Vibration Monitoring with Video Cameras

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ABSTRACT

While close range photogrammetry has been widely applied for static deformation analysis, video cameras have many characteristics that make them the sensors of choice for dynamic analysis of rapidly changing situations. They also have limitations.
This paper explores the potential of a video system for monitoring dynamic objects. The system consists of two camcorders, VCR, and PC with frame grabber. Basic characteristics of the video camera and frame grabber were investigated in static and dynamic modes. Then, sequential images of a moving car were captured, and digitized in 1/15s intervals. The image coordinates of targets attached to the car were acquired by IDRISI, and the object coordinates were derived based on DLT. This study suggests that home video cameras, PC, and photogrammetric principles are promising tools for monitoring of moving objects and vibrations as well as other time dependent situations.

KURZFASSUNG

Wie die Nahbereichsphotogrammetrie weitgehend für statische Deformationsmessungen eingesetzt wird, sind Video - kameras für die Messung schnell sich ändernder Vorgänge geeignet.
In diesem Artikel wird die Anwendung eines Videosystems für die Messung beweglicher Objekte beschrieben. Das System besteht aus zwei Camcorder, VCR und PC mit Framegrabber. Die Eigenschaften von Videokameras und Framegrabber wurden für statische und dynamische Objekte untersucht. Anschliessend wurde eine Bildserie für ein anfahrendes Auto aufgenommen und alle 1/15 Sekunden digitalisiert.
Die Bildkoordinaten der Zielmarken am Auto wurden üder IDRISI erhalten und mit Hilfe der Direkten Lineartransformation(DLT) in Objektkoordinaten übertragen. Die vorliegende Untersuchung bestätigt, dass eine einfache Videokamera, zusammen mit PC und photogrammetrischer Auswertung ein brauchbares System für die Messung und Kontrolle bcweglicher Objekte und deren Schwingungsverhalten abgibt.

1. INTRODUCTION

It is well known that photogrammetry is ideally suited for precision non-contact measurements for industrial applications, particularly for objects which are difficult to be precisely measured by a direct or contact method. Most of the research in this field has been related to three dimensional positioning. When imaging changing situations in dynamic processes, the amount of data to be manipulated with conventional analogue or analytical methods becomes prohibitively large. Recent developments in solid state cameras, image processing techniques, and microprocessors have raised the interesting possibility of a fully automated photogrammetric system for close range applications. Compared to conventional cameras, it provides sequential images based on TV standards. The use of video cameras and frame grabbers for non-contact measurement of physical dimensions, shape or motion is becoming increasingly popular in many fields of science and industry, including photogrammetry, computer vision, robotics and biomechanics.
The final objective of this research is to develop a fully automated real time photogrammetric system capable of monitoring dynamic processes. In order to reach high accuracy, the system requires sensors capable of taking images in short time intervals, data storage devices handling large amounts of data with high speed, and image processing tools that analyze the interesting features efficiently. Precise target location methods and positioning algorithms with suitable calibration techniques are a prerequisite for meeting the accuracy requirements. In the past few years, some photogrammetrists have attempted to tackle the above mentioned problems(Baltsavias & Stallmann, 1991, Laurin, 1993).
The aim of this research is to gain experience on this topic, to develop new algorithms and test existing ones, and to determine failures, their causes, and possible

solutions. As a pilot system, hand-held camcorders, VCRs, frame grabber, and PC were used to take sequential images. Basic image processing software, DLT, and UNBASC2 were used to derive object coordinates. To analyze the characteristics of the camcorders, preliminary tests were conducted with still and moving targets. Then, to estimate the performance of this system for vibrations, a car was imaged covering several phases when starting to drive. The images were recorded on VCR. 15 images per second were digitized in an off-line mode by frame grabber and the targets attached to the rear bumper were traced using Direct Linear Transformation(DLT).

2. VIDEO SYSTEM

2-1. Camcorder

In a video system, the sensor converts light energy into electrical signals. As a sensor, a video camera is an image plane scanner unlike the line and push-broom scanners that operate as object plane scanners. This means that a 2-dimensional image of the object space, defined by the field of view of the camera, is formed on the imaging surface of the tube or a solid state array. This latent image, scanned by an electron beam(tube camera) or the photovoltaic seats of the sensor array(solid state camera) are read-out to generate a video signal, an amplitude modulated voltage signal. The video signal is then formatted to produce a 2 dimensional raster image by means of accurately supplied synchronization pulses(Vlcek, 1988).
The video image is made up of a series of horizontal scan lines, scanned left to right and from top to bottom much as a page of text is read. Within the scan, the voltage level of the signal is varied in proportion to the image brightness. In most systems the use of television standards plays a role because the image is often transferred from camera to the frame grabber by an analogue television signal. The television signal can be a source of errors and excludes the use of sensors with more rows than defined in the standard. The video industry uses several standards for encoding and decoding video signals. For example, the NTSC standards calls for a video frame, or image, to be scanned every 1/30s. Because this is a rate sufficiently slow for flicker to be apparent, the frame is divided into two fields, containing alternate scan lines, each displayed every 1/60s. This concept, called an interlaced signal, eliminates the flicker problem in ordinary television viewing. Two types of CCD camcorders supporting NTSC standards were used in this research.

