# UBIQUITOUS DIGITAL PHOTOGRAMMETRY BY CONSUMER GRADE DIGITAL CAMERA

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**ABSTRACT:**

Convenient 3D measurement using consumer grade digital cameras are enormously expected from various application fields according to appearance of the high resolution digital cameras. In these circumstances, the authors have been concentrating on developing a convenient 3D measurement method using consumer grade digital cameras. Software “3DiVision” has been designed to perform convenient 3D measurement under the key words; 3Dimension, Digital image and Visualization, and “3DiVision” shown the capability to perform automatic interior orientation without GCPs and subsequent 3D measurement.
However, there were some issues for realize a ubiquitous digital photogrammetry such as everybody can perform digital photogrammetry at wherever with easily. The main problem is interior orientation procedure which is implemented beforehand using test sheet or test target, the previous interior orientation procedure should be removed in ubiquitous digital photogrammetry using consumer grade digital cameras. In order to resolve the issue, triplet images are used in 2nd Version of “3DiVision”.

## 1. INTRODUCTION

Recently, pixel numbers of consumer grade digital cameras are amazingly increasing by modern semiconductor and digital technology, and there are many low-priced consumer grade digital cameras which have more than 5 mega pixels on the market. For example, 10.1 Mega consumer grade digital camera which is priced at 350 US$ has already appeared on the market in Japan.
In these circumstances, convenient 3D measurement using consumer grade digital cameras are enormously expected in various application fields. Therefore, performance evaluations for consumer grade digital cameras have been investigated from the view point of digital Photogrammetry (Fraser, 1997; Kunii et al., 2001, Noma, et al., 2002; Habib, et al., 2003), and it has been concluded that consumer grade digital cameras are expected to become useful tool for convenient digital photogrammetry (Kunii & Chikatsu 2001).
On the other hand, developing low-cost photogrammetric system have been ranked as one of the important issues during last decade in the ISPRS WG regarding Cultural Heritage; WG V/5 (World Cultural Heritage) for 1996-2000, WG V/4 (Image Analysis and Spatial Information Systems for Applications in Cultural Heritage) for 2000-2004, WG V/2 (Cultural Heritage Documentation) for 2004-2008.
With this motive, the authors have been concentrating on developing a convenient 3D measurement using consumer grade digital cameras, and software “3DiVision” has been designed to perform convenient 3D measurements (Chikatsu & Kunii 2002). Application of 3DiVision to 3D modelling of historical object was also performed (Nakada & Chikatsu 2003). However, there are some issues for practical 3D measurements using consumer grade digital cameras. One of the problems is interior orientation procedure which is implemented beforehand using test sheet or test target.
In order to remove the issue and to promote a convenient digital photogrammetry using consumer grade digital cameras, 3DiVision is improved in this paper.

## 2. 3DiVision

“3DiVision” under the key words; 3Dimension, Digital image and Visualization has been designed to perform convenient 3D measurement using consumer grade digital cameras. The main algorithms of the 3DiVision is simultaneous adjustment for left and light image by coplanarity condition and subsequent bundle adjustment, and the 3DiVision have capability to perform exterior orientation without GCPs and 3D measurement for the following 3 cases in addition bundle adjustment with self-calibration using GCPs.
Case1: Parallel stereo image is taken, flying height $H_1$ and $H_2$ (distance from exposure position to object field) for the left and right images are measured using photogrammetric system (Figure 1) and direction of X axis are given.

Figure 1. Photogrammetric System

Case2: Parallel stereo image is taken using photogrammetric system, scale distance D and direction of X axis are given.
Case3: Conversion stereo image is taken without the system as the third case under the assumption that parallel stereo image often doesn't taken. Distance in the object space is measured and original point ($P_1$) and direction of X axis are given on the image. Furthermore, in order to control an influence of rotations, height value for $P_2$ and $P_3$ point are given (Figure 2).
Figure 2 shows the concept for the 3 cases, and Figure 3 shows geometric conditions as using 3DiVision.

