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Experiences with a digital aerial camera at Institut Géographique National (France)

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ABSTRACT

In order to follow the developments in digital processing and instrumentation in the field of cartography, the Institut Géographique National started a few years ago to investigate high resolution CCD sensors to develop an aerial digital camera. A digital aerial photographic system has been designed around a 4096x4096 pixels CCD sensor. Even if the sensor characteristics are unfortunately not those expected for an aerial application, a photographic survey has been performed and the first results are presented here.

1. INTRODUCTION

The project of using a digital camera for photographic surveys was born in the Institut Géographique National a few years ago, following the developments of digital photogrammetric instrumentation and supported by the production of the data bases for topography and cartography. The use of digital cameras versus photographic-film based cameras provides many benefits to aerial surveys. Section 2 of this paper presents these benefits but also the limitations due to some characteristics of digital systems. Then, Section 3 describes the prototype of the camera we operated and shows the results obtained with the first lot of 45 images covering an area of 12 per 20 km. Finally, Section 4 describes the prospects for future improvements of this type of camera.

2. CCD CAMERAS VERSUS TRADITIONAL CAMERAS

The advantages of CCD sensors compared to traditional photography are, among others, size, weight, dynamic range, sensitivity, linearity, stability and durability. These characteristics show that CCD sensors are good photogrammetric instruments. But they still do not match some important specifications of traditional photography such as format, frame rate and cosmetic quality (Janesick, 1987).

2.1. Advantages

2.1.1. Dynamic range of the pictures

The dynamic range with CCD sensors is usually defined as the Signal/Noise ratio, with Noise the noise value measured in the darkness. It may be also represented by the number of grey levels contained in a picture. Since the sources of noise in a CCD image are very different from those of a digitized silver halide image, comparing their dynamic ranges is not so easy. With a CCD, the various sources of noise are well known. The most important are the *read noise* due to the electronic readout system and the *shot noise* which is prevalent at high illumination. The dynamic range with good digital imaging arrays can reach 4000 while their Signal/Noise ratio at high illumination (noise then equals read noise plus shot noise) can reach 500. On a digitized photo, the most important noise is due to the film emulsion. Measurements made in our laboratory have shown that the Signal/Noise ratio of a digitized photo does not exceed 60 with a 50 μm pixel. This means that, in a digital CCD image, very dark or very bright zones still contain useful information while they do not in a digitized image. This is particularly important for pictures with large shaded areas such as those obtained during mountain photographic surveys or for pictures taken early in the morning or late in the afternoon. Digital imaging reduces the photographic survey conditions.

2.1.2. Sensitivity and linearity

For a CCD sensor, sensitivity expresses the number of photocharges generated by a given exposure. It is well known that a CCD sensor is much more sensitive than a silver halide film. We would compare it with a 3000 ASA film.
With CCD sensors, the output signal is directly proportionnal to the exposure. Linearity is limited by secondary effects such as output amplifier non-linearity (generally less than 1%) but deteriorates rapidly when approaching saturation. The response of a silver halide film to exposure is not linear.

2.1.3. Geometrical and radiometrical stability

The sensor is geometrically stable because it is a solid-state device which is, moreover, cooled. The sensor is also radiometrically stable : its response to a given illumination is always the same in opposition to silver halide photo which depends on the photographic emulsion and on the development process as well.

2.1.4. Availability

Digital images are available immediately after the landing or even on board, whereas traditional photos need first to be developed and digitized if an application so requires. For applications which require fast delivery of the images, CCD based systems can be very effective.

2.1.5. Records and reproduction

Even if they involve a large amount of data, digital photos can be kept on media such as hard disks, magnetical recording tapes, optical disks,... With such storage systems, images can be kept a long time without any damage and means can be imagined to put them easily at the users service. In opposition, silver halide photos are kept in boxes, which results in a large physical storage volume. Besides, films are damaged by time and manipulations.
Compared to silver photos, digital photos can be reproduced with no loss of information.

