES is being developed on commercial off-the-shelf hardware, and will incorporate both proprietary and public domain software. Major components of the system include an image scanner, a digital stereo photogrammetric workstation and geographic information systems. This paper will describe the system components, discuss associated development issues and outline the system's projected use for digital database generation applications and future research activities.

INTRODUCTION

The U.S. Army Engineer Topographic Laboratories (USAETL) has initiated a program to design and develop the Terrain Information Extraction System (TIES). TIES represents an effort to develop a test-bed system which will integrate many diverse capabilities drawn from the fields of photogrammetry, remote sensing, automated cartography and geographic information systems; all within a distributed, digital environment. The aim of this project is to create an extensible, modular system which will be used to develop more responsive and reliable techniques to generate digital spatial databases. TIES will allow users to update existing data which is not current or lacks sufficient detail as well as generate new data where information is unavailable.

A tremendous hindrance to Army systems developers, as well as to the utilization of geographic information systems in general, is a simple lack of digital spatial data. TIES is one strategy for addressing this problem. Where standard digital data are unavailable or unsuitable, it makes sense for a user to generate the required database for a particular application. TIES will provide this capability by functioning as a "softcopy" mapping workstation where all the operations of an analytical stereo plotter will be available, though the imagery will be in a digital format. In fact, a softcopy workstation environment will allow much greater capabilities, on less expensive hardware, than an analytical stereo plotter can offer using film positives. This development should represent a significant step forward in database generation technology, methodology and digital image exploitation.

The objective of this paper will be to describe the various components of TIES and the advantages provided by working within a softcopy workstation environment. The paper will also discuss associated development issues, and outline the system's projected use for digital database generation applications and future research activities. A brief historical background from which the system concept has evolved will be provided as well.

BACKGROUND

The concept of automated mapping systems is not new. As early as the mid 1950s Rosenberg (1955), and Williams and Rosenberg (1956), first proposed development of an "electronic" photogrammetric system for automated data acquisition and processing. While this early system successfully demonstrated relief measurement and orthophoto production, automated feature extraction has remained "the major problem of today's systems" (Gruen, 1986). Further, Gugan and Dowman (1986) report that "the concept for a completely digital stereoplotting system was first suggested by Sarjakoski (1981)."

Work on automated feature extraction has continued with varied success. While no fully automated mapping technology has emerged, progress has been made in developing interactive and semi-automated mapping systems. Significant advances have occurred in software design for automated elevation data extraction, stream delineation from elevation data, automated "road followers" for delineating roads and other linear features using computer vision techniques, and feature extraction through classification of multispectral data. Much progress has also been made in developing interactive automated mapping systems. These systems have essentially integrated the functionality of a number of traditional photogrammetric instruments, such as comparators and stereoplotters, with mapping software and geographic information systems (GIS) technology.

The design of TIES has evolved from this integrated mapping system model. Also, the TIES design has been greatly influenced by past work in the development of the Computer Assisted Photo Interpretation Research (CAPIR) system. The CAPIR and other integrated systems have basically linked GIS and automated mapping software with analytical stereoplotters and map digitizing tables to generate high accuracy, digital spatial databases from hardcopy aerial photos and maps. The CAPIR system is unique in that it was the first system to integrate an analytical stereoplotter with a stereo graphics superposition capability, which is very valuable for on-line quality control (Lukes, 1981). Today, emerging technology has made it possible to design softcopy mapping systems which offer additional advantages. These advantages, the TIES components, and some of the development issues will be discussed next.

TIES COMPONENTS AND DEVELOPMENT ISSUES

The Terrain Information Extraction System could probably best be described as a wholly integrated "beginning-to-end" digital mapping and exploitation system which will include interactive and semi-automated spatial database generation and analysis tools. Figure 1 shows a simplified schematic of the system configuration. Though a large majority of the project deals with software development and/or implementation, two workstations are being constructed which are key to the success of the program. One workstation is being built as an Image Digitizing System (IDS) or image scanner, and the other will function as the Digital Stereo Photogrammetric Workstation (DSPW) or digital stereoplotter. A brief discussion of the various system components follows.

