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RADIOMETRIC PERFORMANCE ANALYSIS OF MOBILE PHONES CAMERAS

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ABSTRACT: The radiometric capabilities of two mobile phone cameras are examined and compared against two off-the-shelf digital cameras. The radiometric performances are measured in terms of resolution by MTF analysis, noise analysis and linearity test. All tests are conducted with the use of a Siemens Star chart.

1. INTRODUCTION

Mobile Mapping has been an issue within the geospatial community already for some years. Among various hardware and software components mobile phones constitute an interesting option for image data acquisition and processing for obvious reasons: They are very inexpensive, light, portable and have digital cameras and CPUs. We anticipate interesting future possibilities for on-line processing of acquired image data by mobile phone cameras. This opens the path for a paradigm shift from "Mobile Mapping" to "Mobile 3D Modeling".

This project examines the potential of mobile phones to be used as a front-end sensor for photogrammetric procedures and applications. In previous work we have presented the geometrical performances (in terms of testfield calibration, accuracy testing, JPEG testing and temporal stability testing) of different mobile phone cameras (Gruen and Akca, 2007; 2008). This paper, as continuation of the work, presents the radiometric performance of the same mobile phone cameras (Sony Ericsson K750i and Nokia N93) and compares it with two off-the-shelf digital cameras (Sony DCS-T100 and Sony DSC-F828).

The next chapter introduces the cameras and our test setup. The radiometric performance assessment contains three steps: Modulation Transfer Function (MTF), noise and linearity analysis. Chapter 3 and 4 discuss the results of these procedures.

2. THE CAMERAS AND THE SETUP

Four cameras are used (Figure 1). Two of them are mobile phone cameras (Sony Ericsson K750i and Nokia N93) and two of them are off-the-shelf digital still video cameras (Sony DSC T100 and Sony DSC F828). Among those only the T100 has an image stabilizer. The technical specifications of all four cameras are given in Table 1. For all tasks we use the Siemens Star chart (Figure 2). The chart contains 144 sinusoidal cycles in a radial structure and has a 290 x 270 mm size. The four black patches (at the corners) with a small white square inside are used to automatically detect the position of the Siemens Star. The star is surrounded by 16 linearly ramped grey level patches (Figure 2b).

Table 1: Technical specifications of the cameras.

| | <i>K750i</i> | <i>N93</i> | <i>DSC-T100</i> | <i>DSC-F828</i> |
|----------------------|-------------------|--------------------|--------------------|-----------------------|
| <i>Sensor type</i> | CMOS | CMOS | CCD | CCD |
| <i>Sensor size</i> | 4.5 x 3.4 mm | 4.5 x 3.4 mm | 5.8 x 4.3 mm | 8.8 x 6.6 mm |
| <i>Pixel size</i> | 2.8 μm | 2.2 μm | 1.8 μm | 2.7 μm |
| <i>Image format</i> | 1632 x 1224 | 2048 x 1536 | 3264 x 2448 | 3264 x 2448 |
| | 2 Mpixel | 3.2 Mpixel | 8 Mpixel | 8 Mpixel |
| <i>Lens</i> | N.A. | Zeiss Vario-Tessar | Zeiss Vario-Tessar | Zeiss T* Vario-Sonnar |
| <i>Focal length</i> | 4.8 mm | 4.5 – 12.4 mm | 5.8 – 29.0 | 7.1 – 51.0 mm |
| <i>Optical zoom</i> | No | 3x | 5x | 7x |
| <i>Auto focus</i> | Yes | Yes | Yes | Yes |
| <i>Aperture</i> | F/2.8 (fixed) | F/2.8 (fixed) | F/3.5 – 4.4 | F/2.0 – F8.0 |
| <i>Output format</i> | Only JPEG | Only JPEG | Only JPEG | JPEG and TIFF |



Figure 1. Cameras used in our tests. (a) Sony Ericsson K750i, (b) Nokia N93, (c) Sony DSC T100, (d) Sony DSC F828.

