COMPUTER AIDED INTERPRETATION OF TURN POINT PHOTOGRAPHS

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Presented at the XXII OSTIV Congress, Uvalde, Texas, USA (1991)

1. INTRODUCTION

One of the more arduous tasks in running a gliding competition is the interpretation of turn point photographs. Frequently, photographic interpreters (PI) perform their jobs with technology little more advanced than a magnifying glass. The main problems are:
1) All interpretation is performed on negatives, not positives.
2) PI's can suffer eye strain from extensive viewing of negatives.
3) Difficulties exist when discussing penalties with pilots if printing or viewing facilities are not available to expand the negative.
4) Penalties are inevitably awarded from the PI's visual interpretation of the negative rather than an accurate analysis.

This paper discusses a system based upon a low cost IBM PC computer, which can provide significant advantages for competition photographic interpretation.

2. HARDWARE

2.1 Introduction

A block diagram of the system is shown in Figure 1. The negative is back-illuminated by a light box and imaged by a charge-coupled device (CCD) monochrome camera. The camera is connected to a digital frame store, installed in an IBM PC, which digitises the image, displays it and stores it in memory. The black and white image is displayed using a 14" monitor separate to the computer monitor. The computer has control over the frame store and may, thus, manipulate the image. A detailed discussion of each part is now given.

2.2 Imaging System

A CCD camera was chosen, in preference to a vidicon type, owing to the low cost and high performance of these devices.

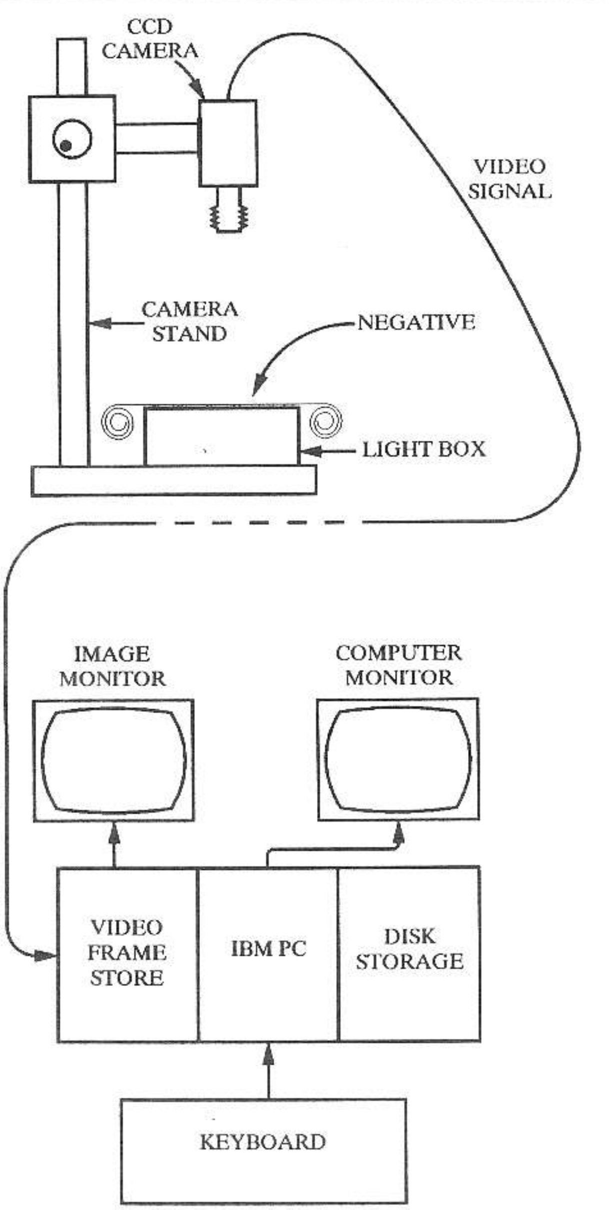

FIGURE 1. Outline of computer based photographic interpretation system.

The camera had a light sensititivty of 5 lux which, although relatively low, was adequate for the application since the negatives were backlighted from a standard photographic light box. The camera was fitted with a 49mm/1.8 lens which, when connected to the camera via a 5mm tube, allowed the whole of one frame of a negative to be imaged, correctly focused, and displayed on the system. The camera was fixed to the arm of a standard photographic copy stand. The light box and negative were placed on the platen as shown in Figure 1. The distance between the camera and negative could be varied by adjusting the height of the arm. This feature was occasionally useful and allowed a 'blow up' of a small part of the negative to be made.