2.1.6. Size and weight

In our study, the CCD sensor used is a 9 cm^2 piece of silicium. The size of the camera head where the sensor is placed is approximately 30x15x15 cm^3, including the shutter and the lens. This box contains also the first part of the electronic unit for the sensor commands and the digitization of the video signal. This part of the system is small and light. One can imagine to fasten this part outside the fuselage, thus avoiding the need for photographic traps. Any aircraft would then be suitable for photographic surveys.

2.2. Disadvantages

2.2.1. Format of the images and real-time storage of large amount of data

Until today, the largest CCD imaging array we have found is a 4096x4096 pixels sensor from Loral Fairchild Imaging System (the largest digitized photos used today in our institute generally consist in 10000x10000 pixels). However, these large CCD sensors are still prototypes and do not yet match the aerial photography specifications. Anyway, we have worked and still work with one of these sensors and we present below the various problems encountered but also the results obtained. The problem with such large photos is the real-time storage apparatus which must match the airborne specifications (in our study, measurements have shown that those are not very strict). It a lso must be fast enough to obtain a 60% overlay between images and must be able to store a large amount of data. In our system today, the images are stored on a 1 Go hard disk, so we cannot exceed 50 images per photographic survey . This capacity is enough to carry out the first experiments but not sufficient to perform a traditional photographic survey.

2.2.2. Frame rate

The frame rate, in our system, is limited by the readout time of the CCD sensor. Since the storage is performed concurrently with the sensor readout, it takes 18 seconds to read and store on the hard disk the 16 million pixels of a single image. The frame rate is therefore approximately 3 per minute.
This is a limiting factor for the minimum ground pixel size we can obtain. With a plane speed of 100 m/s, to match an overlay between images of 60% with a readout time of 18 s, the smallest pixel size we can get today with a focus lens of 24 mm and a sensor pixel size of 7,5x7,5 μm^2 is a little more than 1 m^2.

2.2.3. Overillumination

In aerial photography, scenes containing water, metallic or glass surfaces are usual. Those surfaces cause very strong local illuminations. When a pixel is overilluminated, the excess charges can spill over to neighbouring pixels (blooming phenomenon). Some CCD have an antiblooming diode implanted at each pixel to prevent the phenomenon. But on large CCD arrays, this antiblooming system cannot be implanted due to the lack of space. It is for us a real problem especially if we take into account the very low full well capacity of each pixel of the Loral 4K sensor. This problem has no satisfying solution.

2.2.4. Pixel size

The pixel of the 4Kx4K Loral sensor is a square of 7,5 x7,5 μm^2. This is a limiting factor for the lens aperture since the Airy spot size (image of a dot due to diffraction) is inversely proportional to the lens aperture. In our case the lens diaphragm cannot be set lower than f/5.6 to reduce the light illumination because the Airy spot size would then be greater than the pixel size.

2.2.5. Cosmetic aspect

Large CCD imaging arrays present, more or less, defects which degrade the cosmetic aspect of the pictures. The CCD sensors we worked with presented various types of defects :

- black or white columns one (or more) pixel wide.
- partial dark columns due to pixels in the CCD matrix which behave like electron-traps. Since the sensor is read by moving each line of the matrix towards the read register, if one pixel is an electron-trap in a line, the next pixels in the column appear to be dark.
- partial bright columns caused by defective pixels for which the dark current due to thermal agitation is locally very strong.

- shifted columns for which moreover the charge transfer efficiency is worse than for the other columns. (We don't exactly know which kind of defect is the cause of this problem.)
- defective columns due to "spurious potential pocket". This term represents the loss of charges due to improper potential well shape and/or depth beneath the pixel.
- various types of spots (usually black) scattered in the whole image. They may be due to small deposits on the CCD surface.

3. THE PHOTOMETRICS DIGITAL CAMERA

The camera we used for the first digital photographic survey is a prototype built by the American manufacturer Photometrics around the 4Kx4K CCD sensor produced by Loral Fairchild Imaging System.

