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A Study on the Implementation of an Integrated Digital Photogrammetric System

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Abstract

An object-oriented design was carried out for the digital photogrammetric processes. Classes were identified and implemented to develop an integrated digital photogrammetry system using a 3 dimensional self-calibration model for CCD cameras. This integrated system is deemed to be a significant progress from the conventional photogrammetric system which is a series of discrete processes. Object oriented methodology was selected for the implementation of the integrated photogrammetric sysstem because it would be a very complex task to get the same result using a procedural programming language. Besides the simplification of development effort, object oriented methodology has further benefits of better management of program in case when updates to parts of the program are necessary. Using the classes designed in this study, a 3 dimensional self-calibration model was developed for a CCD camera. Classes for data input and image handling as well as classes for bundle adjustment were implemented. The bundle adjustment system was further enhanced with member functions to handle additional parameters for principal point coordinates and focal length, thereby, enabling the application to non-metric CCD cameras.

Keywords : *Object-oriented programming, CCD camera, Resection, Intersection, Digital photogrammetry*

1. Introduction

The overall photogrammetry process involves measurement objects and undergoes selection of object points, tests, and positioning, in this order. Likewise, the process uses geometric conditions like collinearity conditions and applies the measurement values to established mathematical-model transformation factors, thus determining such transformation factors and consequently determining specific mathematical models. The accuracy of determining such mathematical models can be enhanced by using surplus measurements, and this can be generally adjusted by statistical methods like the least squares method.

Many processes in the abovementioned mathematical model equation are treated by matrix computation, and the composition and processing of matrixes serve as the basis for various processes. Also, since each process has its proper computing process, one can make hierarchy diagrams for each digital photogrammetry process, separate common-use parts, and unique computing processes, and have a sketch of the overall program to be able to understand the process easily and accurately, thus enhancing intuitive understanding.

Towards this end, research is needed to improve the previous whole photogrammetry process, beginning with improving images through image acquisition and digital processing and automatically extracting conjugate points from both right and left images, as well as to extract the three-dimensional position of measurement points. When one crafts classes for each theme of digital photogrammetry as an object-oriented concept, structures a single integrated environment, and handles all processes in portable and economical personal computers, one can conduct real-time photogrammetry (Andres, 1993).

This study conducts close-range digital photogrammetry in the integrated environment formed by object-oriented programming using CCD cameras, with the following research scope and limitations.
① The CCD camera had a focal distance of 16 mm, and was capable of displaying a maximum 811×508 pixel that was resampled as 640×480 in the used image board. Thus, errors from image resampling in the

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hardware were not considered.

② Considering situations wherein fiducial marks were provided, hough transformation classes were formed, but hough transformation was not included in the analysis of the application results in this research, which uses CCD cameras without fiducial marks.

③ Considering the features of measurement models with consistent object shapes, the correlation coefficient method, which compares the brightness value of two images in a certain area near the matched point and conducts image matching, was used as an image matching method.

④ Only the focal distance and the movement distance of principal points were considered in the additional bundle adjustment. Lens-test-related items were included in the lens calibration model, which thus separately calculates test items on systematic errors in the process of close-range digital photogrammetry.

2. The Integrated Environment of Digital Photogrammetry

This research conducts close-range digital photogrammetry using CCD cameras, as it uses the object-oriented programming technique to classify each process of digital photogrammetry into user-defined data class formats and links these to make models by theme.

Components of such modules include the process of transforming shot photos into images, the process of transforming image coordinates into photo coordinates, the process of determining fiducial marks' coordinate values through hough transformation, a matching process aimed at finding conjugate points from right and left images, the resection process of determining shooting points through conjugate points' coordinates and collinearity conditions, and the intersection process of determining three-dimensional positions all through these processes. To accomplish such modules, digital processing and hough transformation classes, coordinate transformation and image matching classes, resection classes, and intersection classes were designed.

Furthermore, an integrated environment was structured to integrate these designed modules and conduct real-time digital photogrammetry.

To apply the developed classes, a process (shown in Fig. 1) of acquiring images using a CCD camera was established, entirely with the use of a computer, including the process of determining three-dimensional positions, thus enabling real-time digital photogrammetry.

Unlike a metric camera, a CCD camera does not have image test factors or fiducial marks, thus requiring tests.

