AN INSTALLATION FOR INTERACTIVE TRANSFER OF INFORMATION FROM OBLIQUE AERIAL PHOTOS TO MAPS

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The ancient monument protection service of the Rhineland has installed a system for transforming archaeological information in oblique aerial photos to 1:5000 base maps. A comprehensive software-hardware plan was implemented. Windowing, enhancement, pseudo-color density slicing and merging are employed. A simple map compression scheme which offers a reasonable compromise between bit rate and computing time has been developed.

The major river valleys in the temperate parts of Europe have been occupied by man for many thousands of years. During this time he has constructed dwellings, settlements, fortifications, roads and cemeteries, and has completely transformed the appearance of the landscape with agriculture. It is one of the major tasks of modern archaeology to trace this development, and it is the function of an archaeological monument protection service to conserve as much of the fragmentary evidence as possible. Unfortunately, the qualities of the land which made an area attractive for settlement in the past often continue to do so in the present. Hence the rate of destruction of these vestiges through modern construction is high. The best way to preserve the cultural heritage of material remains lying in the ground is to leave them there untouched as long as possible for future planned scientific exploration and study. This presupposes foreknowledge of what is there and where it is. Accurate data must be provided for planning authorities so that modern works may by-pass important archaeological concentrations whenever possible. At the least, the field archaeologists must be given advance warning of impending destruction of an ancient buried monument so that they will not have to excavate in haste.
Up to now, long lists of endangered sites, found by walking through the fields and looking for traces of remains on the surface, have been used. This is of limited use for few planning authorities have enough personnel to deal with them. What is needed is a set of overlays for the largest scale map available, preferably the same scale

as used in planning. These can be placed over the planning maps and one may see at a glance what is there.

How do archaeological sites come to be buried? Most structures either collapse after a time due to natural decay processes or they are pulled down on purpose and leveled. Subsequent agriculture and natural soil movement due to weather and earthworms buries the remains. Little or nothing is visible on the surface. However, just below the surface there is an anomalous zone which has different physical and chemical properties from that of the surrounding undisturbed earth. A buried wall, for example, is more poorly drained than the surrounding soil and retains less moisture. A buried ditch, filled with fine surface loam is more water retentive. Under appropriate dry conditions, crops grow poorly over buried walling and better over better ditches as shown below.

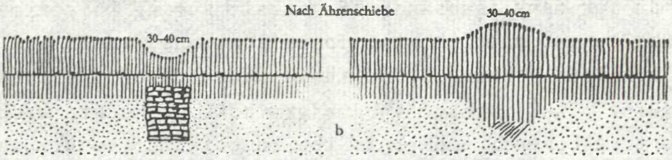


Figure 1

From the air, these markings can be clearly seen and photographed with normal panchromatic film when flying at low altitude. Maximum contrast is in the yellow-green region reflecting differences in the chlorophyll xanthophyll and carotene concentrations in growing plants. This technique has been used for the last fifty years or so, starting in southern England in 1924 and since 1960 in France and Germany to explore systematically for buried archaeological sites (Scollar, 1970). At the Laboratory for Field Archaeology where the technique was introduced by the first author, many thousands of black and white photographs made from a low flying light aircraft with a hand held camera have been produced. Typical examples are shown in Plates 1 and 2. In the left lower center of Plate 1, the dark gray outline of a square enclosure with rounded corners can be seen along with a number of irregular markings. This is due to the buried defensive ditch of a small late Roman fort. Plate 2 shows the outline of the foundation walls of a Roman farmhouse. Both photos are exceptionally clear and they require no enhancement. Precise mapping of the sites means using analytic photogrammetric techniques (Scollar, 1975). With coordinate information derived from points visible in the photographs also visible on the base maps, the position of the aircraft and the angles of view can be computed by an interative technique. From this knowledge, the projective transform matrix can be obtained. With a pair of pictures, height information can be obtained. The photos are usually taken in a sequence of five or more when flying around the site in a tight circle. Using the set as pseudo-stereo pairs, points of archaeological interest can be converted to map coordinates. Vertical air cover obtained by mapping cameras do not show as much detail. The archaeologist-photographer unconciously snaps the picture when he observes maximum contrast in the viewfinder. This contrast only appears at certain angles relative to the sun's illumination, and the likelihood that a vertical picture will produce this by chance is small.