3.1. The Loral 4Kx4K CCD sensor

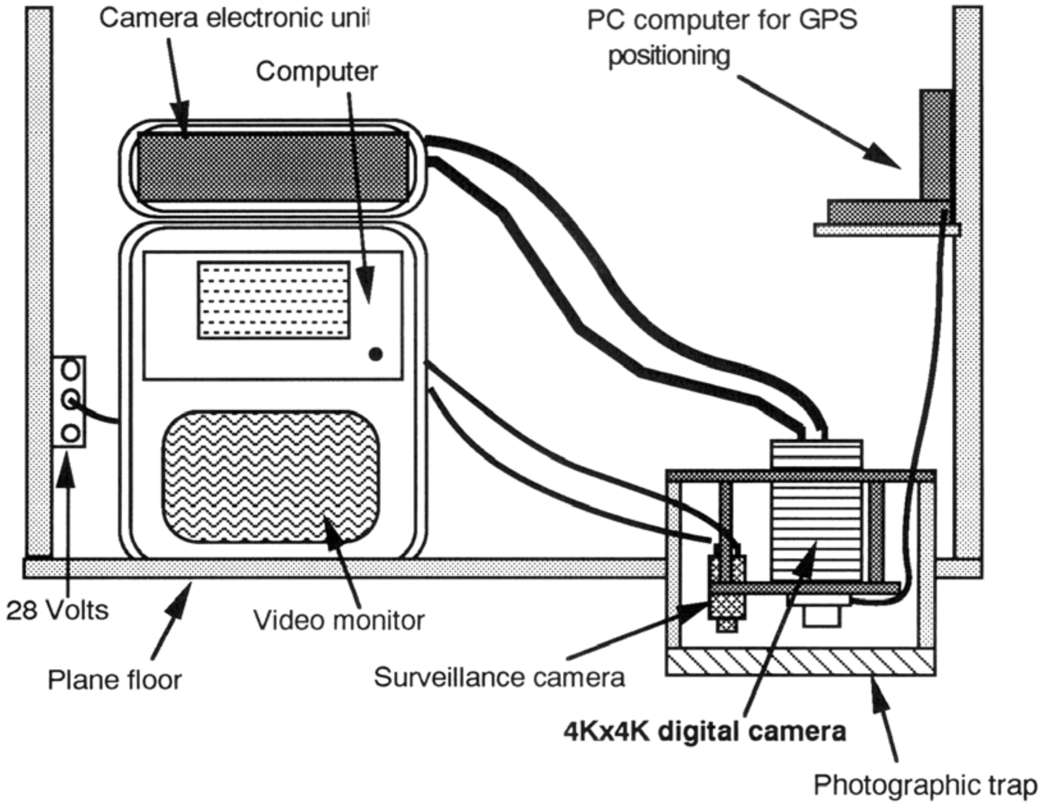
Three sensors have been successively installed in the camera but none of them matched our specifications. The main problems with these sensors are the too low saturation level and the too many defective columns.
The saturation level of the sensor installed today in our camera is about 6.000 electrons (compared to the 1Kx1K CCD saturation level which can reach 500.000 electrons). Since we have not been able to find an appropriate fast shutter, the minimum exposure time is 20 ms. Our experiments show that, in normal photographic survey conditions, we have at least 64 times too much illumination. We therefore must add neutral density filters to reduce the illumination received by the sensor, thus reducing the image quality.
The dynamic range of the sensor we use is only 70. While the dynamic range of the 1Kx1K from Thomson is almost 500. It is obvious that we can expect a lot from the future improvements in large CCD arrays fabrication.

3.2. The whole system

The digital photographic system is composed of the camera head, including a 24 mm focus lens and its electronic unit, a computer with a 68040 processor and a 1 Gbytes hard disk to save the 16 Mpixels images. The images are displayed on a video monitor as we take them, for control purpose. The images of a video camera placed close to the 4Kx4K camera can be displayed on the video monitor to control in real-time the area which is photographed. This second camera is also used to control in real-time the plane movements by a correlation method. Before each new flight strip, it gives us an approximate value of the plane speed and drift to adjust the frame rate in order to obtain the 60% overlay between images.
A GPS receiver is installed on the plane. In our case, the digital camera shutter is connected with this positioning system and commands its measures. In this way, we can record the position of the plane for each photo.

