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On the suitability of digital camcorders for virtual reality image data capture

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ABSTRACT

Today's consumer market digital camcorders offer features which make them appear quite interesting devices for virtual reality data capture. The paper compares a digital camcorder with an analogue camcorder and a machine vision type CCD camera and discusses the suitability of these three cameras for virtual reality applications. Besides the discussion of technical features of the cameras, this includes a detailed accuracy test in order to define the range of applications. In combination with the cameras, three different framegrabbers are tested.

The geometric accuracy potential of all three cameras turned out to be surprisingly large, and no problems were noticed in the radiometric performance. On the other hand, some disadvantages have to be reported: from the photogrammetrists point of view, the major disadvantage of most camcorders is the missing possibility to synchronize multiple devices, limiting the suitability for 3-D motion data capture. Moreover, the standard video format contains interlacing, which is also undesirable for all applications dealing with moving objects or moving cameras. Further disadvantages are computer interfaces with functionality, which is still suboptimal. While custom-made solutions to these problems are probably rather expensive (and will make potential users turn back to machine vision like equipment), this functionality could probably be included by the manufacturers at almost zero cost.

Keywords: Camcorder, calibration, accuracy

1. INTRODUCTION

Different types of solid state sensor cameras are being used today to acquire image data for applications of digital close range photogrammetry. Besides the categorization into standard (videonorm) CCD cameras, high resolution cameras and high speed cameras, these cameras can also be categorized into machine vision type cameras, which need to be permanently interfaced to a host computer, and standalone consumer market cameras like camcorders or stillvideo cameras. While large format digital stillvideo cameras have found their way into photogrammetry as a versatile autonomous instrument for image data acquisition already several years ago, the use of camcorders has been limited so far, although their inherent image sequence storage capabilities are of interest for an increasing number of applications. One of the reasons for this retention was the analogue nature of video image data storage and the problems of computer interfacing and data quality connected with this. Meanwhile, there are digital camcorders on the consumer market, which can be used both as still cameras and for image sequence acquisition, storing up to 90'000 compressed digital images on magnetic tape. Most of them come with PC interfaces for data download. Being cheap, autonomous and easy to handle, these devices seem to be an interesting option for virtual reality image data capture.

In the following, we will examine three rather different cameras, which are all based on standard videonorm CCD sensors, in combination with three different framegrabbers on their suitability for photogrammetric VR data caption applications. This includes a discussion of features of the cameras as well as a detailed accuracy test.

2. CAMERAS AND FRAME GRABBERS

Three different camera types in combination with three different frame grabbers were tested.

2.1 Sony XC-77

The XC-77 is a monochrome video camera module designed for the industrial market. The camera uses a 2/3-inch IT CCD sensor with 768x576 pixels. The pixel size is about 11 µm x 11 µm. For the tests a FUJINON-TV 1:1.4 / 9 mm lens was used.

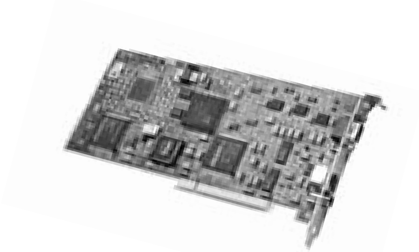
2.2 Sony DCR-VX700E

The Sony digital handycam DCR-VX700E records images in digital format on a Mini DV cassette. The images are stored in DV format with a size of 720x576 pixels and 24 bit colour resolution. The DV format is a sony proprietary compressed digital video and audio recording standard. A single image in this format has a size of about 140kB. The camera is equipped with a 1:1.4 / 6.1 to 61 mm zoom lens. It has DV digital video output, S-Video (S-VHS, Hi8) output and RCA pin jack video output. The camera can be used in the photo-mode, which permits the acquisition of still images.

2.3 JVC GR-S77

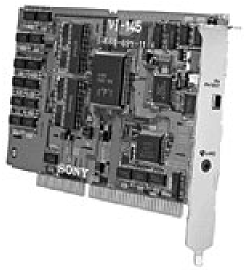
The JCV VideoMovie S-VHS GR-S77 records in S-VHS HQ format on S-VHSC cassette. The images are stored in analogue form in S-VHS format. The camera is equipped with a 1:1.4 / 8.5 to 68 mm zoom lens and has S-Video output. An accurate accuracy test of this camecorder can be found in the paper of Höflinger and Beyer [4].

