Resolution Limits for Smartphones – Video Playback

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Abstract

This study aims to determine an upper discernible resolution limit for smartphone displays showing video. A range of resolutions varying from 150-600 PPI were evaluated by 43 subjects at 300mm equivalent distance. Results of the study conclusively show users can discriminate between 450 and 600 PPI video playback.

Author Keywords

Acuity; Resolution; Human Factors; Smartphone; Video; PPI

1. Introduction

There is a keen interest in understanding the maximum resolution that can be discerned by users of smartphones. The resolution of smartphones has steadily been increasing over the past few years; with latest models now reaching 470 Pixels Per Inch, PPI (See Figure 1.) One key discussion point of smartphone displays is whether there is any net user benefit to such high resolution. It is often quoted that the resolution limit for the eye is approximately 1 arcmin, which is equivalent to 290 PPI at 30 cm, the typical viewing distance of a smartphone display.

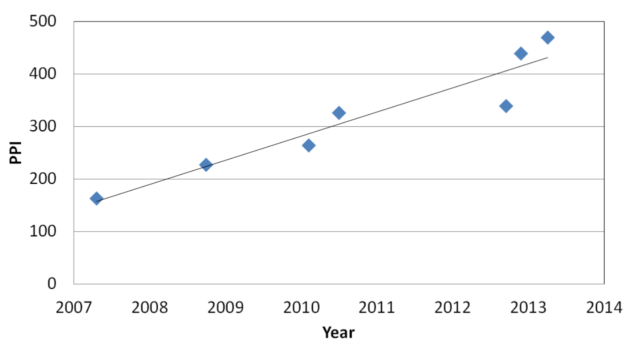


Figure 1. Showing the increase in smartphone resolution over the past 6 years. Trend line shown as guide to the eye.

However this figure is derived from the visual acuity of a person with 20/20 vision. Visual acuity is an angular measure of minimum resolvable black and white line pairs; typically measured at 20ft or 6m. A visual acuity of 1 arc min is considered to be the limit at which no corrective action is required. The discernible limit for a single black line on a white back ground may be a small as 1 arc second [1].

In addition to this discernible limit there is a further measure, Vernier acuity, which defines the ability to resolve offset lines and is 5-10 greater than visual acuity [2]. This fact is the underlying principle which allows us to so accurately read a vernier scale.

Previous investigations in to discernable limits for screen resolution performed on TV sized panels have shown that an angular resolution of 60 cycles per degree approaches the limit for natural images [3-4]. This is equivalent to 580 PPI at 30 cm viewing distance. Additionally a previous study performed on simulated smartphone displays resulted in a resolution limit of a similar value of 500-600 PPI for natural images and beyond 1000 PPI for computer generated graphics with high contrast diagonal lines [5].

The motivation of this work was to understand what the resolution limit is of the human visual system for smartphones displaying video. All the previous studies have focused on static images, whereby users have had time to analyse specific areas of an image to help make the decision. Moving images or video represent a significant proportion of smartphone usage including video calls, movies, social networking and video games. It is important to understand if moving images reduce the discernible resolution limit as this is more closely represents real world usage of smartphones.

2. Experiment

A wide range of resolutions were to be tested, 150-600 PPI. At the time of experimentation no 600 PPI displays were available of a suitable size. To compensate for this a 10.1” tablet with a resolution of 2560x1600 (300 PPI) with Luminance 400cd/m^2, contrast ratio 900:1 and colour gamut 50% NTSC ratio (CIE 1976) was used at a 60cm working distance. Results were then calculated based on a simulated working distance of 30cm such that 300 PPI at 60cm is equivalent to 600 PPI at 30cm. Given the close proximity of results for discernible resolution of static images of TV (4.3m viewing distance) and smartphones (30cm) this approximation is valid.

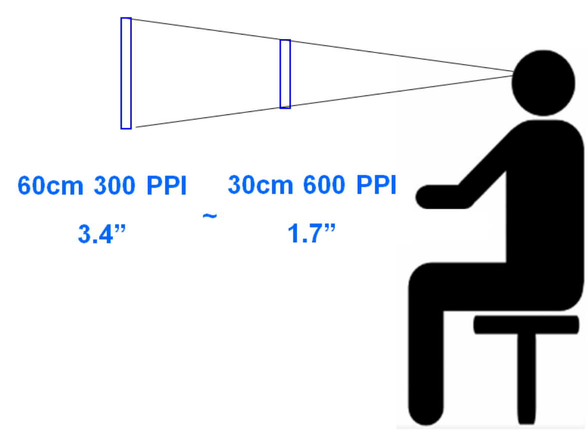


Figure 2. Showing 300 PPI tablet display equivalent to 600 PPI at 30cm. Eight videos shown on screen simultaneously, each 3.4” screen diagonal.