3.3. First photogrammetric experiment

We have carried out a photographic survey with the last CCD sensor installed in the camera. This survey has been performed in mid-february 1993, between 15h15 and 16h (so shadows were large). The weather was slightly foggy. The main problem we had was due to a defect which had appeared on the sensor in December 92. This defect shows itself by the presence of a lot of dark columns on each side of the pictures. This is a very variable defect which sometimes (but not often) disappears.



Installation of the system in the plane.

Unfortunately, the day of our photographic survey, there were 1000 dark columns altogether. To overcome this problem, we had to increase the overlay between flight strips. For all these reasons, we did not have the best conditions for a photogrammetric experiment but anyway we brought back 45 digital images covering an area of 12x20 km^2.
The pixel size is 1 meter, the longitudinal overlay is around 55% and the lateral overlay is 40%. With the minimum shutter aperture of 20 ms and the plane speed of 100 m/s, the image motion is 2 meters, i. e. 2 pixels.

3.3.1. Image quality

First, we have studied the image quality of this survey. Of course, the dark columns on each side of the picture and the defective dark or bright columns elsewhere in the picture greatly degrade the cosmetic aspect of the images. But almost all the defective dark or bright columns can be more or less well corrected by a digital image reconstruction process. Unfortunately, we cannot correct the dark columns on each side of the pictures.
The aerial image quality is also degraded by a problem which had not appeared so obviously with the images taken in laboratory : the right side of the images is blurred. The problem is that the sensor plane is not exactly perpendicular to the lens axis. We have measured the tilt of the CCD and we are now planning to build a device to solve the problem.
Various pictures with comments are given at the end of this paper. They are printed with a Postscript laser printer 300 dpi.

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3.3.2. Image exploitation

This first lot of digital images is used to build, by means of a quasi-automatic process, a unique digital orthophoto map covering the whole photographed region.
Before the realisation of the orthophoto, the images need to be transformed. Actually, the pixels are coded on 12 bits and saved on 8 bits by taking their square root value (this compression is valid because of the kind of noise in a CCD image). Due to computation time and memory size, we work on 8 bits images. So we need to decompress the images and then put them in 8 bits range.
Our images are oriented along the flight direction and not perpendicularly as usual because it was previously planned to compensate the image motion by shifting the lines of the CCD matrix of the appropriate quantity. To simplify the photogrammetric processing of the images, we need to turn them.
The numerous defects contained in the pictures significantly disturb numerical processes such as correlation. So we need to correct the images. It requires a lot of time (around 15 minutes for each image) because of their size, the quantity of defects and the process algorithm which is powerful but slow.
These various processes, which seem easy, are complicated because the image size is greater than the memory size of the computer we work with.
Then the various operation steps for the realisation of the orthophoto are :

- pointing control points on the digital images,
- automatic aerotriangulation process, with pictures common points obtained by a correlation method,
- terrain model calculation using correlation method on the whole pairs of images,
- and finally, calculation of the orthophoto map of the photographed area.

The first interesting use of this new process is industrial manufacture of fast delivery orthophotos, especially in urban areas. In that last case, the large reduction of the production costs will stimulate the realisation of dense photographic surveys to keep up to date the cartographic data base.

4. PROSPECTS FOR IMPROVEMENTS IN AERIAL DIGITAL CAMERAS

As we said before, one major problem of our system today is due to the sensor which is adapted to astronomical observation rather than to aerial surveys. The number of defective pixels is also too high to produce good quality images. Moreover, we have been recently informed that Loral Fairchild Imaging System is going to close its 4Kx4K sensors facility in september 93. We are now looking for a satisfactory replacement.
This solution could come from Canada. Actually, at a recent SPIE conference on electronic imaging in California, the canadian company Dalsa announced the achievement of a 5120x5120 pixel CCD sensor called Megasensor (Chamberlain, 1993). This sensor has been designed for aerial reconnaissance and therefore has the right characteristics for our own application. The values of the parameters announced by the manufacturer are significantly better than those of the Loral 4kx4k device. The most important parameters in our case are given below :

Full well capacity (saturation level) =	130000 electrons	(versus 6000 for Loral sensor),
Dynamic range (signal/noise) =	300	(versus 70),
Frame rate =	1,8 s^{-1}	(versus 3 mn^{-1})
Pixel size =	12 μm	(versus 7,5μm).

