EVALUATION OF A LOW COST DIGITAL PHOTOGRAMMETRIC SYSTEM FOR MEDICAL APPLICATIONS

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ABSTRACT:

The availability of low cost, off-the-shelf digital imaging equipment and PC-based software has the potential to bring digital imagery and digital photogrammetry to a wider range of users. This paper investigates the possible use of such systems in the medical field, a field in which photogrammetry has been widely investigated as a measurement tool but with limited success to date so far as routine usage is concerned. These digital systems may offer not only a low cost solution but also a degree of automation, both of which are seen as essential if the use of photogrammetry is to increase in this application area.

1. INTRODUCTION

Photography is already widely used in medicine for recording purposes but there now exists the possibility of changing to digital imagery. Digital cameras are easily obtainable at a reasonable cost and still video cameras, such as the Kodak DCS series, are as convenient as normal film cameras in terms of portability and handling. Digital imagery may also be obtained through high resolution scanning of conventional photography, with Kodak PhotoCD being a particularly attractive system for small format photographs. This system, discussed in Thomas et al (1995), is available through many electronics and photographic outlets, and provides photographic quality digital imagery on compact disc at a low cost. Handling of digital imagery requires a PC workstation with software to read the image format and to manipulate it, whilst the operator needs some computer skills.

Having obtained digital imagery, digital data processing is able to produce photogrammetric measurements at a reasonable cost and with some degree of automation. Several low cost packages are now available incorporating image processing operations, automated image correlation and stereoplotting capabilities. Moreover these software packages may be operated by those with a limited knowledge of photogrammetry.

This paper discusses the use of a low cost, off-the-shelf digital photogrammetric system in the medical field. Two particular applications are featured to illustrate the possibilities: one relates to the planning of oral surgery, the other to automated back shape measurement. In both cases, methodologies are outlined and initial results are given.

2. EQUIPMENT USED

2.1 Digital data capture

Digital data capture for this work was either by a Kodak DCS200 still video camera or by a Hewlett Packard (HP) desktop scanner.

2.1.1 Kodak DCS200 still video camera: This camera is based on a conventional 35 mm camera body (the Nikon N8008s) and provides high quality, digital colour output direct to a PC. The imaging area of the CCD chip is 14 mm x 9.3 mm, which is the same aspect ratio as 35 mm film but the dimensions are smaller by a factor of 2.6. The same coverage as for a 35 mm camera can therefore be obtained using a lens with a focal length that is shorter by a factor of 2.6 (e.g. a 20 mm lens instead of a 52 mm lens). The chip contains 1524 x 1012 pixels which gives a pixel size of 9 micrometres. The camera is used in a similar way to any 35 mm camera and the images are downloaded to a 80 Mb internal hard disk. 50 exposures can be made before the disk is full and must be downloaded. The current cost of a Kodak DCS200 camera is around $10000. This camera is just one of a range of Kodak DCS cameras and further details may be found in Graham (1995).

2.1.2 HP ScanJet Plus desktop scanner: This is an A4 size flatbed scanner. It is able to produce a 4-bit or 8-bit grey scale digital image from a conventional photograph and has an optical resolution of 300 dots per inch (dpi) giving a pixel size of around 25 micrometres. An A4 size image can be scanned in around 10 seconds. The current cost of an equivalent scanner is $500.

2.2 Data processing

2.2.1 Computer hardware: A Research Machines PC-560 Professional, equipped with a 60 MHz Pentium processor, 32 Mb RAM, 1Gb hard disk, 2Mb graphics accelerator card and a 17 inch Super Video Graphics Array (SVGA) monitor was employed in this project. Such a machine, which delivers workstation-like performance, is necessary for the efficient handling of large, digital data files and currently costs around $3000.

2.2.2 Computer software: Several software packages were used in this project.

Adobe Photoshop v3.0.5, which is an advanced image processing and photo-retouching package, was used as an electronic darkroom. This package will accept imagery in colour or grey scale, obtained from digital cameras and by scanning conventional photography, in a variety of formats. The current cost of this package is $700.

