Book Scanner Buyer´s Guide

Will Digital Cameras Ever Replace Scanners?

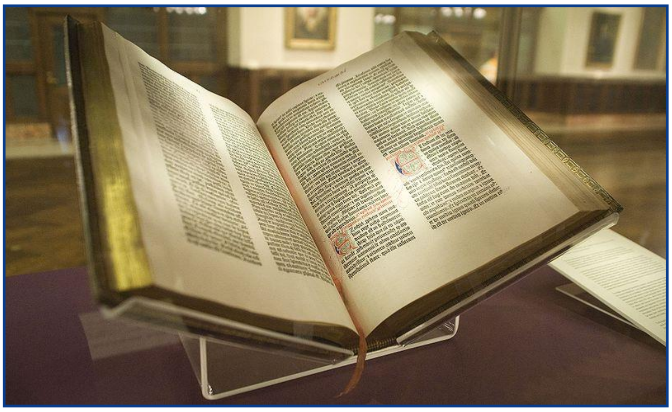
SCAN VERSUS PICTURE

▶ EXPLANATION VIDEO

This **Book Scanner Buyer’s Guide** is published by Image Access, the worldwide market leader in the book scanner business. Image Access produces various models of book scanners as well as other scanners and has several decades of experience in successfully developing scanning technologies.

The reader will understand what to expect from various scanning technologies and will also understand what kind of results can be expected from a digital camera. Many of the technical terms and their explanations can also be verified in Wikipedia and other sources and we explicitly encourage the reader to verify our statements.

Scanning Books



Book scanners are different than any other document scanner because books do not have a flat surface. Mechanically, books are a nightmare to handle and if they would be reinvented by today´s engineers, they would come in an endless form like film, probably rolled into two small tubes. If this were the case, there would be no need for a dedicated book scanner at all.

Unfortunately, Johannes Gutenberg did not think about scanners when he invented books in today´s form about 600 years ago therefore, it is unavoidable to familiarize oneself with the special mechanics of a book.

Although it is possible to scan a book on a flatbed scanner by pressing it flat against the glass plate, this can be damaging to the book's spine and is not really the right way to scan a book. We highly recommend using a book scanner which will scan an open book from above, the same way you normally read it.

Various book cradles and other supports have been developed all of which have their benefits and disadvantages. Because the mechanical impacts on a book are obvious to everyone who sees a book scanner physically, in a video or even in a brochure, we have refrained from analyzing these aspects. Instead we want to focus on the more subtle features of book scanners, which are also more vulnerable to misleading or incorrect information.

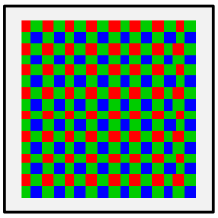
The book scanner market is dominated by three major vendors, **Image Access, I2S and Zeutschel,** but many small companies are also trying to grab their share. Unfortunately for the customer, some of these companies claim very unrealistic specifications for their devices and are raising expectations above the limits defined by today´s knowledge of modern physics.

In the last couple of years, some vendors have mounted digital cameras on a stand and equipped with a screen to compete with real book scanners. They also call their digital camera systems "book scanners", which they are not because a scanner scans a document and a digital camera takes a picture. This has lead to some level of confusion in the market and the intent of this document is to explain the different techniques and their impact on image quality, book handling and expected lifetime in a non-biased way.

The intention of this **Book Scanner Buyer's Guide** is to explain certain technical terms and their impact on quality, speed and handling of book scanning in an unbiased way. The second intention is to provide easy to use measurement tools and tables to determine the resolution, amount of pixels in the cameras and other factors necessary to achieve the desired quality.

