**GEM-TN-94-608**

# Application of Miniature Cameras in Video Straightness Monitor Systems

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*Abstract*

Miniature monochrome video cameras made by Chinon and VVL Corporations are reviewed for application as sensors in Video Straightness Monitor systems. Test frames and scans are presented for three different cameras in a VSM system running across an 8-meter optical baseline.

# Application of Miniature Cameras in Video Straightness Monitor Systems

*-- J. Paradiso, June 1994*

## 1) Introduction

The Video Straightness Monitor (VSM) system, as portrayed in Fig. 1, is an upgrade to the standard RASNIK-variety Straight Line Monitor (SLM), which has been developed for L3[1,2] and applied in other endeavors, such as SDC R&D[3]. The VSM systems, which have been described extensively in Refs. [4,5,6,7], offer wider range, better fault-tolerance and error-correction, plus potentially simpler implementation than the standard SLM design. They were baselined as 3-point projective alignment monitors for the GEM muon system[8].

In the years since L3 was installed, dramatic progress has occurred in video technology and image processing. These advances have been exploited in the design of the VSM. Here, instead of putting a quadrant photodiode at the focal plane (as in a standard SLM), an imaging array is placed there to collect much more information (i.e., tens of thousands of pixels, as opposed to only four). Likewise, instead of imaging a simple spot, as in previous efforts[9], we project a complicated pattern.

This approach has two major advantages. First, since the image is projected and detected over a full frame with many pixels, there is much more tolerance to local defects in the projected image and the focal plane array (this relieves much of the tedious calibration and component selection needed by SLM systems). Second, the operating range is greatly increased. Only a portion of the projected image need be seen by the sensitive array; if it is unambiguous, a correlation with the mask template will determine the offset between the array and the global image.