For measurement, the R-Wel Inc. Desktop Mapping System (DMS) v4.0 was selected. This is a PC-based, low cost ($6000), digital photogrammetric system incorporating image processing operations, automatic image correlation and stereoplotting capabilities. Further details of the system can be found in Welch (1989).

The differences between the back measurements produced digitally and analytically were analysed with the Land Survey System (LSS) software package produced by McCarthy Taylor Systems Ltd. This is a PC-based DTM and mapping package currently costing $3500.

The total cost of the hardware and software used is in the order of $25000 at current prices. This is low in terms of the general high cost of photogrammetric equipment.

3. APPLICATION 1 - PLANNING OF ORAL SURGERY

This application, undertaken in conjunction with the University School of Dentistry, relates to the use of digital imagery in the planning of oral surgery for the correction of facial deformity. This is an application where conventional imagery is already in use (Fanibunda, 1983) and in which it is necessary to superimpose several lateral view images of the patient's head (in particular, a conventional profile image and a skull X-ray) in order to get the full picture for planning purposes. The resulting scaled composite image, which portrays the hard and soft tissues of the face in their correct relationship, is of great help to the surgeon in planning an appropriate operative procedure for the patient. The particular planning that this is designed to help is in relation to surgical repositioning of the upper or lower jaw, and the effects of this movement on the patient's facial profile. The final profile is obviously of some concern as the surgical procedure is of a permanent nature. Consequently planning must be carried out as accurately as possible and anything that can be done to put this on a more scientific footing is highly desirable. A positioning accuracy in the order of +/- 1 mm is required.

The composite image is currently produced, with some considerable difficulty, through normal photographic darkroom techniques. The use of digital imagery has the potential to make the handling of these images and their superimposition much easier. Further, the planning of the surgery, which typically involves a movement of the jaws, can be undertaken by simply cutting and moving a portion of the final digital image on the monitor screen and several different solutions can be quickly assessed.

3.1 Method

The imagery of each patient was taken in the School of Dentistry, where radiological equipment is available which could be calibrated for use in this work.

When taking the imagery, the patient's head was immobilised in a cephalostat, as employed for routine radiographs, by means of two ear-rods. A projected line of light and adhesive targets placed on the skin were used to ensure that the head was kept in a constant orientation, with the Frankfurt plane horizontal. A 300 mm steel ruler with serrated edges was attached to the cephalostat in the mid-sagittal plane and aligned with its edges vertical. This ruler, being steel, imaged on the radiograph as well as the digital image.

The cephalostat was permanently mounted on a wall and the X-ray tube could be positioned such that its principal axis was perpendicular to the mid-sagittal plane and the principal point coincided with the centre of the ear-rods of the cephalostat. Further, its focal spot was positioned at a fixed distance (approx. 2 m) away from the radiographic film plane. When in this position a radiograph was exposed.

The X-ray tube was then moved vertically upwards by a fixed amount. A mount (Figure 1), fixed to the X-ray tube, allowed the Kodak DCS200 camera to be positioned such that the front nodal point of its lens coincided with the focal spot of the X-ray tube when the radiograph was taken. The principal axis of the camera in this position was again perpendicular to the mid-sagittal plane and the principal point coincided with the centre of the ear-rods. After positioning the camera, an exposure was made.

The digital colour image from the Kodak DCS200 camera, originally stored in a Kodak proprietary format, was downloaded from the camera's hard disk through a SCSI controller using the Kodak Twain driver into Adobe Photoshop. Various image enhancement techniques were then applied to improve, as necessary, such features as brightness, contrast and colour balance.