Digital Stereo Photogrammetric Workstation

The Digital Stereo Photogrammetric Workstation may be considered as the "heart" of the TIES (Figure 2), and much of the discussion will be directed towards it due to its importance in the overall system design, and because most of the work to date has been devoted to its development. Also, it should be acknowledged that software engineering for the DSPW is being performed under contract by General Dynamics. The DSPW though, represents a "new era" in terms of photogrammetric instrumentation (ie. digital stereoplotter) that researchers have been working to develop. Gruen (1989) articulates a number of added capabilities provided by a softcopy workstation environment. A few of the many characteristics which he points out include: "data acquisition, processing, editing, storage and administration in a single system," "high degree of interactivity" with a "combination of automatic and operator controlled processing," and "the capacity for the management of large amounts of data." The DSPW will of course retain conventional photogrammetric capabilities such as interior and exterior orientation measurements, aerotriangulation solution software and high accuracy feature mapping. However, the source material will now be digital or digitized stereo imagery as opposed to film based material.

Several authors have eloquently discussed the advantages offered by such a softcopy system (Sarjakoski, 1981; Gugan and Dowman, 1986; Gruen, 1989) and some of these points, in addition to those previously mentioned will be reiterated. The outline presented by Gugan and Dowman (1986), summarizing Sarjakoski, concisely states five most significant advantages of a digital stereoplotter, those being: "(1) There are no high precision optical or mechanical components, or the necessity of regular instrument calibration. (2) Digital imagery is inherently stable, and therefore no inner orientation is needed. (3) Image presentation can be optimized, such as by contrast stretching. (4) Many procedures are, or can be automated, such as loading images from storage, and image correlation. (5) On-line measurement systems can be developed." These advantages, along with continuing advancements in technology, will inevitably transform photogrammetry from its traditional role into a more diverse "vision discipline." Here, it may be used in conjunction with computer graphics and image processing techniques and employed in many new applications, including those related to a three dimensional visualization and modeling environment (Gruen, 1989).