2-2. VCR

Video recording is a form of electronic imaging whereby standard analog television signals are recorded on magnetic tape or disks. The raw video signal is a fluctuating DC voltage. The amplitude-modulated, DC-voltage video signal is converted into a frequency-modulated signal by video cassette recorder(VCR).
As the video image is used to measure geometric figures, we have to consider its resolution. The vertical resolution of recorded video imagery is determined by the fixed number of interlaced scan lines. The horizontal resolution, in comparison, is determined largely by the maximum recording frequency. For broadcast television, this frequency bandwidth is fixed by FCC(Lusch, 1988). In photogrammetric applications, the video image is generally not collected for broadcast purposes. In this context, the horizontal resolution of video image is determined by the quality of video camera/lens and the VCR. While VHS format provides a maximum recorded horizontal resolution of about 240 lines, regardless of how many lines the camera produces, S-VHS format provides more than 400 lines of horizontal resolution. Two S-VHS VCRs were used to record the left and right images in this experiment.
The frequency-modulated video signal, called the luminance or Y signal, carries the black and white information of the scene. This achromatic data provides the spatial detail in the video image. The color information in the video signal, the crominance(or croma) signal, is converted by the VCR to a lower-frequency, non-modulated subcarrier. Two different color carrying formats, composite video and S-Video, are mainly used, depending on the recording format. We used S-Video to get a high spatial quality from the video image.

2-3. Frame Grabber

CCD sensors most commonly use one of three addressing strategies: interline transfer, frame transfer, column-row transfer. In the frame transfer organization, the sensor consists of vertical columns of CCD shift registers divided into two zones. One zone, where charge accumulates during integration time, is photosensitive. When integration is complete, the whole array is transferred in parallel to the opaque storage area of the second zone(Dunbar, 1986).
The A/D converters of most frame grabbers resolve the analogue light intensity signal coming from the camera into 8 bit pixels, which is equivalent to 256 shades of gray, ranging from 0 for black to 256 for white or vice versa. A separate device, fabricated by a completely different integrated circuit process than the imager, performs the conversion. It was not until 1978 that the single-chip video rate "flash" analog to digital converter was invented.
If ADC and /or memory is too slow, every image frame will not be stored. At a frame rate of 30 frames per second, it becomes necessary to cope with data sets of 640*480*8 bits in 1/30 s. No conventional PC can cope with these demands within 1/30 s and it is necessary to introduce additional processing power into the PC. This can be done by installing a video digitizer board, also known as frame grabber. This device converts a frame of imagery to digital data, stores it in computer memory, and regenerates a video image from the stored data. We used a popular frame grabber for the PC, Video-BlasterSE. It is designed to work with VGA display standards, and support NTSC, S-Video, and TIFF file formats.

3. MATHEMATICAL MODEL

3-1. Sub-Pixel Target Location

With the emergency of digital photogrammetry, expectations have been raised that the photogrammetric process may be automated. Precise sub-pixel target location is required for the measurements of digital images in photogrammetry for control points and points of interest. This task can be accomplished by either the center of gravity method, the least-squares template matching, or the edge extraction method. Trinder's et al(1995) investigation on the precision of digital target location showed that the weighted centroid method delivers good results for flat circular targets and is less complicated than the other two methods.

Wong and Ho(1986) developed the center of gravity formula based on the threshold window. However, target pointing by this formula was found to be subject to variations in window size, position and threshold value. Trinder(1989) added to the formula a weighting factor w_{ij} for each pixel that is equal to the intensity value of the pixel above the threshold. The central high intensity pixels therefore influence the determination of the pixel location more than the surrounding low intensity pixels: i.e.,

$$x = 1/m \sum_1^n \sum_1^m j * g_{ij} * w_{ij}$$

$$y = 1/m \sum_1^n \sum_1^m i * g_{ij} * w_{ij} \qquad \ldots\ldots\ldots\ldots\ldots(1)$$

$$m = \sum_1^n \sum_1^m g_{ij} * w_{ij}$$

3-2. Determination of the Object Coordinates

According to Faig(1975), a non-metric camera is a camera whose interior orientation is completely or partially unknown and frequently unstable. Because self-calibration and DLT are the most commonly used methods among the data reduction approaches not requiring the use of fiducial marks, DLT and UNBASC2 were selected for the determination of the object coordinates.