Formerly, our technique was to measure contact transparencies in a stereo comparator and type film coordinates and map coordinates for ground control points along with points of archaeological interest into a terminal connected to a time-sharing remote machine. The interactive analytic photogrammetry program returns ground coordinates for the archaeological features, and these are plotted by hand on the base maps. The technique allows for no enhancement of the image, is very slow and subject to human error through fatigue. Of the thousands of photographs in the Landesmuseum's collection, only a tiny fraction have been treated in this way.

In the Rhineland, we are fortunate in having a nearly complete base map survey. It was decided that all aerial archaeological finds must be recorded at this scale, or in some instances at 1:1000 where the detail required it. In other parts of the world like England, where aerial archaeology has been going on for nearly two generations, there are at least a million photos in the files of various services awaiting evaluation and mapping. Before the backlog in Germany becomes quite so great, it was decided to automate the method by introduction of image processing techniques. We obtained financial support for the purchase of a dedicated system. This made it possible to think in terms of a problem-oriented "top down" design, starting with the anticipated application software, chosing the appropriate type of operating system, and only then selecting the hardware to implement the concept.

The principal operations envisaged are enhancement, windowing, inter-

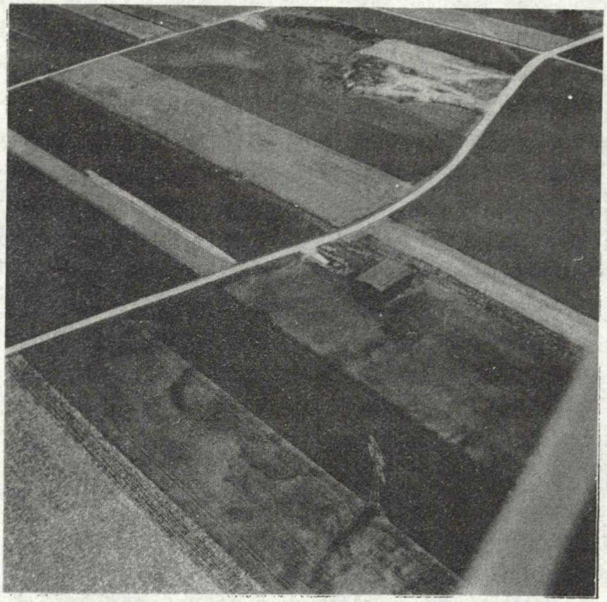


Plate 1- Roman Fort in the Rhineland, Freig. Reg. Präs. D'dorf.
16/28/5515

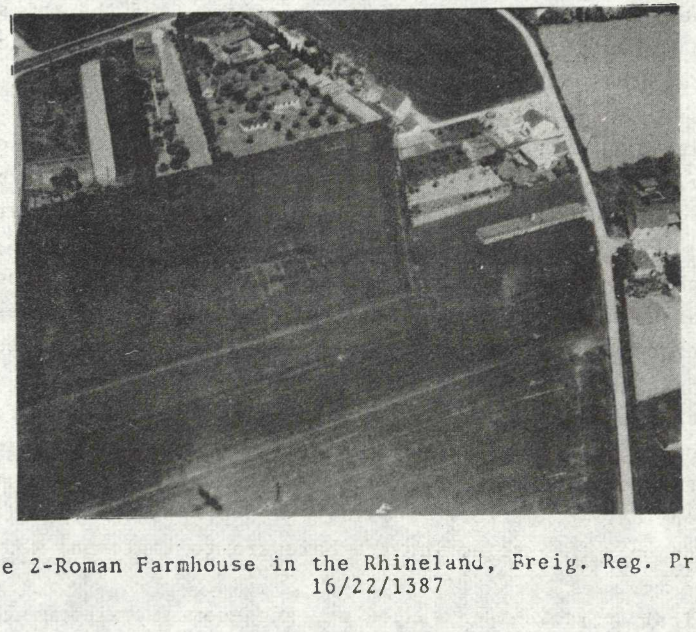
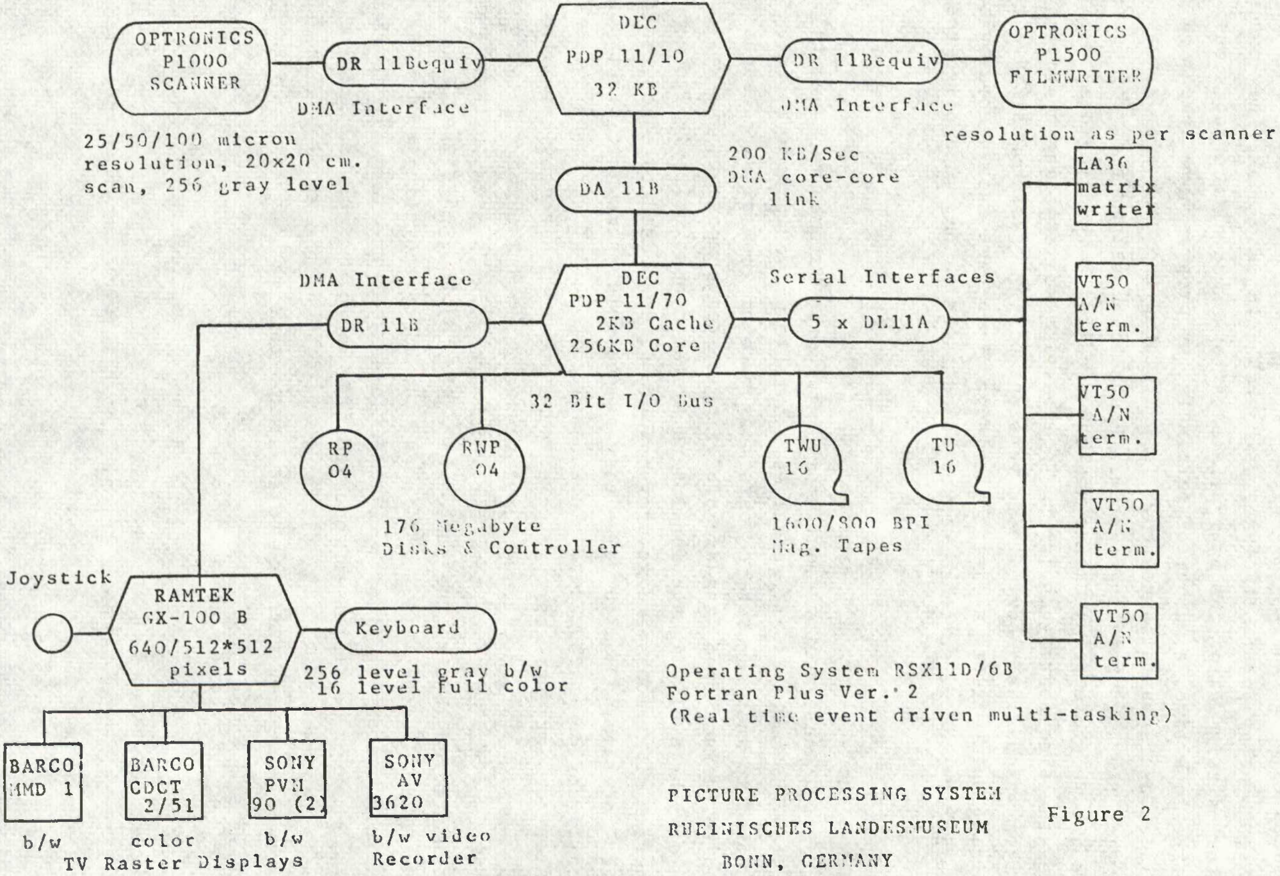


Plate 2-Roman Farmhouse in the Rhineland, Freig. Reg. Präs. D'dorf.
16/22/1387

actively controlled feature extraction, photogrammetry and merge with scanned base maps. Automatic recognition of archaeological features appears to be beyond the state of the art. Hence the system was designed as an interactive one, with archaeologists unskilled in computer matters making the appropriate pattern recognition decisions. At the same time, a number of terminals for program development by skilled users was also needed. This dictated the choice of a real-time or time sharing operating system. Financial considerations of overhead, core store requirements and the need for a swapping disk eliminated the time sharing choice and a real-time multitasking operating system was decided upon. Later versions of this system must have time slicing which allots a finite time segment to each task according to a priority scheme so that compute bound tasks cannot monopolize the CPU.