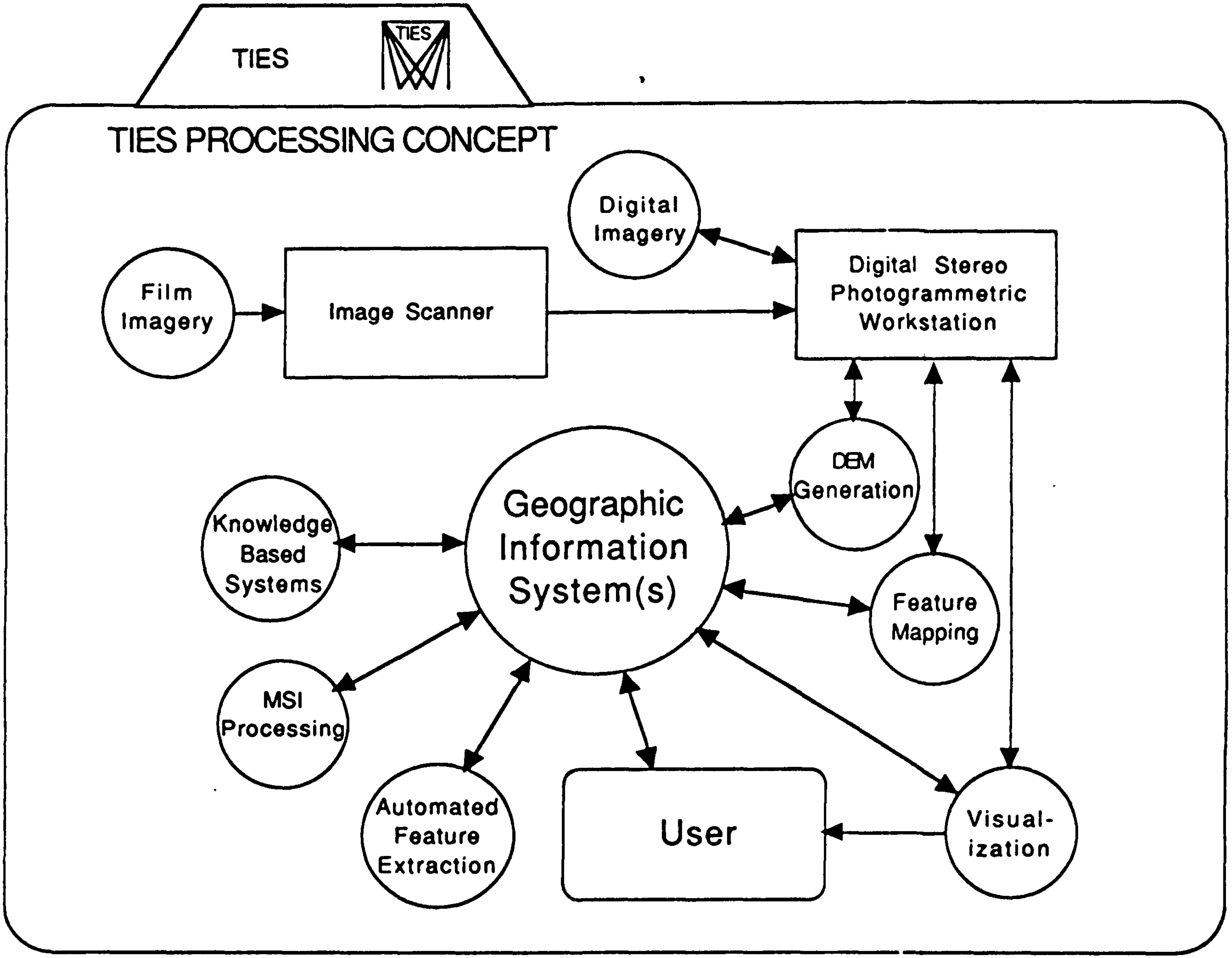
TIES
TIES
TIES PROCESSING CONCEPT
Digital Imagery
Film Imagery
Image Scanner
Digital Stereo Photogrammetric Workstation
DEM Generation
Geographic Information System(s)
Knowledge Based Systems
Feature Mapping
MSI Processing
Automated Feature Extraction
User
Visual-ization