A range of five video types showing both natural and computer generated scenes were used in the test each running in a loop between 14 and 20 seconds (See Figure 3). On the display, eight videos, of the same type, were simultaneously played in a 2x4 grid array, each comprising 800x640 pixels. 4 separate resolutions were tested, 150,300, 450 and 600 PPI both aliased and anti-aliased resulting in eight combinations as defined in

Table 1. These eight videos were randomly positioned within the 2x4 grid array to remove any positional bias.

In total 43 test subjects were randomly selected to participate in the experiment, (mean age 33). Each subject was given a near view eye test, whilst wearing any corrective eyewear, to determine visual acuity at 30 cm (mean 20/19). The age and acuity distributions of the subjects are shown in Figure 4.

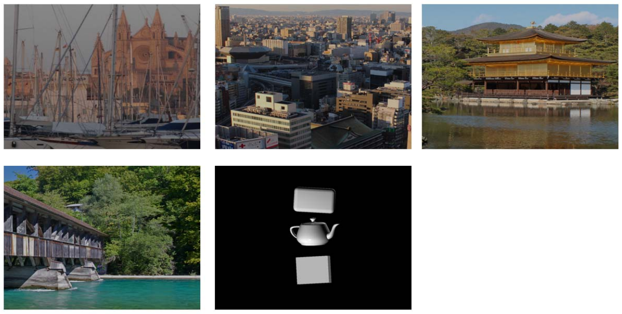


Figure 3. Still Images from videos used, Boat, City, Temple, Bridge and Teapot.

The display was placed in a fixed position relative to the subjects, and the test was performed with no ambient light to prevent any impact on surface reflections off the display interfering with results.

Test subjects, positioned 60cm from the display were requested to view 8 simultaneous videos for a video type and make a ranking judgment of worst to best in terms of video clarity sharpness and smoothness, where 8 is the worst and 1 the best. Subjects were given a time limit of 5 minutes per video type. The ranking decision, time to rank and explanation of how the subject came to make their decisions were recorded. This procedure was repeated for the other 4 videos.

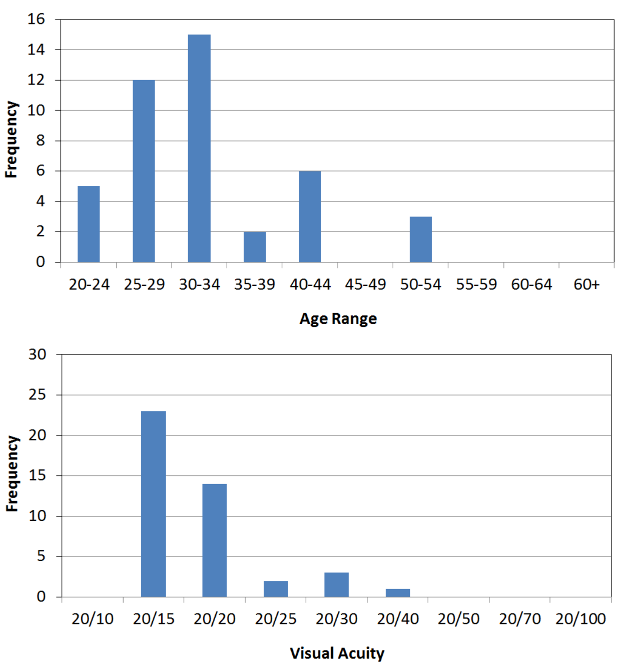


Figure 4. Distributions of test subject's age and visual acuity.

Table 1. Resolutions under test, all scaled to 800x640

Video #	Rendered resolution	Scaled factor	PPI equivalent at 30cm
1	200x160	4x	150
2	400x320	2x	300
3	600x480	1.33x	450
4	800x640	1	600

3. Results

Ranked results: For both aliased and anti-aliased videos the rank number reduces, i.e. image quality improves, as the resolution increases (See Figure 5.) This clearly shows users can positively discriminate between low and high resolution displays. Aliased data shows a near linear correlation of rank and resolution, whereas the anti-aliased videos show some sign of reduced gradient at higher resolutions.