After development, the radiograph was in the form of a diapositive. This was then scanned at 300 dpi using the

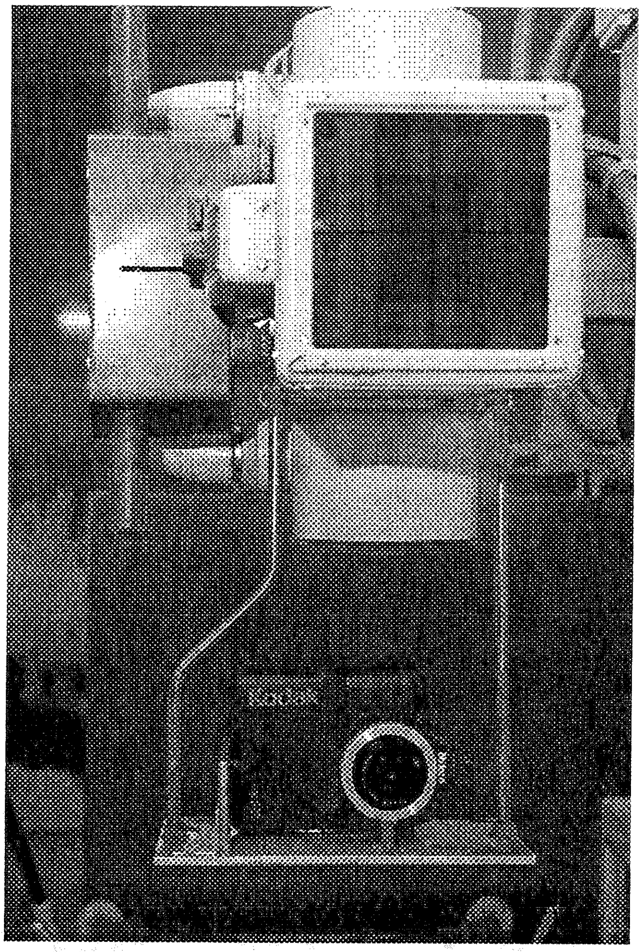

Figure 1 - DCS200 camera mount fixed to X-ray tube.

Figure 2 - Combined radiograph and digital image of the head.

HP ScanJet Plus scanner. It was soon apparent, however, that the resulting digital image was poor, lacking both contrast and brightness, so that the bone structure could not be determined, and subsequent improvement of its radiometric characteristics in Adobe Photoshop proved very difficult. This problem arose because this scanner was designed for use with prints only and, even after placing a white sheet of paper behind the radiograph at the time of scanning, the result was still unsatisfactory. Consequently, it was decided to use the Kodak DCS200 camera instead of the scanner to convert the radiograph into a digital image. The radiograph was placed on a light table and the camera was aligned with its principal axis perpendicular to the light table and passing through the centre of the image of the ear-rods. The photographic distance was chosen such that the radiograph just filled the frame. This method produced a much better image. The image was downloaded into Adobe Photoshop, changed to monochrome and enhanced as necessary to highlight the bone structure.

The two images imported into Adobe Photoshop, were brought to a common scale and then the X-ray superimposed on the photograph. To adjust the image scale, the distance between two serrations on the steel ruler was determined from the measured pixel coordinates taken on the conventional profile image. The same distance was then measured on the radiograph and a scale factor determined which was applied to the radiograph so as to bring both images to a common scale. The next step involved highlighting the radiograph as a floating selection so that it could be moved around over the photograph until the position of the centre of the ear-rod matched on both images. Some adjustments to the transparency of the overlain radiograph were also needed to ensure that the two images were both clearly visible. Following this, a rotation of the radiograph about the ear-rod was applied until the serrations on the ruler matched. Finally, the combined image was brought to a known scale (such as 2 pixels = 1 mm) so that any measurements made on it would be meaningful.

This image file may be passed to the oral surgeon who can manipulate the file in Adobe Photoshop. The 'select and move' function enables any portion of the image, such as the lower jaw, to be selected and moved around and the effects of the movement on the profile can be seen. Once an acceptable position is found, the amount of movement from the existing position may be measured on the image.

A high quality hardcopy output can be obtained from a file produced at any stage of the work through the use of a dye sublimation printer. An example of the final output is shown in Figure 2.

3.1 Discussion

The replacement of conventional imagery by digital imagery in this application area is seen to offer the following merits:

- handling of the images and their superimposition is much easier.
- portions of the combined image can be easily moved and the effects of the movement displayed.
- the images are in a convenient form for long term storage, with CD one possible storage medium.
- good quality hardcopy output can be obtained, if necessary, for the patient's file.
- the potential response of the soft tissue profile to a given amount of bone movement following surgery can be demonstrated.
- off-the-shelf hardware and software and existing facilities are employed, with minimal modification.
- the analysis can be handled by the surgeon.