Originally, a metal guide was used to hold the negative in the correct position underneath the lens. However, after some use under competition conditions, this was discarded since it was far easier for the PI to hold the negative onto the light box surface in the correct position manually. The drawback to this approach is that the negatives must be completely dry, otherwise, the emulsion surface of the negatives tend to get damaged by movement over the light box surface.

2.3 Computer, frame store and monitor

A standard IBM PC AT compatible with a 80286 processor was used for this application. No special features were required other than a hard disk for ease of use.

The frame store was a Visionetics Inc. VFG-512, which consists of a single plug-in card for an IBM PC/XT or AT. When installed in the PC, the frame store is powered from the PC power supply and is connected to the outside world by a 9 pin connector located on the back of the backplane of the PC. A lead supplied with the frame store connects to the camera and the image monitor. The frame store digitises the incoming video signal from the camera at the rate of 25 frames per second. Each frame is made up from a grid of 512 horizontal by 512 vertical picture elements, or pixels. Each pixel conveys a light intensity level with a resolution of 8 bits. Thus, each pixel can display one out of a total of 28 = 256 different intensity levels, or grey levels, which are usually ordered from 0 to 255 produces a fully bright pixel. The intensity level of a pixel is referred to its pixel value; the position of a pixel in the 512 by 512 grid is referred to as the pixel location. All of the information for each of the 262,144 pixels which comprise a single frame is stored in the memory of the frame store. The contents of the memory are continually reconverted to a video signal by the frame store and displayed on the image monitor. The PC can access the frame store and is able to examine and change the value of any pixel, and instruct the frame store to 'freeze' the contents of the memory, i.e. to prevent any more information from the camera being stored in the memory. In this situation, the image monitor displays a 'still' of the last image the camera saw before the instruction was given. Similarly, the computer may load the frame memory with an image that has been previously stored on disk.

The image monitor used was a standard 14' black and white monitor more normally used, as would be the camera, for security and closed circuit television use.

3. SOFTWARE

Application software written in the C programming language allows the following features:

3.1 Positive image display

As so far described, a negative image by the camera and displayed on the image monitor would appear as a black and white, negative image. Although experienced PI's adapt very quickly to viewing negatives, it is far easier, especially when discussing penalties with pilots, to view the photograph as a positive image. This may easily be achieved by appropriate computer programming.

Figure 2 shows a block diagram of the processes involved in converting the frame store memory to an image [1]. The digital data from the memory are seen to pass through a look-up table (LUT) before being converted to a video signal by the digital to analogue converter (DAC). The LUT is a 256 byte memory, programmable by the computer, which has its input connected to the frame memory and its output connected to the DAC. By default, the LUT gives an output which is the same as the input. This is shown in Figure 3a), which is a graph of LUT input versus output. However, if the computer programs the LUT with the transfer function of Figure 3b), then it is seen that an input of 255 (i.e. white) gives an output of 0 (i.e. black) and so on. The displayed image of a negative will now appear as a positive.

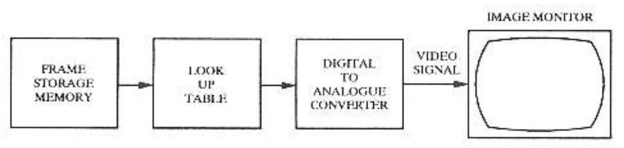

FIGURE 2. Block diagram of image display process.

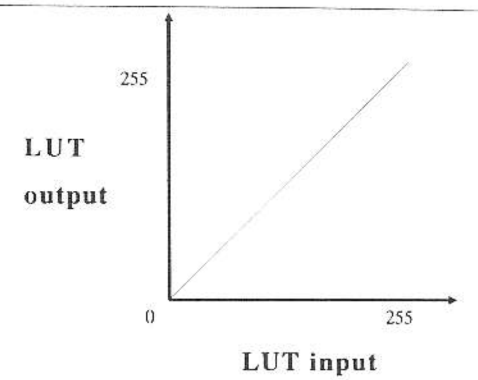

FIGURE 3 (a). LUT transfer function for positive camera image.