Recent advances in imaging technology and related microelectronics have

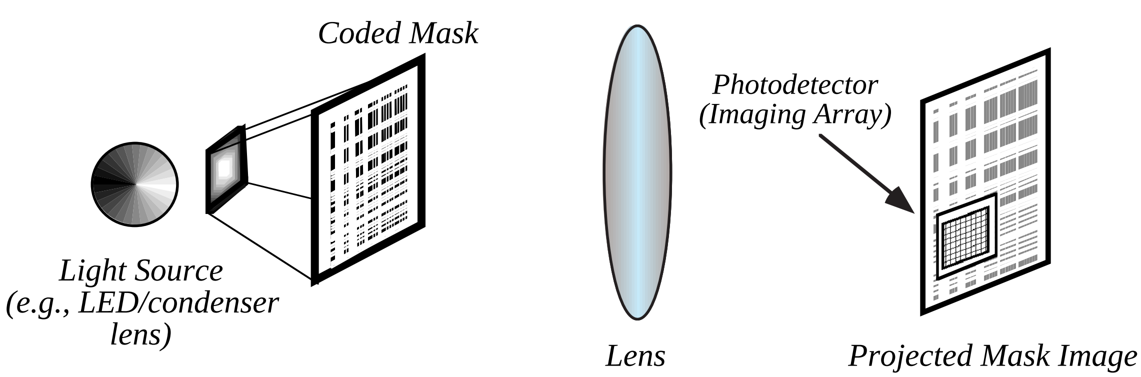


**Figure 1: The Video Straightness Monitor (VSM) system**

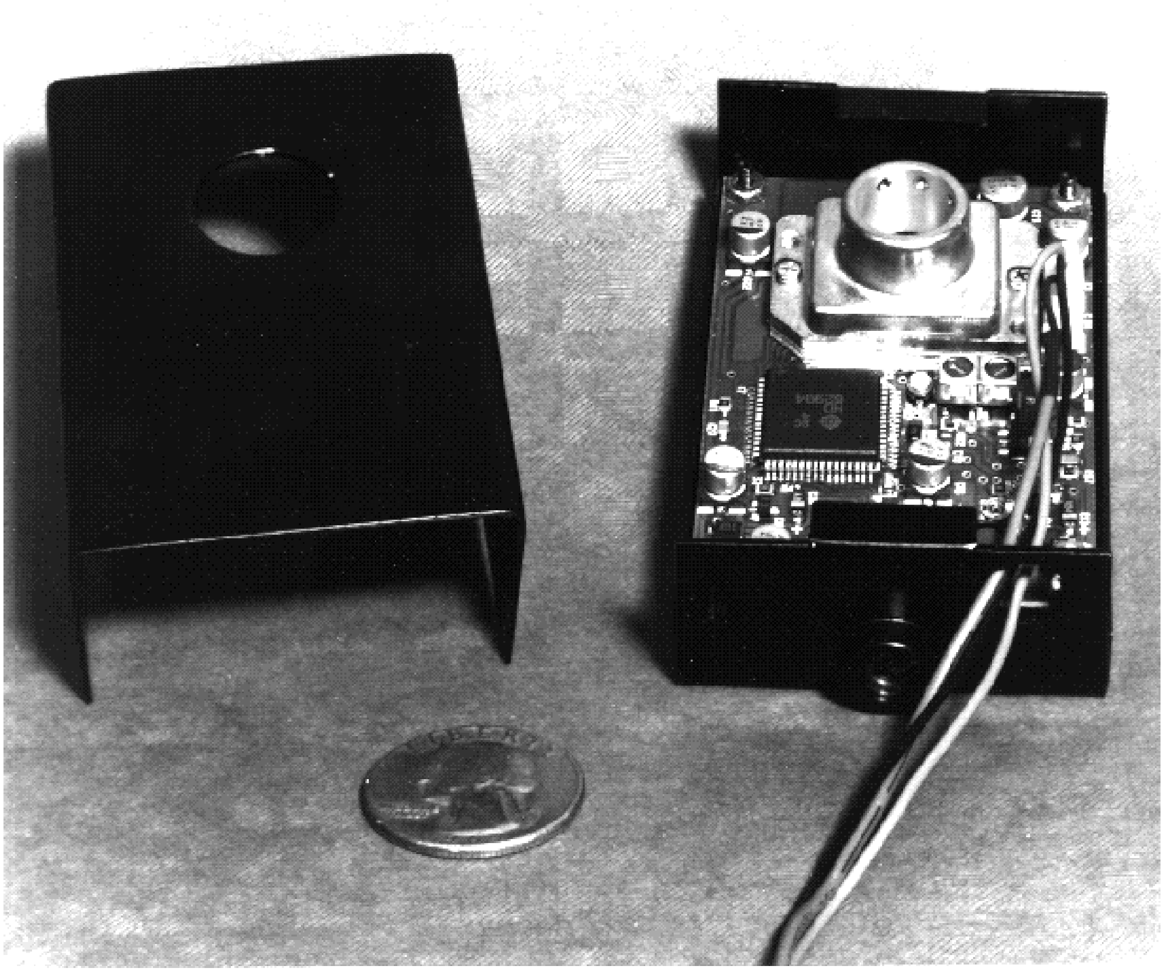

**Figure 2: The CX-102 Monochrome Video Camera**

dramatically reduced the cost and size of solid-state video cameras. Highly integrated, miniature monochrome cameras are now available, costing below $100 in moderate quantities. They are self-contained, in that they typically require only 7-16 V of power and will output composite RS-170 video onto a 75 Ω cable. This document describes several of these units and tests them for VSM application.

## 2) Cameras

Most of the original GEM tests were performed on the Chinon CX-102 camera[10], shown in Fig. 2 next to a US quarter for size comparison (the black housing is the standard case supplied with this unit). This device measures 4.6 x 7 cm, weighs 37.4 grams, and includes a $^{1}/_{3}$" MOS multiplexed photodiode array of 324 x 246 elements, with all array clocking, analog processing, and composite video formatting circuitry on-card. It is a self-contained camera; i.e., 7 to 14 Volts DC is input (it

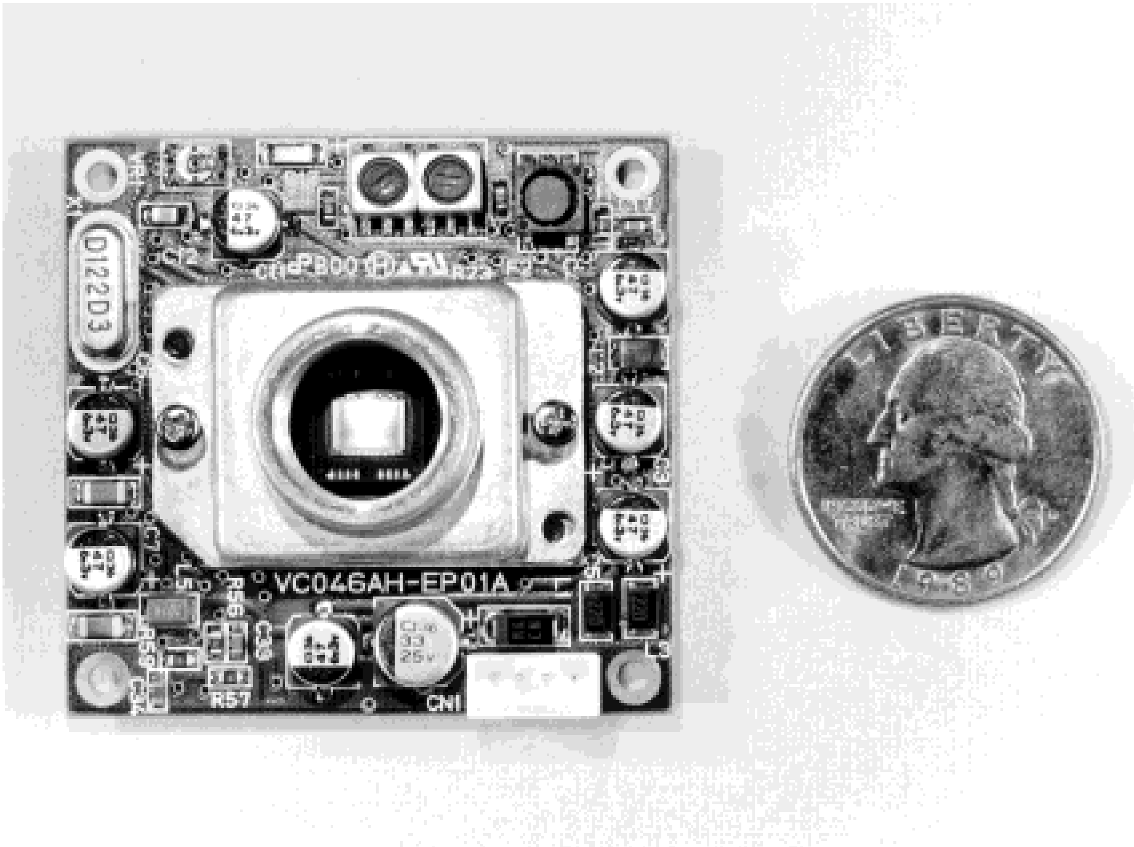


**Figure 3: The CX-103 Monochrome Video Camera**

consumes 1 Watt; i.e., 80 mA), and 1 Volt (p-p) RS-170 video is produced with a 2:1 interlace at a vertical frequency of 60 Hz. Only two cables are required; i.e., power in and video out. It is specified to perform down to 2 Lux (@ F/1.8) with a spectral response ranging from 400-1000 nm, and automatically adjusts its exposure time ($\frac{1}{60}$ - $\frac{1}{15000}$ sec) and video gain.

This camera was purchased during the initial VSM R&D at GEM in early 1993. Since then, Chinon has cut the length of this device nearly in half, releasing the CX-103 camera[10], illustrated next to an analogous quarter in Fig. 3. It has identical specifications, except for its size (4.6 x 4.4 cm) and weight (28 grams). Several of these units were purchased by LLNL for use in the GEM Alignment Test Stand[11]. The CX-103 currently is priced at $95. in quantities of 1000.