There are however some limitations with the digital approach:

- the method is not rigorous in photogrammetric terms because it has been kept simple to try to ensure its acceptability. The accuracy requirement has, however, always been kept in mind in its design.
- whilst the two images are in their correct relationship to each other in any chosen plane, there is a scale change between the ear and the mid-sagittal plane. The amount of this change depends on the width of the face and with the present set up has a maximum value of around 4% and is thus of little consequence.

4. APPLICATION 2 - BACK SHAPE MEASUREMENT

The second application concerns automated back shape measurement. Over the years, there have been many applications of photogrammetry and other competing optical techniques for the measurement of back shape, particularly in relation to spinal deformities resulting from scoliosis (Gabel et al., 1992; Mitchell, 1994). Many of these have involved the use of sophisticated and expensive equipment and methods. This work, however, uses a low cost digital solution and relates to measurements carried out on a mannequin. The work could not be carried out on a living person, since there was access to only one Kodak DCS200 camera, but it is anticipated that similar results would apply. The accuracy of the system has been determined by comparing the automatically generated DEM's with measurements made on the same subject from metric photography using a Zeiss P3 analytical plotter.

4.1 Method

As mentioned earlier, this work was done on a mannequin and therefore permanent control points, in the form of white crosses on a black background, could be placed on the back for the duration of the study. Seven points were marked, with a good distribution over the back and these points were coordinated by theodolite intersection using a Leica TC1010 total station, with estimated standard deviations of +/-0.1 mm in x,y and z. This value is smaller than the pixel size on the back for the imagery taken.

The back of the mannequin presented a smooth but featureless surface. Consequently, it was necessary to project some form of texture onto the surface to facilitate image correlation. The R-Wel DMS employs an area-based least squares matching algorithm and several different textures were tried and tested - a random pattern of trees appearing on a remote sensing image, a random pattern of letters, and a grid. Of these, the best texture, in terms of the results produced, was found to be provided by the trees on the remote sensing image (Figure 3).

Stereo imagery of the back was taken using the Kodak DCS200 camera with a 28 mm lens. The camera to object distance was 1.7 m, the base to distance ratio around 1:1.5 and the convergence angle of camera axis to the baseline approximately 15 degrees. With this configuration, the pixel size on the object was 0.42 mm. It was decided to use convergent photography because it afforded a better base to distance ratio than photography with no convergence and thus a more accurate measurement of parallax. The images were downloaded into Adobe Photoshop, rotated and converted to grey scale. Adjustments were then made to the brightness and contrast and an edge enhancement filter was also used to optimise the images of the targets.