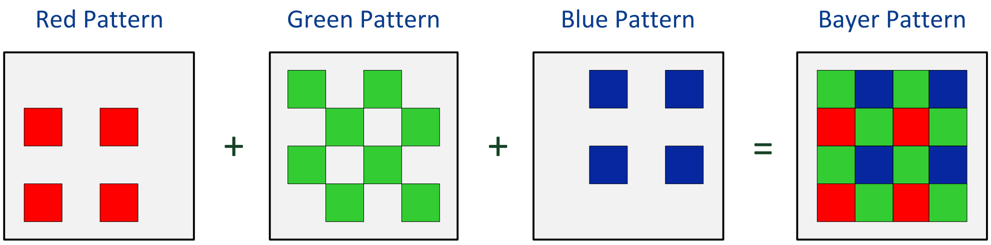
Digital Cameras

Bayer Pattern CCD



Digital cameras use area CCDs comprised of many extremely small pixels, which are covered with a **Bayer Pattern** consisting of two green, one red and one blue pixel arranged in a quadruple. This reduces the resolution by a factor of two for the green channel and by a factor of four for the red and blue channels. Their small size also increases noise compared to linear line sensors. These area CCD image sensors are not suitable for scanners since they do not scan but rather, take pictures.

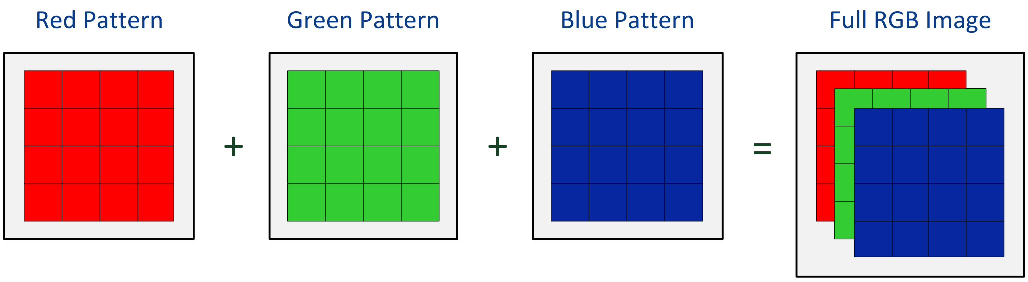
The following diagrams show how a Bayer Pattern image from a digital camera is generated.



If a vendor claims to offer a "scanner" with a one shot camera, a matrix camera or a chip, it will most likely be an ordinary digital camera mounted on an overpriced frame.

There is an exception from a another book scanner vendor. They are using a high resolution monochrome sensor and take **three exposures with different filters** in front of the sensor. Each exposure uses all pixels and afterwards they are composed to a full RGB image like all other ordinary scanners do. Since each exposure takes a few seconds, it must be assured that absolutely no movement of the object or the scanner camera is present, otherwise the three images will not match. The best model of this vendor uses 140MPixel chips to get 600dpi resolution on an area of DINA2.

The following diagram shows how a full RGB Image is composed with three exposures taken with red, green and blue color filters. **Only three shot cameras** with color filters have the same quality as scanners with line sensors.



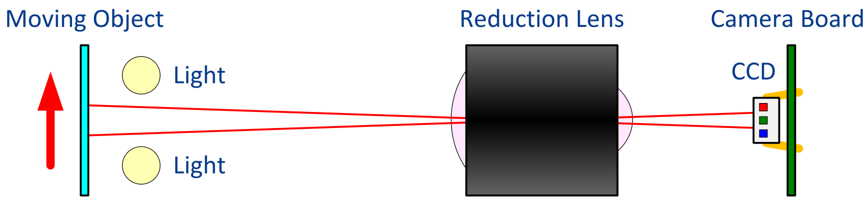
It is possible to achieve good results with this technique, provided that the book is completely flat which implies that it is pressed against a glass plate.

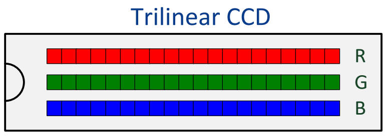
A digital camera is designed to take pictures of objects at various distances, some being in focus other being out of focus. A digicam is not designed to replace a scanner.