Dalsa has decided to build a camera based upon this sensor. It should be available by the end of summer 93.
However, this camera will not be usable immediately for photographic surveys. Numerous developments are required to realise a whole aerial photographic system. First, an electronic signal processing unit must be developped to deal with the 4 digital 12 MHz outputs. An appropriate storage system with high capacity and high data rate must be found to take advantage of the good CCD frame rate. Optical problems must be solved to get suitable lens and shutter for this type of camera and application.
This implies that we might look for a cooperation contract with various partners to associate each one's knowledge in the realisation of a whole digital photographic system which could achieve high performances.

5. CONCLUSION

The first results are satisfying even if the image quality could have been better. These first images provided us with a possibility to test the whole system, from the photographic surveys to the quasi-automatic orthophoto production process. Some improvements achieved on our system today can increase significantly the image quality .
The realisation of a compact and reliable operational system, around the Dalsa 5120x5120 pixels camera will require time. It is therefore interesting to continue working on the 4Kx4K Photometrics camera. But the Dalsa camera seems to be the solution to our problem in the near future.
With these first experiments of digital photographic surveys dedicated to photogrammetric applications, we will be able to define more accurately the interest of digital images for IGN production and the applications for which digital camera is fully well adapted.

6. REFERENCES

Janesick, J. R. (1987): Scientific Charge-Coupled Devices, Optical Engineering, August 1987, Vol 26 no 8, pp 692-714.

Chamberlain, S. G. et al. (1993): A 26.2 Million Pixels CCD Image Sensor, SPIE Electronic Imaging Conference, February 1993, (to be published).

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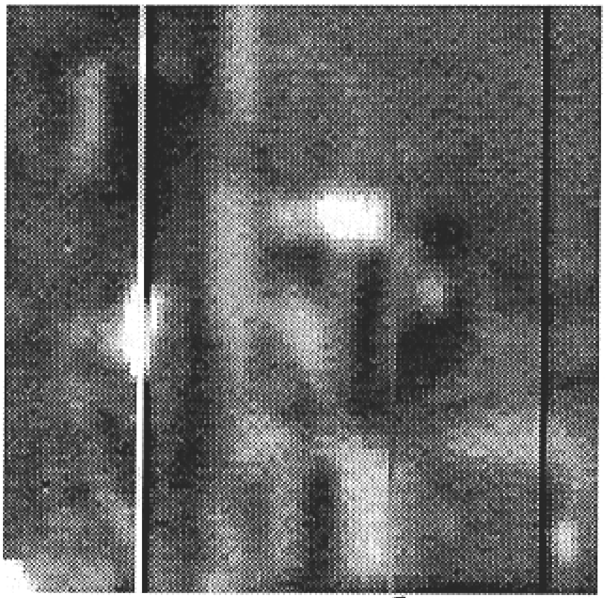
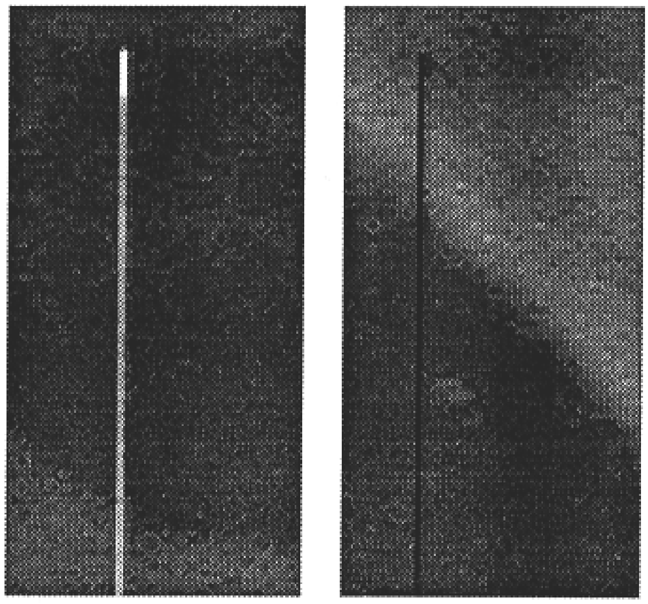


Dark and bright columns.