2.4 Matrox Meteor



The Matrox Meteor was installed on a PC Pentium 66 MHz. It is a colour and monochrome PCI frame grabber that provides real time image transfer to host. It has a composite video (PAL or NTSC) input, a S-Video (S-VHS, Hi8) input, independent RGB inputs and a TTL trigger input to synchronize acquisition to an external event. It decodes the colour image at 24 bit with a 768x576 resolution. With the independent RGB inputs it is possible to store simultaneously 3 monochrome (8 bit) images from 3 synchronised monochrome cameras. Due to its bus mastering capabilities, a realtime image transfer to host memory is principally possible, thus allowing for image triplet sequence acquisition at 25 Hz. The related software works under Windows environment. An additional library of C++ routines (MIL) gives complete control over the acquisition process. The Matrox Meteor frame grabber is therefore suitable for the integration of image acquisition process in custom developed systems.

2.5 Sony DVBK-1000E



The Sony DVBK-1000E Digital Image Capture Board DVBK-1000E was installed on a PC Pentium 66 MHz. It is specially designed for Sony Digital Handycams and it captures single frames from digital video via DV interface, i.e. it converts frames from Sony's Digital Handycam to PC format digitally. The DV format video is 720x576 pixels and the decoded image size is 768x576 pixels. It does not capture full-motion video direct from the camera but it can capture image sequences in slow-motion mode from the tape. Sequences at full 25 Hz temporal resolution can only be grabbed interactively by alternating grabbing and forwarding the tape by one image. The related software works under Windows 95 environment. This capture board can be defined as "hobby" frame grabber. It's suitable for home video purposes, like acquisition of single shots or short sequences.

2.6 Data Cell S2200

The S2200 is a single SBus frame grabber for Sun SPARCstation that provides real-time image acquisition of a colour image or three monochrome images. It has a composite video (PAL or NTSC) input, a S-Video (S-VHS, Hi8) input, independent RGB (CAV) inputs and a TTL trigger input. It decodes the colour image at 24 bit with a 768x576 resolution. Using the three RGB inputs, it can acquire 3 monochrome (8 bit) images simultaneously. The related software works under OpenWindows environment. The capturing process can be totally controlled by C routines. Due to inefficient memory mapping and the lack of bus mastering capabilities under UNIX, the image sequence acquisition rate is rather limited. As the Matrox Meteor, the DataCell S2200 is suitable for the development of machine vision, image analysis and imaging systems.

3. TEST ON ACCURACY POTENTIAL

Though not of highest importance for many VR application, a thorough accuracy test was performed for the camera/frame grabber combinations presented above in order to be able to define the range of possible applications.

3.1 Test configuration

To investigate the accuracy potential of the cameras and the frame grabbers, a number of images of a reference field with an extension of ca. 3x2x1.2 m (Fig. 1) were taken with each camera. The image coordinates of the signalized points were determined with subpixel accuracy by least squares template matching, using some known 3-D coordinates for an automated dataflow. Employing self-calibrating bundle adjustment techniques, camera model parameters were determined simultaneously with camera orientation data and 3-D object point coordinates. The sensor model [2] used in the test contains three parameters of interior orientation (camera constant and principle point coordinates) and five parameters modelling radial and decentring lens distortion. This model was extended for the use in digital close range photogrammetry by two additional parameters of an affine transformation, modelling a horizontal scale factor and a non-orthogonality of the image coordinate axis [3]. These parameters do mainly cover deviations of the pixel shape from the designed values and effects of the A/D conversion.
The 3-D coordinates of 186 signalized points on the reference field (Fig. 1) had been determined using a theodolite system. Unfortunately in the time of the tests, some construction work was performed in the building so that the previous accuracy (0.02-0.03 mm) of the measurement could not be guaranteed. The reference field was used in two modes:

- In the mode 'free network', a self-calibrating bundle adjustment was performed as a free network adjustment, including the 3-D coordinates of the signalized points as unknowns into the adjustment process. This allows for the derivation of figures on the theoretical precision of photogrametrically determined object points coordinates. From comparisons with the reference coordinates, statements on the practical accuracy could be drawn. In our conditions (accuracy of the measured 3-D coordinates is not guaranteed) these results can be only used for a qualitative comparison between the different tests.