Direct Linear Transformation(DLT): The innovation in the DLT approach is the concept of direct transformation from comparator coordinates into object space coordinates, thus bypassing the intermediate step of transforming image coordinates from a comparator system to a photograph coordinate system(Abdel Aziz & Karara, 1974). As such, the DLT solution makes no use of fiducial marks. The expanded method is based on the following pair of equations:

$$x + \Delta x = \frac{L_1 X + L_2 Y + L_3 Z + L_4}{L_9 X + L_{10} Y + L_{11} Z + 1}$$

$$x + \Delta y = \frac{L_5 X + L_6 Y + L_7 Z + L_8}{L_9 X + L_{10} Y + L_{11} Z + 1} \qquad \ldots\ldots(2)$$

$$\Delta x = (x - x_0)(K_1 r^2 + K_2 r^4 + K_3 r^6 + \ldots) + [r^2 + 2(x - x_0)^2]P_1 + 2(y - y_0)(x - x_0)P_2$$

$$\Delta y = (y - y_0)(K_1 r^2 + K_2 r^4 + K_3 r^6 + \ldots) + 2(x - x_0)(y - y_0)P_1 + [r^2 + 2(y - y_0)^2]P_2$$

where

$r^2 = (x^2 + y^2)$

x, y : comparator coordinates of image points

x_0, y_0 : position of the principal point in the comparator coordinates

X, Y, Z : object coordinates of the points imaged

P_1, P_2 : decentering lens distortion parameters

$L_1 \ldots L_{11}$: unknown transformation parameters

K_1, K_2, K_3 : radial lens distortion parameters

Two different approaches can be used in the formulation of a least-squares solution by means of equation(2). Each object point which has known object space coordinates(X,Y,Z) gives rise to two observation equations. If we take into account only K_1, we can derive a direct linear solution. After having obtained initial values for the unknown parameters from the linear approach, the non linear solution of equation (2) is computed by an iterative least squares adjustment.

The University of New Brunswick Analytical Self Calibration Method (UNBASC2): The analytical self calibration method was developed at UNB, and is based on two fundamental restraints: colinearity and coplanarity. The basic unit for the calibration in this method is the multiplet stereo model consisting of two or more photographs. The collinearity equation is the main function of the solution, while the coplanarity is a supplementary function which is used optionally only if the multiplet configuration is not strong enough to effect a good solution. All the calibration parameters are computed for each individual photograph involved in the solution. Detailed derivation of this method was omitted here(see Moniwa, 1977).

4. EXPERIMENTS

4-1. Preliminary Test for Video System

When using a non-metric camera for measurements, usually the vendor does not provide useful specifications required for data reduction processing. For that reason, the basic characteristics of the camcorder and the quality of video image had to be known, before 3 dimensional measurements were undertaken. First, it was necessary to confirm whether the video measuring system was structured correctly and works as expected. Secondly, we need data on the radiometric characteristics and the lens distortion of the camcorder. Thirdly, we are interested in the image by the camcorder of the moving objects. In order to get these objectives, we designed a simple test, and conducted the experiments described below.

System Set-Up: Basically we set up our 3 dimensional measuring system with hand-held amateur camcorders, VCRs, and a frame grabber used in the PC. They have a common drawback of low metric characteristics. On the other hand, it is easy to access and manipulate the tools, their prices are low, and the renewal interval is shorter than for the metric equipment. As an image processor, we use IDRISI for Windows. Table 1. lists the hardware and software of the system used to obtain the imagery of moving objects.

Geometric and Radiometric Characteristics of the Camcorders: In order to obtain basic characteristics of camcorders, VCR, and frame grabber, we took images under various conditions. There are many precise methods to find lens distortion. We opted for an on-the-job calibration, using a plane board with 5×5 circular marks as control points. To coincide the optical axis of the camera with the center target of the board, a cross hair drawn on a glass was placed in front of the target board. Using a theodolite, the central target and the cross hair on the glass plate were aligned. Then the camcorder was adjusted such that its optical axis coincided with this line.