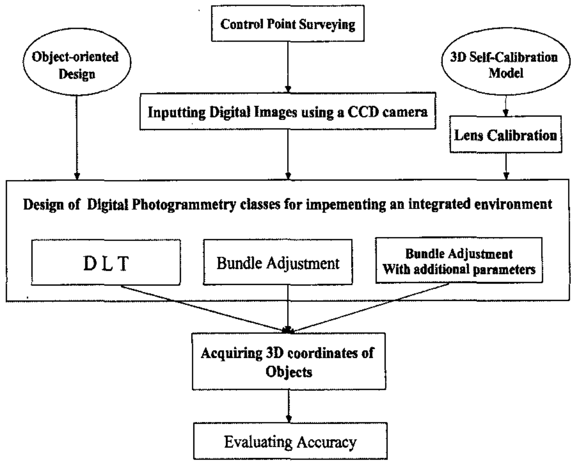

Fig. 1. Process of conducting close-range digital photogrammetry.

This study develops a three-dimensional model equation aimed at determining digital-image-tested image coordinates, matching acquired right and left images using correlation coefficients to extract their conjugate points, and determining photo coordinates from right and left image coordinates using the coordinate transformation equation and lens distortion test factors (Karara, 1989).

This study, based on the abovementioned determined photo coordinates, conducts close-range photogrammetry through direct linear transformation (DLT) and bundle adjustment to identify the three-dimensional positions of objects, and compares the accuracy of such position determination.

Also, to enhance the ordinary-use CCD camera's utility as a metric camera, boost the possibility of conducting real-time photogrammetry, and increase the accuracy of determining the three-dimensional position of objects, a bundle adjustment method was developed by adding test items on images' principal point coordinate movement quantity when acquiring images with a CCD camera, and lens focal distance at the exposure station, and its effect was verified.

3. Implementation of an Integrated Environment for Close-range Digital Photogrammetry

3.1 An Integrated Environment for Digital Photogrammetry by Object-oriented Programming

3.1.1 Comparison of the Procedural Method and Object-oriented Programming

The object-oriented programming design establishes a hierarchical structure between classes, whereby each class is a module wherein data attributes and models are defined together. Fig. 2. shows a comparison of the existing procedural method and object-oriented programming (Schenk, 1996).

The procedural method has an n number of independent processes and requires an n number of independent programs to treat an n number of processes. If new research achievements or change elements are added to this, an n number of results is again produced and subsequently, a 2n number of independent environments is made to exist.

Meanwhile, the object-oriented programming concept is this: if each process is grouped into classes according to similar themes in a single integrated environment, an n number of processed results is produced in a single integrated environment. Likewise, if changed elements are added to this, they are added as a class in the integrated environment, and a 2n number of processed results can be produced in a single integrated environment.

The existing procedural method needs three independent programs to get three-dimensional coordinate values using direct linear transformation, bundle adjustment, and bundle adjustment with self calibration, in order to process close-range photogrammetry values. When the three-dimensional lens calibration method developed in this study was applied to each case to conduct a real-time, on-the-scene measurement, three other independent environments were added and six individual independent environments were made to exist.

The photogrammetry process based on object-oriented programming can reconstruct the course of processing measurement values by class by integrating each process into single environment, thus structuring one integrated environment instead of requiring three independent

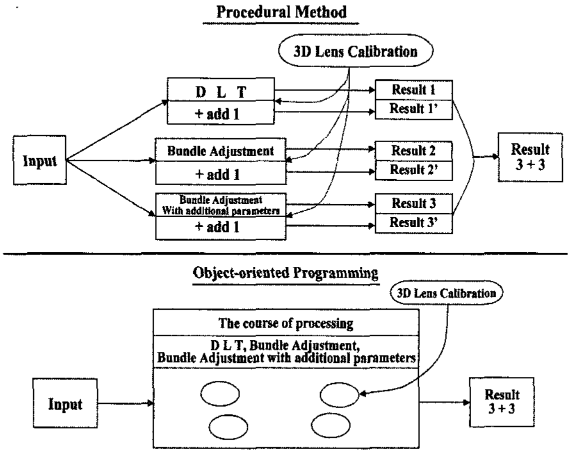

Fig. 2. Comparison of the procedural method and the object-oriented method.

programs. If new research achievements are added to this as classes, the above mentioned process can be conducted in another renewed integrated environment.

Since this object-oriented programming constructs close-range digital photogrammetry, the number of independent environments does not continue to increase as research achievements continue, but it can continue to accumulate research achievements in the existing integrated environment by adding new classes.