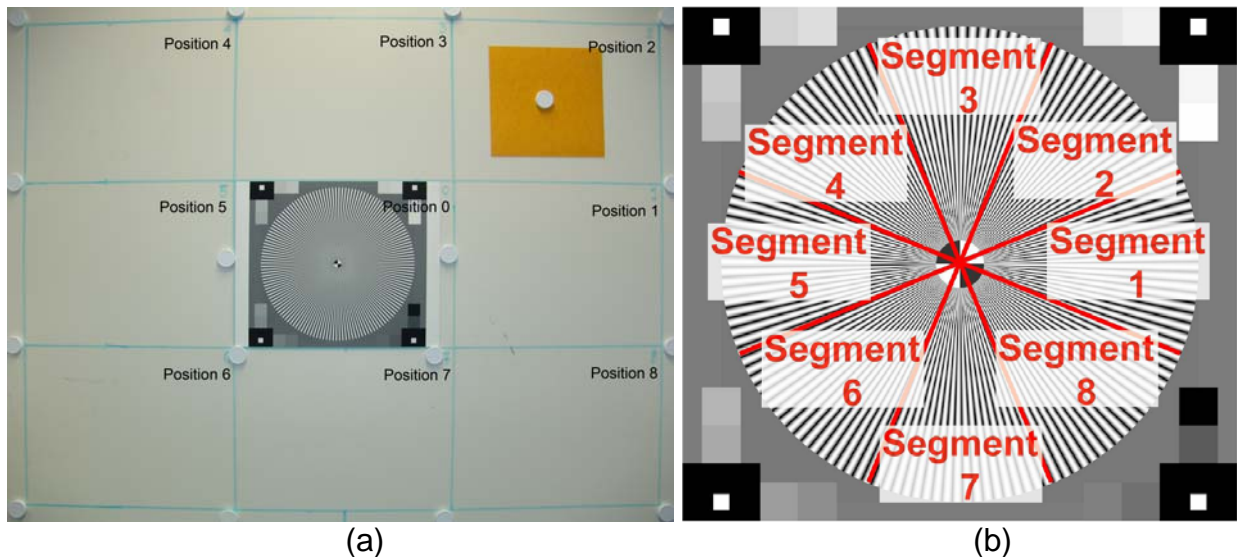


Figure 2. (a) The Siemens Star chart is located at 9 positions of the image. This picture shows the position 0 of the K750i. (b) The software computes the MTF graphs at 8 sectors of the chart.

We analyze the camera resolution (based on the MTF analysis) at 9 image locations by aligning the chart in 3 columns and 3 rows (Figure 2a). The software divides each star into 8 segments (Figure 2b). Individual MTF graphs for each segment are computed. The pictures are taken in short object-to-camera distances (camera constant focused to 1.30 m, 1.20 m, 1.20 m and 1.02 m for the K750i, N93, T100 and F828, respectively) in

order for the camera field of view (FOV) to just cover the 3x3 grid (Figure 2a). Thus, the computed MTF values are rather for comparative purposes, and show higher resolution values than the ones pictures taken in operational distances, e.g. with the focus set to infinity. The pictures of all 4 cameras were taken at the same time span, under the same illumination conditions and using the same setup. The focal lengths were set to the smallest values, which give the widest angles of the FOV.

The Siemens Star chart and the associated software are provided from Image Engineering, Germany (www.image-engineering.de). The algorithmic details of the approach are given in Loebich et al. (2007).

3. RESOLUTION TEST BY MTF ANALYSIS

Image resolution is related to the ability of a camera to reproduce fine details. We set 40% contrast as the MTF limit value. The results are given in Figures 3, 4, 5 and 6 as spider diagrams.