Image of Moving Objects: As we know from aerial photography, the relative motion between the sensor and the object causes image blur. When it comes to imaging of moving objects, image motion depends on the speed of the moving object, the pixel size in direction of the motion, object distance, camera focal length, and shutter speed. Theoretically, in order to get a clean image, the ratio of motion of object during exposure to the width of a TV line should not exceed 0.5. To get practical recording of this phenomenon, we took images with specified shutter speeds, of the target board falling from different heights.

Hard/Software	Maker, Model	Specifications
Video Camera I	Panasonic, AG-455P	1/3" CCD, S-VHS, S-Video, 1/2" tape
II	Samsung , H-33	1/3" CCD, VHS, S-Video, Hi-8 Tape
VCR	Panasonic, AG-1970	S-VHS, S-Video
Frame Grabber	CreativeLab, VideoBlaster SE	Resolution: 640*480(VGA)
Video Tape	Sony, Sony V	S-VHS
PC	Dell, Dimension P100C	Intel 100MHz Pentium, 16Mb Ram
Image Processor	Clark University, IDRISI	Window 95, compatible with TIFF

Table 1. System Components

4-2. 3-D Measurements of a Moving Car

Outline of Model: The objective of this research is to find out the performance of a conventional video system, and to suggest better ways to get higher performance and accuracy in monitoring moving objects and vibrations. To achieve this objective, we selected a car as the vibrations-and moving object, and planned to take images of the process when a driver and passenger get into the car, start the ignition, then drive ahead. We expected 3 directional movements from small to large size in the process.

As shown in Fig. 1, two pairs of targets were attached to the left and right side of the rear bumper, and one pair was attached to the license plate of a car. For control, we put a 3 dimensional control frame in front of the car. The control frame has 20 control points distributed randomly, which were coordinated precisely with the Kern E2 Electronic Theodolite System.

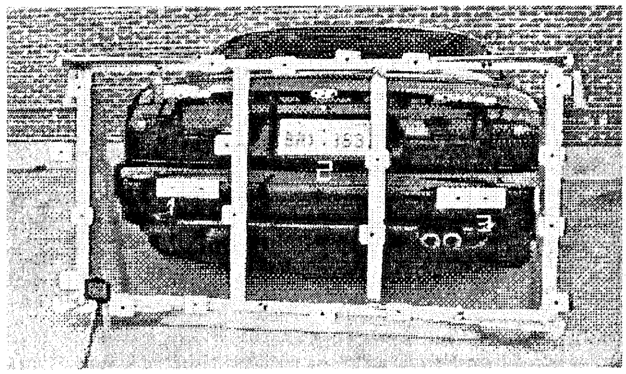

Fig. 1. Right Image of a Car and a Control Frame.

Imaging Geometry: The adopted imaging geometry for a network is a central factor in determining the object point positioning accuracy. To obtain a near-homogeneous distribution of object space precision, a convergent multi-imaging geometry is mandatory. In the case of a series of images for a moving object, we must take into account the amount of image manipulating, therefore we used the minimum number of cameras, namely two.
An increase in the B/D ratio for near normal imaging configurations is accompanied by both an improved level of mean object point precision and enhanced reliability. In this context, we took images at three different base lengths, to compare the precision, and chose the best base length for the test .

Photographing Condition: Based on the preliminary tests we fixed the shutter speed at 1/1000 s. Considering the field of the view of the camera(17~20°) and the size of the control frame sufficient to encompass the car, we decided on the camera stations. The diameter of circular targets that could be imagined larger than 3 pixels in x, y directions was calculated. We used black circular stickers on white background as targets. The diameter of the stickers was 19mm and the width of the background was 3 times that of the sticker's. The average distance from the camera to the objects was 2.7m. resulting in a photo scale of 1: 270. Additionally, to get a clean image of a car outdoors without artificial illumination, we needed sun shine. Unbalanced or poor illumination causes a lot of problems in target detection and location processes.

Synchronization for Sequential Images: It is very important to synchronize the left and right images. Baltsavias & Stallmann(1991) used one electronic device between the camera and the VCR to add a vertical line of high contrast and binary pattern to the video signal. The binary pattern provided a code for the sequence of each image during recording and permitted safe identification of each image during the digitization. In this research, a stopwatch was attached to the front of the control frame.

It refreshes its digits every 1/100s, and could be used as a code of the sequence. As an auxiliary method, the frame advance function of the VCR can also be used for that purpose provided a significant starting point was identified in each image.

