Journal of Special Topics

P1_5 The Megapixel Limit

Roisin A. Boadle, Emma Wigfield, Amanjit S. Dulay
Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.
November 13, 2009

Abstract

This article discusses the megapixel (MP) limit for a camera- the point at which the resolution of the print matches that of the eye. The limit is calculated for normal sight and for the best possible sight. It is found that for print sizes from 6x4”-18x12” the megapixel limit is 8.61-71.31MP (best sight) and 2.90-23.99MP (normal sight). The variation of the megapixel limit with viewing distance is also addressed; for an 18x12” print the megapixel limit drops below 1MP for viewing distances above 2m. Some factors affecting the visual acuity of an eye are given, and their potential effects on the MP limit mentioned.

Introduction

Digital camera technology is continually improving, making it possible to produce better, cheaper, higher megapixel (MP) CCDs which end up on the commercial market. It is a common belief amongst digital camera purchasers that the more MPs a camera has, the better the photo will be- a 5MP CCD which takes a 5MP photo, consisting of $5x10^6$ individual points (or pixels), is better than a 1MP version. Whilst this is true to some extent, an unaided eye has a maximum resolution, R_{EYE} (in MP). This is the maximum number of pixels the eye can distinguish between (resolve), largely dependent upon the density of cones and rods in the eye. This article focuses on the MP limit, *n*, of a print, defined as the point at which $n = R_{EYE}$. Beyond this limit, more MPs would be pointless as the eye cannot resolve the detail.

Theory

Visual acuity (*VA*) is the most important factor affecting the spatial resolution of the eye; it defines the ability of the eye to see fine detail,

$$VA = {}^{1}/_{\varphi} \quad (1)$$

where φ is the angle (in arc minutes) subtended at the eye by the corner to corner size of the two smallest, resolvable pixels (shown in Fig.1). ‘Normal’ sighted people (20/20 vision) have a visual acuity of 1.0 [1], although under ideal viewing conditions this can rise to a maximum of 1.7 [2]. A photo at a viewing distance, *L*, from the eye subtends angles (fig1)

$$\alpha = 2tan^{-1}\left(\frac{x}{2L}\right) \quad (2)$$

$$\beta = 2tan^{-1}\left(\frac{y}{2L}\right) \quad (3)$$

where *x* and *y* are as shown in figure 1, α and β in degrees.

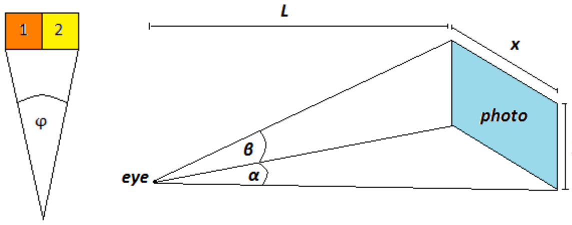


Figure 1, Left: diagrammatic definition of angle φ where the coloured squares 1 and 2 are equal sized pixels. Right: Geometry used in (2)-(5)

The maximum number of pixels the eye can distinguish is given by

$$p_x = \left(\frac{120}{\varphi}\right)\alpha \quad (4)$$

$$p_y = \left(\frac{120}{\varphi}\right)\beta \quad (5)$$

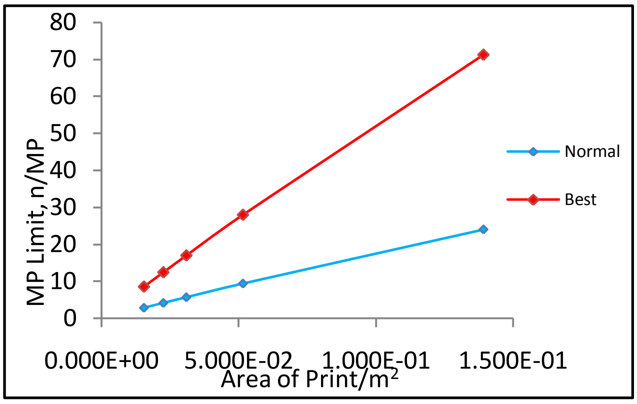
where p_x and p_y are the number of pixels in the horizontal (*x*) and vertical (y) directions, and 120 is due to conversion from arc minutes to degrees (1’=1/60˚), and geometry as φ is the angle for two pixels. Thus, the MP limit of the camera, *n* (MP), is

$$n = \frac{p_x p_y}{1x10^6} \quad (6)$$

So a MP limit of *n*=5MP would indicate that the maximum number of useful pixels in the entire print (*x* by *y*) is 5MP ($5x10^6$ pixels).

Results

The theory above was applied to the situations of normal sight (*VA*=1.0) and best possible sight (*VA*=1.7) to produce graph 1. The photographic print dimensions (*x, y*) used are matched to standard printing sizes, usually given in imperial inches (6x4", 7x5", 8x6", 10x8", 18x12"). This assumes that the printer can faithfully reproduce each pixel from the camera, and that the camera lenses do not limit the performance of the CCD. The viewing distance, *L*, is held constant at approximately arm length, 0.5m.



Graph 1: Print size and MP limit. Each marker indicates a print size from 6x4"-18x12".

Graph 2 is a plot of the variation of *n* with *L* for normal sight and an 18x12" print.

Graph 2: MP limit variation with L for an 18x12" print. At sensible viewing distances, the MP limit approaches 0MP, but does not reach it.

It is apparent that the MP limit drops off quickly with the distance from the photograph. For a viewing distance, *L* >2m, a 1MP print would appear as detailed as a 20MP print, since the eye would not be able to resolve the additional detail in the higher MP print.

Discussion

The results above, including that for normal sight, have been found assuming almost ideal conditions. Visual acuity is affected by many factors including pupil size, illumination, eye motion and the area of the retina that is stimulated [2]. This last factor is perhaps the most important; the majority of cones in the eye are found within the central 2˚ of the eye, thus visual acuity can drop by 25% just 1/6˚ from the centre and sharply after that [1]. This means that whilst the MP limits found above are valid when the innermost section of the retina is considered (when looking straight ahead), they would be lower further from the centre (towards the edges of the field of view). The use of a constant viewing distance for graph 1 means that the larger prints fill more of the field of view, encouraging the eyes to move around the photograph to take in detail. Eye motion degrades the visual acuity of an eye- even during steady fixation, the eyes move at a speed of approximately 0.05˚/s [2]; this has not been accounted for here. These factors would undoubtedly decrease the MP limit.

Conclusion

It has been found that the MP limit ranges from 8.61-71.31MP and 2.90-23.99MP for best and normal sight (calculated using print sizes 6x4"-18x12"). For an 18x12" print, and normal sight, the MP limit drops off quickly with viewing distance, falling below 1MP when *L* >2m. This means, for example, that the Nikon D3X DSLR, with 24.4MP [3], would be unnecessary when printing at sizes less than ~10x8" (best sight) or ~18x12" (normal sight). Other limitations to the visual acuity (illumination, contrast etc) have not been included in the results; these factors can decrease the MP limit. Hence, for eye pleasing photos it is feasible to use a much lower MP than these limits suggest, because unless concentrating hard in optimum conditions on a central spot, the eye would not notice a large difference in detail.

References

[1] J Beynon, Phys. Educ. **20** (1985) pp234-237
[2] webvision.med.utah.edu/KallSpatial
[3] www.engadget.com/2008/04/15/24-4-megapixel-nikon-d3x-dslr-in-the-work