For GEM application, these devices must perform in a magnetic field, which can reach the neighborhood of 2 Tesla in the muon region. The CX-102 has been seen to fail at fields beyond 1 KG, because of an inductive DC-DC converter used on the card, and

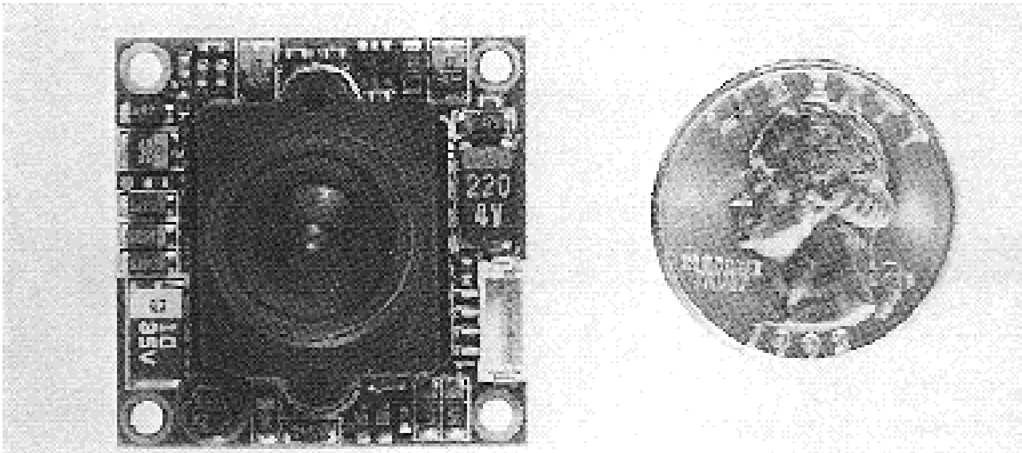

**Figure 3: The CX-060 Single-Chip Monochrome Video Camera**

potentially because of saturation in another pair of inductors used with the video processing circuitry. Analogous problems are expected with the CX-103.

These difficulties are not anticipated with a new product announced by Chinon[10], the CX-060, shown (again next to a quarter) in Fig. 4. This device is based around a single monolithic, which includes 512 x 496 element $^1/_3$" CCD array together with all clocking, video processing, and RS-170 formatting circuitry. The circuit card otherwise contains various decoupling components, a crystal, and some power conditioning (which can now be readily bypassed in case of magnetic problems). Its sensitivity is significantly improved relative to the previous Chinon cameras (i.e., 0.5 Lux @ F/1.8), which relieves some of the burden on the VSM mask illuminators. As expected, this camera is also much smaller (the card measures 3.175 x 3.175 cm) and lighter (17 grams). The current consumption is rated at 120 mA with a 9 VDC supply (±1 Volt). Unfortunately, this camera was not available until this month, which precluded VSM testing under the GEM close-out activity. This device will cost $99. in lots of 1K.

Another single-chip monochrome camera, however, was available for GEM close-out testing. This is the "Peach" video camera[12], as shown in Fig. 5 (once more next to the quarter; the lens assembly is swiveled up to view the internal circuitry) from VVL corporation in Edinburgh, Scotland. The complete camera (with housing) measures 3.5 x 3.5 cm. The CMOS monolithic inside integrates the sensor (operating down to 5 Lux @ F1.8) with all video formatting and signal processing. It contains a $^1/_2$" array of 312 x 287 photodiode pixels, and produces standard CCIR video; the video may also be output synchronously with an external clock (a block diagram of the monolithic and the circuitry contained in the Peach are shown[13] in Fig. 6). As of last year, the Peach chip[14] (ASIS-1011-B) was separately available for under £30. (and the complete Peach