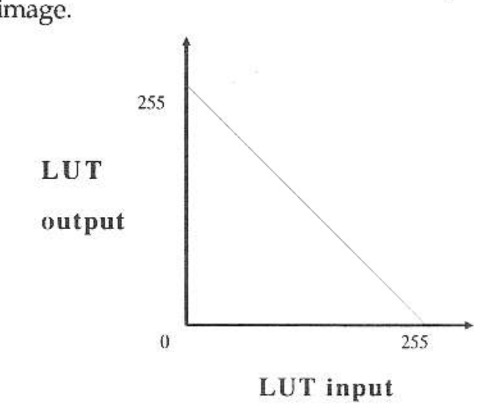

FIGURE 3 (b). LUT transfer function for negative camera image.

3.2 Image enhancement

Some photographs are difficult to interpret if a loss of visual acuity has occurred. A typical example of this is the photograph taken from high altitude on a hazy day. Similarly, infrequent changing of the film developer and fixer can lead to poor quality negatives. Although it is very rare to encounter a photograph which is completely uninterpretable, hazy photographs present an added complication to the PI. To overcome this problem, a simple image processing technique was sought which would give appreciable image enhancement yet not place too much of a processing burden on the computer; an image enhancement technique which gives crystal clear results is unlikely to be of great use to a PI if it takes the computer 5 minutes to perform the calculations.

A technique called histogram equalisation [2] being a very simple algorithm, was found to give respectable results for hazy pictures. The technique works by calculating the histogram of the occurrences of pixel values in a given image. A perfectly clear image is usually characterized by a uniform use of all pixel values, i.e. there is an even spread of all grey levels. However, a hazy picture will be found to contain a large concentration of pixels having a small spread of grey levels. The essence of histogram equalisation is to find a way of remapping the pixel values so that all grey levels are used equally. The basis of this technique is found in Appendix 1. Plate 1 shows an image from the monitor of such a hazy photograph. Plate 2 shows the same photograph after the computer has performed the histogram equalisation technique. It is noted that Plate 2 is far clearer than Plate 1.

Histogram equalisation does not require extensive arithmetic operations by the computer, but it does need to access every one of the 262,144 pixel locations in the frame store in order to construct the histogram and thus, there is a large data transfer overhead. The software developed, which was written in C, took 25 seconds to process. However, if the code was written in assembly language then a processing time of several seconds should be achievable.

3.3 Image storage

Photographs that need further discussion with the pilot or competition director can be stored on disk. Each image requires 256kb of disk space and hence a 20Mb disk is capable of storing 80 images. The software developed took 20 seconds to retrieve or store an image. In the longer term, a purpose designed database which would allow access to stored images according to competition day, aircraft number and turn point would improve this facility. Although this facility does not obviate the need for storage of negatives in general, it does help in situations where penalties have not been agreed several days after the competition day.

3.3 Glider position determination

3.3.1 Introduction

To perform his or her job, the PI has to evaluate the glider position from a visual analysis of the turn point photograph. The majority of turn point photographs do not require very accurate positional determination since it will be obvious that the glider is within the sector, even allowing a large margin of error. However, photographs that are marginal pose a problem to the PI since the degree of penalty must be assessed. Although techniques have been described for calculating the glider position [3], these are time consuming and usually require a photograph rather than a negative in order to perform the calculation. Thus, ther is a need for a relatively easy-to-use technique which allows the PI to quickly evaluate the glider position from the negative.

By computer analysis of the photograph, the 3 dimensional position of the glider may be calculated using a technique taken from photogrammetry called resection. This involves picking identifiable points on the image (using a computer mouse and cursor on the image monitor) and inputting the coordinates of these points, taken from a survey map, to the computer. The computer determines the glider position by iterative calculation. A discussion of the technique is now given.

3.3.2 Theory

Figure 4 shows a camera imaging three objects A,B, and C which lie in some terrain for which a survey map is available. The three lie in an object coordinate system, (X,Y,Z). In the real world, the object coordinate system is synonymous with the survey map coordinate system. Thus, the position of, say, object A is (X_a, Y_a, Z_a). The perspective center of the lens of the camera lies at position 0 and has object coordinates (X_o, Y_o, Z_o).