Scanners

The following companies only use line sensors for their scanners: Avision, Canon, Contex, Colortrac, Cruse, Epson, Fujitsu, Graphtec, HP, Image Access, Kip, Oce, Panasonic, IBML, Inotek, Microtek, Kodak, Ricoh, Rowe, Xerox, Zeutschel, none of these vendors use digicam technology for their scanners and there are good reasons for this. Professional scanners have linear sensors capturing red, green and blue lines, one after the other, from a document illuminated with white light. The image is reduced by a lens and projected on the linear CCD sensor. The object (document) is moving in synchronization with the exposure of the CCD elements. In a book scanner, the camera, lens system may be moving or a rotating mirror scans over the object simulating a movement.

The red element will capture one line of an image followed by a green element and a blue element. After the computer has shifted these lines into the correct order, the image will consist of RGB values at the full resolution without any Bayer pattern artifacts.

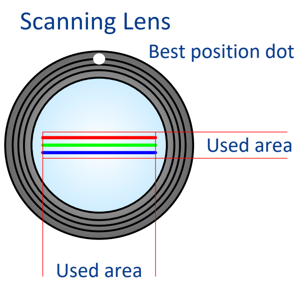


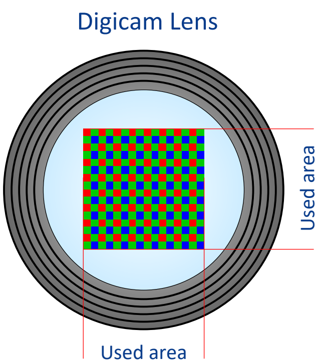


Trilinear sensors convert light on its surface into electrical signals. Color filters for red, green and blue on three consecutive rows of CCD elements provide a very high color gamut, which is typical for CCD scanners. Pixel sizes for high quality CCD sensors are rather large; 10µm x 10µm is a typical value and size matters. Larger pixels help to reduce noise and other image degrading effects.

Scanner Lenses

A pixel on the original at a resolution of 600dpi has a dimension of 64µm x 64µm, therefore a reduction lens 1:6.4 must be used in case the CCD elements are 10µm x 10µm. This results in a long track length with a large focal depth. Almost all book scanners today use a camera consisting of a lens and a linear CCD element aligned in a way that only the distance between these elements changes to keep the correct focus during the sweep over the book.





The quality of the reduction lens is a very important factor influencing the overall quality of the scanning system but constraints are a lot less compared with high quality digital camera lenses. The reason for this is the fact that only the middle section of the lens is used due to the nature of the line sensor. Not only would a digicam lens have to be almost twice as big in diameter, it would also show significant color aberrations, geometric inaccuracies like pin cushion distortions and a loss of intensity in the outer corners. Scanners are also used for quality control applications far beyond the point where only a picture has to be taken therefore, precision is a key factor.

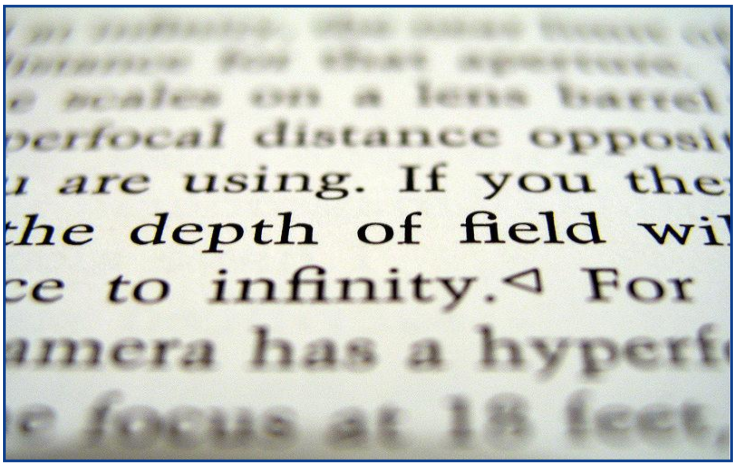
A "nice locking picture" is not a substitute for a precise scan.