Notice the darkened column on the right side of each dark column and the effect of saturation on defective columns. Notice also the defect due to a spurious potential pocket.



Partial bright and partial dark columns.

The beginning of some bright columns depends on the illumination; this does not simplify automatic correction.

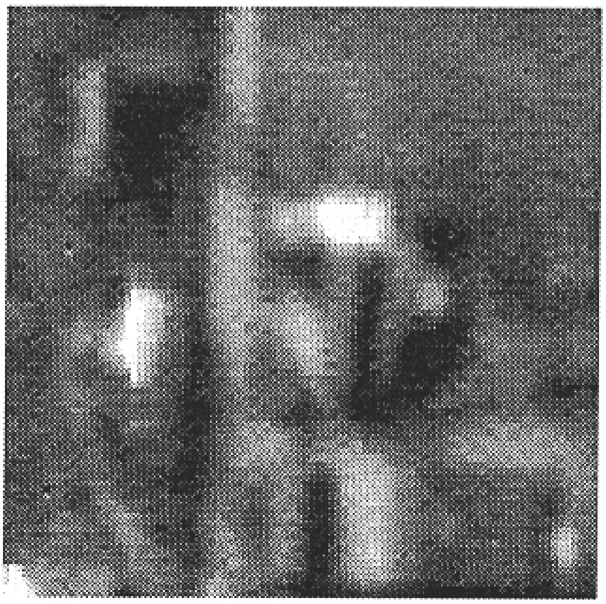
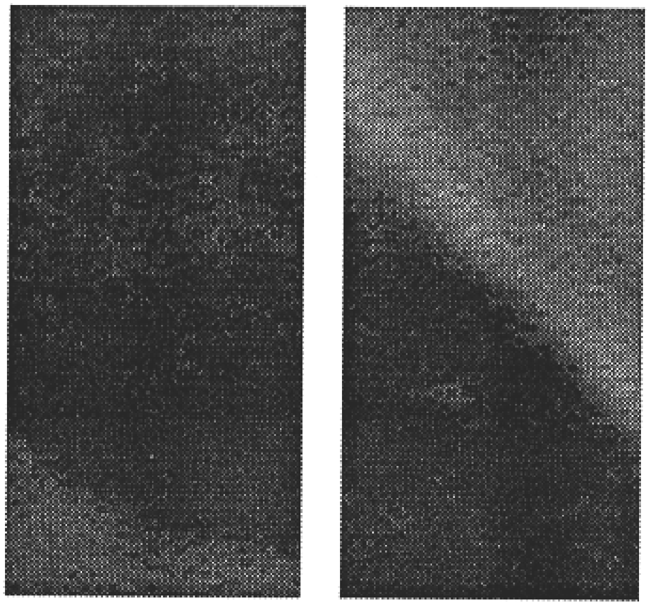