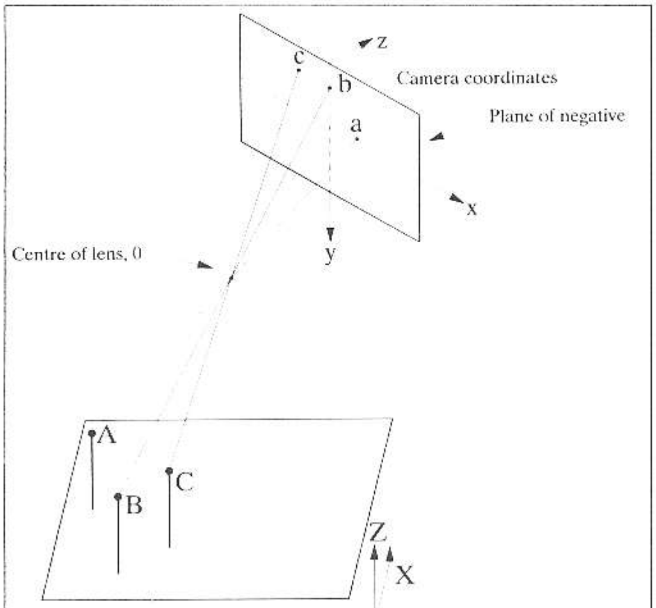

FIGURE 4. Coordinate systems used in glider positional determination theory.

It is the determination of these coordinates that is of interest. The photographic negative lies in a plane which is a distance f, the focal length of the camera, away from O. The camera has its own coordinate system (x,y,z), with origin O; the origin of the object coordinate system is arbitrary. Taking the object coordinate system as a reference, the orientation of the camera coordinate system is described by three sequential rotations, W, ø and K, about the x, y and z axis as shown in Figure 5; a rotation is taken to be positive if a clockwise rotation occurs when viewing along the positive direction of an axis. A ray of light passing from object A through the center of the lens, O, will impinge on the negative plane at position (X_a, Y_a). Since the negative is viewed from the side not visible in Figure 4, it is more useful to consider the negative plane to be situated on the reverse side of O, i.e. a distance f from O toward the objects. If this convention is taken, then the 3 dimensional camera coordinate position of A becomes $(X_a, Y_a, -f)$.

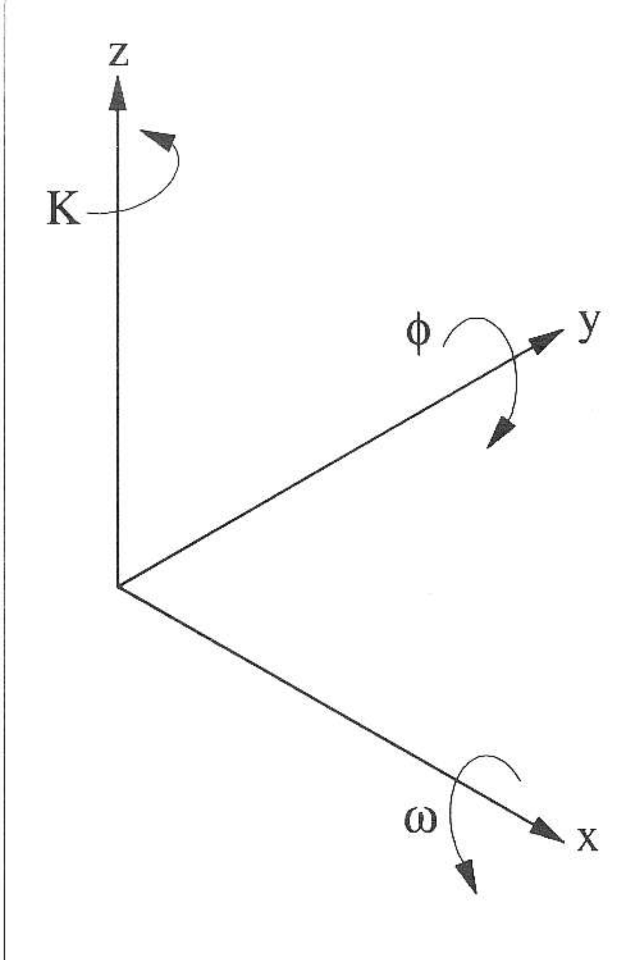

FIGURE 5. Rotation of camera coordinate system.