Figure 1

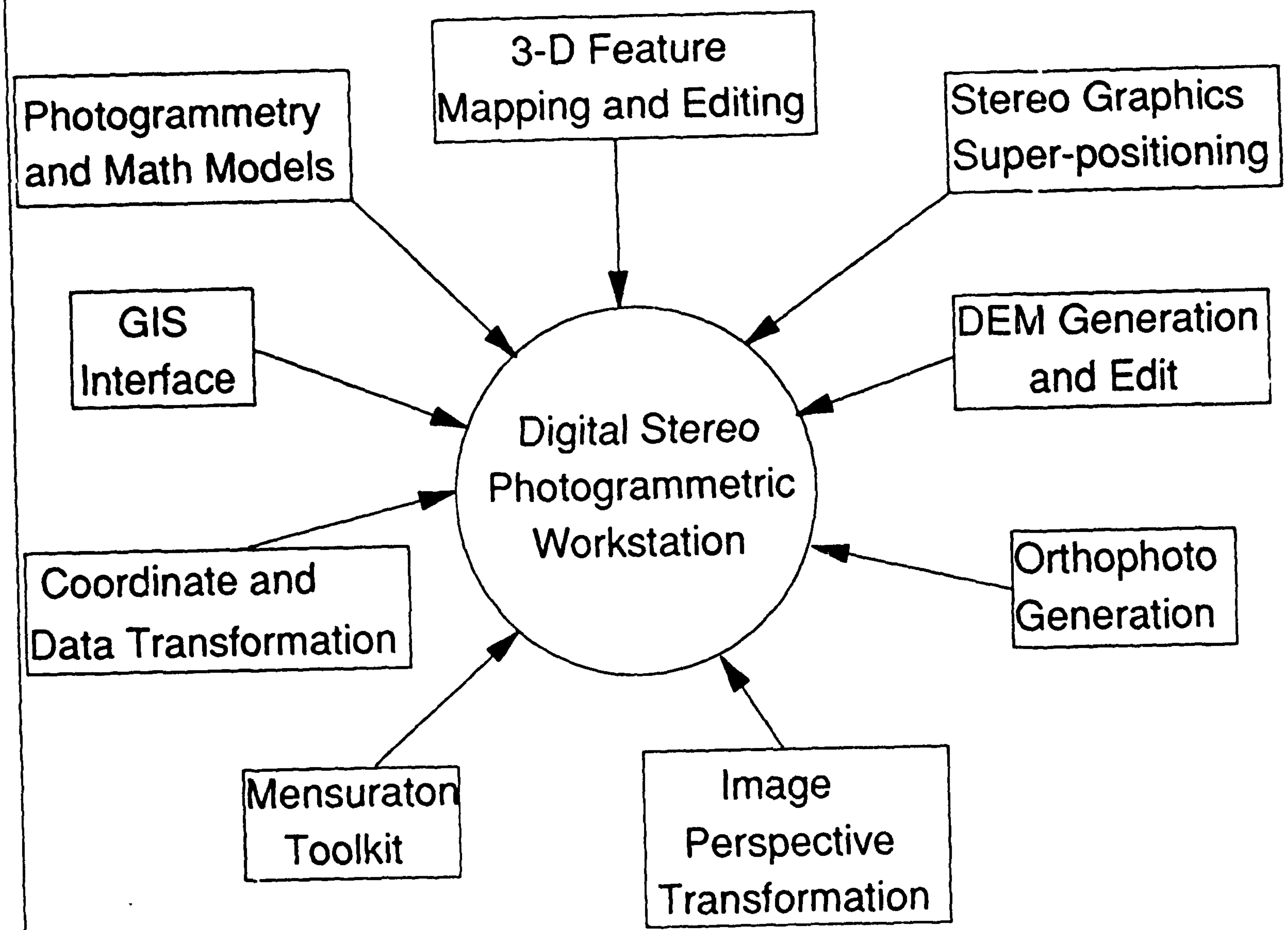
3-D Feature
Mapping and Editing
Photogrammetry
and Math Models
Stereo Graphics
Super-positioning
GIS
Interface
DEM Generation
and Edit
Digital Stereo
Photogrammetric
Workstation
Coordinate and
Data Transformation
Orthophoto
Generation
Mensuraton
Toolkit
Image
Perspective
Transformation

Figure 2

Initially, the DSPW will function primarily as a database generation tool, deriving highly accurate point positioning data, digital elevation data, and two and three dimensional feature data from a wide variety of digital and digitized monoscopic and stereo imagery. These image sources include, among others, digitized standard frame aerial photos, digitized high resolution point positioning database photos (HR PPDB), SPOT and LANDSAT data. Some of the key capabilities of the workstation include interactive feature mapping with stereo superposition graphics for on-line editing and quality control, variably spaced automated digital elevation model creation using the hierarchical relaxation correlation method developed by Helava Associates, Inc. and digital orthophoto production.

To achieve this high accuracy database generation capability, photogrammetric software incorporating rigorous math models for these different sensors must be implemented on the system. An issue which will need to be addressed is to assess the accuracy and suitability of several of these new sensor models. A trade-off may exist between a rigorous triangulation solution compared to a "rubber-sheeting" approach due to the application, accuracy, cost and performance required by a particular mapping project.