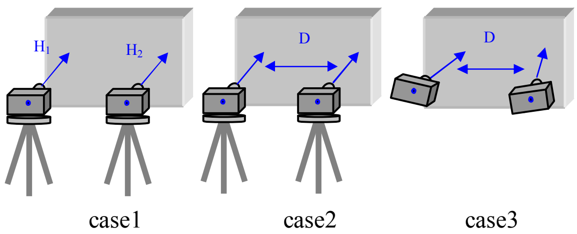


Figure 2. Image acquisition in the 3DiVision

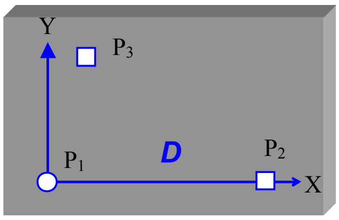


Figure 3. Geometric condition in the 3DiVision

Table 1. Accuracy of the imaging case

| | | Results of 3DiVision $\sigma_{XY}$(mm) | $\sigma_Z$(mm) | Resluts of Bundle 9GCPs $\sigma_{XY}$(mm) | $\sigma_Z$(mm) |
|---|---|---|---|---|---|
| **Case 1** | Z:Not given | 1.634 | 4.210 | 0.427 | 1.012 |
| | Z:Given | 1.783 | 2.812 | | |
| **Case2** | Z:Not given | 0.644 | 2.309 | 0.427 | 1.012 |
| | Z:Given | 0.923 | 2.480 | | |
| **Case3** | Free1 | 0.656 | 1.120 | 0.400 | 0.580 |
| | Free2 | 0.951 | 1.447 | 0.422 | 0.562 |
| | Free3 | 0.803 | 1.661 | 0.407 | 0.464 |

Actual 3D coordinates for unknown points can be calculated via absolute orientation using the flying height or scale distance after relative orientation using interior orientation parameters which were previously acquired with test target.
In order to estimate 3DiVision, stereo image was taken with about 3m flying height, and accuracy for the 3 cases were estimated using RMS error for 42 check points on the test target. Table 1 shows the RMS error for XY and Z coordinates for the each case. Some differences can be found between the case1 and case2. Nevertheless, it can be said that the case 1 is useful and convenient in severe condition that can't approach object space. If it is possible to measure scale distance on object space, the case 2 is recommended for obtaining high accuracy than the case 1. Furthermore, it can be seen that the accuracy for the case1 and 2 are improved by giving Z value for the point ($P_2$) on the X axis.
Height value for the point ($P_3$) in the Y axis direction is needed more than the point ($P_2$) on the X axis in case 3 since $\omega$ and $\kappa$ cannot be estimated as 0 degree as well case 1 and 2 using photogrammetric system. Free1, 2 and 3 in the case 3 means different stereo model, but each model show higher accuracy compare with the other cases. Accuracy for the each case is lower 2 or 3 times compare with results of the bundle adjustment, however, it was concluded that the 3DiVision is useful software for convenient digital photogrammetry.

## 3. 2nd VERSION OF 3DiVision

There are many software for digital photogrammetry using consumer grade digital cameras, interior orientation procedure is implemented beforehand using test sheet or test target in these software including 3DiVision. However, the previous interior orientation procedure should be removed in ubiquitous digital photogrammetry using consumer grade digital cameras. In order to resolve the issue, triplet images are used in 2nd version of "3DiVision".