3.1.2 Establishment of an Integrated Environment for Close-range Digital Photogrammetry

Object-oriented programming first recognizes and defines classes and establishes construction rules, thus constructing classes through them. Likewise, the method uses such established classes and objects to derive new classes or revise them to fit requirements, thus completing overall class hierarchy diagrams was completed.

In constructuring an integrated environment for digital photogrammetry, images should first be digitized and then processed. This means that images should be displayed in the form of matrices and then processed. Also, in the mathematical model equation for processing measurement values, the direct transformation and bundle adjustment methods process the measurement values using the least square method. Since most of the processes are conducted by matrix computation, the composition and processing of matrices serve as the bases for processing measurement values. This research thus allows the process of matrix components and computation to be conducted through matrix classes and separates the computation process of matrices from the proper computation process of digital photogrammetry. The composition and processing of matrices serve as the bases of each class, and the process was designed to first classify this procedure and place it in the upper class, and inherit and process various processing computation courses from the upper class, and then process (Mikhail, 1976).

For photo rotation factors (κ , ϕ , ω), this study composed photo rotation factor classes to allow matrix computation functions to be supplied from matrix classes, and rotation matrix classes to only consist of rotation factors. In the direct linear transformation, only input coordinates were separately classified, and in the bundle adjustment, both the resection and the intersection parts were separated to conduct their respective processes. For the bundle adjustment aimed at obtaining three-dimensional coordinates of objects, classes were composed to link and process related classes, and their hierarchy diagram was drawn (Methley, 1986).

By specifying such hierarchical relationships, an overall program framework can be formed to make programs clear and easy to understand, thus enhancing intuitive understanding. Additional functions can only be added through class inheritance, to expand their reuse. The process can select the most suitable classes among the established class hierarchy structures, establish their new sub-classes, and add these to new material structures and models or substitute them for the latter, thus continuing to structure classes. This research classifies each process of close-range digital photogrammetry according to theme, constructed classes, crafted hierarchy diagrams according to process, and separated common-use parts and each of their proper computation processes, and structured a single integrated environment consisting of these classes (Pitas, 1993).

This study uses bundle adjustment, which considers direct linear transformation, bundle adjustment, and additional parameters aimed at processing measurement values, and differentiates class compositions using the object-oriented programming concept in an integrated environment and not each independent individual program based on the procedural method, to obtain the resulting values, thus being able to implement the digital photogrammetric process (Schalkoff, 1989).

The classes constructed in this research are shown in Table 1.

Table 1. Construction of Classes and their Details.

Name of Class	Outline
Deg2Dms	Angle expression method
Dms2Deg	Angle expression method
Deg2Rad	Angle expression method
Matrix	Matrix equation calculation
Ratation	Photo rotation factor transformation
Collinear	Coordinate transformation using the collinearity
Resection	Resection
Intersection	Intersection
HoughTransformation	Hough transformation
Imghough2	Hough transformation
Vector	Hough transformation
DLT	Direct linear transformation
Relative	Relative Orientation
Absoulte	Absolute Orientation
ModelConnection	Model connection
Bmp	Input and output of Bmp files
RawImage	Input and output of raw files
Bmp2Image	Transformation of Bmp files into raw files
Resampling	Resampling

4. Analysis of Measurement Values

This study designed a three-dimensional measurement model to conduct real-time close-range photogrammetry in an integrated environment. The shooting model design is shown in Fig. 3.

The measurement used a school's rooftop and a nearby playground. After conducting measurememts to test lenses on the nearby playground, images were acquired using CCD cameras, and two CCD cameras were mounted onto the frame installed top of a vehicle to secure three-dimensional positions. Since the test-field is outdoors, the cameras could be shaken by wind; and to prevent this, supports were erected in the back of the measurement model and pegs were driven into the ground and connected using steel wires to fix the model.

4.1 Determining the 3-D Positions of Objects

In determining the three-dimensional positions of objects, this study compares linear transformation and bundle adjustment to compare the accuracy of measurement values. This study develops bundle adjustment with additional parameters according to the CCD camera's features, and compares and analyzes the accuracy of determining coordinates in each case. The above mentioned measurement model arbitrarily selected 16 points, including surplus measurement values, and used other points as examination points to evaluate the accuracy of the three-dimensional positions of objects.