5. TEST RESULTS AND ANALYSIS

5-1. Radiometric & Geometric Characteristics

Radiometric Characteristics: As Curry et al(1986) have noted, radiometric criteria include sensor response linearity, system noise, and system stability over time. System noise is defined as fluctuations in pixel gray levels caused by random and systematic perturbations in the CCD sensor and A/D converter. Systematic noise is seen as a repeated spurious response by the sensor element. For detecting the system noise of the cameras used, dark images were captured by running the camera in the dark(lens cap on) and measuring the output for each pixel. When the gray value of a pixel exceeded 3 times the standard deviation from the mean of the image, it was assumed to be a blemished pixel. Fig. 2 shows the results. In Fig. 2(A), black spots mean too low gray values, and white spots mean too high gray values. We found that every dark image of a video camera at an instance has some noise, but the position of noise pixels changes with time, and rarely fell on the same pixel position in different images. Moreover, the image of white paper doesn't show the noise pixel. In Fig. 2(B), two groups of black spots on the lower corner of each side are caused by unbalanced illumination, not noise. In this context, the images of the video cameras don't have serious intrinsic noise that should be corrected before target location determination.

(A) (B)

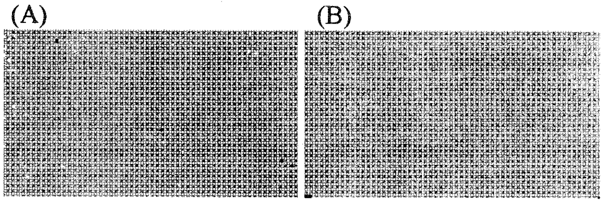

Fig. 2. Noise Pixels of Dark and White Image

Generally, shutter speed influences the image quality. In order to investigate the influences, a rectangular window consisting of 25*20 pixels was picked out from the black target area, and another same size window was picked out from the white background area . The test images of target and background were captured under indoor florescent light and outdoor sun shine at different shutter speeds, then the ranges of gray values for each window were collected, and plotted in Fig. 3. The images captured outdoors show uniform ranges of gray values in spite of varying shutter speed, but the gray values of images captured indoors changed with the shutter speed. The sensitivity of the sensor gradually decreased when the shutter speed increased. Therefore, when photographing indoors with short exposure times(e.g. less than 1/2000s), we should provide enough illumination according to the surrounding conditions.

Geometric Characteristics: Compared to metric cameras, non-metric cameras' lenses are designed for high resolution at the expense of geometric quality. Interior orientation parameters lack stability, and there are no fiducial marks. In addition to the above disadvantages, the size of unit pixels of video images changes in the course of digitizing, and the scale changes with the display format. We only have approximate data for the object distance, focal length, and pixel size of the video images. We therefore derived lens distortion based on some approximations. The horizontal and vertical pixel sizes of the CCD were deduced from dividing the length of each side by the total number of pixels in the corresponding direction. As seen in Fig. 4(A), the camera has different distortions in vertical, horizontal, and diagonal directions. This means it has radial and decentering distortions. But, it is hard to estimate the amounts of distortion. We derived another lens distortion curve showing typical radial distortions by using the calibrated focal length and adjusting the pixel sizes(Fig. 4(B)). The maximum distortion was 3.5μm, which is quite acceptable.

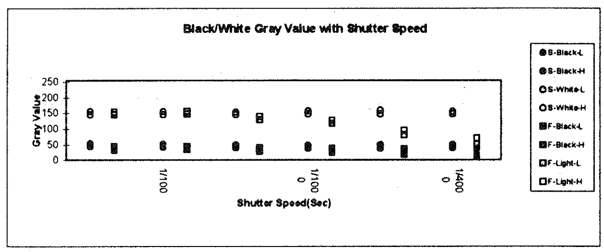

Fig. 3. Change of Gray Value with Shutter Speed

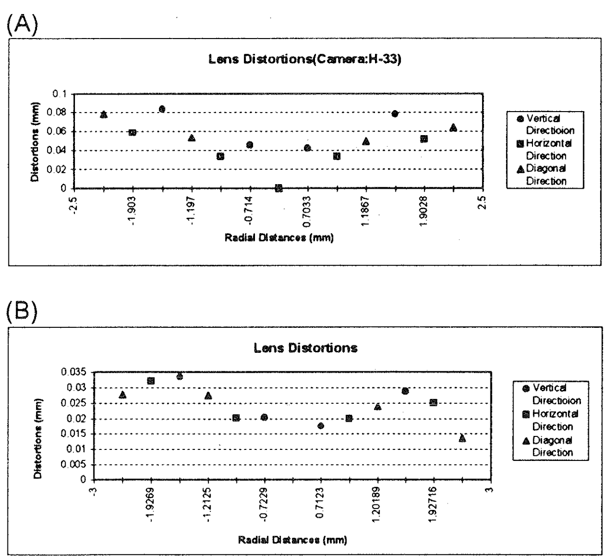

Fig. 4. Lens Distortions(Camera: H-33)