Thus, the task to be completed is to find X_o, Y_o, Z_o, W, ø and K given that all of the other variables are known. Note, that in the context of interepreting turn point photographs, the actual values of W, ø and K are of no significance but are, of course, instrumental to the overall solution. The equations used to solve for the glider position are based upon a collinearity condition, namely, the object, its position in the negative and the center of the lens all lie on a straight line. The derivation of the collinearity equations is complicated and is described in reference 4. The results, for object A, are stated here:

$$x_a = -f\left[\frac{m_{11}(X_a-X_o) + m_{12}(Y_a-Y_o) + m_{13}(Z_a-Z_o)}{m_{31}(X_a-X_o) + m_{32}(Y_a-Y_o) + m_{33}(Z_a-Z_o)}\right] \quad (1)$$

$$y_a = -f\left[\frac{m_{21}(X_a-X_o) + m_{22}(Y_a-Y_o) + m_{23}(Z_a-Z_o)}{m_{31}(X_a-X_o) + m_{32}(Y_a-Y_o) + m_{33}(Z_a-Z_o)}\right] \quad (2)$$

where m_{12}, m_{22} etc. are elements of a matrix used to orientate the camera and object axes as described earlier. There are:

m_{11} = Cosø•CosK
m_{12} = SinW•Sinø•CosK = CosW•SinK
m_{13} = -CosW•Sinø•CosK + SinW•SinK
m_{21} = -Cosø•SinK
m_{22} = -SinW•Sinø•SinK + CosW•CosK
m_{23} = CosW•Sinø•SinK + SinW•CosK

$m_{31} = \text{Sin}\phi$
$m_{32} = -\text{Sin}W \bullet \text{Cos}\phi$
$m_{33} = \text{Cos}W \bullet \text{Cos}\phi$

Similarly, 4 more equations for objects B and C can be described. Thus, there are 6 equations to find 6 unknowns. Owing to the linear nature of these equations, simultaneous solution is not possible and an iterative approach based on Newton's first order approximation [4] is employed. Although, in theory, only 3 identified points should yield a solution, in practice it can lead to large errors in the positional determination and, sometimes, failure of the algorithm to converge, as a general rule, it should be aimed to examine at least 5 points on any given photograph. Since the system is now over-redundant, a least mean squares technique is also employed in order to find the most probable solution from the input data.

3.3.3 PC implementation

The positional determination technique has been implemented on the computer. To perform this process, the following steps are taken:

a) The PI images the photograph so that all edges of the negative are visible on the monitor. A command is then issued to freeze the frame store.

b) Using a mouse to move a cursor around the monitor, the four corners of the negative are identified by clicking a cursor button. Since the computer can evaluate the cursor position, this operation allows the computer to calculate the center of the negative and thus find the position of the origin of the x,y plane of the camera coordinate system. Furthermore, the computer can calculate a scaling factor since the longest edge of a negative is 36mm, and finally, a compensation can be made if the negative is not exactly parallel to the coordinate system of the frame store.

c) Again, using the cursor, the position of 5 or 6 known objects are identified. With knowledge of the camera focal length, the computer can now calculate the object position in camera coordinates. For high accuracy the points should be well spread out over the image and not all lie on a straight line.

d) Using a standard survey map, the 3 dimensional coordinates of the previously identified objects are found and entered into the computer together with a scaling factor which relates the scale of the camera coordinate system to the scale of the survey map coordinate system.

e) An estimate of the 3 dimensional glider position is entered to the computer.

f) An estimate of W, ø and K needs to be made. In practice, it is found that an initial assumption of the glider being vertically above the turn point is sufficient. Thus, only K need be considered and can be estimated from the camera horizontal bearing.

g) The computer can now calculate the glider position. The PI has control over the number of iterations. After every iteration, the computer shows the estimated position and the error. With some practice the PI can assess, by the nature of the convergence, whether the input data were correct and a sensible result is forthcoming. Occasionally, it is necessary to repeat the process due to some mistake in entering the data. In practice 5-15 iterations are sufficient to give a consistent position estimate; the computing time involved in each iteration is negligible.

3.3.4 Accuracy of the glider position determination

Unfortunately, there are many errors involved in reaching a position determination by the previously described method. The principle error lies in the glider cameras, the lenses of which are not designed to produce distortionless negatives. Furthermore, the exact focal length and position of the center of the lens are rarely known. Other errors include stretching of the negatives, errors in the computer imaging optics and human error in positioning the mouse on object of interest.

