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Perceptual Picture Quality Analysis of UHD signals in terms of Spatial Information and Noises

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Abstract

As UHDTV displays have become increasingly available in the market, more UHDTV programs are being produced. On the other hand, it has been reported that the perceptual video quality differences between UHDTV and full HD signals are minor in some cases. Consequently, there is an increasing need for UHDTV service references and measurement tools, which can quantify the UHD signals. In this paper, the perceptual image quality of full HD (1080p) and UHD signals is compared along with other formats (720p, 540p, 360p) when they are displayed on a UHD display. We performed subjective tests using a UHDTV display and the subjective scores of the various picture sizes were analyzed.

Introduction

As UHDTV services have become increasingly available, there has been an increasing need for UHDTV service references and measurement tools. In general, UHD signals show better picture quality (Fig 1.). However, it was also observed that UHD signals didn't produce improved perceptual quality compared to lower resolutions in some cases. Thus, it is desirable to understand UHDTV signal characteristics. In this paper, we investigate which types of pictures may benefit from UHD resolutions.

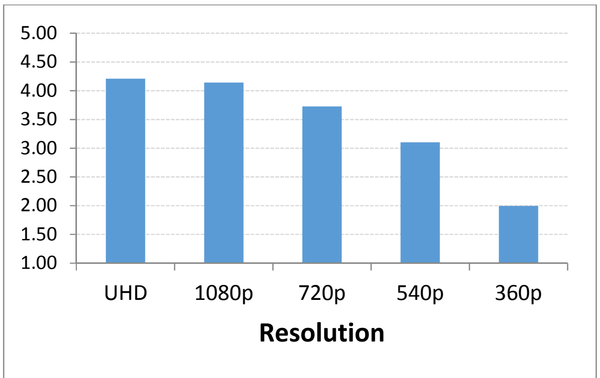


Figure 1. *Quality comparison of various resolutions (average of 40 SRCs).*

We investigated the characteristics of pictures, which sometimes showed improved picture quality at higher resolutions. It is observed that some pictures retained high perceptual picture quality, even though they were displayed at a lower resolution. We investigated two perspectives: spatial information (SI) and noise factors (NF). Through subjective tests, we studied the relationship between the perceptual picture quality at various resolutions based on SI/NF values.

The rest of this paper is organized as follows. Section 2 presents a description of the subjective experiments for image quality comparison and analysis. In Section 3, the experimental results are reported along with further analysis. Finally, concluding remarks are drawn in Section 4.

Methods

Subjective Test Design

We selected 40 high quality UHD resolution images. We first reduced the images to 1080p, 720p, 540p and 360p. Then the reduced images were enlarged back to their original UHD sizes using an interpolation method. The original and enlarged lower resolution images were displayed on a UHDTV display. Perceptual picture quality scores were obtained through subjective tests.

Fig. 2 shows some examples of reduced images (cropped area) and Fig. 3 shows some differences in the cropped areas. Fig. 4 shows the spectrum characteristics of the difference images. It can be seen that when the picture was more highly reduced, more high frequency components were lost.

The subjective scores were analyzed from two perspectives: spatial information (SI) [1] and noise factor (NF) [2]. The SI value is computed as follows:

$$SI=std\_space\ [Sobel(I(x,y))] \quad (1)$$

The SI value represents the spatial complexity of a given image. If the UHD image contained high spatial frequencies, it was more likely that quality loss would occur when the image resolution was reduced. The noise factor is computed as follows [2]:

$$NF=\sqrt{\frac{\pi}{2}}\frac{1}{6(W-2)(H-2)}\sum_{image\,I}\left|I(x,y)*N\right| \text{ where } N=\begin{bmatrix}1 & -2 & 1\\ -2 & 4 & -2\\ 1 & -2 & 1\end{bmatrix} \quad (2)$$

The NF value indicates the noise level of a given image. If the image contained a high level of noise, the perceptual quality of the UHD images sometimes suffered. On the other hand, when such noisy images were reduced, the noise influence was weakened due to the low-pass filtering effects of resolution reduction.

Laboratory environment

In the past, a number of subjective evaluation methodologies have been described in ITU-R Recommendation BT.500 and ITU-T Recommendation P.910. These recommendations also describe the environment setting in terms of laboratory brightness, viewing distance, and display brightness. We performed the subjective tests in accordance with these recommendations.