- In the mode 'resection' the known coordinates of the signalized points were used as control points and spatial resections were performed to determine the interior and exterior calibration parameters. This can also be done for each image individually, allowing for the determination of one independent parameter set for each camera position. Once more, the results of these tests suffer from effects of the reference coordinates and can only be used as a comparison tool for the different cameras and frame grabbers.

3.2 Performed tests

For each camera/frame grabber configuration a total of 16 images were taken: from 5 camera stations (L2, L1, C, R1, R2) at two heights and additionally at 3 camera stations (L1, C, R1) with two different roll angles (+90˚, -90˚). Figure 1 shows the reference field and the test configuration.

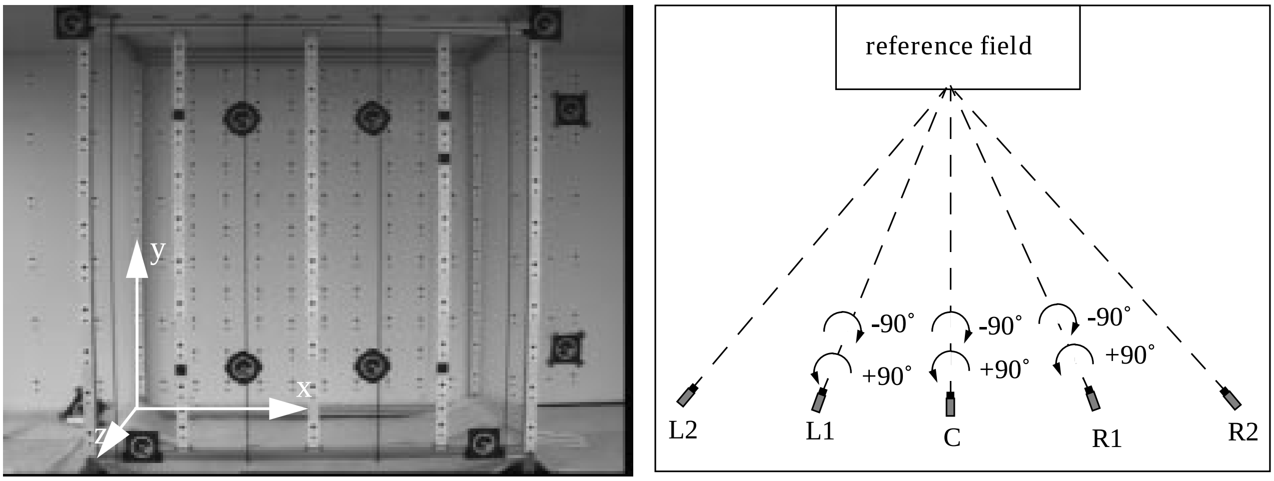


Fig. 1: Reference filed and test configuration

The performed tests are summarised in table 1.

test	camera	frame grabber	connection	storage
DCR-DV	DCR-VX700E	DVBK-1000E	digital video	direct grab
DCR-P-DV	DCR-VX700E	DVBK-1000E	digital video	photo-mode
DCR-T-DV	DCR-VX700E	DVBK-1000E	digital video	Mini DV tape
DCR-T-SVHS	DCR-VX700E	DataCell S2200	S-Video	Mini DV tape
DCR-T-RGB	DCR-VX700E	DataCell S2200	1 RGB	Mini DV tape
DCR-T-MET	DCR-VX700E	Matrox Meteor	1 RGB	Mini DV tape
JVC-SVHS	JVC GR-S77	DataCell S2200	S-Video	direct grab
JVC-T-SVHS	JVC GR-S77	DataCell S2200	S-Video	S-VHSC tape
CCD-RGB	Sony XC-77	DataCell S2200	1 RGB	direct grab
CCD-MET	Sony XC-77	Matrox Meteor	1 RGB	direct grab