4.1.1 Acquisition of Objects' Coordinates through Direct Linear Transformation

The DLT process based on object-oriented programming

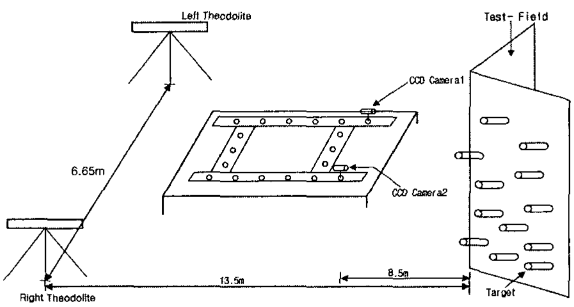

Fig. 3. Measurement model.

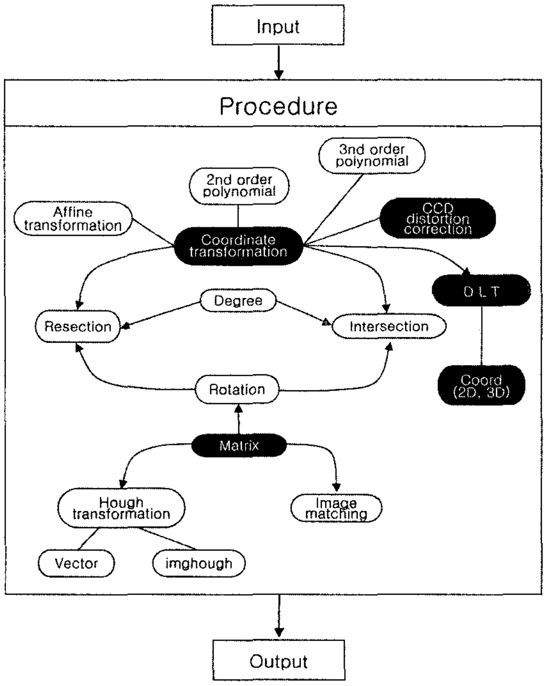

Fig. 4. Process of direct linear transformation based on object-oriented programming.

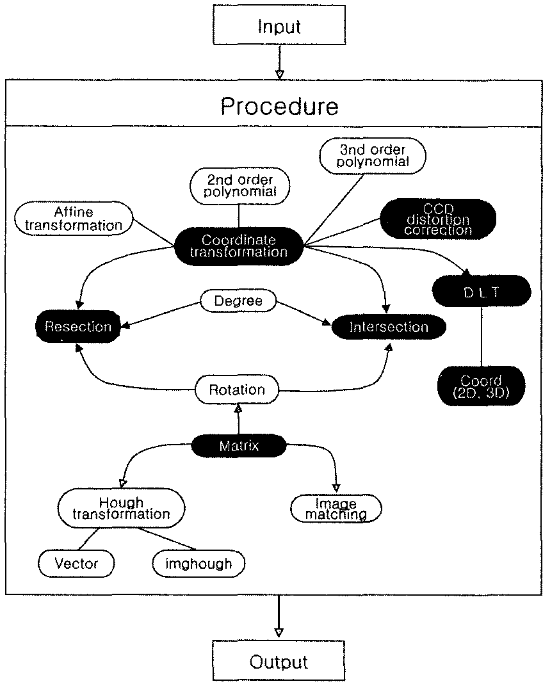

Fig. 5. Process of bundle adjustment based on object-oriented programming.

is shown in Fig. 4. To obtain a total of 11 DLT coefficients, at least 6 points were needed, and 8 points were added as surplus measurement values to achieve accuracy.

4.1.2 Acquisition of Objects' Coordinates through Bundle Adjustment

This study applies image coordinates of measurement points to bundle adjustment to determine the three-dimensional positions of objects for acquired digital images, as well as control point measurement results, thus determining exterior orientation parameters. Fig. 5. shows bundle adjustment using the object-oriented programming concept.

4.1.3 Acquisition of Objects' Coordinates through Bundle Adjustment with Additional Parameters Added according to CCD Camera Features

Since a CCD camera is for general use, in order to apply it to close-range photogrammetry, its lens distortion should be tested. Likewise, since the camera is not for metric use and has no fiducial marks that are necessary for photogrammetry, it would be difficult to determine principal-point coordinates in the actual acquisition after the testing. Additional parameters were thus added.

Only in connection with direct linear transformation, bundle adjustment, and bundle adjustment with additional parameters added according to CCD camera features, corresponding root mean square errors were calculated based on measurement values of selected object points' ground coordinates, as determined through indirect trigonometric leveling. The results are shown in Table 2 and Fig. 6.

5. Comparison and Analysis

This study categorizes the process of digital photogrammetry according to theme and crafted classes and

Table 2. Standard Deviation of Coordinate Values.