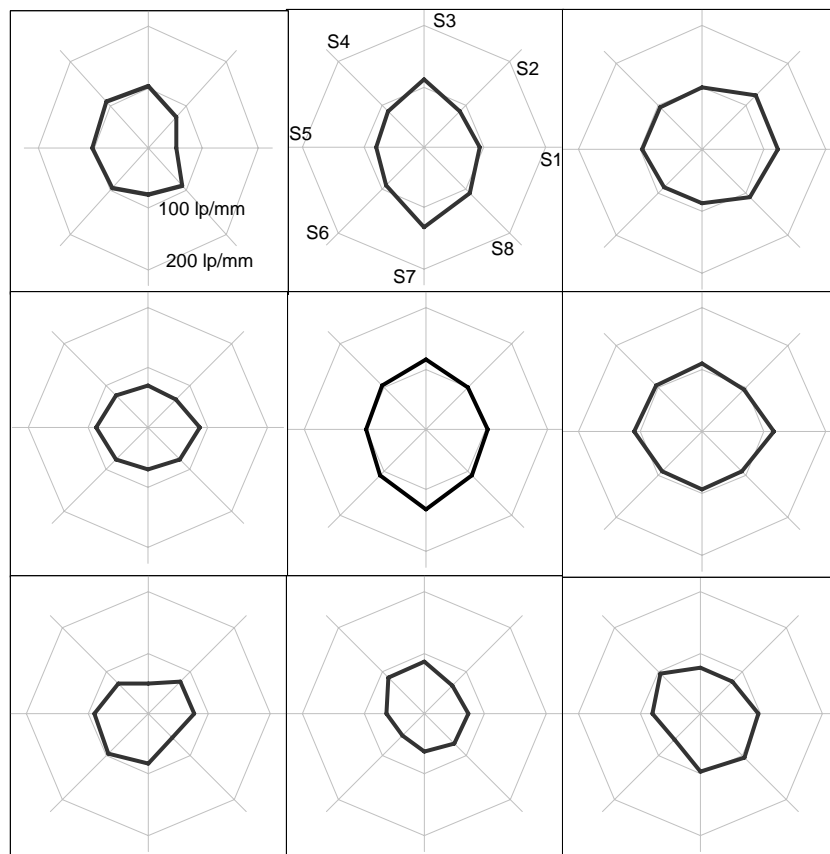


Figure 3. Resolutions at all 9 Siemens Star chart locations (according to Figure 2a) for the 750i. Each location contains the results of 8 directional segments (S1, S2, ..., S8). The first octagon of the spider diagrams stands for 100 line-pairs per mm (lp/mm) and the second stands for 200 lp/mm. The same notations are also used for Figures 4, 5 and 6.

The K750i gives the worst results among all cameras (Figure 3). The average resolution of all 9 chart locations considering all segments is 89 lp/mm. However, the resolution is heterogeneous over the image format, i.e. worst at the lower left area and better at the upper right area. The change of the resolution from the upper right (103 lp/mm) to the lower left (73 lp/mm) is significant.

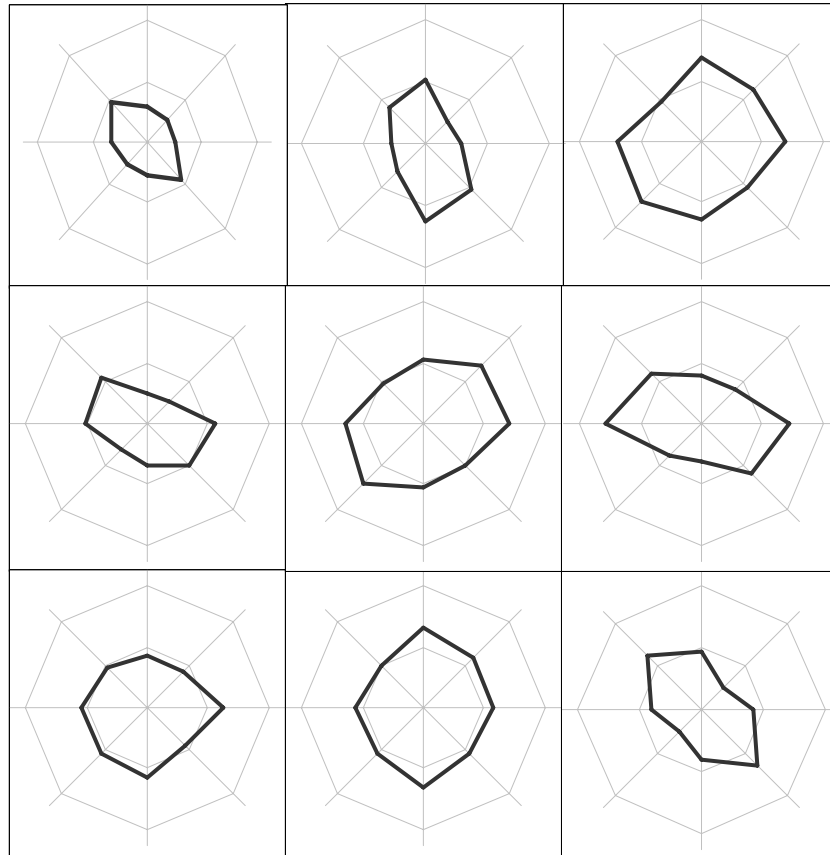


Figure 4. Resolutions for the 8 segments of all 9 chart positions of the N93.