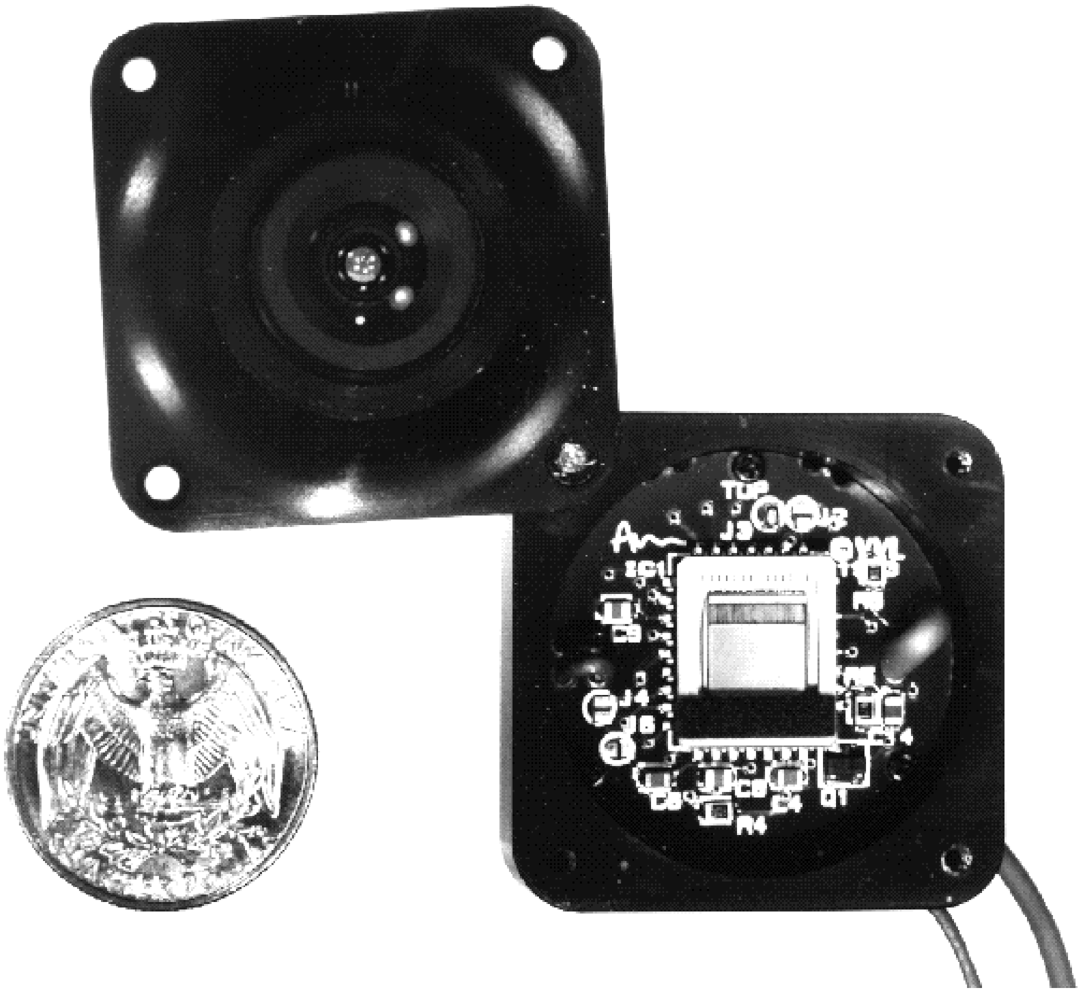

**Figure 4: The "Peach" Single-Chip Monochrome Video Camera**

camera for £50.), priced in quantities of over 200. The Peach takes 40 mA of current at 7 - 12 VDC.

This technology has an exploding future in many emerging commercial media applications, and is still being aggressively developed. VVL has announced the development of superior chips with a 512 x 512 matrix[14]. Other companies produce and distribute such devices; i.e., Marshall Electronics[15], which produces the 1206 camera (card measuring 4.6 x 7 cm with $^{1}/_{3}$" 542 x 492 element CCD, running at 0.5 Lux). The 1206 costs $189. in single-unit quantities, and engineering support is readily available at Marshall to modify it as needed (e.g., remove the DC-DC converters). Marshall are also distributing the VVL Peach camera in the USA, and will be releasing a single-chip RS-170 device shortly.

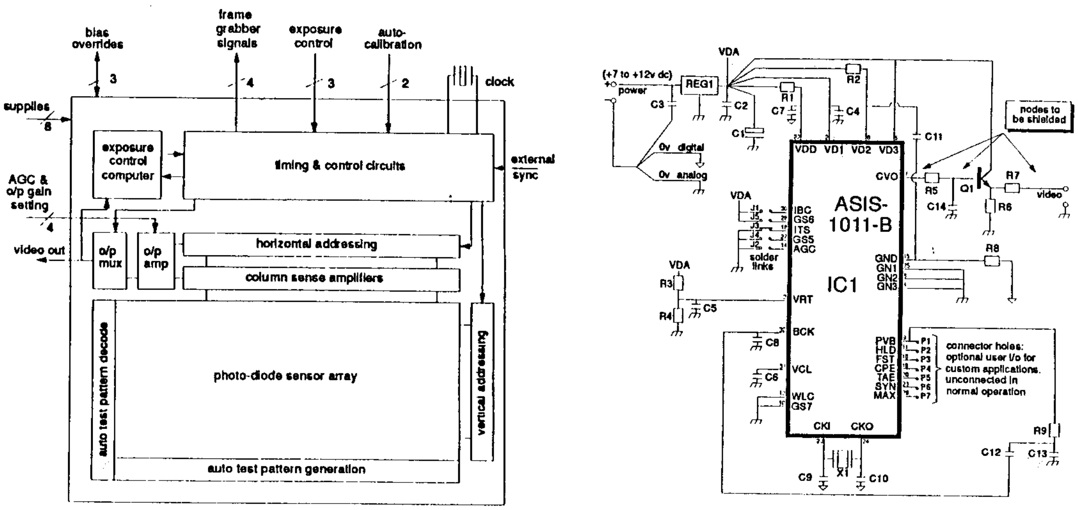


**Figure 5: Block diagram of the VVL chip (left) and its recommended support electronics (right)**

In addition, these devices must accommodate some level of radiation background or damage, depending on where they are installed. It is anticipated that they will tolerate the expected radiation dose in GEM the muon region, although the GEM program concluded before these units could be radiation tested. If the VSM concept is desired to be used in worse radiation environments, camera cards can be designed around Charge Injection Devices (CID's), which can tolerate very high levels of neutron flux[16]. This will lead to additional expense, however, both for the chips themselves and for the design effort required to adapt them into a camera card.

### 3) Lab Tests

An 8-meter, folded-baseline, 1:1 VSM prototype was constructed at Draper Lab, as described in Ref. [6], and used to test the CX-102, CX-103, and VVL Peach cameras. The LED-bank illuminator[6] of Fig. 6 was used in all of these tests.

The Chinon frames were captured by a Data Translation DT2861 frame grabber in an IBM PC that digitized each frame into 512 x 512 pixels. The Chinon cameras, however, did not use the entire field; an inner area of 498 x 480 pixels had usable gray-scale information. The VVL frames, on the other hand, were digitized in a SCION LG-3 frame grabber[17] modified to accept CCIR video, running in the Macintosh NuBus. The VVL/SCION frames were somewhat larger, measuring 768 x 512 pixels, in accordance with the CCIR aspect ratio. All pixels in this case contained usable gray-scale video data.