Method / Direction	D L T	Bundle	
		normal	self-calibration
X (mm)	27.8639	9.2533	6.3480
Y (mm)	31.2488	9.4331	7.1893
Z (mm)	22.2792	20.4891	15.1427

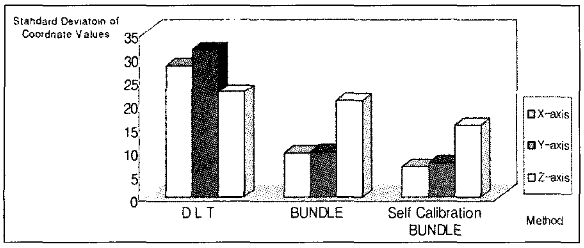

Fig. 6. Comparison of the accuracy of coordinate values.

structures these classes' hierarchy diagrams, thus implementing an integrated environment. Also, based on its results and using CCD cameras and personal computers, this study could acquire digital images, process measurement values on the field, and perform close-range photogrammetry.

In the mathematical model equation for processing measurement values, direct linear transformation and bundle adjustment process measurement values through least square adjustment, although most of these values are processed by matrix computation. The composition and processing of such a matrix serve as the bases for various processes. This study thus composed the matrix into classes and separated it from the proper computation process for photogrammetry. Also, this study crafts a class of photo rotation elements, enables matrix computation functions to be supplied from the matrix class, and the rotation matrix class to be composed only of rotation factors. In direct linear transformation, the part wherein coordinates were inputted was classified separately, and in bundle adjustment, the resection and intersection parts were separated from each other, thus being made to be processed independently. Likewise, to determine the coordinate values of objects, the process was made to be integrated. Since this process has a proper computation process, a class hierarchy diagram of the process of digital photogrammetry was crafted, thus separating the common-use part and each proper computation process.

This study implements the process of direct linear transformation and bundle adjustment, aimed at processing measurement values, not using independent individual programs but by composing classes in a single integrated environment. Table 3 shows a comparison of the existing procedural method and object-oriented programming.

Since a CCD camera is not for metric use but for regular use in acquiring images, the 16-mm CCD camera used in this study was tested for its image distortion. The existing two-dimensional CCD scanner test model equation revealed a minimal effect on close-range photogrammetry, so as to prevent the occurrence of surplus parameters, p3, p4 of the existing-plane CCD-sensor lens distortion test coefficients as well as mobile items of the CCD sensor (a1, a2, and a3) were eliminated, and to conduct a lens test on the field, the Z item was used in the coordinate transformation equation to establish the three-dimensional model equation. This three-dimensional lens distortion test equation enabled

Table 3. Comparison of the Procedural Method and Object-oriented Programming.

Method / Features	Existing Method (Procedural Method)	This Study's Method (Object-oriented Programming)
System	DLT / Bundle Adjustment / Bundle Adjustment with additional parameters → Two 3-D Lens Calibration → 6 Independent Environments	Digital photogrammetry integranted environment
Reusability	Coordinate transformation, the 3-D lens calibration equation, and the calculation, process are duplicated in each independent environment	Coordinate transformation, the 3-D lens calibration equation, and reuse of classes
Extendability	6 Independent Environments → Two real-time GPS research achievements → 12 Independent Environments	Developed Integrated Environment → Real-time GPS research achievements → A single new integrated environment

the research to determine the tested image coordinates of CCD camera images.

Since objects are shot in film and since the images are digitalized using a scanner and undergo several other steps of digitalization, digital photogrammetry may cause the occurrence of error factors; but by minimizing such error factors, the non-metric CCD camera was made to enhance its surveying usage.

When conducting close-range photogrammetry using a CCD camera, if the limited image resolution becomes the main cause of lower accuracy of position determination and if objects appear as distorted images, errors such as mismatched objects can occur. The accuracy of image measurement is determined by the resolution of digital images; thus, in order to enhance measurement accuracy with a limited resolution, the center of marks was determined up to the sub-units of images to produce coordinates.

The image matching of the tested images found that most relative coefficient values were above 0.9, and thus, well-matched. Likewise, visual observation confirmed a positive evaluation and only a slight radial distortion, which was attributed to the fact that prototype marks had almost the same shapes as those on their right and left.

This research, using a distortion test model equation, tests CCD cameras, conducts close-range photogrammetry to determine the three-dimensional absolute coordinates of objects through direct linear transformation and bundle adjustment, and compares the results. Also, to enhance the accuracy of position determination, this research develops and uses bundle adjustment with additional parameters, including test items for principal-point coordinates according to CCD camera features and for focal distance, and determines and compares the results.