The 450 PPI video of the city exhibited severe moiré artifacts that were not seen in other videos. This was caused by interference between the pixel pitch and the near vertical lines of the foreground building. Many of the subjects described this artifact as a reason for ranking this image poorly.

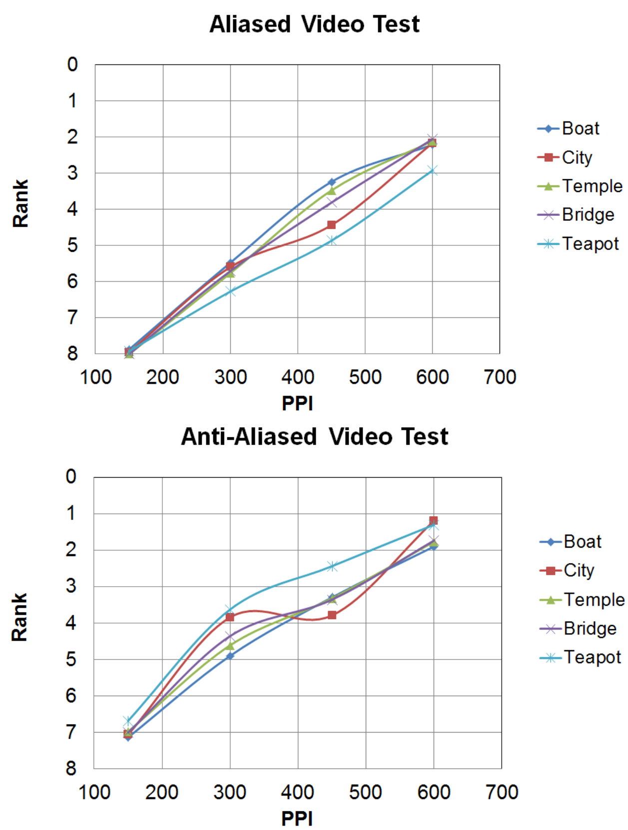
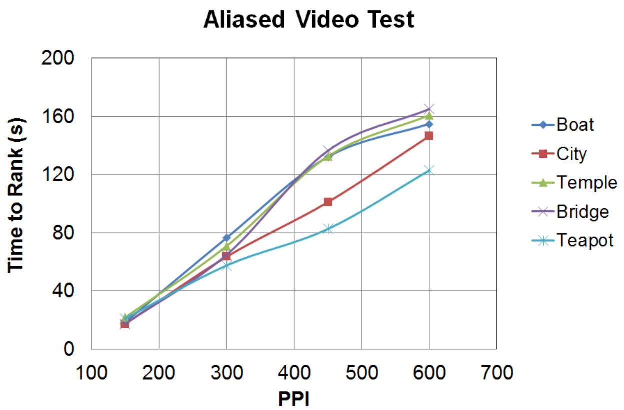


Figure 5. Rank data for aliased (top) and anti-aliased (bottom) videos, 8 (worst), 1 (best).

When analyzing the ranked data it gives a clear indication of how users perceive the displays, but ranking's inherent non-parametric nature means it is difficult to perform cross image analysis.

Time to rank: There is a strong correlation between the curve shape of ranked and time to rank data. Plotting the time to rank rather than the ranked data of aliased and anti-aliased videos allows a direct comparison across image types (see Figure 6). As these results are now parameterized it can be seen that the aliased computer generated teapot is the fastest to be ranked, indicating it benefited greatly from increasing resolution and subjects could quickly identify this. Videos containing man-made and natural scenes such as Boat, Temple and Bridge all resulted in very similar profiles. It is anticipated if the 450 PPI City image had not suffered from Moiré this would also have resulted in the same profile.

The linear nature of the aliased videos suggests that 600 PPI, the highest resolution measure, has not approached the resolution limit. For anti-aliased videos a subtle change in gradient can be seen along the curve indicating that further benefit can be gained by increasing resolution, but the gains are reducing in magnitude.