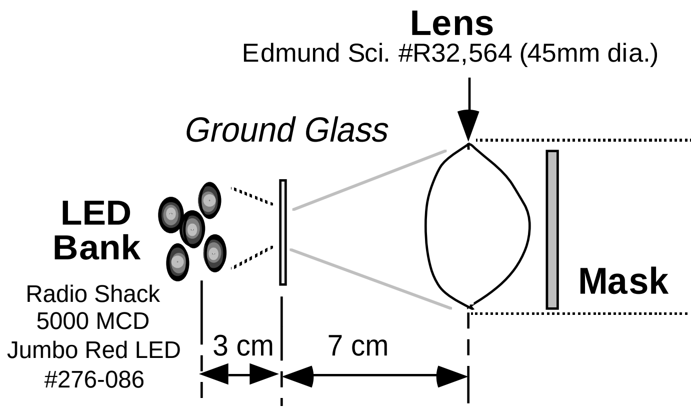


**Figure 6: Illumination of mask with bank of 5 visible LED's**

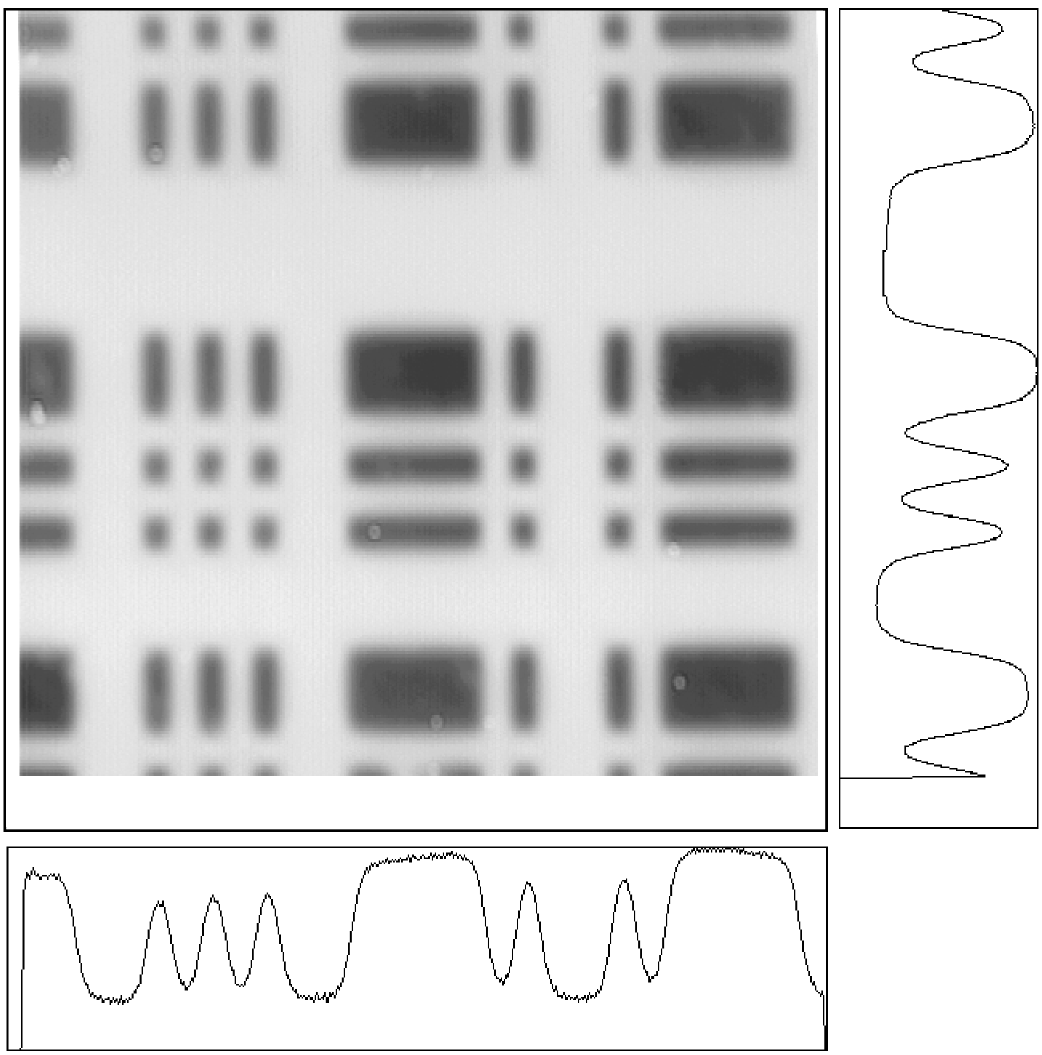

**Figure 7: Frame from CX-102 camera, together with horizontal and vertical projections**

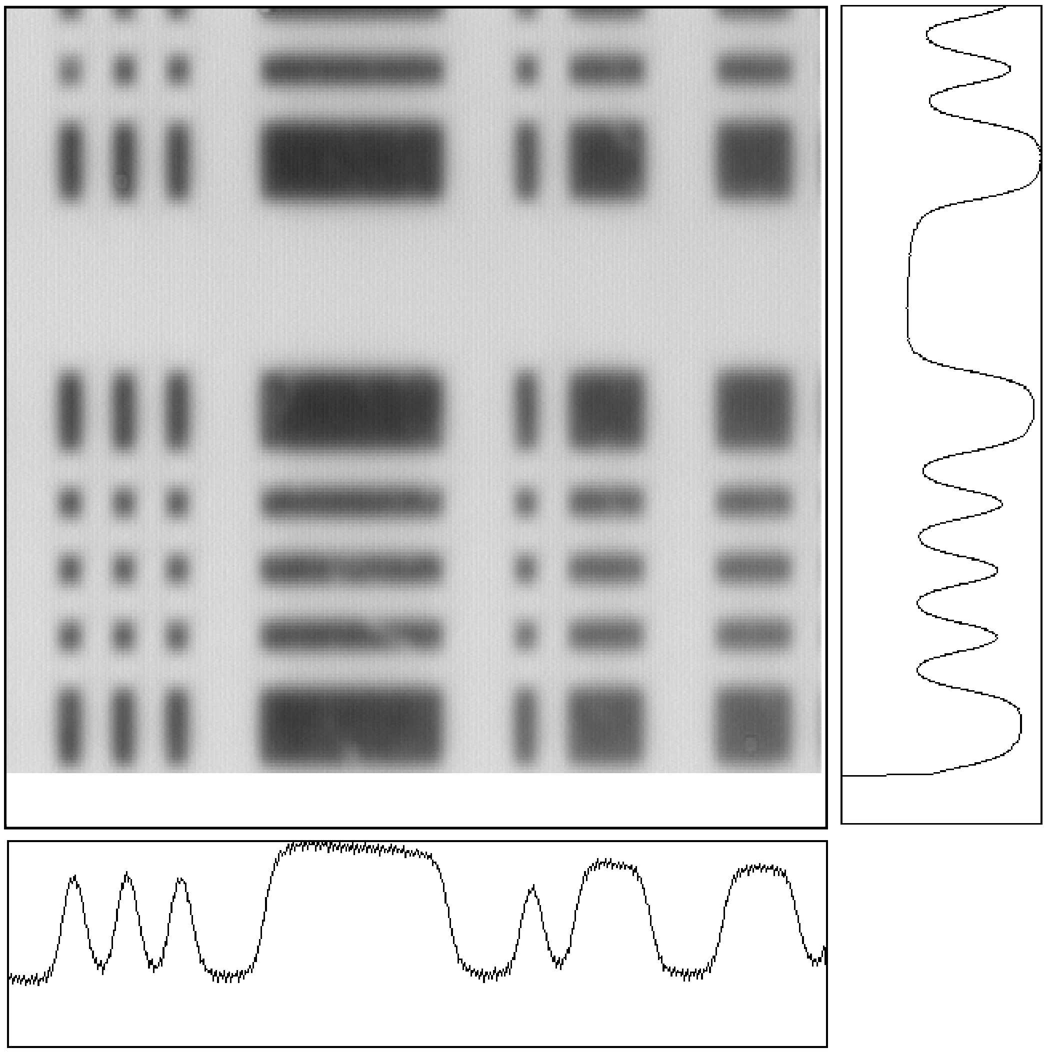

**Figure 8: Frame from CX-103 camera, together with horizontal and vertical projections**

In acquiring frames and horizontal/vertical pixel projections for analysis, averages of 15 frames (at 1 Hz each) were taken to smooth atmospheric effects[6]. The Data Translation grabber did this averaging internally, but truncated each frame to a 4-bit gray scale to avoid overflow in the 8-bit integer registers contained on the card. In contrast, the SCION averages were all performed in the Macintosh (using the Image 1.51 program[18]), using full 32-bit operations and no truncation.

Figs. 7-9 show 15-frame averages captured in the VSM system for the CX-102, CX-103, and VVL Peach cameras, displaying a portion of the coincident 2D barcode[5] pattern. Below and to the right of the image are unfiltered horizontal and vertical projections (i.e., summing all pixels into a single row and column), which are used in the barcode position analysis[5]. The blemishes visible on the images arise from smudges on