### 3.1 Calibration Procedure in 3DiVision Ver.2

Let make n is image number and m is number of GCP, n and m should be satisfied following relationship from the view point of collinearity condition,

$$(2n)m \quad 6n+6+3m \qquad (1)$$

In the case of 2nd Version of 3DiVision, 52 unknown parameters such as exterior orientation parameters for the triplet images {($X_{OL}$, $Y_{OL}$, $Z_{OL}$, $\omega_L$, $\varphi_L$, $\kappa_L$), ($X_{OC}$, $Y_{OC}$, $Z_{OC}$, $\omega_C$, $\varphi_C$, $\kappa_C$), ($X_{OR}$, $Y_{OR}$, $Z_{OR}$, $\omega_R$, $\varphi_R$, $\kappa_R$)}, interior orientation parameters {$f$ (focal length), $x_0$, $y_0$ (principal points), $a_1$, $a_2$, (scale factor), $k_1$ ,$k_2$ (factor of lens distortion)} and 3D coordinates for 9 quasi-GCPs should be adjusted simultaneously. Here, actual 3D coordinates for quasi-GCP doesn't necessary but image coordinates for the points and scale distance $D$ are requested. Therefore, these GCPs are called quasi-GCP in this paper.
On the other hand, 54 equations are obtained from collineality conditions using 9 quasi-GCPs for triplet images. In order to obtain convergence solution with stability, one quasi-GCP is defined as the origin point as same as 1st 3DiVision, and direction of $X$, $Y$ axis is defined using quasi-GCP $P_2$ and $P_3$. Furthermore, height value for $P_2$ and $P_3$ are given in Figure 4.

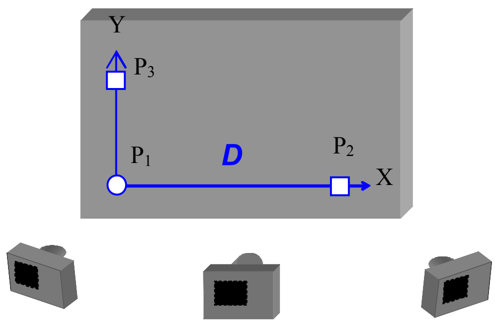


Figure 4. Concept of 2nd Version of 3DiVision

Consequently, 7 unknown parameters are reduced since coordinate for the quasi-GCP $P_1$, $P_2$ and $P_3$ are given as (0, 0, 0), ($D$, 0, 0), (0,$Y_3$,0) respectively.
Figure 4 shows concept of 2nd Version of 3DiVision, and calibration procedures are as follows.

+ Relative Orientation
  Initial 3D model is generated using relative orientation parameters for the left and right image.
+ Absolute Orientation
  Model coordinate which was generated by relative orientation is transformed to actual coordinate system using scale distance *D*.
+ Self-calibration for the center image
  In order to estimate interior orientation parameters, self-calibration for the center image is performed using quasi-GCP which were generated by the former procedures.
+ Simultaneous adjustment
  45 unknown parameters are self-calibrated simultaneously using triplet images under LSQ.

### 3.2 Evaluation

In order to evaluate an accuracy of the 3DiVision Ver.2, experiment was performed using digital camera (EPSON, CP-900Z, 3.3 Mega). Figure 5 shows test target, 9 black circular points are quasi-GCPs which haven't exact 3D coordinates, and 36 white check points are check points. Triplet image were taken with 1.0m altitude under the fixed focal length. Image coordinates for each point were given as the center of area gravity by image processing. Figure 6 shows triplet images.

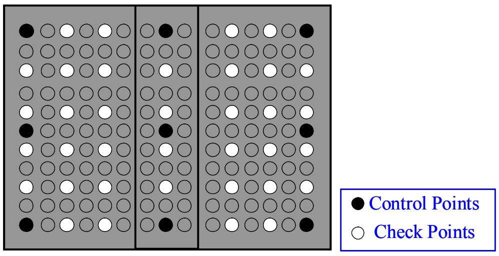


Figure 5. Test target

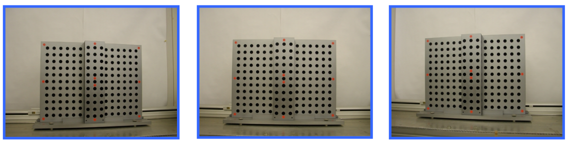

Figure 6. Triplet images

Table 2. R.M.S.E. of check points

| | σ xy (mm) | σ z (mm) |
|---|---|---|
| Case1 (Ver.2) | 0.154 | 0.112 |
| Case2 (Ver.1) | 0.189 | 0.456 |
| Case3 (Bundle Ad.) | 0.056 | 0.117 |
| S.E. (Standard Error) | 0.047 | 0.121 |