Unskilled users are not expected to interact with the operating system directly. An executive monitor is interposed between them and the system and controls all resources. A table driven parser is to be adapted to analyse user requests. As much of the software as possible had to be made from standard operating system components and written in a high-level language for future system compatibility. Since peripherals of various manufacturers had to be connected together, software interfacing had to be as easy as possible, and where practical nearly device independent. Thus standard manufacturer's hardware interfaces of only one type were to be used. Other considerations, such as total cost, hardware maintenance support, number of systems produced and length of time for which operating system software has been offered lead to the choice of a Digital Equipment PDP 11 as the basic machine with a version of the RSX11 operating system. Picture processing is extremely I/O intensive when large areas of the image cannot be stored in core memory. Therefore the PDP 11/70 which has a separate I/O bus 32 bits wide as well as the usual Unibus was chosen. The configuration built around this machine is shown in Figure 2.

High requirements for geometric accuracy and long term stability were imposed on the hard copy output device. In addition gray scale capability for future plans to create photo mosaics was also specified. A large format film was needed. The Optronics P 1500 drum writer met most of these requirements. The input pictures are mostly on 5 inch aerial film with a square image area of 11x11cm. Contact trans-



Operating System RSX11D/6B
Fortran Plus Ver. 2
(Real time event driven multi-tasking)

PICTURE PROCESSING SYSTEM
RHEINISCHES LANDESMUSEUM
BONN, GERMANY

Figure 2

parencies are to be scanned, four at a time, to minimize handling of precious unrepeatable original negatives and to reduce mechanical operations in the scanner. A very wide range of gray level resolution with good accuracy was needed since films vary considerably in density and gamma. High geometric accuracy for determination of control point information along with long term stability was needed. These features were also of great importance when scanning the reduced base maps. The Optronics P 1000 with 25-100 micron resolution met the requirements. It does not, however, provide convenient rapid random access to any area of the image. An image point is digitized or written every 33 microseconds and two pixels are buffered before going as double bytes to the interface. Every 16 microseconds a word has to be transferred to or from the computer. Although the transfers are direct memory access (DMA), to avoid Unibus conflicts it was thought advisable to buffer a complete scan or write line before transfer to PDP11/70 memory by interposing a PDP11/10 as a data concentrator. This small machine runs under a stripped down version of the multi-tasking system. The link to the PDP11/70 is essentially two DMA units back-to-back with synchronization of the Unibusses during transfer of a line of data. The transfer rate of the link is 50% faster than that of the combined data rate from the scanner and the writer, so that no bottlenecks occur. A separate task in the 11/70 writes the scanned lines immediately to disk, or takes a line from disk into core and sends it out over the link when ready.

Pictures reside on big disks as direct access files. This allows some degree of random access to any data point. A circular buffer scheme is used in the 11/10 so that overlapped operation of the writer, scanner and link is feasable. A picture pipeline design was decided upon for best throughput. While one set of up to four pictures is being scanned, the previously scanned set is being worked on, and the results from the set before that combined with map data is going to the writer. In this way it is hoped to achieve throughput times which are commensurate with the time needed to change films in scanner and writer and develop output images, after fine tuning of the system. The use of the big disks for main picture sotrage required two units, so that input and output operations reside on separate machines. This allows some overlapping of input/output operations. The system is capable of a resolution which would result in 64 megabytes for four images of the size stated. The amount of I/O required at this resolution would clog the pipeline. In practice it has been found unnecessary to digitize the input images to better than 50 microns, and the output maps, if done one at a time can also be written at this resolution. for a 20x20 cm area. Thus considerable reserve storage on the disks is available for program and system files. Back-up for the disks, both for short term storage of images and for long term storage of maps is given by two 1600BPI tape units. For programming purposes there are four alphanumeric terminals and a matrix printer terminal for paper copy.