Scanning Principles

Books do not have a flat surface, which makes it necessary to scan along the curved surface of the book while constantly adjusting the focal length to stay in focus. There are two ways to scan a book, which is typically laid out on the scanning bed in a landscape orientation. One way is to scan from the top to the bottom (or vice versa) and the other way is to scan from left to right (or right to left). Both methods have their advantages but there are two distinctive differences; the required number of pixels in the CCD camera is higher if scanning top down compared to scanning the shorter edge. The factor is approximately 1:1.4 because this is the factor between the longer edge and the shorter edge of an open book in a DIN format. The other difference is that the scanner has to travel a shorter distance if scanning top down and the scanning time is shorter.

If a scanner is capable of scanning from the side and if it also is capable of continuously adjusting the focus and the resolution while moving over the curved surface, it can be built to scan flat documents, open books and even books not fully opened while resting in a V-shaped cradle. If a scanner scans top down, it can do the same with the exception of the capability to scan flat and V-shaped documents at the same time.

Some vendors use digital cameras and claim, that these are also book scanners, which is obviously not true. A digicam can only take a picture of a perfectly flat document and is also not well suited for high resolution black and white print. To overcome this to some degree, these vendors use a very long focal length which makes their scanners very tall.



Another way of hiding these problems is to use cheap low resolution chip cameras because the lower the resolution, the more focal range.

Useful Lifetime

Book scanners can achieve more than 5 millions scans over the lifetime of the scanner. Digital cameras quit well before 1 million, details can be found here: www.olegkikin.com/shutterlife.

Be aware that the marketing departments of some of the digicam vendors are more creative than their engineering departments. We have seen book cameras advertised at **300.000.000** exposure cycles, which translates into a typical life expectancy of 240 years! Many customers have already regretted their purchasing decisions which were based on published specification or even on data entered in official tenders since some of these specs are very misleading, if not completely wrong.

Hold the vendor responsible for his specifications. Before you buy, ask for sample scans at the highest claimed resolution. Do not believe any dpi or megapixel numbers before they have been verified by yourself.

But what is resolution and how much resolution does a certain digitization project need? This is one of the most confusing topics in the book scanner market and the following chapter intends to explain the unbiased truth from a scientific approach.

Screen Resolution

Today´s TFT screens have 1600*1200 pixels at 23” diagonal width or maybe 1920*1080 at 24” diagonal width. This typically gives a pixel resolution of 96 pixels (actually triplets of red, green and blue pixels) per inch. Let us assume 100dpi for a normal screen to make the following computations easier.

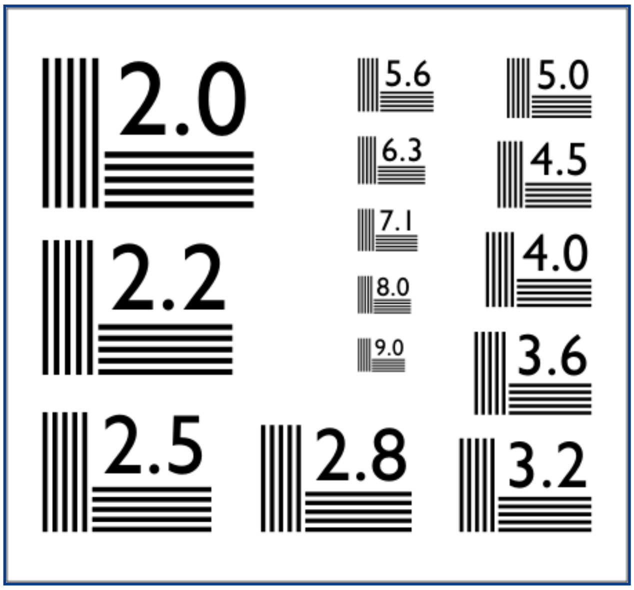
If you display a scan conducted at a resolution of 100dpi in its original size (1:1, each pixel is shown) on a typical TFT screen it will match the original size perfectly. At 200dpi the image on the screen is twice as wide and twice than the original. At 400dpi, it is enlarged by a factor of four. With this knowledge you can easily do a quick check of the geometric resolution and compare it to what is advertised. You might not believe it but some vendors really cheat. We have seen a 150dpi scan advertised as 400dpi and in this specific case even the file properties were faked.