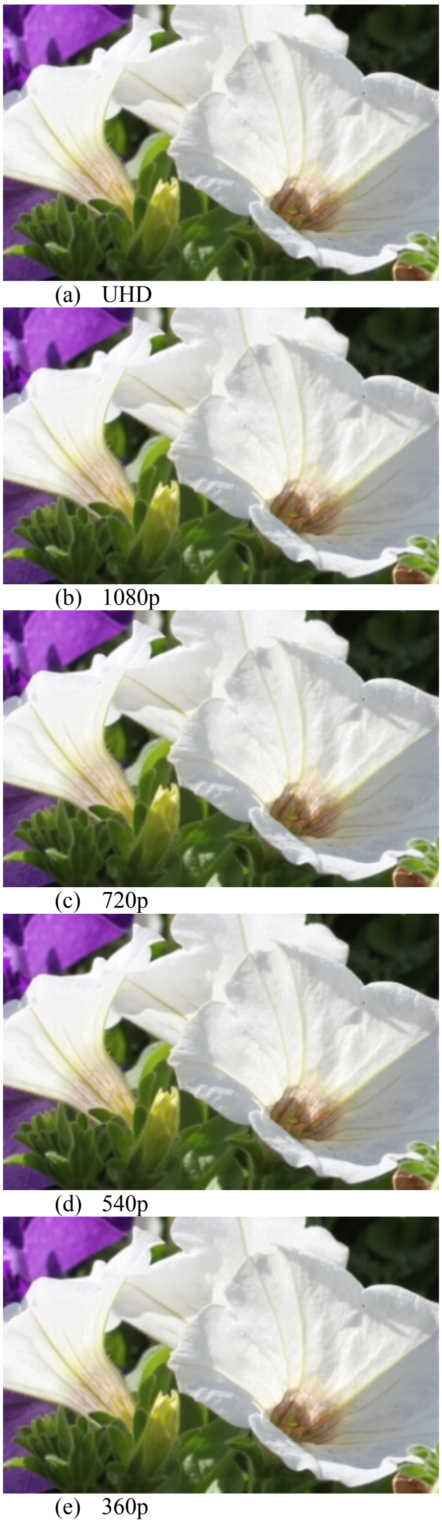


Figure 2. *Examples of reduced images (cropped areas).*

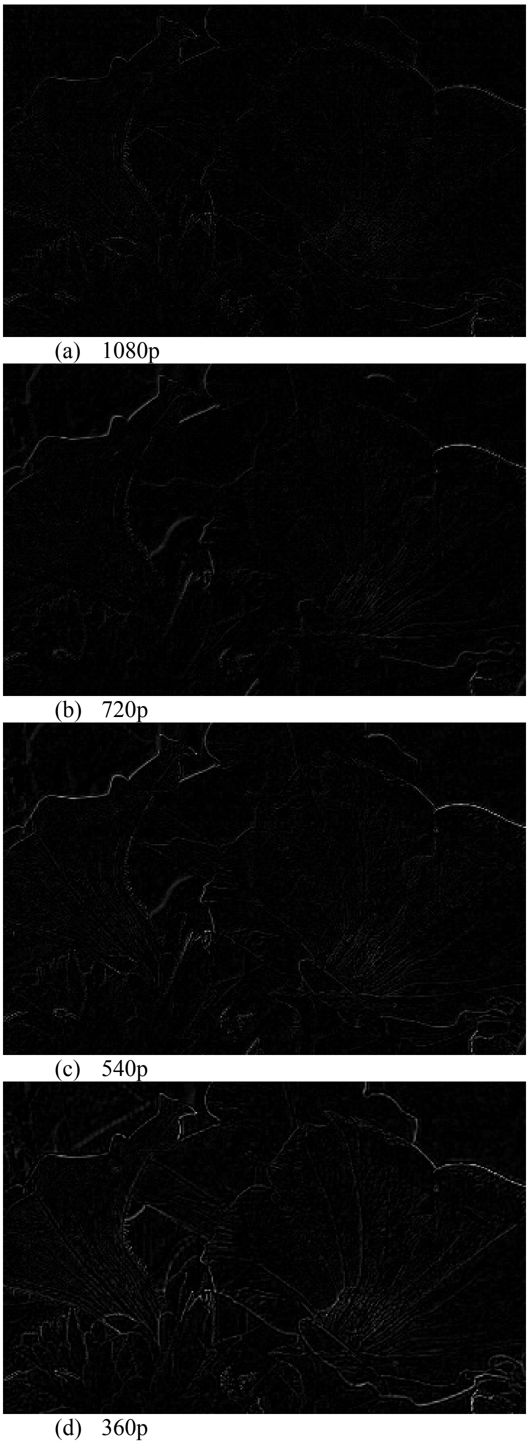
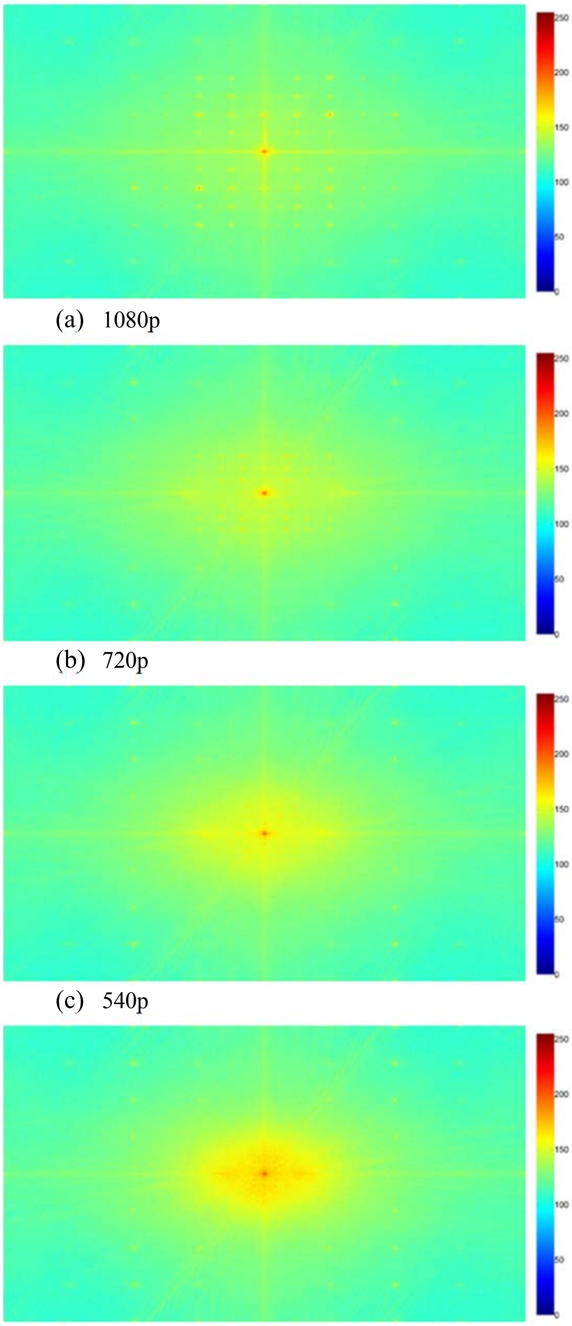


Figure 3. *Differences of the cropped areas.*



(a) 1080p

(b) 720p

(c) 540p

(d) 360p

Figure 4. *Fourier transform of difference images.*

Display system

We used a 65” LCD UHDTV with a resolution of 3840 x 2160 pixels. The viewing distance was three times the display height (3H). Fig. 5 shows the viewing environment used in the subjective experiments.

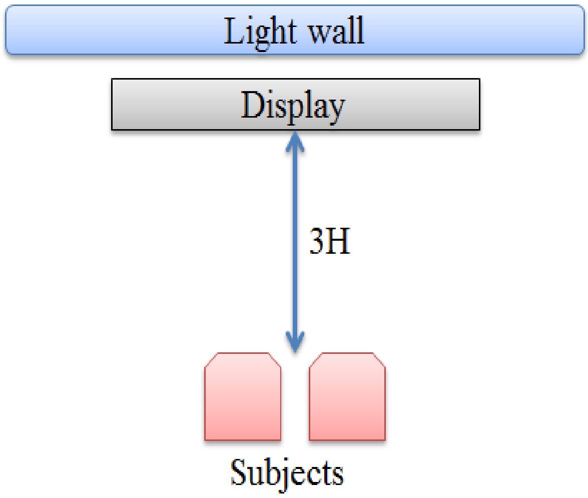


Figure 5. *Viewing environment used in subjective experiments.*

Test stimuli

A total of 40 images were chosen with different colors and spatial characteristics. Table 1 shows the SI characteristics of the source images. Figs. 6 shows the histogram of the SI values.