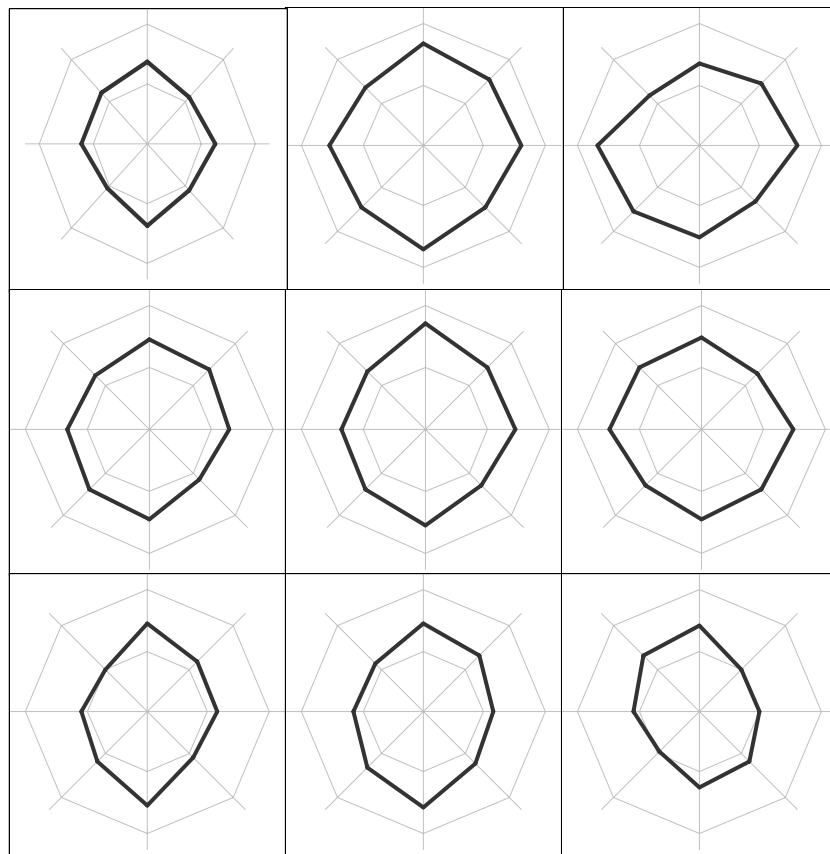


Figure 5. Resolutions for the 8 segments of all 9 chart positions of the T100.