In practice, the system gives results which are consistent with estimates made by experienced PI's; however, there is no indication of how accurate these results are. To resolve this issue, use was made of a photograph taken from the observation level of the Empire State Building in New YOrk, a building of known position and typical glider flying height. The photograph use is shown in Plate 3 and a plan view of this photograph, together with the actual and computer predicted camera positions is shown in Figure 6. The photograph shows the view of Manhattan looking southwest taken from the most westerly corner of the 86th floor observation level. Using a US Geological Survey Map of Manhattan, it was possible to identify 5 points on the photograph which correspond to corners of the pavement. These points are shown in Figure 6. The positional error in the plan position determination is 15.4m. The computer predicted the height above ground level (agl) to be 302.5m whereas the observation level is in reality 320m agl, thus giving a vertical error of 17.5m.

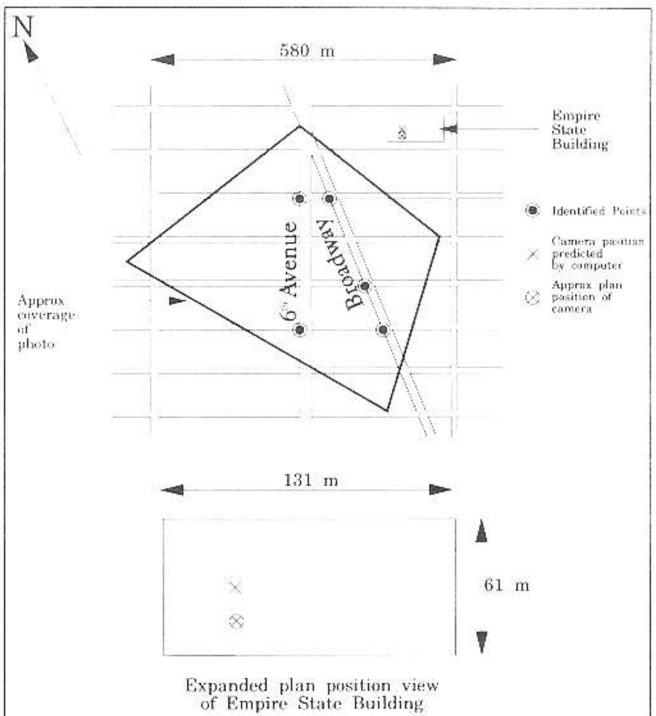

FIGURE 6. Result of positional determination of Empire State Building.

The plan position error is small compared with the width of the penalty bands used for turn point and start zone penalties under both BGA and OSTIV rules. Under these rules, the widths of the penalty bands are either 200m or 100m depending on which side of the turn point the glider is situated [5]. Thus, it may be seen that the glider positional determination technique is potentially accurate enough to correctly assess turn point penalties.

APPENDIX 1.

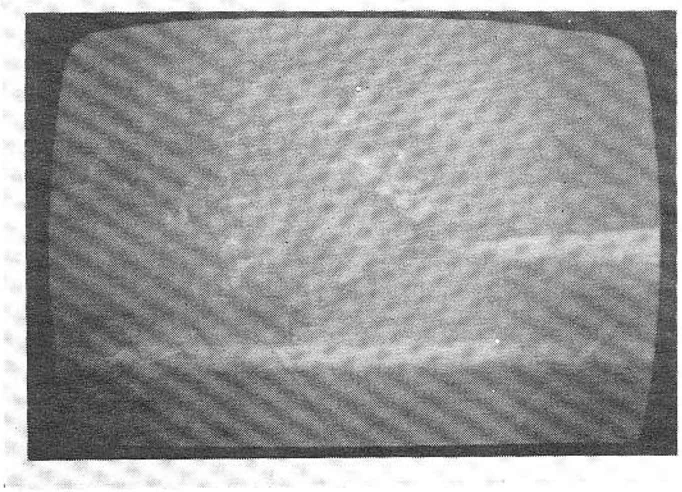

PLATE 1. Poor quality turn point photograph (taken from image monitor).