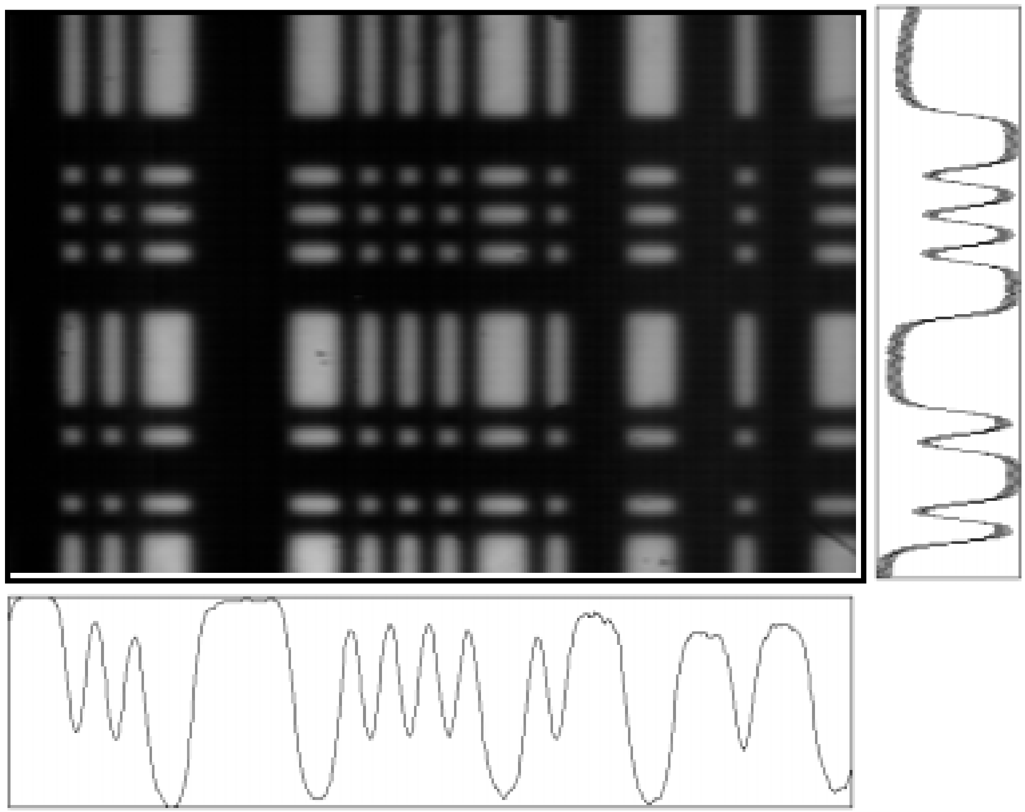

**Figure 9: Frame from VVL Peach camera, together with horizontal and vertical projections**

the sensitive array (certainly several developed on the CX-102, as I had once put a piece of tape over the imaging array while testing it in a magnetic field), and on the barcode carrier and condenser lens. These smudges have little effect on the alignment measurements, since the entire frame is used in the analysis.

As expected, the two Chinon cameras have nearly identical characteristics. The VVL camera, in comparison, looks somewhat different. Because of its lower sensitivity, the VVL frame seems considerably "muddier", although the barcode can nonetheless be well discerned. In addition, the VVL profiles show considerably more noise on the vertical (row) projections than on the horizontal. This is because of nonuniformities in the row amplification circuitry on the chip (the Chinon profiles show a similar, but smaller, effect in the column [vertical] projection; again, this is due to the way in which the imager produces its output). This noise is of little consequence for the barcode analysis, as it is of a much shorter period than the bar width, hence can be easily filtered out before the projection is processed.