Response to Moving Objects: We expected no friction when the target board was falling through the stand, but the images show that was not quite the case. The target plate shown in Fig. 5 fell from 40cm height above the optical axis. Theoretically the speed should be 2.8m/s, but its actual speed was about 1.7m/s. The image blur was improved with the shutter speed. The relative motion during exposure was 30 rows In Fig. 5(A), 12 in (B), and 3 in (C). Image (D) is one later field(1/60s) of Image (C). Vlcek(1988) suggested that the relative motion during the exposure should not exceed 0.5 pixel for a clear image. Although we have not reached 0.5 pixel, we expect that relative motion lower than 0.5 pixel will provide a clean image without blur. To lower the relative motion, a short exposure is mandatory.

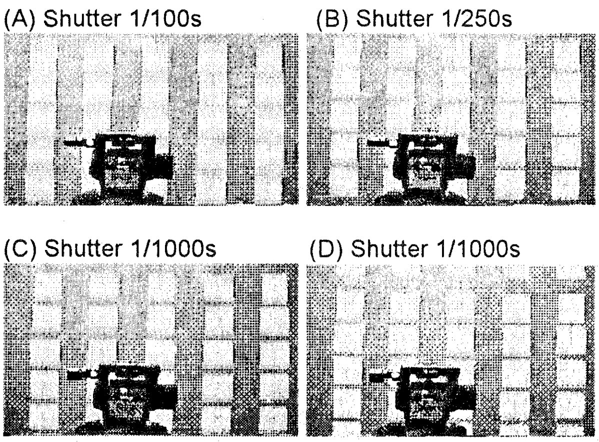

Fig. 5. Falling Target Images at Various Shutter Speeds.

5-2 Dynamic Monitoring

Source Sequential Imaging and Pre-Processing: The left and right video images were recorded on each S-VHS VCR. Then the VCR was connected to the PC installed frame grabber. We planned to use the stopwatch's 1/100s digits as a code for synchronization. However its letter size was too small to identify it when it was attached to the control frame located close to the rear of the car. There was no other alternative than using the frame advancing function(1/60s) of the VCR. Before capturing the real sequential image, significant scenes(e.g. lights on and off, door open and close) were designated as milestones. We counted the number of fields between each milestone several times. It does not exceed 2 field's(1/30s) difference during 10s. In this context, we captured every 4th field(1/15s), comprising synchronized sequential images for monitoring the movement of a car. The PC works on a S-VGA display board, and the resolution of the images captured using the frame grabber is 788(H)*468(V). Each captured image was saved in TiFF format, its file size is 1.1Mb. This image is a 24-bit Band-Interleaved-Pixel(BIP) format, and was converted into Band Sequential(BSQ) images in the "IDRISI for Windows" format. There were no significant image quality differences between the S-VHS and VHS video cameras when the images were recorded by S-VHS VCRs using the S-Video format. 77 pairs of sequential images were digitized from S-VHS VCR. Image coordinates of three points in each image were processed to determine their object coordinates.

Sub-Pixel Target Coordinates: The image coordinates of the targets were generated from the preprocessed video image in four-step process:

- Noise removal using median filter.
- Searching window centered a target.
- Reclass based on a threshold.
- Determination of the target center coordinates using equation(1).

These processes for the sequential images were conducted by batch job using the macro command of IDRISI.

The enhanced images using median filter showed more condensed gray value dispersion than the original images in the histogram, and more ideal circle appearance. Target windows were detected manually, while the threshold was determined from the histogram. The change from background to target was clear in the histogram, and generally it was very close to the threshold [(maximum + mean of gray value)/2] suggested by Wong & Ho's(1986). In order to see the significance of the threshold, the target coordinates were calculated using another threshold (original threshold - 4), the differences of target center coordinates obtained by each threshold were within 0.1 pixel. In Fig. 6., (A) is the original target image, (B) its filtered image, and (C) its reclassed image. It was known that image enhancement causes target shift to some extent. In this test, the mean difference between two was nearly zero, and the maximum difference was 0.02 pixel in 20 targets.