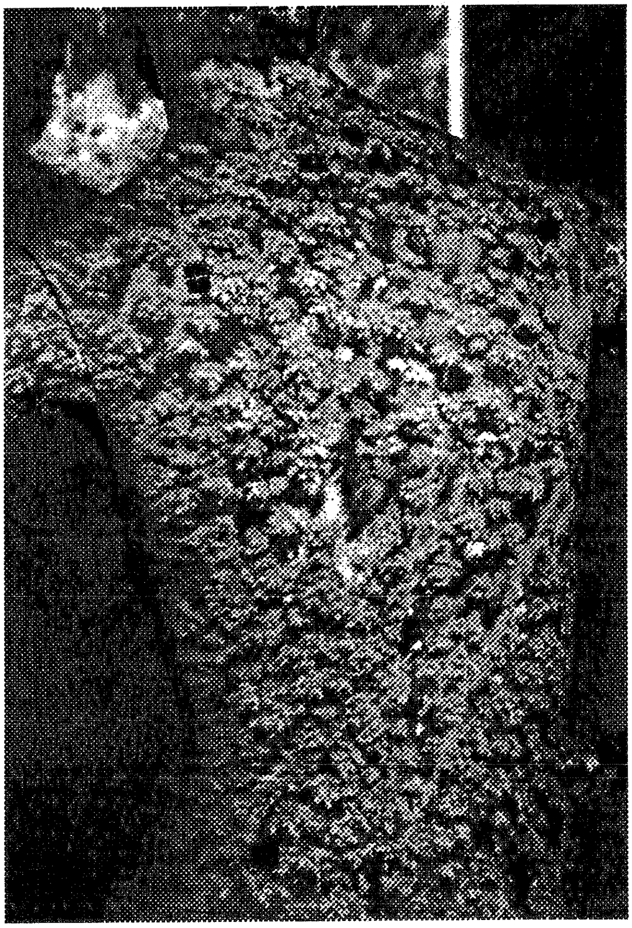

Figure 3 - Image of back showing texture and control points.

The back was also photographed with an Officine-Galileo metric camera and a DEM of the back with a 5 mm grid interval was subsequently measured from this imagery in the Zeiss P3 analytical plotter. This provided reliable reference data for the accuracy tests, the standard deviations at the control points being +/-0.2 mm in x and y and +/-0.4 mm in z. This DEM was taken to represent the true shape of the back when assessing the accuracy of the digital method.

Measurement of the Kodak DCS200 imagery was undertaken in the R-Wel DMS within the Softcopy Photo Mapper module. This module allows the orientation of a stereomodel through a separate space resection of each photograph using a minimum of 5 control points. The 4 corner points (the principal point was assumed to be in the centre of the image as defined by these points) and 6 control points were measured on each image and the results of the orientation are shown in Table 1.

Orientation parameters	Image 1	Image 2
X (mm)	1571.213	2388.558
Y (mm)	9680.940	9674.683
Z (mm)	1910.263	2011.815
ω (degrees)	2.4	2.4
ϕ (degrees)	-21.1	12.1
κ (degrees)	0.5	-1.2
pixel size (mm)	0.410	0.415
image scale	1:447	1:452
RMSE (pixels)	1.45	0.62
RMSE (mm)	0.59	0.26

Table 1 - Orientation parameters for the images used.

After orientation, the area of the stereomodel was defined and the resulting stereo images were used for the generation of the DEM's. The number of pixels between the DEM points (post spacing) and the dimension of the correlation matrix for the matching have to be specified, as do the maximum and minimum z values expected to be encountered during the creation of the DEM. In this work, DEM's were generated using post spacings of 5, 10 and 15 pixels and with correlation matrices of 11x11 and 17x17 pixels, to determine which gave the most accurate results. Inputting the elevation range is an iterative process. The expected elevation range was input and the software gave the actual elevation range after measurement. The DEM then has to be regenerated based on this new range and the process repeated until the output range falls within the input values. The input elevation range definitely affects the resultant DEM and further investigation into this is underway.

For each generated DEM, the R-Wel DMS indicates the completeness of the correlation and this was normally in the order of 99%. This value is merely an indication of the success of the matching and gives no indication of its accuracy. The time taken to generate the DEM's obviously increases with a smaller post spacing (the 5 post spacing DEM had 41475 points compared to 4582 for the 15 post spacing) and larger correlation matrix. For this particular work, the generation times were 2, 10 and 27 minutes for 15, 10 and 5 post spacings respectively for a 17x17 correlation matrix, with the 11x11 matrix taking 0.5, 4.5 and 14 minutes respectively.

The resulting DEM can be viewed in the 'View 3D perspective' module as a wireframe model from any desired angle and with the image draped over it if required. It is possible to edit erroneous points either stereoscopically or by running a smoothing filter over the DEM. The models were not, however, edited and were simply rectified, then translated to xyz format for export to the LSS software package. At the rectification stage, the DEM can be clipped to the required area. It is also possible to mask areas where the correlation fails, such as the edges of the mannequin in this case, but again, this facility was not used.