In the case of direct linear transformation, the ground coordinates' root mean square error was at sx = 27.86 mm and sy = 31.24 mm, leaving the plane error at sp = 41.85 mm and the height error at sz = 22.27 mm.

In the case of bundle adjustment, the ground coordinates' root mean square error was at sx = 9.25 mm and sy = 9.43 mm, leaving the plane error at sp = 13.21 mm and the height error at sz = 20.48 mm. Bundle adjustment was more accurate than the direct linear transformation in terms of plane and height error by about 68% and 8%, respectively.

Direct linear transformation was less accurate than bundle adjustment in terms of the accuracy of determining three-dimensional positions. Since there was no need for initial values to determine the camera's exterior orientation parameters, however, non-metric cameras like a CCD camera could be used effectively in speedily determining real-time measurement results, and the resulting values could be used as initial values of exterior orientation parameters in bundle adjustment.

Considering features such as when the CCD camera changes its focal distance whenever it acquires images, bundle adjustment was conducted with the test items for focal distance and principal-point coordinates were added to it. The ground coordinates' root mean square error was thus at sx = 6.34 mm and sy = 7.18 mm, leaving the plane error at sp = 9.58 mm and the height error at sz = 15.14 mm. Compared to general bundle adjustment, the method could enhance accuracy by 26% on the plane position in the case of a 27% height error.

This research classifies the process of digital photogrammetry into classes according to theme, thus preparing a single integrated environment, and groups related classes in the integrated environment, which enables it to process the measurement values. By structuring such an integrated environment, when new themes or research results are added, other independent individual programs are not added to it but new research results are added as classes to the classes structured in the integrated environment. Thus, existing structured classes can be renewed or used in another renewed integrated environment, and the reuse and extendability of programs can be enhanced.

This research structures a single integrated environment for digital photogrammetry and provides shared classes that link GPS in real time which enabled it to provide the basis for structuring a renewed integrated environment by allowing GPS and research results to link with the existing integrated environment.

By the nature of its features, the CCD camera can shoot photos and simultaneously obtain digital images, thus speedily conducting the process of close-range photogrammetry. If this is capability is combined with real-time GPS , it is deemed to be of great help in digital photogrammetry.

In case various CCD cameras with higher resolutions are developed, they would be even more effective for close-range photogrammetry.

6. Conclusion

This study designed classes for each theme of photogrammetry and based on the results of such, using CCD cameras, conducted close-range digital photogrammetry. It came up with the following conclusions.

1. The study classified the process of digital photo-

grammetry according to theme, designed classes to be able to conduct a multiple-step process through object-oriented programming, and structured class hierarchy diagrams, thus composing a single integrated environment to conduct digital photogrammetry.

2. The study developed a three-dimensional lens calibration model equation for testing CCD cameras to obtain measurement results fast on the field, thus enhancing the use of CCD cameras as metric cameras.

3. For the interpretation of measurement values, the study added parameters for focal distance and principal-point coordinates to bundle adjustment, considering the CCD camera's feature of changing its focal distance whenever it acquires images, and conducted close-range digital photogrammetry, thus enabling it to enhance the accuracy of determining the three-dimensional positions of objects.

4. The study, using object-oriented programming, structured the basis of a standard environment for close-range digital photogrammetry, and prepared an environment to link to GPS and others through shared classes.

Reference

1. Andres, M. (1993). Visual C++ Object-oriented Programming. SAMS Publishing.
2. Karara, H.M. (1989). Non-topographic Photogrammetry. American Society for Photogrammetry and Remote Sensing, pp. 1-14.
3. Schalkoff, R.J. 1989. Digital Image Processing and Computer Vision. John Wiley & Sons, Inc.
4. Lee, S. (1997). Visual C++ Programming Bible Ver. 5.X. Youngjin Publishing Co.
5. Schenk, T. (1996). Concepts in Digital Photogrammetry. Lecture notes, pp. 115-148.
6. Mikhail, E.M. and Ackermann, M. (1976). Observations and Least Squares. Harper & Row Publishers.
7. Methley, B.D.F. (1986). Computational Surveying and Photogrammetry. Blackie.
8. Jensen, J. (1986). Introductory Digital Processing Algorithms. Prentice Hall, pp. 17-18.
9. Pitas, I. (1993). Digital Image Processing Algorithms. Prentice Hall.