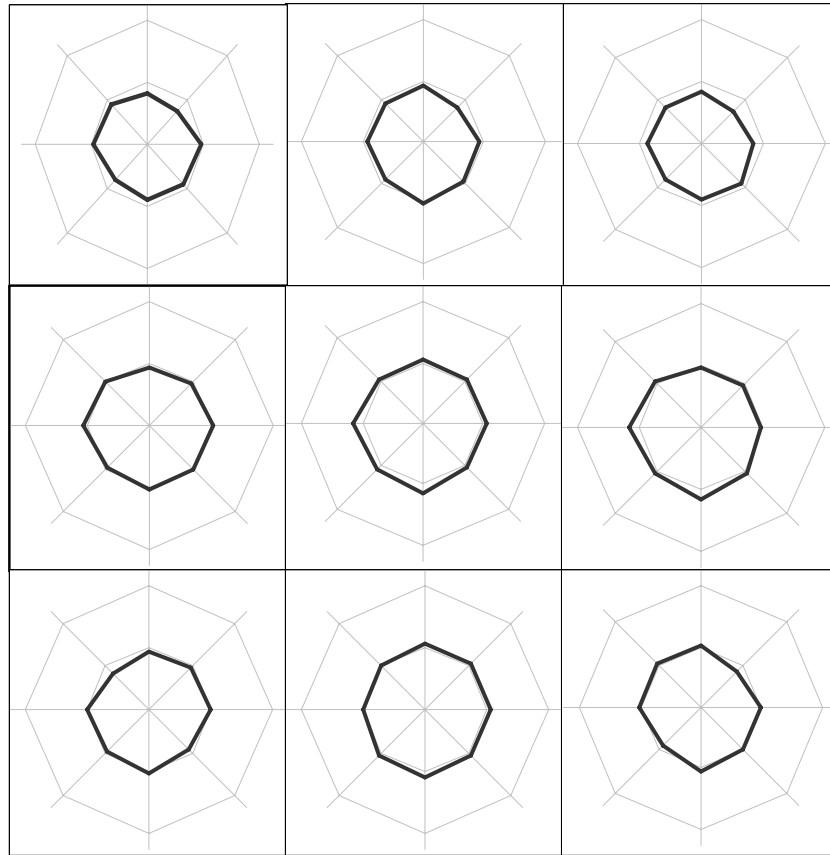


Figure 6. Resolutions for the 8 segments of all 9 chart positions of the F828.

The MTF results of the N93 (Figure 4) are slightly better than those of the K750i in terms of average resolution (98 lp/mm). However, the resolution values are again not homogenous and isotropic over the chart locations and segment directions in image space. The average resolution value at the upper left corner is minimal (63 lp/mm), while the upper right has the best value (124 lp/mm). The maximal change of the resolution inside the image plane is by a factor 2.

Although the T100 (Figure 5) gives the best average resolution (135 lp/mm) and F828 (Figure 6) has a smaller value (96 lp/mm), the F828 is the best among all cameras considering homogeneity and isotropy.

4. NOISE AND LINEARITY ANALYSIS

The 16 linearly ramped grey patches (Figure 2b) are used for the noise and linearity analysis. For all four cameras, the images at position 0 (Figure 2a) are used for the computations. At 16 ramped grey patches the means and the standard deviations of the grey levels for each channel (red, green, blue) are calculated. The standard deviations show the noise characters of the cameras (Table 2).

Table 2. statistical results of noise and linearity analysis.

| Camera | Min and max of grey values | | | Standard deviation of grey values | | | |
|--------|----------------------------|--------------|--------------|-----------------------------------|-------|-------|-------|
| | R | G | B | R | G | B | Mean |
| K750i | 63.4 – 176.4 | 63.7 – 175.0 | 62.9 – 171.2 | ± 2.0 | ± 1.9 | ± 2.7 | ± 2.2 |
| N93 | 10.7 – 166.2 | 12.2 – 171.0 | 12.0 – 173.7 | ± 3.2 | ± 2.8 | ± 4.2 | ± 3.4 |
| T100 | 19.0 – 205.3 | 19.5 – 194.9 | 17.7 – 178.1 | ± 2.4 | ± 1.8 | ± 2.9 | ± 2.4 |
| F828 | 17.6 – 198.2 | 21.1 – 204.2 | 24.0 – 197.0 | ± 1.8 | ± 1.5 | ± 2.0 | ± 1.8 |