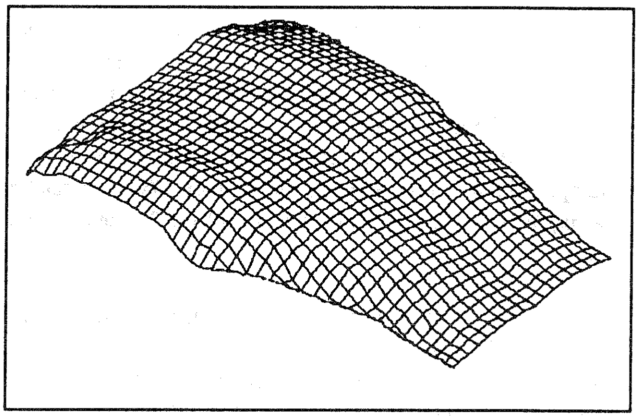

Figure 4 - Wireframe model of generated DEM of the back.

In order to make the comparison in LSS, a survey needed to be set up and the data from the Zeiss P3 read in. A separate survey then had to be created for each generated DEM. The DEM measured in the Zeiss P3 was used as the base survey and each generated DEM was subtracted from this to create differences between the two data sets at around 2000 points. The integrity of the original Zeiss P3 data was thus maintained. The differences were then analysed by reading the LSS files into a spreadsheet and calculating the standard deviation of these differences. The results are given in Figure 5.

4.2 Discussion

Examination of Figure 5 indicates that the best results were achieved with the densest post spacing and with the largest correlation matrix - in this case, a post spacing of 5 pixels and a 17x17 correlation matrix. With this configuration, the standard deviation of the depth differences over the DEM was 0.94 mm which is equivalent to 2.3 times the pixel size. A standard deviation of 1 mm is considered adequate for a number of anticipated applications that could arise through the use of a low cost, off-the-shelf system such as this and so the 10 pixel post spacing (standard deviation 1.02 mm) may also be acceptable.

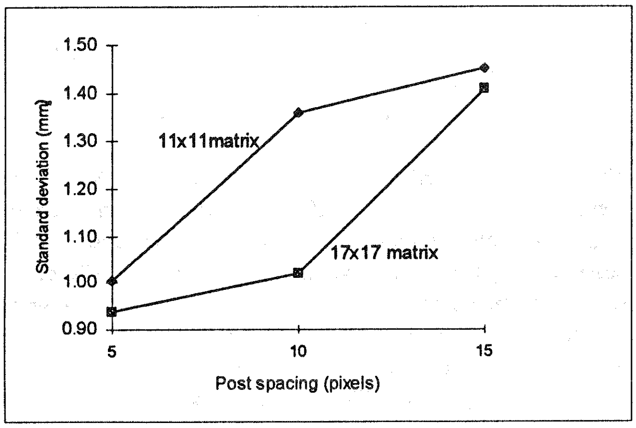

Figure 5 - Standard deviations of the differences between R-Wel DMS and Zeiss P3 DEM's, for different post spacings and correlation matrices.

As already mentioned, it was decided to use convergent photography for this work because it was expected to give better results. Photography with no convergence was, however, also taken with a base to distance ratio of 1:2.7 and initial tests show that the standard deviation increased as expected. For example, for a 5 post spacing DEM with 17x17 correlation matrix, the value is 1.42 mm and this is also 2.3 times the pixel size.

These initial results have been achieved without a full calibration of the system. No account has been taken of lens distortion effects or of any other random geometric effects in the CCD chip. These will be investigated in further work.

Several other aspects also need further consideration before a working system is complete:

- it will be essential to employ a synchronised pair of digital cameras when dealing with a living subject. This is seen to present no real problems, except possibly cost.
- it will be necessary to ensure that the shutter speed used is as fast as possible to arrest any movement whilst at the same time any projected pattern must remain visible. The current exposure time of around 0.25 secs. is possibly too long for a patient to remain still.

5. CONCLUSIONS

The requirement for medical practitioners to demonstrate the effectiveness of any treatment is increasing and with this will come a greater demand for measurement to support particular methods of treatment. This work has investigated the potential of a low cost digital photogrammetric system, which offers a degree of automation, to provide an effective medical measurement tool. Such systems are capable of being used by medical practitioners themselves, which was not the case with analytical and analogue systems, and this could be a decisive factor in extending the use of photogrammetric measurement in medicine. Early indications suggest that such systems are able to provide many of the measurements needed to the required accuracy and within the desired time schedule, and further work is in hand to confirm these findings.

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