Many design and development considerations for a digital stereoplotter, predominately dealing with hardware specifications and their implications, are discussed thoroughly by Gruen (1989). In terms of hardware configuration, the DSPW components consist of a Sun 4/260c-32 computer, a VITec image processor board set housed within the Sun, and a Tektronix stereo display monitor utilizing the liquid crystal display (LCD) device. This device displays a 512 x 1024 pixel active stereo image, or a 1024 x 1024 pixel monoscopic image. The system operator must also wear a pair of circularly polarized glasses which allow stereo viewing with the LCD. The reticle, or floating mark, is fixed while the images scroll relative to this point. The XYZ position of the floating point is controlled by a special mouse which also contains a thumb wheel for Z (X-parallax) control. A major, and somewhat costly development issue which has arisen is a need to upgrade the current VITec image processor. This is necessary because the system as it exists now does not adequately scroll and manipulate both images simultaneously to allow real-time stereo maintenance and more efficient use of the system.

Several functional capabilities or "essential features of a digital stereoplotting system" are listed by Gugan and Dowman (1986). They are "(1) real-time scanning [ie. roam or pan] of a three dimensional model. (2) stereo viewing (3) capability of handling large images [and] (4) sub-pixel measuring accuracy." The combination of these essential capabilities, along with the planned hardware configuration, are the major factors affecting the design and development of an effectively useful system. Real-time roam and stereo viewing are discussed above and these capabilities will exist when the image processor is upgraded.

Large image handling and sub-pixel measuring accuracy will be accommodated as well. Sub-pixel accuracy is required for precision point positioning and geodetic ground control measurement, and is supported by some of the conventional image processing programs resident on the system. Large images may be handled too. The image memory is 24 megabytes, but just as importantly, very fast disk to image memory transfer rates will be achieved by using data blocks or "image tiles." Further, an image fringe loading module will be implemented which will load adjacent image tiles into memory based on the distance to the edge of the displayed image and the direction of the reticle movement.

Image Digitizing System

Vast quantities of archived film based imagery exists which represents important mapping and temporal documentation of the environment. To date, one of the most accurate means for digitizing these images was to use a micro-densitometer. However, these instruments are extremely slow and require frequent calibration and maintenance. Other film scanners exist which are relatively faster, but the geometric and radiometric fidelity do not meet the high accuracy input requirements of TIES. Therefore, a new image digitizing system, utilizing charge-coupled devices (CCDs) technology, was designed so that the TIES would not be dependent on digital data alone or on sub-par scanned data. The actual system engineering of the IDS is being performed to Government specifications under contract by Intergraph Corporation.

There are a number of salient characteristics this new image scanner has which makes it a state-of-the-art instrument. The resolution, or "spot" size may be as fine as 7.5 microns with a specified geometric accuracy of a 2 micron mean square error (MSE) across the full image scan. The maximum image format size is 9.5 inches by 9.5 inches. Additionally, a full black and white image may be scanned in less than 12 minutes (triple that for a color image), compared to the many hours required when using a micro-densitometer. The system includes red, green, blue and neutral filters to accommodate both color and panchromatic imagery. The dynamic range of the IDS is 11 bits though only the most significant 8 bits are used.

The image digitizing system will also be able to scan a number of different image types as input to the DSPW. This will complement the multiple math models residing on the system, thereby increasing its flexibility for mapping projects. A unique design aspect of the IDS is its ability to rotate frame mapping photography, up to plus or minus five degrees, to align the photo axis with the scanner axis. It may be possible as well to align the scan along the epipolar plane of the image, which is an important feature when considering digital image input to an automated correlation algorithm for deriving elevation data. Another important capability is that the IDS will be able to perform and store interior orientation measurements which may then be used by the DSPW aerotriangulation software.

TIES Subsystem Software Modules

The TIES subsystem modules shown in Figure 1, such as the DEM generation and feature mapping software, the geographic information systems, the multispectral image (MSI) processing system, and the software related to expert systems and automated feature extraction, are all vital to the system concept. This design represents a multi-purpose and flexible system where many functional capabilities are linked. The TIES network concept is shown in Figure 3. In terms of system development these interrelated components are at present separate initiatives, some more mature than others, which need to be integrated to work within a networked system architecture. Obviously, many technical issues must be worked out regarding subsystem interfaces, data formats and conversions, and network protocols, and these problems are presently being addressed.