Table 1: performed tests

3.3 Test results

The results achieved in the tests are summarized in Table 2:

test	$\hat{\sigma}_0$	$\hat{\sigma}_x$	$\hat{\sigma}_y$	$\hat{\sigma}_z$	μ_x^*	μ_y^*	μ_z^*	$\hat{\sigma}_{0(1)}$	$\hat{\sigma}_{0(16)}$
DCR-DV	0.517	0.107	0.099	0.327	0.170	0.191	0.310	0.554	0.521
DCR-P-DV	0.562	0.121	0.110	0.367	0.323	0.280	0.867	0.639	0.579
DCR-T-DV	0.506	0.105	0.097	0.319	0.163	0.187	0.346	0.545	0.520
DCR-T-SVHS	0.832	0.212	0.166	0.567	0.790	0.524	0.834	1.07	0.999
DCR-T-RGB	0.831	0.172	0.159	0.525	0.709	0.463	0.654	1.07	0.996
DCR-T-MET	0.427	0.097	0.084	0.279	0.149	0.164	0.356	0.483	0.457
JVC-SVHS	0.862	0.174	0.161	0.566	0.775	0.401	1.108	1.27	1.18
JVC-T-SVHS	0.844	0.180	0.164	0.581	0.806	0.389	0.861	1.12	1.18
CCD-RGB	0.800	0.151	0.142	0.460	0.708	0.496	0.713	1.15	1.02
CCD-MET	0.329	0.065	0.048	0.156	0.138	0.142	0.317	0.453	0.402

Table 2: Results of free network and resection tests (* to be interpreted with care due to insecure testfiled)

for the free network mode: $\hat{\sigma}_0$: standard deviation of unit weight [μm]
$\hat{\sigma}_{x,y,z}$: standard deviation of object point coordinates [mm]
$\mu_{x,y,z}$: rms of control point differences [mm], to be interpreted with care due to insecure testfield

for the resection mode: $\hat{\sigma}_{0(1)}$: standard deviation of unit weight with one parameter set [μm]
$\hat{\sigma}_{0(16)}$: standard deviation of unit weight with 16 individual parameter sets [μm]

3.4 Interpretation of results

In general, the accuracy potential of both camcorders can be considered quite high. In all tested configurations, the standard deviation of unit weight was smaller than 1/10 of a pixel. As mentioned above, the comparisons with the reference coordinates of the calibration testfield are partly inconsistent due to effects of construction work on the testfield; therefore the RMS coordinate differences $\mu_{x,y,z}$ and the results from the resections are of rather limited interpretability. Statemets on the accuracy potential are therefore drawn only theoretically.

The best results were achieved with the combination Sony XC-77 plus Matrox Meteor framegrabber, whereas the Datacell S2200 framegrabber on the SUN workstation did perform much worse. The results achieved with the digital camcorder DCR-VX700E are about 50% worse than the results achieved with the machine vision type XC-77. No significant differences could be found between direct data capture, capture from digital tape and the photo mode of the digital camcorder. Related to the dimensions of the testfield, the theoretical relative precision potential of the DCR-VX700E in lateral 3-D coordinate direction reaches almost 1 : 30’000. Although this figure is based only on internal precisions provided by the bundle adjustment, it indicates that precision arguments will hardly limit the use of this camera in virtual reality applications. The results obtained with the analogue camcorder are about 50% worse than the results achieved with the digital camcorder, but were probably smeared by the Datacell framegrabber.

In the following figures, the residuals of a spatial resection are shown graphically.

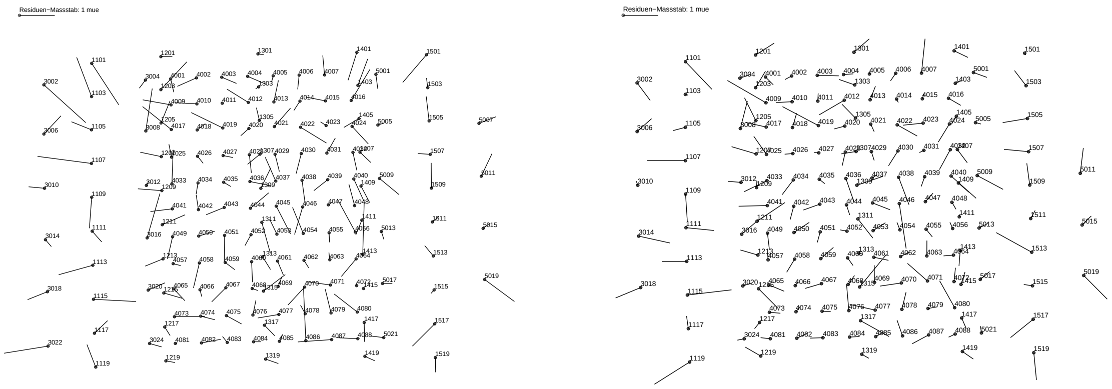


Fig. 2: Image coordinates residuals for DCR-T-DV (left) and DCR-T-MET (right)