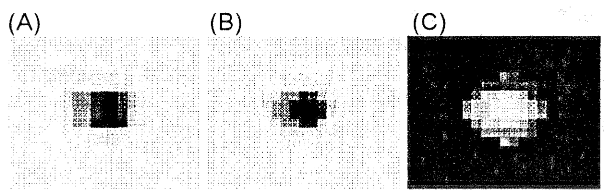

Fig. 6. Images of Circular Target

3-D Object Coordinates: For 3-dimensional tracking of the targets in each image sequence, we prepared image coordinates of all control points and targets in the first image. Under the assumption that the control frame was fixed, the target coordinates were only prepared in the remaining image sequences. This tracking scheme reduces the work from obtaining image coordinates to running the program. As described in section 3-2, DLT and UNBASC2 could be used to derive 3-dimensional object coordinates using non-metric image coordinates. While DLT affords pixel unit as a input data, UNBASC2 requires metric units. Pixel units may be considered as comparator coordinates having different scales for each axis, but UNBASC2 failed to obtain the object coordinates. Therefore, the pixel sizes of the two cameras were derived by trial and error. UNBASC2 then provided more accurate results than DLT in the test image. However, DLT was used for this experiment because it can cope with sequential data that may recourse to the same position in another sequence when above tracking scheme was adopted.

It is well known that the imaging geometry plays a great role in determining the accuracy. When the imaging geometry is ill conditioned, the accuracy of DLT becomes worse when increasing the number of parameters. Fig. 7 shows the average root mean square errors of DLT(12 unknown parameters) for different B/D ratios. Just 20 control points were used as image coordinates. In the adopted coordinate system, the base line direction is the X axis, the azimuth direction is the Y axis, the optical axis direction is the Z axis. The error decreased when the B/D ratio increased, so we chose the images photographed at 0.46 B/D. In order to construct an optimum control set, one control point, who showed the largest RMS error was sequentially excluded from the control points. At last, optimum control points were obtained except for 2 points.

This optimum control point set provides a little smaller RMS error with the unknown parameters of DLT increased. However, the RMS errors of the unknown points were minimum when the unknown parameters were 12. Therefore, 12 parameters were adopted to determine the tracking of targets attached to the moving car. As shown in Table 2, RMS errors in z direction are always larger than for the other two directions. Especially, target 2 provides smaller RMS errors than control point set in all directions, and its magnitudes in x and y directions are within 1mm. Generally, the accuracy between rows(y axis) is much better than that of columns in the video images. RMS errors in x direction of targets 1 and 2 are about 1.5 - 3 times those in y direction. But target 2 shows a reverse phenomenon.

At last, we got the trajectory of targets attached to the car. In Fig. 8(A), we can see the vibration of the car in positive x direction owing to the impacts of shutting the driver's door , and the vibration in negative x direction owing to shutting the passenger door. After these two impacts compounded, it gradually becomes weakened. The second half of diagram describes the trajectory when the car starts to drive ahead. Target 3 was attached to a little rounded surface, and its narrow intersection angle between two cameras might cause some large deviation of the trajectory compared to the other two targets. In y direction, the settling of the car body when driver and passenger get into the car, rebound, and final equilibrium state are recorded very clearly. In z direction, it remains still while the driver gets into the car and starts ignition. When the car starts to drive ahead, the targets' trajectories grow farther.

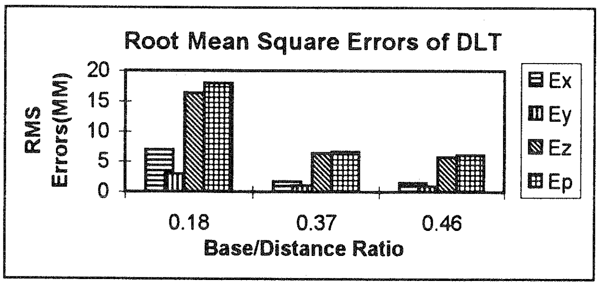

Fig. 7. RMS Errors of DLT for Different B/D (Unknown Parameters: 12)

	Ex(mm)	Ey(mm)	Ez(mm)	Ep(mm)
Control Points	1.4	1.0	4.9	5.2
Target 1	14.8	10.0	73.2	75.3
Target 2	0.4	0.9	1.7	2.0
Target 3	16.2	4.8	37.4	41.2

Table 2. RMS Errors of Object Coordinates (Unknown Parameters of DLT:12)

6. CONCULSIONS

Two video cameras and VCR combined with frame grabber were investigated and tested for vibration and movement monitoring. The quality of digital images photographed with the video camera, recorded on S-VHS VCR using S-Video, and digitized with the frame grabber is good enough to monitor these dynamic phenomena. However, the TV broadcasting standards prevent a better high resolution video image. It will be improved with the advent of HD-TV. In order to secure a blurless image of a moving object , it is necessary to take into account the imaging geometry, shutter speed, and illumination. Although the frame advance function of the VCR was satisfactory for synchronization in this experiment, more elaborate devices are indispensable to monitor high frequency vibrations. Image processing software for the PC(e.g. IDRISI) was a usable tool for image preprocessing and target centering. For the real time photogrammerty system, its macro command must be improved to manipulate Windows without manual assistance. DLT was an appropriate model for the non-metric imagery except its accuracy is lower than for the self-calibration model. In conclusion, a video system and appropriate photogrammetric principles provided the expected results for monitoring of a moving car.