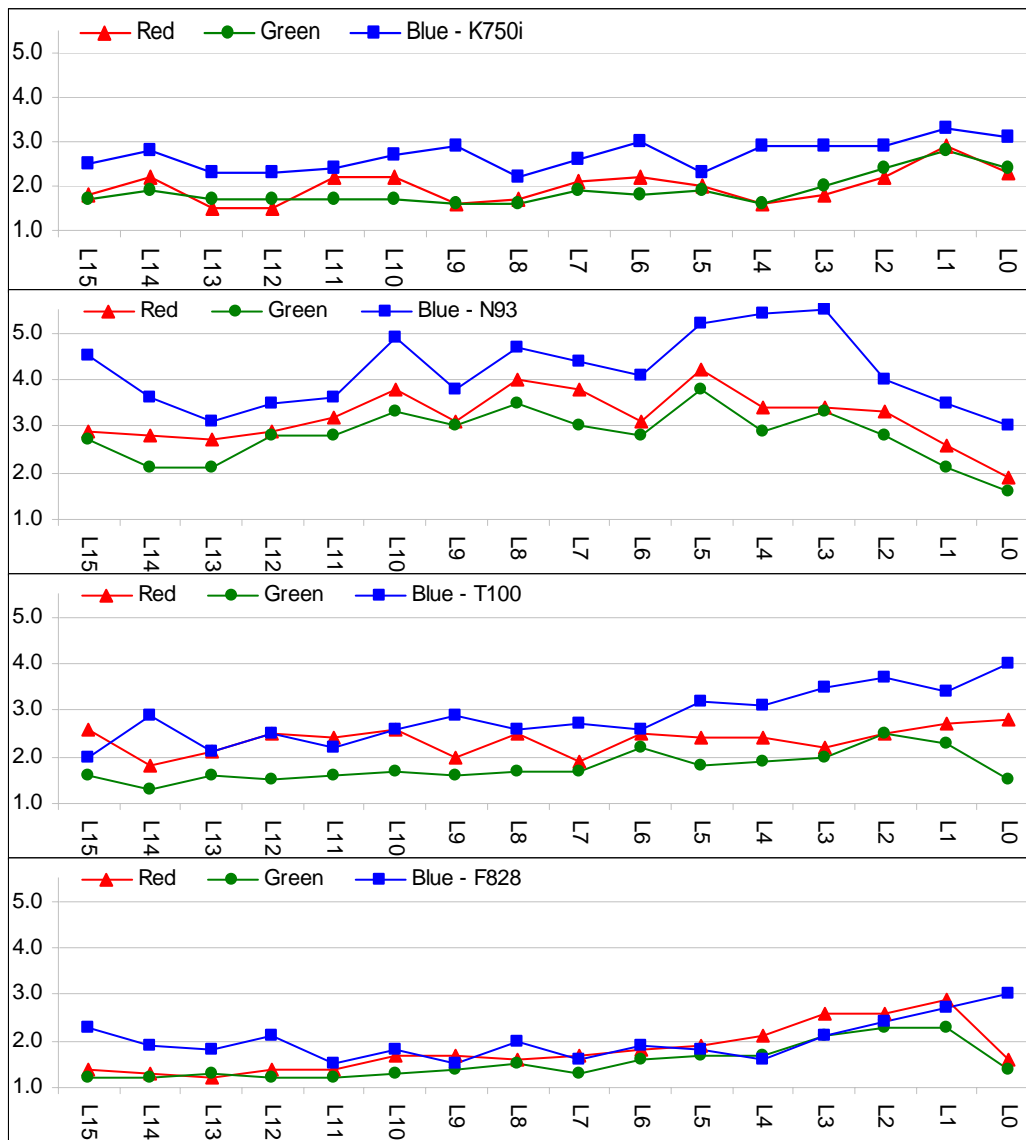


Figure 7. Noise levels of the red, green and blue channels at 16 grey levels from white to black (L15, L14, ..., L0). L15 stands for the white and L0 stands for the black. From top to down the graphs stand for K750i, N93, T100 and F828, respectively.

Although the K750i has a no-name lens, its noise is smaller than those with Carl Zeiss Vario-Tessar lenses, i.e. the N93 and the T100 (Figure 7). This is most probably due to chip level image sharpening of the K750i. The F828 gives the smallest noise.

The K750i uses the smallest range in the image histogram (Figure 8). The K750i and N93, as mobile phone cameras, give smaller grey value ranges than the off-the-shelf cameras T100 and F828. None of the cameras gives a linear or near-linear response (Figure 8).

5. CONCLUSIONS

Our analysis shows that the radiometric performance of the mobile phone cameras is lower than that of the off-the-shelf digital cameras in terms of resolution. On the other hand they give identical results in the noise analysis. Given the large price difference between both camera types the overall performance of the mobile phone cameras is quite remarkable. With proper calibration and thorough understanding of the geometric

and radiometric limits, they can be used for many kinds of 3D measurement and modeling tasks.