Another change is in the aspect ratio between RS-170 and CCIR frames and in the scale difference between the imagers (the Chinon devices are $^{1}/_{3}$" arrays, whereas the

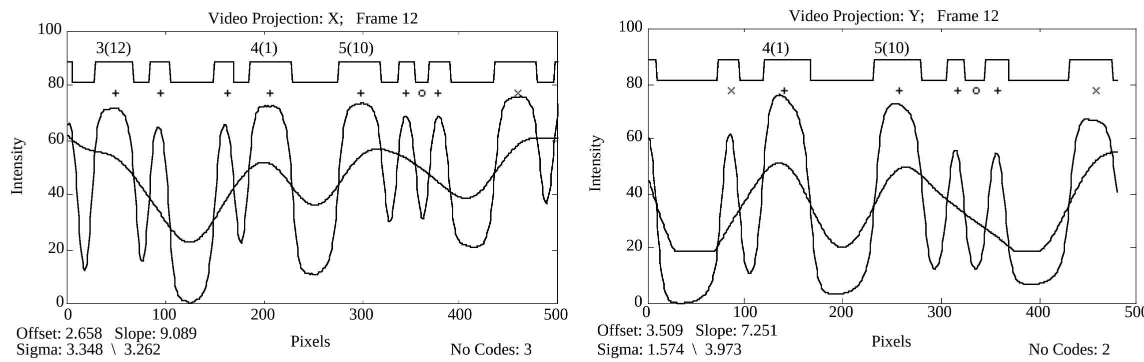


**Figure 10: Horizontal (left) and vertical (right) projections as analyzed from the CX-103**

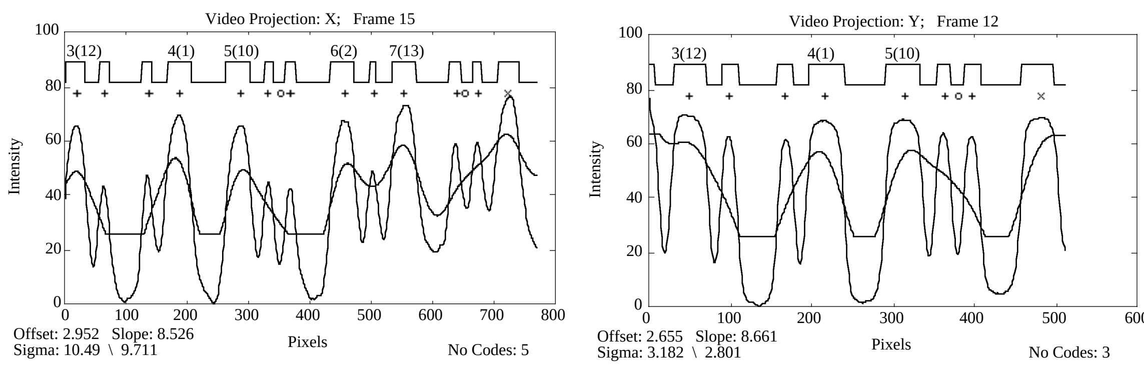


**Figure 11: Horizontal (left) and vertical (right) projections as analyzed from the VVL Peach**

VVL device covers a full $^1/_2$" of diagonal area). In the VVL case, we see many more complete barcode digits per frame, since the barcode dimension was designed with the Chinon size in mind (i.e., at least one complete digit could be read in the horizontal and vertical coordinate anywhere across the barcode when imaging at 1:1). This has ramifications in the dynamic range of measurement; the VVL device can use a longer code length (more bars per digit), particularly in the horizontal, which translates into a larger barcode and more dynamic range. This is illustrated in the sample horizontal and vertical frame projections analyzed in Fig. 10 for the CX-103 and in Fig. 11 for the VVL Peach (the meaning of symbols on these plots is explained in Ref. [5]). The horizontal projection of the Peach decodes up to 5 full digits here, vs. only 3 with the Chinon; the vertical projection is likewise seen to be significantly denser. In addition, prefiltering of the projections before they are analyzed is seen to remove the noise superimposed over the raw projections of Figs. 8 and 9 without deteriorating the barcodes.