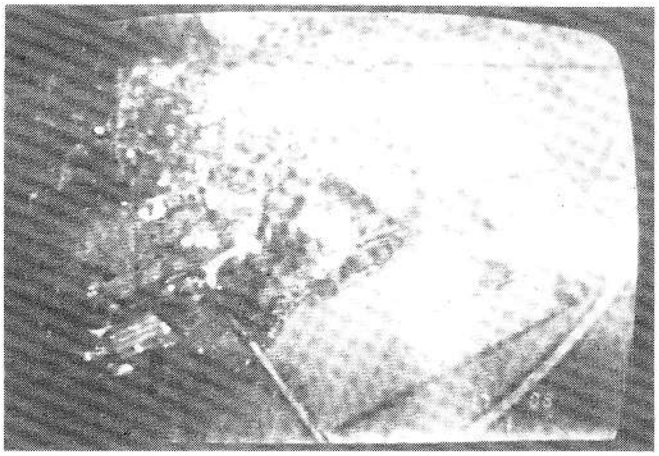

PLATE 2. Enhanced image of Plate 1 (taken from image monitor).

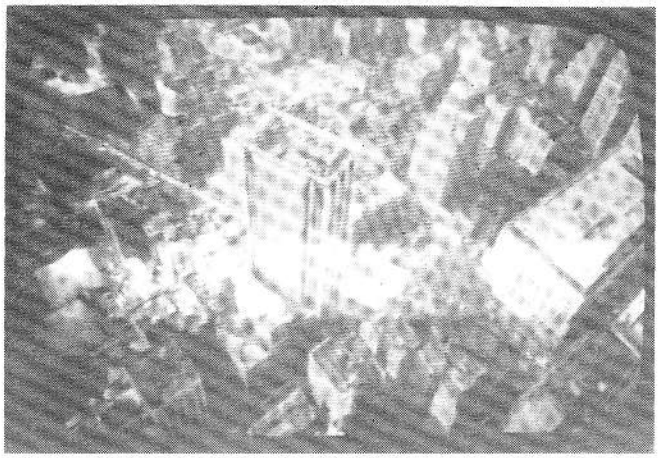

PLATE 3. Photograph taken from Empire State Building, New York used to test glider positional determination accuracy (taken from image monitor).

4. COST

The cost of the equipment (£sterling 1991) is:

Computer	800
Frame store	990
Camera	300
Lens	30
Stand	165
Light box	90
Total	£2375

It is possible that, with the exception of the frame store, most of these items are already available at gliding clubs and competitions.

5. FUTURE WORK

The image processing system has demonstrated considerable potential in the field of photographic interpretation. The following lists areas in which this work could be continued:

a) Development of user friendly software package which integrates the ideas discussed previously.

b) Development of interface for quickly inputting identified object map coordinates into the glider position determination program. This could take the form of a separate digitised image of the map where the coordinates are found by moving a cursor across the screen.

c) Development of database for storing contentious turn point images.

d) Development of pattern recognition software which can automatically extract the time information from photographs taken by cameras with time recording backs.

e) Development fo software to assess automatically the turn point error given the turn point map coordinate and the flight line in and out.

6. CONCLUSIONS

An image processing system suitable for aiding in competition photographic interpretation has been described. The system allows a positive image of the negative to be displayed on a standard video monitor. The computer image of the turn point photograph may be enhanced by the histogram equialisation technique which shows good results for hazy photographs. Thus, turn point photographs are instantly and easily viewed by the PI.

Images may be stored on disk and easily recalled, thus obviating some of the problems of storing negatives.

The glider position may be determined by computer aided analysis of the turn point photograph. This has been demonstrated to have a horizontal positional determination error of only 15.4m for a photograph taken at typical glider flying height. The system is thus, potentially accurate enough to resolve turn point penalties in situations where the PI is unable to assess correctly the penalty by visual interpretation. The ultimate limitations of the system will become apparent when more field experience has been gained.

In the context of surveying, rather than gliding, the equipment would be described as cheap. However, most of the components, particularly the computer, are becoming increasingly available in gliding clubs thus reducing the overall cost.

9. ACKNOWLEDGEMENTS

This work could not have been possible without the help and enthusiasm of many people. The author would like to thank:

- Peter Hearn, GEC Marconi, UK and Nobby Clarke, GEC Sensors, UK for sponsorship.
- Ngozi Onyekaba, who researched the glider position determination work for her MSc.
- Geoff West, Tim Ellis and Don Stirling, City University, for help with image processing and photogrammetry.
- Peter Purdie, Lasham National Competition Director 1988-91, for many useful discussions and unfailing enthusiasm.
- The pilots of the 1990 Lasham Competitions for their criticism, constructive or otherwise.

10. REFERENCES

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