With regard to automated feature extraction and expert systems modules, this software is still within the realm of basic research. Though the software for automated drainage delineation is completed and will be installed on the system early on, other functional modules will not be completed for some time. These would include software for road and building delineation as well as terrain analysis and photo interpretation rule-based expert systems.

The multispectral image processing and GIS modules are better defined. Since the DSPW is an interactive mapping system, and database integrity and topology are so important, a vector based GIS is most appropriate. The output format from the DSPW will be compatible for input to the ARC/INFO geographic information system, a proprietary package from the Environmental Systems Research Institute (ESRI). It will be within ARC/INFO, running on a Sun workstation, that various spatial analyses will be performed.

Initially, the multispectral image processing component of TIES will consist of both public domain and proprietary software for evaluation and testing. It will include the Land Analysis System (LAS), which is being developed by the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA), and will be hosted by a Sun workstation. The other system being used is a personal computer (PC) based Earth Resources Data Analysis System (ERDAS). These packages will be used for performing image enhancement and classification functions for feature extraction. The unique capability provided by the integration of these image processing systems within TIES however, is that now it will be possible to perform very accurate geometric corrections on the imagery through the use of rigorous sensor math models within the DSPW. This will be valuable for many purposes including change detection and other applications where two or more images must be registered to within a pixel or better.

Finally, the data derived through image processing may then be used within either the Geographic Resources Analysis Support System (GRASS) GIS, or by using the GIS capabilities which reside within the ERDAS system. These are both raster systems which are very compatible and appropriate for the analysis of data derived from remotely sensed imagery. It is also planned to have an accurate hardcopy map output capability which will be provided by interfacing a large format, single pass plotter.

FUTURE RESEARCH ACTIVITIES

Several future research activities are foreseen at this time and may be divided into two general areas; these being system integration and applications. Certainly, system assessments and refinements, as well as continuing development and integration of knowledge based expert systems for terrain analysis and automated feature extraction capabilities, will