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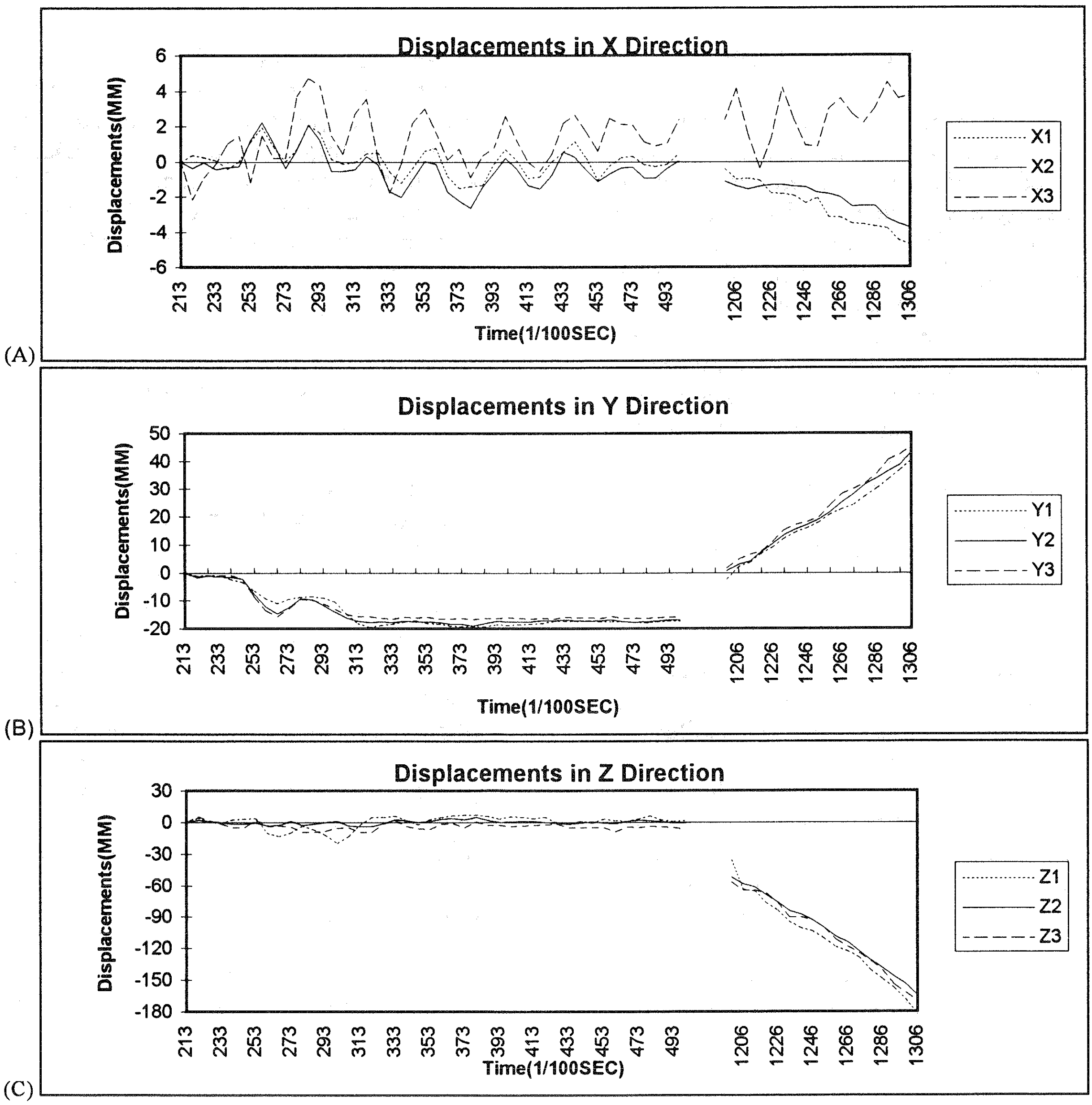

Fig. 8. Trajectory of Targets Attached to a Moving Car