Find a detail in the original document which is as large as the shorter edge of your business card and measure whether this detail on the screen is as long as the longer edge of your business card for a 200dpi scan, 1,5 times longer for a 300dpi scan and twice as long for a 400dpi scan.

Scanner Resolution

Most confusing is the fact that the term “resolution” in the digital world does not describe the system resolution anymore but rather the geometric resolution of the optical elements, typically the CCD elements. The geometric resolution was checked in the previous chapter. The picture on the previous page has the same geometric resolution of 300dpi at the top and bottom as well as in the middle. Clearly, the capability to “resolve details” is good in the middle but bad above and below the focal plane.

A widely accepted way of determining the real system resolution is using various resolution test charts. One of the most popular and easy to use charts is the one shown to the right. This line pair test target can be found on many other test targets like the CSTT test target from Image Access or the UTT test target (Universal Test Target) www.universaltesttarget.com



The target consists of various patches of five black lines separated by four white lines in different sizes. The number 2.0 for example, means that there are two line pairs (two black ones and two white ones) per millimeter.

Other test targets are used to test variations of the illumination, the grey tone balance, color fidelity and geometric distortions. An objective measurement can be done with tools from third parties like Image Engineering, as well as with tools from book scanner vendors like Image Access. None of the digital camera vendors who claim to produce book scanners is known to support automatic quality control via the UTT test chart or any other charts.

To determine the **system resolution** of a scanner **in dpi**, you should scan a test target like the one above. A high quality, paper based target like the CSTT from Image Access is good enough up to 6.0 line pairs per mm, above this value a high resolution film based target must be used to obtain correct results. To avoid any sampling effects which can produce moiré artifacts, the test target should be oriented at a 45° angle. Look at the scan in its original size (1:1) and try to count the black lines. Remember the number 4.0 for example, at which you are still sure to see exactly five lines, not more or less. The following table translates this value into the real system resolution. Try it also on the outer edges of a document as these tend to have less resolution, especially if the scan is not a scan but rather only a picture from a digicam.

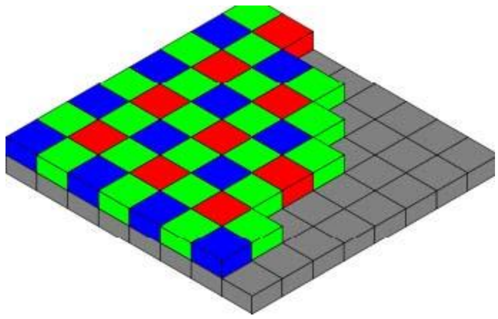
LP/mm	System dpi	Scanning Test Target
2,0	**100**	**High quality print (Image Access CSTT or UTT)**
3,0	**150**	**High quality print (Image Access CSTT or UTT)**
4,0	**200**	**High quality print (Image Access CSTT or UTT)**
5,0	**250**	**High quality print (Image Access CSTT or UTT)**
6,0	**300**	**High quality print (Image Access CSTT or UTT)**
7,0	**350**	**High quality print (Image Access CSTT or UTT)**
8,0	**400**	**High quality print (Image Access CSTT or UTT)**
10,0	**500**	**Film based target necessary (UTT)**
12,0	**600**	**Film based target necessary (UTT)**

Determine the number at which you can still count five black lines, multiply the value by 50 and you get the system resolution in dpi. Disregard any higher value in advertising material, sales peoples' promises and specs.

Sampling efficiency

Sampling efficiency is another way of approaching the same topic; comparing real resolution. A scanner is rated at 300dpi which means that we should see 6.0 line pairs per mm. If we only see 4.0 line pairs per mm (digicams show even less than that) the sampling efficiency is 4.0/6.0 = 66%. The higher the sampling efficiency, the better the overall optical system is. A value above 80% is high enough to be able to claim that the geometric resolution is close to the real resolution. Digital cameras are often lower than 60% which basically indicates that the real resolution is somewhere between 50% and 70% of the claimed resolution.