Image size: 90x90 pixels



Images size: 45x90 pixels

Images after correction

Fig.1 Type of defect : Bright and Dark Columns

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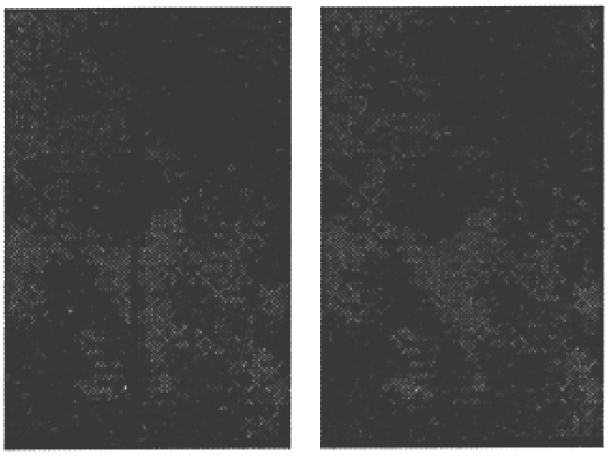
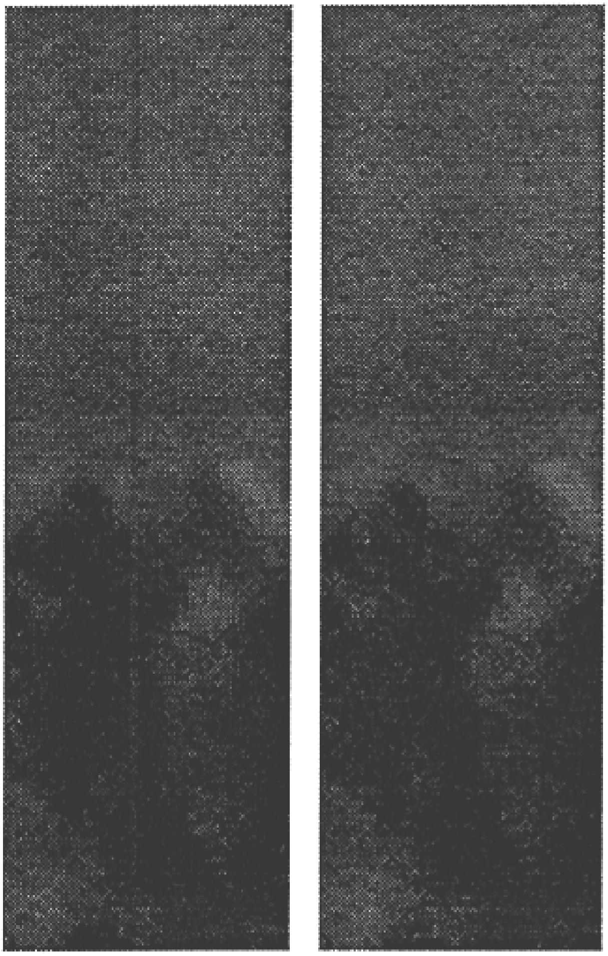
Beginning of the default

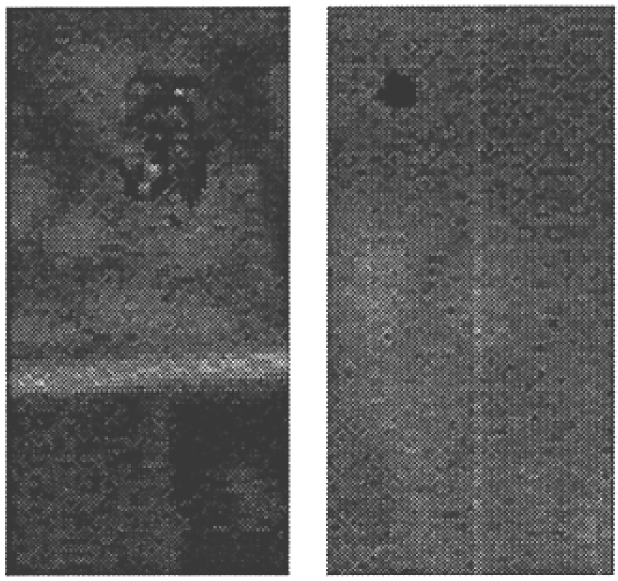


and 300 pixels far down...