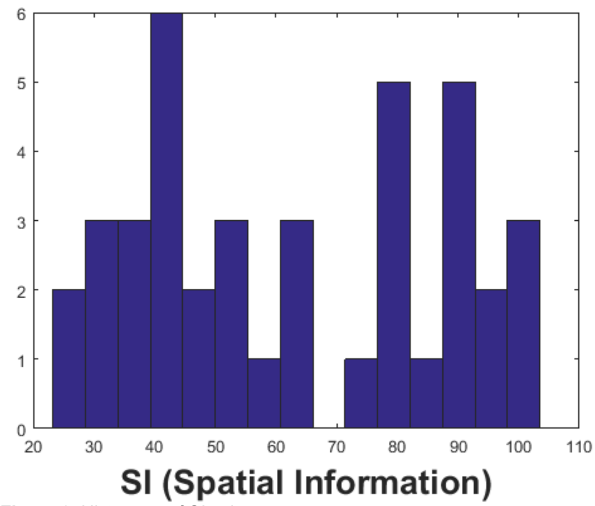


Figure 6. *Histogram of SI values.*

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Table 1. The SI characteristics of the source images.

SRC index	SI value	SRC index	SI value	SRC index	SI value	SRC index	SI value
SRC 01	88.77	SRC 11	41.34	SRC 21	90.3	SRC 31	42.35
SRC 02	84.99	SRC 12	92.31	SRC 22	95.8	SRC 32	58.55
SRC 03	80.34	SRC 13	80.76	SRC 23	72.78	SRC 33	39.59
SRC 04	51.02	SRC 14	34.62	SRC 24	23.24	SRC 34	87.63
SRC 05	65.03	SRC 15	42.99	SRC 25	52.71	SRC 35	64.59
SRC 06	30.71	SRC 16	94.93	SRC 26	39.69	SRC 36	28.8
SRC 07	34.98	SRC 17	78.91	SRC 27	53.52	SRC 37	39.36
SRC 08	63.49	SRC 18	46.39	SRC 28	103.52	SRC 38	25.82
SRC 09	79.77	SRC 19	31.45	SRC 29	98.91	SRC 39	47.76
SRC 10	79.1	SRC 20	91.91	SRC 30	99.39	SRC 40	38.12

Subjective test methodology

We used the ACR (Absolute Category Rating) method described in ITU-R Recommendation BT.500-10 [3]. In the ACR method, all images are presented sequentially to viewers who rate them with reference to the single stimulus scaling method. Table 2 shows the five point category scale of ITU-R Recommendation BT.500. Fig. 7 shows the image presentation and rating procedure. A total of 24 viewers participated in the subjective test, consisting of 14 males and 10 females. A screening test of the observers was performed according to a guideline in ITU-R Recommendation BT.500-11 [4] and P.910 [1]. Observers who produced rating scores significantly different from the average scores were replaced with new viewers. When the SI values were larger than 30, a decisive majority of UHD images were of higher perceptual quality than the corresponding 1080p images.

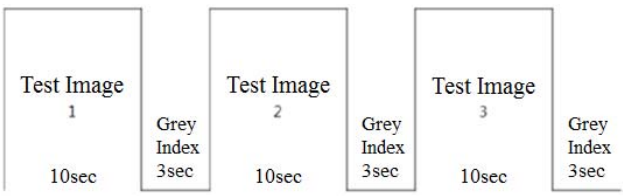

Figure 7. *Example of methods used in the subjective test.*

Table 2. Five point category scale used to rate the degree of picture quality.

5	Excellent
4	Good
3	Fair
2	Poor
1	Bad

Experimental Results & Analyses

Fig. 8 shows the subjective scores of the various resolutions for the 40 source pictures. As can be seen, the original UHD signals almost always showed better perceptual quality than the 720p, 540p and 360p images. On the other hand, the perceptual quality differences of the UHD and 1080p images were much smaller. In some cases, 1080p was slightly better than UHD.

Fig. 9 shows the perceptual quality comparison of the UHD and 1080p resolutions in terms of SI and noise factors. It appears that spatial complexity may affect perceptual quality. In general, the pictures with high SI values benefitted from the UHD resolution.

Also, when the images contained some noises, the lower resolution images sometimes produced improved perceptual quality through the LPF effect of resolution reduction. However, Fig. 9 shows no clear relationship between perceptual quality and the noise factor discussed in [2]. New noise measurement functions may be required for this type of application. Fig. 10 shows the MOS differences between the UHD images and the 1080p images. Although there are some exceptions, it is clear that the differences between the UHD images and the 1080p images become apparent as the spatial complexity increases. Fig. 11 shows a spectrum analysis of the difference of SRC 17 whose UHD score is better than the 1080p score.