Table 2 shows the RMSE for XY and Z coordinate for 36 check points. Case 1 and 2 shows the result for 3DiVision Ver.2 and 3DiVision Ver.1, and case 3 shows the results of the bundle adjustment using 9 GCPs which have exact 3D coordinates. Furthermore, S.E. is standard error for XY and Z accuracy which are computed by following equation.

$$\sigma_{XY} = \left(\frac{Z}{f}\right)\cdot\sigma_p \ , \ \sigma_Z = \left(\frac{Z}{f}\right)\left(\frac{Z}{B}\right)\cdot\sigma_p \qquad (2)$$

Where, *Z*: Altitude, *f*: Focal length (7mm), *B*: Base line (400mm), $\sigma_p$ : Pointing accuracy (0.0003mm)

It can be said from Table 2 that 3DiVision Ver.2 is expected to contribute the various close range application fields since interior and exterior orientation parameters are calibrated simultaneously without any GCPs on object space besides interior orientation procedure which was issue in 3DiVision Ver.1 are resolved.

## 4. ARCHAEOLOGICAL 3D MODELING

In order to investigate an adaptability of the 3DiVision Ver.2 for recording and 3D modelling of structures in architecture and archaeology, triplet images for stone statue and complex high relief sculpture were taken.

### 4.1 Whisper Rakan

Kitain Temple is located at Kowagoe where locates in the western part of Saitama Prefecture, which is 30 km from the central part of Tokyo. 500 Statues of Rakan of the Kitain Temple, which is one of the three major Rakan of Japan. It has approximately 540 stone buddhas that precisely express the human emotions. Figure 7 shows one of scene for 500 statues of Rakan, and these statues were erected from 1782 to 1825.

Figure 7. Scene of 500 Statues of Rakan

Figure 8. 3D model of the Whisper Rakan

The center of Rakan in Figure 7 is one of famous Rakan, who speaks in a whisper. The triples images for the Whisper Rakan were taken by EOS 20D (CANON, 8.2 Mega pixels) with 1m altitude. After the camera calibration using 3Division Ver.2, 3D modelling for the Whisper Rakan was performed. Figure 8 shows the 3D model for the Whisper Rakan.

### 4.2 High Relief Sculpture

Kangiin Shoutendo where locates at Menuma, Saitama, was rebuilt at 1760 after spending 25 years. Shoutendo is one of famous temples in Japan from the view point of elaborate and splendid high relief sculptures, and the temple was designated as important national cultural property at 1984. These high relief sculptures which were sculptured out of keyaki shows extremely complex structure such as shown in Figure 9.

Figure 9. Splendid sculptures decollate temples

Triplets image were taken by EOS 20D about 1.5m altitude with fixed focal length. Similarly, 3D modelling for the sculpture was performed. Figure 10 shows the 3D model for the sculpture.

## 5. CONCLUSION

3DiVision was improved using triplet images, and performance evaluation were investigated in accuracy and operational aspects. It is verified that both accuracy of horizontal and vertical shows almost same values compare with standard error. Similarly, it is verified that both exterior and interior orientation parameters are calibrated simultaneously without GCP on the object space.
Consequently, it is concluded that the 2nd version of 3DiVision is expected to become useful software in the various photogrammetric application fields using consumer grade digital cameras. In particular, the remarkable point of the 3DiVision Ver.2 is its ability to skip previous interior orientation procedures, which was bottleneck for operationalization of ubiquitous digital photogrammetry.

Figure 10. 3D modelling of sculputure


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