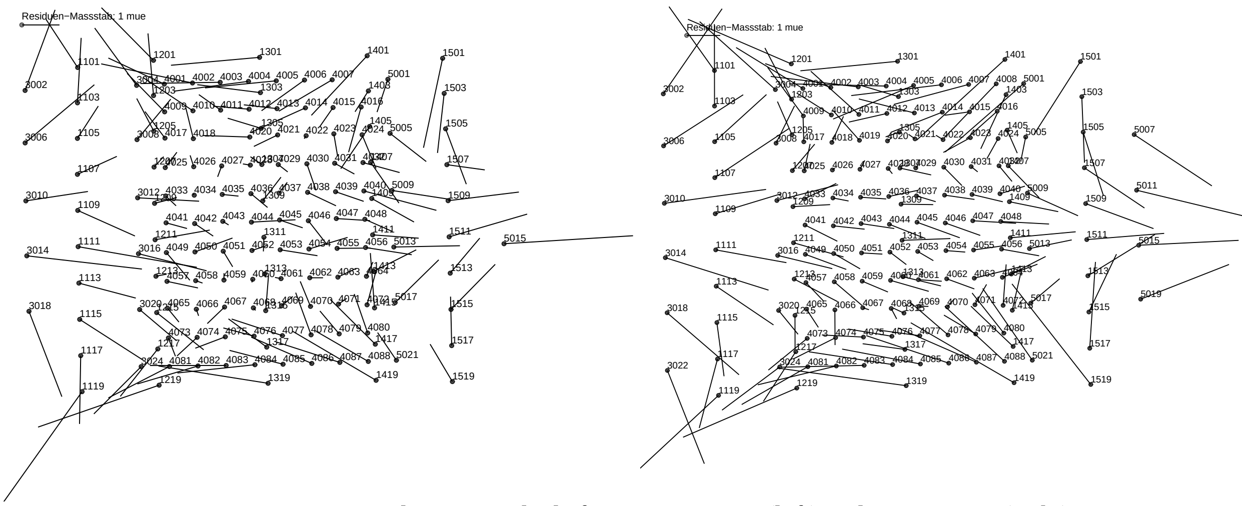


Fig. 3: Image coordinates residuals for DCR-T-RGB (left) and JVC-SVHS (right)