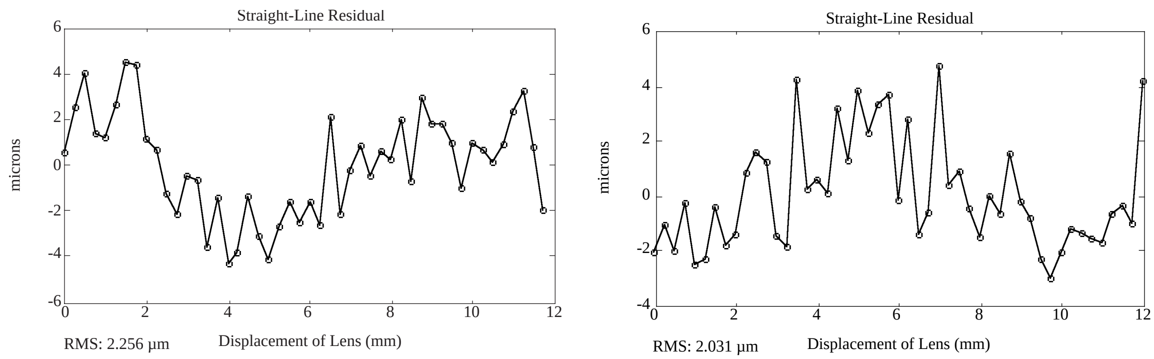


**Figure 12: Horizontal (left) and vertical (right) linear residuals from scans across CX-102 camera**

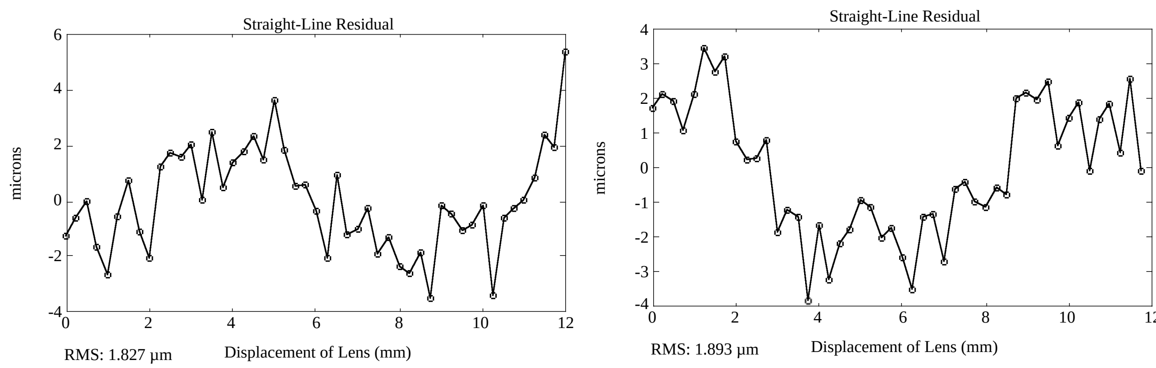


**Figure 13: Horizontal (left) and vertical (right) linear residuals from scans across CX-103 camera**

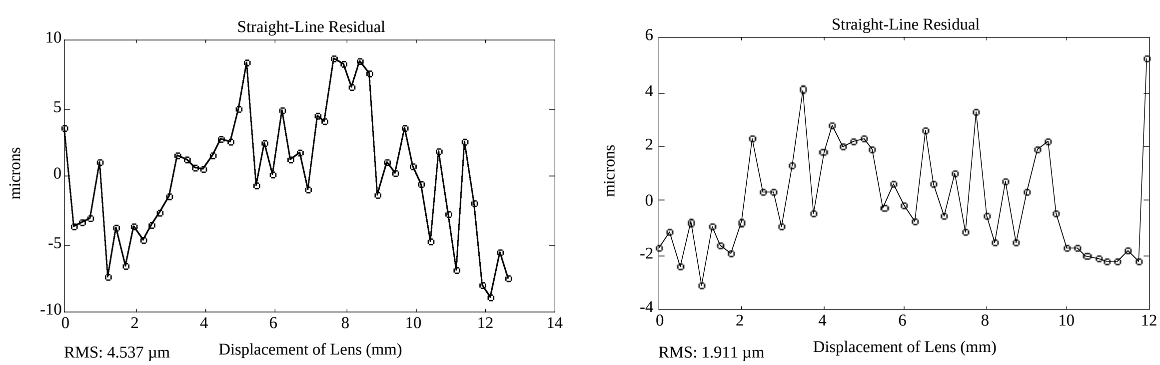


**Figure 14: Horizontal (left) and vertical (right) linear residuals from scans with VVL Peach camera**

The cameras were all tested for VSM precision by scanning the lens across the full barcode range, as described in Refs. [5,6]. In all such scan tests, the lens position computer-monitored by an Ono-Sokki DG-925 precision digital linear gauge, accurate to better than a micron across a range of 2.5 cm. The lens displacements are thus quoted in the scan plots; because of the geometry, the corresponding displacements at the source and detector are a factor of two larger. The scans weren't entirely automated; one had to advance the lens on a motorized micrometer, then command the computers to grab the frames and read the gauge. As a result, the scans took roughly 45 minutes each (sampling every 250 µm over 12 mm of lens motion).

Figs. 12-14 show the linear residuals from the reconstructed camera position on the barcode template as a function of lens displacement as measured by the precision gauge; the left plot is for a horizontal (X) scan, and the right plot is for a vertical (Y) scan. The scan is across the full barcode; i.e., 12 mm at the lens = 24 mm at the source or detector. The magnitude of these residuals reflect the precision delivered by the VSM.

We see that all cameras suffice for the $\sigma < 15$ µm alignment requirement of the GEM projective monitors. The Chinon devices perform nearly identically, with $\sigma \approx 2$ µm for both horizontal and vertical coordinates (as expected, since they are re-packaged versions of the same imaging chip). The VVL results are a bit different; the vertical resolution still looks wonderful, with again $\sigma \leq 2$ µm of deviation from a straight line. The horizontal resolution is a bit worse, however, with $\sigma \approx 5$ µm. This is most probably due to the larger pixel pitch in the VVL horizontal axis (it covers $^1/_2$" with nearly the same number of pixels that Chinon uses to cover $^1/_3$" ), plus effects from the lower light efficiency in the VVL device.

Looking at all of these plots, a similar structure can be noted in the residuals, especially if one is allowed to flip the horizontal and vertical axes (these scans were in different directions, with the barcodes oriented differently as well, hence such flips are in the data). The generic "S" in the horizontal coordinate and bowed "smile" appearance of the vertical plots indicate that these residuals may be dominated by systematic distortion in the mask pattern or lens. Granted, such effects are already below threshold for the needs of most High-Energy Physics detectors (thermal gradients will certainly contribute here as well, especially over long paths), but nonetheless, this data indicates that the potential accuracy of the VSM may be even finer if these systematics are understood and removed; the NIKHEF group has already quoted a VSM resolution of 0.5 µm[19].

## 4) Conclusions

All cameras tested here (CX-102, CX-103, VVL Peach) have functioned well in a VSM system, and surpassed the requirements posed by GEM (and other proposed detectors) on wide-range 3-point alignment monitors. The VVL device has slightly less resolution in the horizontal coordinate, most probably because of its wider pixel pitch and lower illumination efficiency. Newer single-chip cameras, however, such as the CX-060, promise to surpass the performance of all cameras tested, plus offer an extremely small package, more sensitivity, and full functionality at high magnetic fields.

## 5) Acknowledgments

The help of my optics colleagues here at Draper, Jacques Govignon and Dave Goodwin, is much appreciated. Craig West and Joe Mauger of Livermore Lab are earnestly thanked for lending me their SCION grabber and CX-103 camera to complete these tests. The help of Mike Harris of SSC/CERN is also appreciated in organizing the GEM close-out activity that made this effort possible.

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