Digital Camera Resolution

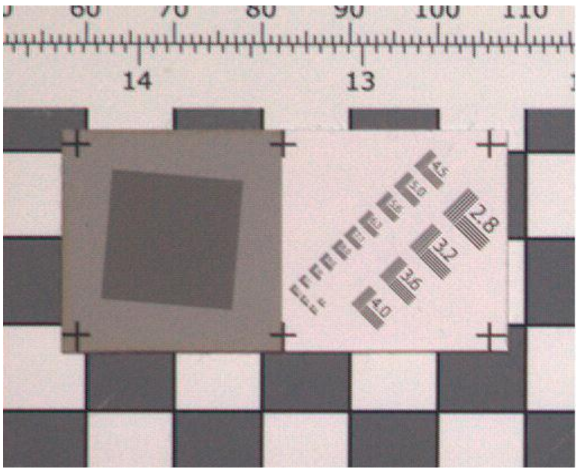


Digital cameras were not invented to **replace scanners**. Their purpose is to **take pictures** of three dimensional objects together with other objects. Since only one focal plane exists, many of the objects on a typical picture taken with a digital camera will be out of focus anyway, allowing for less overall sharpness than what can be captured with a scanner. In a typical picture, the region of interest is somewhere close to the center which hides the fact that the lens loses sharpness, geometric accuracy and color registration at the edges of the image.

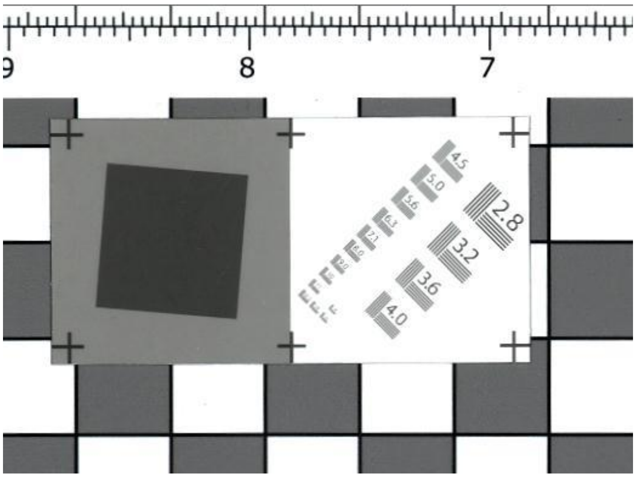
A scanner scans red, green and blue sequentially, one after another, and produces perfectly good RGB pixels from a geometric standpoint.

All digital cameras have a **Bayer pattern**, which cuts the effective resolution in half for the green channel and to a quarter for the red and blue channels. The pixels have to be interpolated in software, which produces even more artifacts.

The picture on the left side below is from a digital camera system, the right image is from a real book scanner. Both are scanned at 200dpi only because this is the maximum resolution the digital camera supports. The vendor calls it a book scanner but if you compare the two images, the difference becomes obvious. The left image is blurry and full of artifacts. It also has a very high noise level which is typical for low end digicams with their extremely small pixel size. Many digital cameras try to smooth out the noise and sacrifice even more details, which is unacceptable for scanning documents.



Picture from a book2net* digicam



Scan from a Bookeye 4 scanner

The inability to produce straight black & white lines also makes it very hard for any OCR software to recognize the blurry text.

A digital camera is <u>not</u> a scanner. It is designed to take pictures of objects at variable distances while a scanner is designed to scan a document at a very well defined distance, producing crisp and sharp images.

Document size

Normal sheet feed scanners have a fixed maximum document width and a somewhat unlimited document length. This is due to the fact that a scanner constantly takes images line by line as long as the document is moving in front of its line camera. It is "scanning" the document line by line in contrast to "taking a picture". From a technical standpoint, there is no difference between a system which moves the document and a system which moves the camera although the second is normally limited in length.