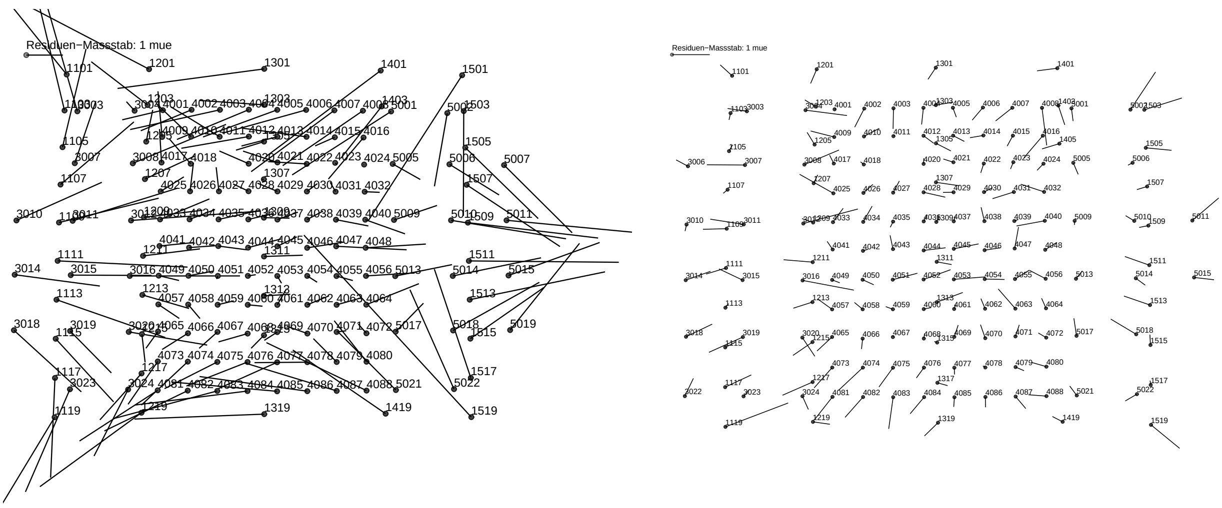


Fig. 4: Image coordinates residuals for CCD-RGB (left) and CCD-MET (right)

In the tests with the DataCell frame grabber (DCR-T-RGB, JVC-SVHS, CCD-RGB) the presence of large systematic errors, which indicate a synchronization problem of the S2200, is clearly visible. The lower precisions of these tests are mostly caused by the frame grabber, while the differences between the cameras are very small: about 4% between CCD and DCR and about 8% between CCD and JVC (see table 2). By the tests with the Matrox Meteor frame grabber on PC (DCR-T-MET, CCD-MET) the residuals are smaller and show a random distribution. This excludes the presence of systematic errors and the differences between the cameras are therefore more evident.

4. TECHNICAL LIMITATIONS

According to the technical features, the digital camcorder is certainly the best suited of the three discussed cameras for virtual reality data capture. As the accuracy test does also show a very good accuracy potential, the digital camcorder may be considered the device of choice for virtual reality applications. However, some technical limitations have to be considered:

- To the author’s knowledge, all digital camcorders are interlaced, i.e. a full frame is split into two fields which are recorded and read out consecutively, thus providing an apparent temporal resolution of 50 Hz (or 60 Hz in the US videonorm). This feature has to be considered rather disadvantageous for all applications dealing with moving objects or moving cameras, as odd and even lines of an image are captured at different times, thus creating a sawpattern in the image. The only way to circumvent this problem is processing video fields rather than full frames, with the disadvantage of halving the spatial resolution in vertical image coordinate direction. When using progressive scan cameras (which are so far only being offered as machine vision type cameras), this problem does not occur.

- The Sony DCR-VX700E cannot be externally synchronized. This does pose a severe limitation to 3-D motion capture applications, which do usually require multiple synchronized imaging devices. Again, most machine vision type CCD cameras do offer this feature. As a mean of synchronising different camecorders, an appropriate time reference object (e.g. an emitting diode [6]) can be introduced into the scene. This type of synchronisation is however limited to one frame cycle time and thus not suited for scenes with high dynamics.

- The camera does come with a zoom lens. The accuracy potential shown before was achieved at a fixed zoom position with the autofocus turned off. If these features are to be used, suitable strategies for control of the parameters of interior orientation have to be applied. Moreover, the camera body is made of plastic, thus making the camera suspect to instabilities in the interior orientation as discussed for stillvideo cameras in the paper of Maas and Niederöst [5].

- The user interface to Sony’s framegrabber DVBK-1000E is quite nice, but does not allow for automatic grabbing image sequences at full 25Hz temporal resolution. Although this can be achieved for sequences of limited length relatively comfortably by using the image increment functions, an automatic full temporal resolution image sequence grabbing mode would be desirable.

All these problems can be avoided when using a set of progressive scan CCD cameras connected to a host computer with a large amount of memory or a powerful realtime disk system. However, the cost of such a system is obviously much higher, and the manageability for the non-expert will be more complex. Basically, it should be relatively easy to solve most of the limitations of digital camcorders as mentioned above. While custom-made solutions to these problems are probably rather expensive (and will make potential users turn back to machine vision like equipment), this functionality could probably be included by the manufacturers at almost zero cost.

5. CONCLUSIONS

Off-the-shelf digital camcorders may be considered measuring devices with a surprisingly high accuracy potential. Due to their capability of storing large numbers of digital images and their status as an autonomous system without requirements to permanent connection to a host computer and external power supply, they do depict an interesting option for virtual reality image sequence data capture. Some technical features like the lack of synchronizability and the interlaced video signal do, however, pose limitations to the range of applications.

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