A very critical point in a system designed around man-machine interaction is the picture display. This item was not available in a proved model on the international market until the middle 70's. When the hardware configuration was made final in May 1975 there were only two systems which fulfilled the quality requirements, but only one, the Ramtek GX100B, which used an all solid state picture refresh memory. It was chosen for ease of maintenance. The display system memory of 327 Kilobytes stores a picture with either 640 or 512 elements per line and 512 lines, interlaced. Each element is 8 bits fed into a programmable look-up table which maps into either 8 bit black and white or to three 4 bit color digital-analog converters. To avoid flicker, the display refresh runs at 30 pictures per second. In order to avoid interference with the 50 cycle power line, Barco CDCT 2/51 and MMD 1 studio color television monitors were chosen. Additionally, a Sony AV3620 black and white video recorder was modified to accept the 577 line 30 frame interlaced Ramtek signal. The recorder is used for documenting programs under test so that they can be examined offline without rerunning them over and over again. The recorder is displayed on the modified Sony PVM90 monitor. The sound track is used to record additional comments. A second Sony monitor is mounted permanently near the display controller for repair purposes. It is used together with the recorder when static screen photographs are inadequate to record errors in the display memory. The user of the system interacts with the Ramtek via a joystick and a keyboard. It is planned to install a graphic tablet in the near future to allow finer control of the software cursors than the joystick affords.

The success of this mixed hardware design was proven during system integration. As components from various manufacturers arrived they were hooked up to the standard DMA interfaces in a matter of a few days. Software integration using a single type of primitive synchronous handler required about two man-weeks to write. The more sophisticated asynchronous handlers now in use needed about three man-months work. Initial component deliveries began in December 1975 and final deliveries and connection in May of 1976. All system software ran correctly in early September of that year. A few application programs and picture utilities were ready for an official opening at the end of that month. At the time of writing, application programs for histogram equalization, convolution filtering, pseudo-color density slicing and contrast enhancement, and polygon coarse feature extraction are in operation.

A few preliminary results, photographed from the display monitor, are shown in Plates 3-6. In plate 3, a windowed area of the Roman fort (Plate 1) is shown without treatment. The original was contact printed with low contrast. This was scanned at 50 microns giving a 2048 by 2048 pixel image. A 512x512 window was extracted and displayed. The density histogram in the small window was extracted and the histogram streched (Hummel, 1975). The result was applied to the look up table in the display memory and the result is shown in Plate 4. A similar procedure was followed with the farmhouse in Plate 5 and 6.

After enhancement, a line following schem being developed will be used interactively, with the archaeologist indicating critical points with the joystick or tablet. The coordinates corresponding to these features will be transferred to the analytical photogrammetry task. The process will be repeated for multiple images in the sequence and the photogrammetry task will return map coordinates to the writer task. This will be followed on a display which has been simulated in Plate 7.

For the Rhineland there are about 4000 base maps at 1:5000. Digitized byte for byte and recorded on tape, these would exceed our physical storage capacity. With a simple table look-up algorithm and a threshold, the byte images are transformed to bit images of the map in black and white. This effects a data compression of 8 times. To obtain further compression, a simple run-length coding scheme has been devised. In this scheme, two 8 bit bytes making one word are used. If the first bit in the first byte is off, then the run length to next black or white is given by the next 7 bits. If the first bit is on, then the run length is given by the 7 bits as before, plus the 8 bits in the next byte. This code, christened 8-16 is particularly rapid to compute for compression and decompression. A test was made on the Deutsche Grundkarte 1:5000, Sheet Rill, 2536 R/5718H, as representative of partly built-up areas in the Rhineland. The map was scanned from