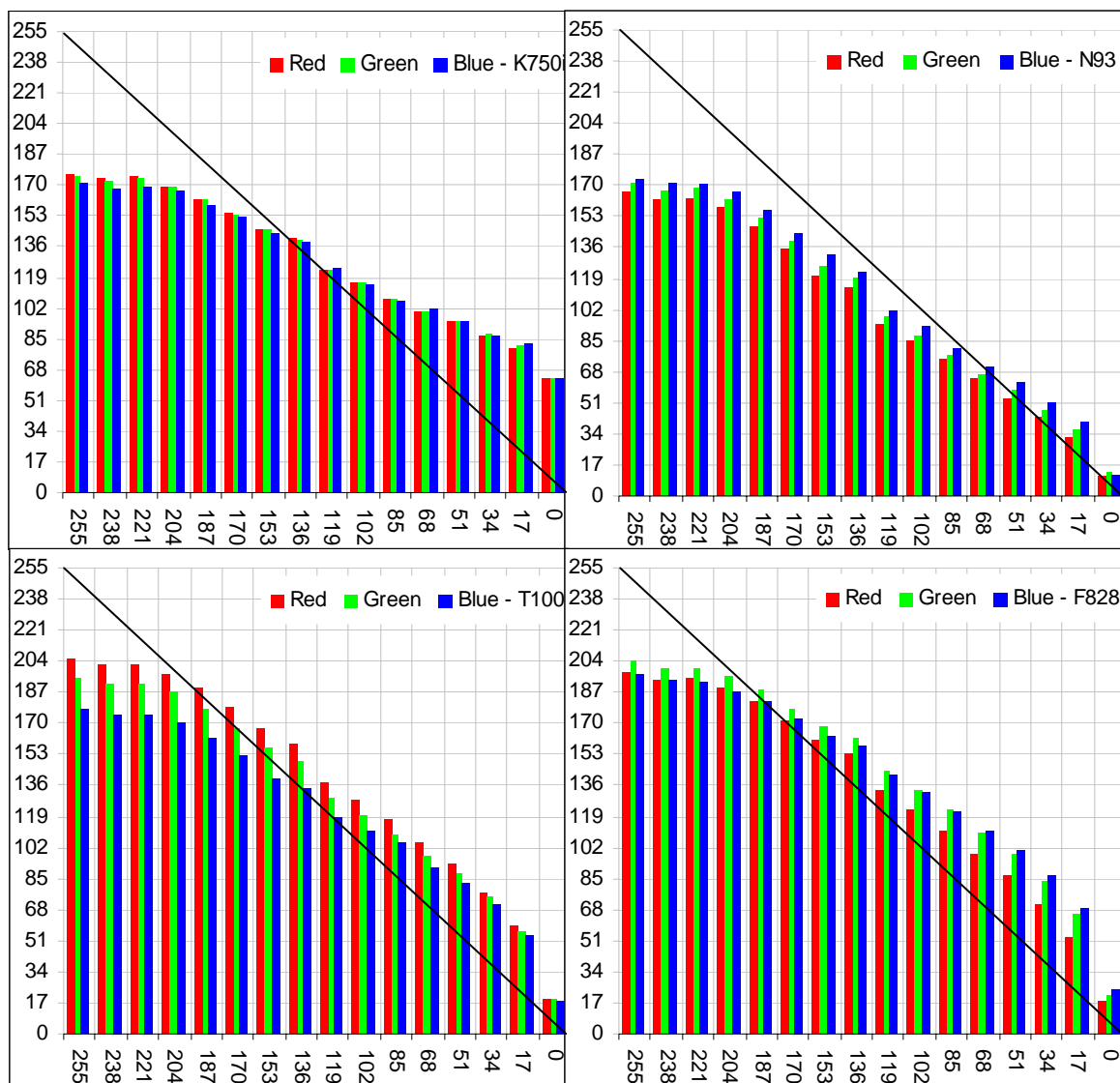


Figure 8. Linearity analysis of the K750i, N93, T100 and F828. Abscissa values are the nominal grey values of the 16 ramped grey patches (L0= 0, L15= 255). Ordinate values are the responses of the cameras in the 8-bits (0-255) grey value domain.

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