Conclusions

In recognition of the fact that UHDTV programs and displays have become increasingly available, we decided to examine the signal characteristics of UHD pictures, which may benefit from higher spatial resolution. The ultimate goal is to develop UHD signal measurement tools to quantify the UHD signals. These tools can be used to evaluate the UHD output signals produced by encoders, editing tools, and decoders at the receivers for monitoring purposes.

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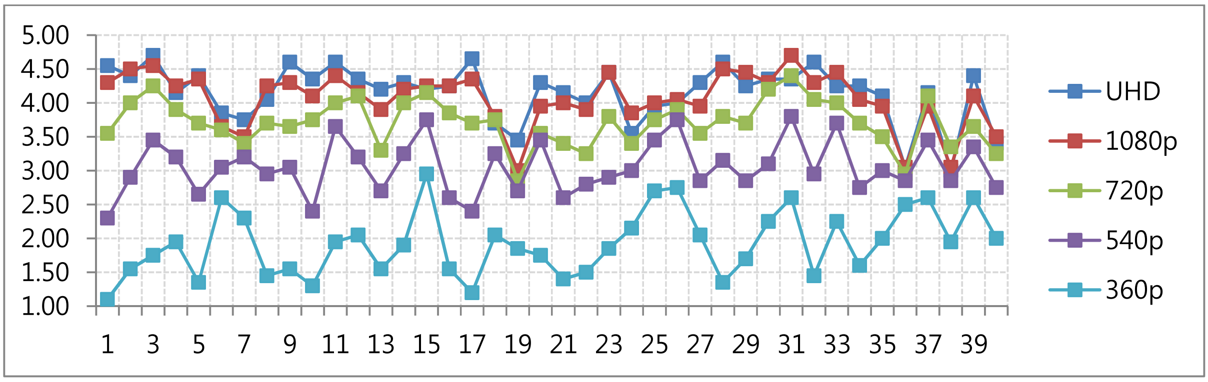

Figure 8. *Quality comparison of various resolutions for each source.*

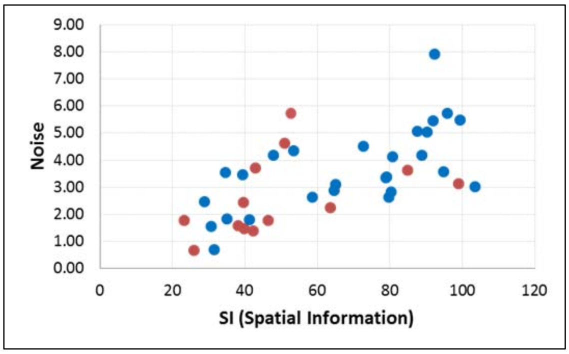

Figure 9. *Quality comparison of UHD and 1080p images in terms of SI and noise factors (red dots: 1080p is better; blue dots: UHD is better).*

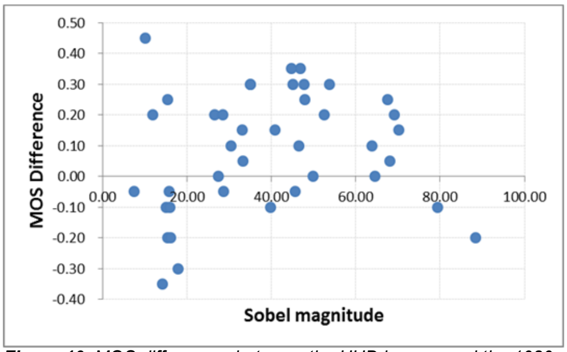

Figure 10. *MOS differences between the UHD images and the 1080p images.*

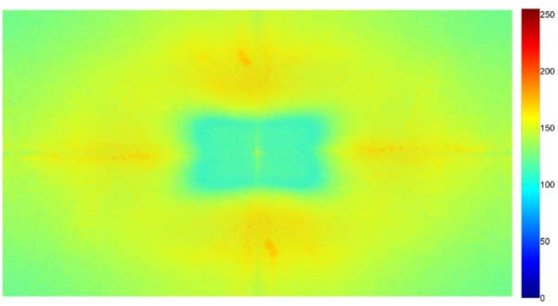

Figure 11. *Spectrum analysis of the difference image of the UHD and 1080p images (SRC17).*

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Author Biography

Chulhee Lee received the B.S. and M.S degrees in electronics engineering from Seoul National University in 1984 and 1986, respectively, and the Ph.D. degree in electrical engineering from Purdue University, West Lafayette, Indiana, in 1992

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