Book scanners have a maximum document width and length and this is typically specified in DIN format. Since they scan a fixed area, the reader should carefully evaluate the real size of the scanning area. The marketing department of one vendor, whose scanner scans only 20% more than A3, came up with the term "almost DIN A2".

After you have determined the appropriate system resolution as discussed in the previous chapter, you need to specify the maximum document size to be scanned. The larger a source document is, the more pixels will be required. The following table shows the number of pixels necessary for a scanner scanning along the longer edge of a document and a scanner scanning along the shorter edge of a document. The first needs fewer pixels and more time, the second needs more pixels and less time.

Some vendors use digital cameras and claim, that these are also scanners, which is not true. All digicams have a single focal plane and therefore, can take a high resolution picture only of a perfectly flat document and a book is never perfectly flat. The inability to adjust the focus during a scan makes it absolutely mandatory to have the camera and the object precisely perpendicular to each other.

Nevertheless, we have listed the megapixel requirements for digicams in the following table. A pixel is defined by a red, green and blue percentage and in the case of the digicam, a pixel has a green and a red percentage with the blue content being interpolated or a green and a blue with the red content being interpolated.

		A0 /E-size	A1 / D-size	A2 / C-size	A3 / B-size	A4 / letter
Scan left to right	**200dpi**	**3 x 6700**	**3 x 4700**	**3 x 3400**	**3 x 2400**	**3 x 1700**
Scan top to bottom		**3 x 9400**	**3 x 6700**	**3 x 4700**	**3 x 3400**	**3 x 2400**
Digicam		**124 Mpixel**	**62 Mpixel**	**31 Mpixel**	**16 Mpixel**	**8 Mpixel**
Scan left to right	**300dpi**	**3 x 10000**	**3 x 7100**	**3 x 5000**	**3 x 3600**	**3 x 2500**
Scan top to bottom		**3 x 14100**	**3 x 10000**	**3 x 7100**	**3 x 5000**	**3 x 3600**
Digicam		**279 Mpixel**	**140 Mpixel**	**70 Mpixel**	**35 Mpixel**	**18 Mpixel**
Scan left to right	**400dpi**	**3 x 13300**	**3 x 9400**	**3 x 6700**	**3 x 4700**	**3 x 3400**
Scan top to bottom		**3 x 18800**	**3 x 13300**	**3 x 9400**	**3 x 6700**	**3 x 4700**
Digicam		**496 Mpixel**	**248 Mpixel**	**124 Mpixel**	**62 Mpixel**	**31 Mpixel**
Scan left to right	**600dpi**	**3 x 19900**	**3 x 14100**	**3 x 10000**	**3 x 7100**	**3 x 5000**
Scan top to bottom		**3 x 28100**	**3 x 19900**	**3 x 14100**	**3 x 10000**	**3 x 7100**
Digicam		**1116 Mpixel**	**558 Mpixel**	**279 Mpixel**	**140 Mpixel**	**70 Mpixel**

Note: If a vendor shows half the pixel count than what is shown in the above list, they count all red, green and blue pixels together and interpolate the missing two colors per pixel. In other words 1/3rd of the pixels are real and 2/3rd are interpolated. The above table assumes 2/3rd of a pixels color information to be real and only 1/3rd interpolated which is still less quality than a scan can produce.

Some vendors claim they can capture **DIN A2** images at 400dpi with their 30 megapixel digicams but the above table proves them wrong because this will require at least **124 megapixels**. At 600dpi, the largest digicam sensors available today, costing thousands of U.S. dollars or Euros, can only produce a mere A4 size image which is far too small for serious book scanning.

All book scanners have high resolution line cameras, otherwise they would not be called scanners. If a vendor using a digicam claims to get close to typical scanner resolutions of 300dpi and above, check the above table and find out the truth.