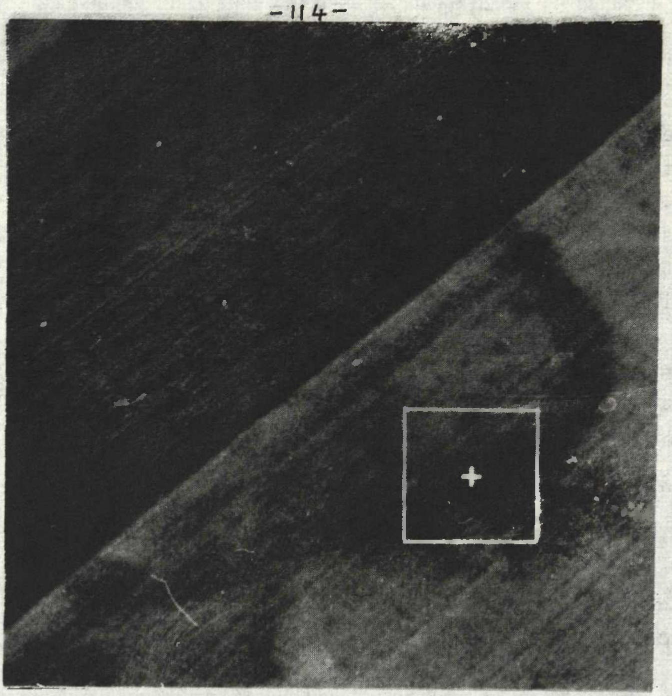


Plate 3- Display Monitor, Unenhanced windowed image

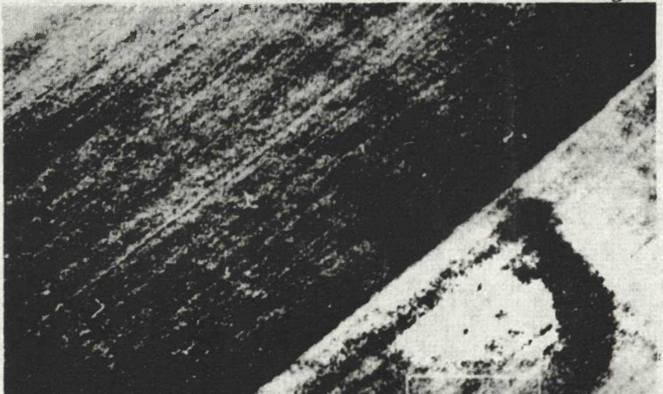


Plate 4- Enhanced image, histogram equalizing from window

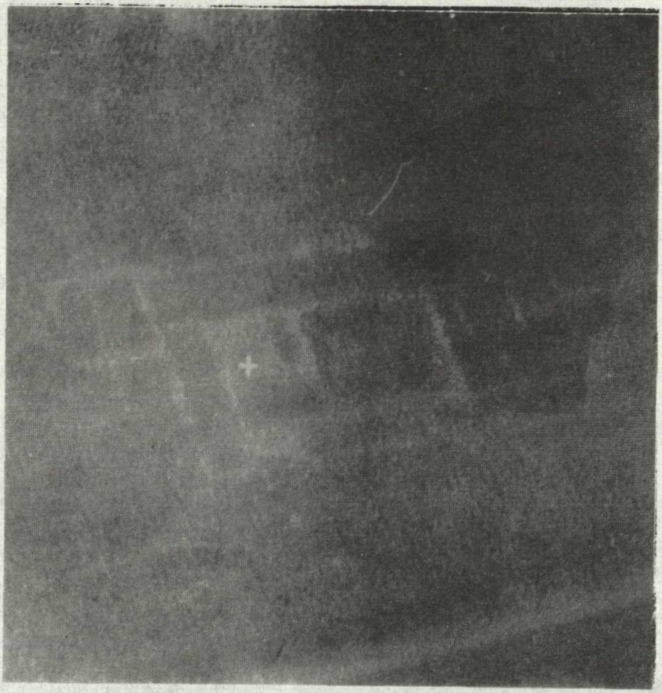


Plate 5-Display Monitor, Unenhanced windowed image

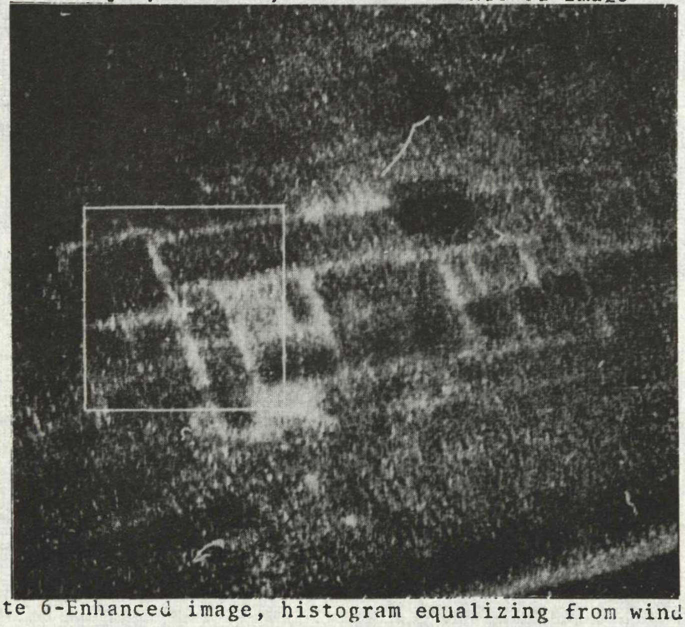


Plate 6-Enhanced image, histogram equalizing from window

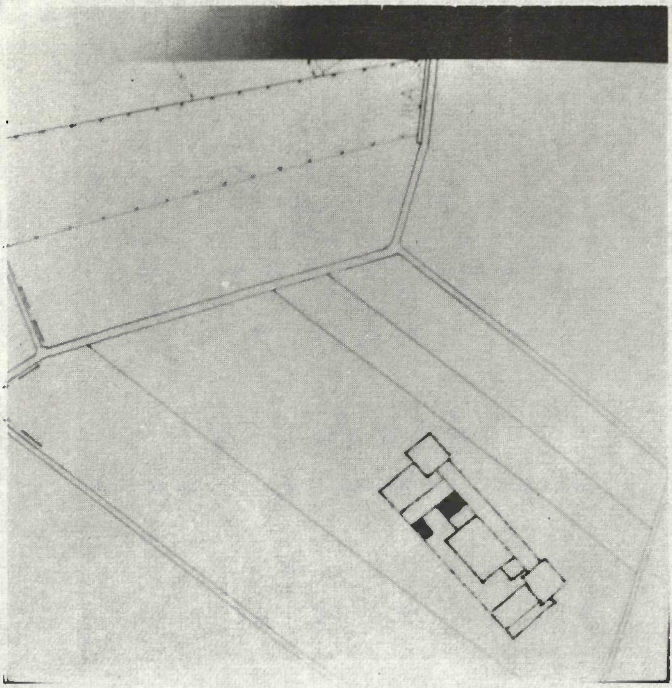


Plate 7-Display Monitor, simulated extracted feature and insertion in scanned map with reference gray scale. The actual scanned and reproduced map with the photomgrammetrically corrected data cannot be reproduced for copyright reasons.

a 20 x 20 cm. negative made from the original plate by the Landesvermessungsamt, Bad Godesberg for us. This is a 2:1 reduction. 50 micron resolution was used giving 16 megabytes. The average white run length was 51.98 pixels, the average black run length was 3.52 pixels. The fraction of black pixels was .063. The bit rate of the 8-16 code in bits per pixel was .304 which corresponds to a compression of 3.3. A code which used 5 or 6 bits for the first term would give more compression at an increase in computing time because packing and unpacking of the data on a bit basis goes more slowly. Using this code plus the byte bit reduction algorithm reduces map storage requirements so that about 50 to 60 magnetic tapes will suffice for the entire collection of 4000 sheets. The archaeology will be kept separately and merged with the maps as required with output on film. Additional data from the Landesmuseum's hundred year old archive will be recorded symbolically in a third file and used when necessary.

Although the image processing system described was originally planned with the problem of mapping oblique aerial photos in mind, it has proven to be quite a general configuration which can be applied to many other problems in archaeology and in other fields. The design of the system from the "top" down made installation and initial operation relatively painless and rapid. It was much easier than comparable systems which were made up of hardware accumulated over a period of time, for which software was composed ad hoc. The approach is highly recommended when planning a new system. The concept of standard hardware interfaces with similar handlers is the key to system integration.

Responsibility:

The first author was responsible for the overall system design and for the hardware configuration. He also designed the 8-16 map compression code. The second author was responsible for the map compression statistics. The third author planned and produced the system software and the windowing and density slicing application software, as well as many utilities. The fourth author programmed the histogram equalization and digitial filtering schemes.

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