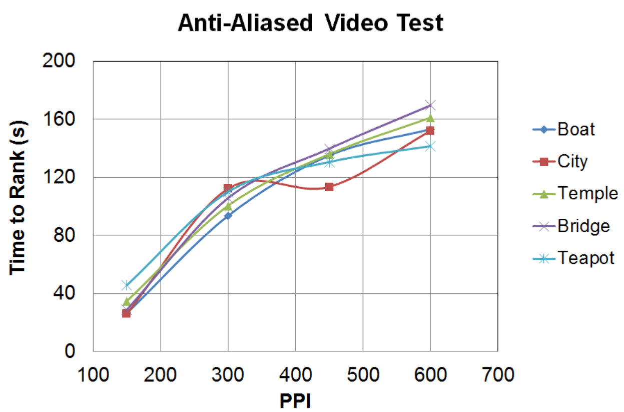


Figure 6. Time to rank data for aliased and anti-aliased video

Statistical Analysis: Subject responses were analysed using a Smirnov Grubbs test to identify outlier results. Videos from each video type were tested in pairs using a paired T-test. The null hypothesis (H_0) was that Display 1 is the same as Display 2 in terms of video smoothness, clarity and sharpness. For example Boat 150 PPI is indistinguishable from Boat 300 PPI. The alternative hypothesis (Ha) stated that Display 1 and Display 2 are not the same. We reject Ho if the statistical p-value from the paired t-test <0.05, i.e. the probability that Display 1 = Display 2 is less than 5%.

A list of p-values for all video types between 150-300 PPI 300-450 PPI and 450-600 PPI can be seen in Table 2, for both aliased and anti-aliased videos. Across all videos there is a clear statistically significant difference between each step of resolution, excluding the 450 PPI anti-aliased City video already discussed. Of all the other videos there is a 0.3% probability (450-600AA Boat) or less that the videos are indistinguishable.

Table 2. Statistical p-values of paired t-test for videos

	Video Type				
	Boat	**City**	**Temple**	**Bridge**	**Teapot**
Aliased					
150-300	0.000	0.000	0.000	0.000	0.000
300-450	0.000	0.000	0.000	0.000	0.000
450-600	0.000	0.000	0.000	0.000	0.000
Anti-Aliased					
150-300	0.000	0.000	0.000	0.000	0.000
300-450	0.000	0.876	0.000	0.001	0.000
450-600	0.003	0.000	0.000	0.000	0.000

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Still vs. Video images: Previous work analysed the discernible resolution limit for still images [5]. A plot comparing measurement data from that study for a typical still image tested against the Temple video data, (considered to be typical response for video) can be seen in Figure 7.

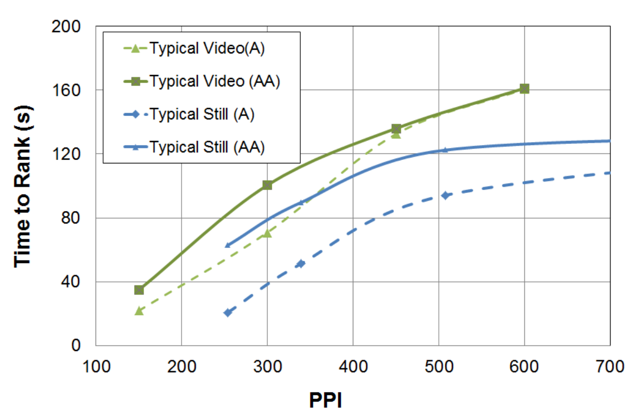

Figure 7. Time to rank data comparing still and moving images, both aliased (A) and anti-aliased (AA).

A direct comparison between the still and video test data is not straight forward due to the different resolutions tested and experimental conditions; the still image experiment used simulated displays. However, it is clear that the general trend show significant similarities, the separation between aliased and anti-aliased is equivalent and they both exhibit a tendency to converge. The indication here is that typical video footage is more difficult to discriminate between than for still images given the longer time to rank. This result was anticipated given that for still images a user has the time to analyse specific parts of an image, whereas for a video any feature on screen only remains so for a short period of time.

4. Conclusion

A range of video types of resolutions 150-600 PPI have been tested in a large scale study to determine if users can discriminate between these resolutions. The results clearly show that users can tell the difference between 450 and 600 PPI video even when using anti-aliasing. Previous studies have already shown that the perceptible limits are in excess of 600 PPI for still images, and here it is shown for the first time that this is also true for video playback.

5. Impact

It is now clear that, for both still and moving images, the 470 PPI of the latest smartphones does not reach the resolution limit that users can perceive. Further increases in display resolution are shown to enhance the user experience.

6. References

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