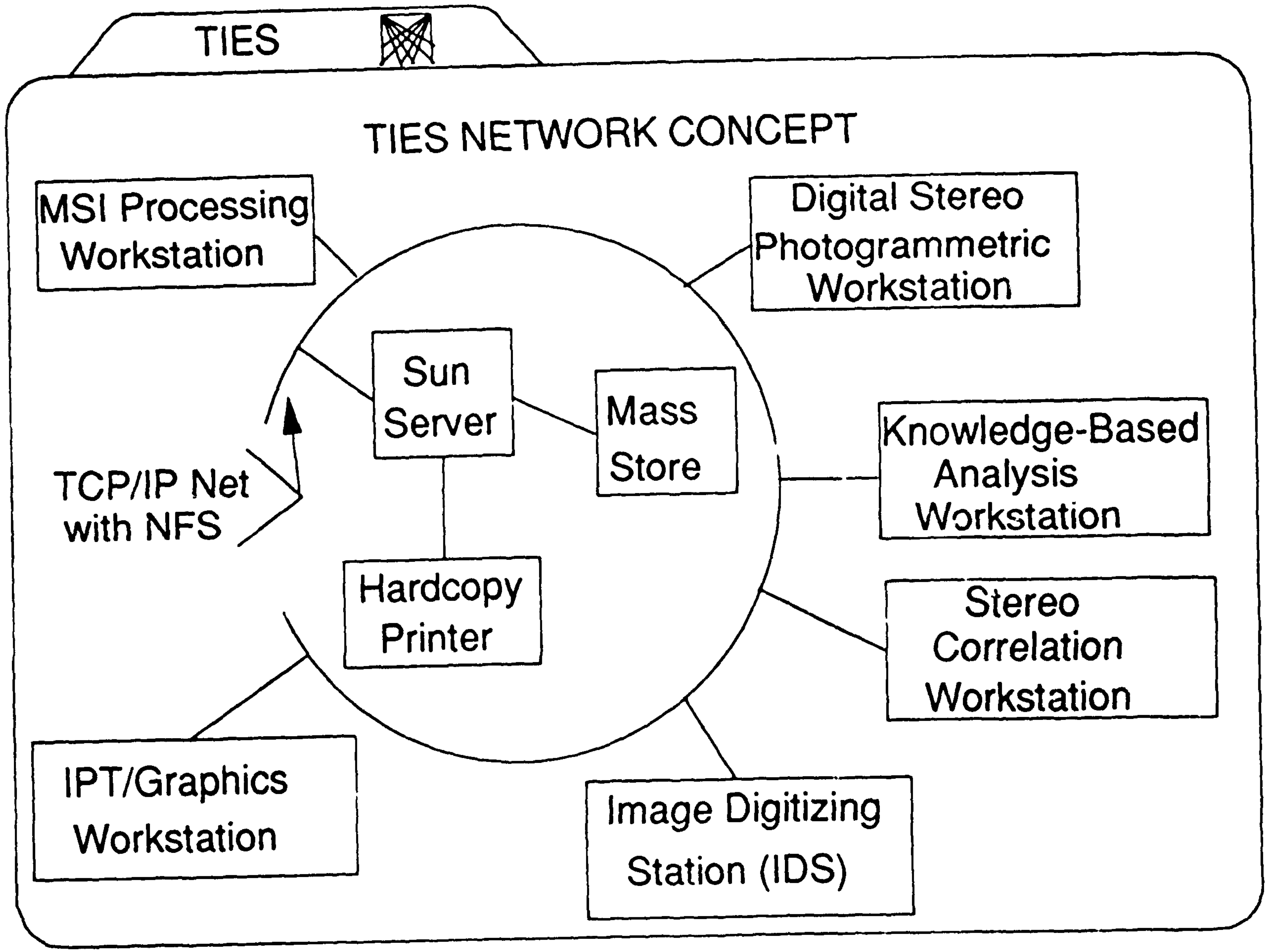
TIES
TIES NETWORK CONCEPT
MSI Processing Workstation
Digital Stereo Photogrammetric Workstation
Sun Server
Mass Store
Knowledge-Based Analysis Workstation
TCP/IP Net with NFS
Hardcopy Printer
Stereo Correlation Workstation
IPT/Graphics Workstation
Image Digitizing Station (IDS)

Figure 3

be an important area of work. Also, the notion that the imagery used for database generation is an important part of the database itself, and should be utilized and saved by the user, will be examined. Possible advantages for this may include solving for ambiguity within a database, and as an image background to GIS overlays for revision purposes. Accuracy assessments of the IDS, sensor models, and derived digital map data must also be made. Visualization of these digital databases using computer graphics, three dimensional modeling, and image perspective transformations is also considered to be an important area of research.

Lastly, technology transfer to different applications must be identified and accomplished. Initially, this effort will focus on terrain analysis databases and environmental monitoring and analyses. Already work is being planned and performed for wetlands delineation, evaluation, and change assessment in response to the Corps of Engineers requirements for enforcing Section 404 of the Clean Water Act. One site assessment using multi-temporal image analysis has supported a violation decision and resulted in a cease and desist order for a major road construction project in Fairfax County, Virginia (Anderson and Davis, 1990). It is believed that TIES and its multiple products and capabilities will find easy acceptance for meeting mapping and spatial analysis requirements from many different disciplines. For instance, the generation of digital terrain databases for various simulators and computer image generation systems is being examined. Database generation is also an issue of concern for many developing systems within the military services. So, even though this technology is in a very early stage of development, there seems to be a "great potential [for] this new category of instruments" (Gruen, 1989), and for the role such integrated mapping and analysis systems will play in the future.

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