Speed and Exposure

The scanning process takes several thousand images per second and is therefore very insensitive to imperfections in the movement of the document, vibrations etc. Scanner cameras only illuminate the small area that they actually scan with a high quality, intense light which in return delivers high quality, low noise images. Typical exposure times are in the range of 250µ to 1.500µs. On the other hand, high resolution "still" digicams have exposure times in the magnitude of a couple of seconds, making them very sensitive to all sorts of movements of the camera, the book, the user and even the floor of the room in which the digicam is installed.

The amount of light is also a quality determining factor. Some vendors claim that their scanners do not need light at all and therefore, do not emit any infrared and UV light. While the second statement is obviously true, the first one is misleading. These scanners completely rely on the ambient light for the scanning process, equivalent to shooting a photo with a digicam without a flash. Everybody knows that the result of such a photo is very unpredictable in terms of color balance, noise, reflections and so on.

Good book scanners have their own well controlled, high quality light source. The light level needs to be high in the area of interest and should not illuminate anything outside of this area. The high level of scanner illumination provided is necessary to boost the "good light" from the scanner to a level much higher than the ambient light, so that it overrides all imperfections introduced by the ambient light. The scanners' light source should typically be 10 – 20 times brighter than the ambient light, lowering the sensitivity to the uncontrolled ambient light level to an invisible level.

At the same time, all areas not being scanned at a given time should only be subjected to limited light exposure in order to protect the books and the scanner operator. Books scanners that obey these rules have a moving light bar of high intensity LED light which sweeps across the surface of the book as it is scanned. The light intensity is controlled during the scan to perfectly illuminate the book even at varying distances and angles. The book scanners from major market players all work with a moving light bar.

A modern book scanner uses a moving light bar generated by high quality LEDs. A device which illuminates the whole scanning area at once or not at all is most likely not a scanner but an overpriced digital camera.

Bits, Density and Noise

Probably the greatest misconception about scanner technology is the one about bit depth per color, also called color resolution. The first thing to remember is that bit depth and dynamic range are NOT the same thing. They are going to sound much the same, but they are not and this difference will be explained here. Most scanners now have at least 30 bit color depth and many have a color depth of 36, 42 or 48 bits. More bits are required to hold numeric values containing better dynamic range. While the two factors are often associated, there is also a second requirement. High quality, low noise CCD and electronics (i.e., expensive) are needed for better dynamic range. The fact that a scanner claims to have 48 bits of color depth has nothing to do with its real optical density. It only means that 16 bit A/D converters are used.

The following table shows the theoretical maximum density for various bit depths. If these values are found in a scanner specification sheet, it is safe to disregard them completely because they only specify the size of the container, not the content.

Total Bits	Binary steps	Max Density (no noise)	Max Density (1bit noise)
30	1024	3.0	2.7
36	4096	3.6	3.3
42	16384	4.2	3.9
48	65536	4.8	4.5

Material	Max Density
Newspaper print	< 1.8
Reflective photographic paper	2.0
Best print on paper	2.6
Best film transparencies	3.2

Real world density ranges are a lot lower than expected. The table to the left lists density ranges for various materials

The message is clear: 36 bits of resolution can hold all numerical values necessary to represent the density range found with the best film transparencies. A bigger container, 42 or 48 bits is a waste, especially because handling more data slows down every system. Some systems may use more than 36bit resolution to allow brightness and gamma correction in software in a later processing step but this does not mean that the density will also increase.

Far more important than the color depth is the noise level of the system. Modern book scanners have line cameras with large pixels up to 10*10µm which can collect many photons before they saturate. More photons mean less noise. If the pixel size is cut in half, it doubles the noise, a problem all high resolution digicams have to cope with. Today, the pixels of a digicam are only one tenth the size of a line camera and a lot of computing is needed to get a halfway decent image out of them. The old saying "bigger is better" fully applies to CCD elements.

36 bit color resolution is more than enough for a book scanner. Anything above that might look attractive in a brochure but is useless. More important are the illumination level and the pixel size.