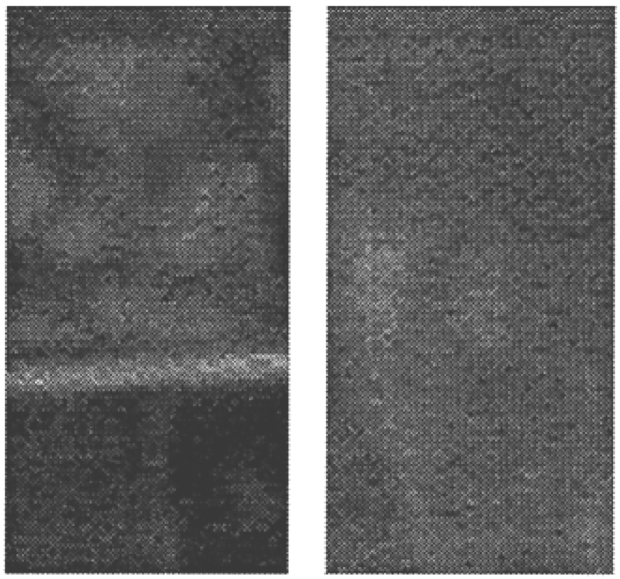
A dark column with a strange behaviour. Charge transfer in those pixels is not efficient at all.

Corrected image



Various types of spot

There is a lot of spots -most of the time black- of various size in the whole image. One column slightly brighter is present in the second image.



Corrected images

Fig.2 A strange dark column and other defects due to small deposits -?- on the CCD surface

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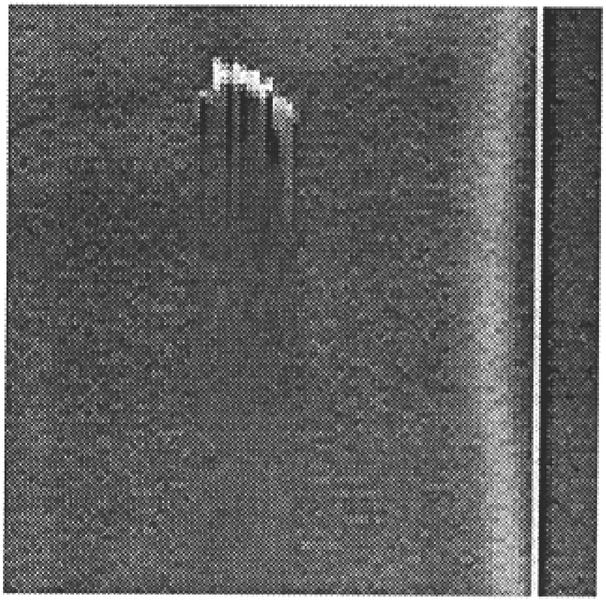
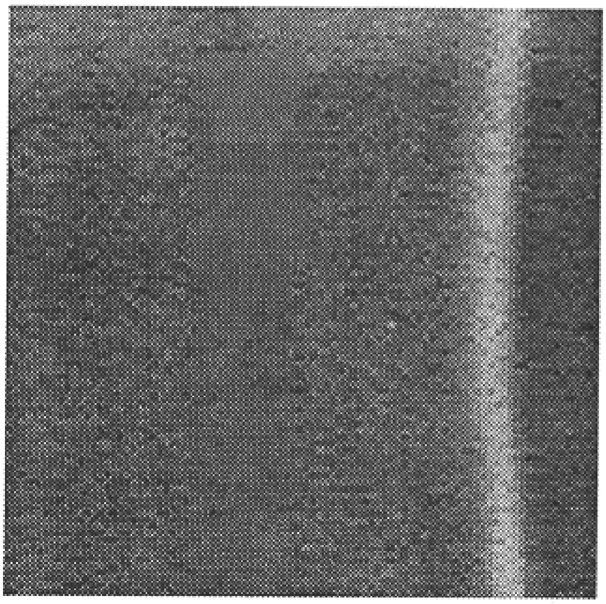


Beginning of the defect

One bright and one dark columns are also present in this image.

Aspect of the image due to the defect

The effect of a spurious potential pocket appears on the left side of the picture. Notice the effect of saturation on the dark and bright columns.



Images after correction

Images size : 90x90 pixels

Fig.3 Type of defect : Shifted Columns

Fig.4 3000x3500 pixels corrected image

- For the printing, one pixel is obtained by the addition of 5x5 pixels and then coded on 17 grey levels -